

**DESIGN AND DEVELOPMENT OF COST EFFECTIVE
ENERGY FREE WATER LIFTING DEVICE**

A THESIS SUBMITTED TO

**Dr. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
MAHARASHTRA (INDIA)**

**IN THE PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE**

OF

**MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**

IN

IRRIGATION AND DRAINAGE ENGINEERING

BY

MR. LINGAVALE TEJAS MANGESH

(Regd. No. ENDPM 2018 / 141)

B. Tech. (Agricultural Engineering)



**DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING,
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH,
DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA).**

OCTOBER, 2020

DESIGN AND DEVELOPMENT OF COST EFFECTIVE ENERGY FREE WATER LIFTING DEVICE

A Thesis submitted to

**DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra (India)**

In the partial fulfillment of the requirements for the degree

of

**MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**

in

IRRIGATION AND DRAINAGE ENGINEERING

by

Mr. Lingavale Tejas Mangesh

(Regd. No. ENDPM 2018 / 141)

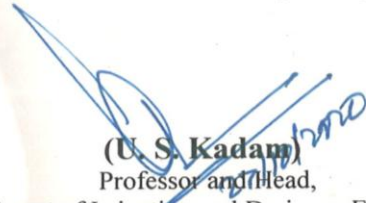
B. Tech. (Agricultural Engineering)

Approved by the advisory committee



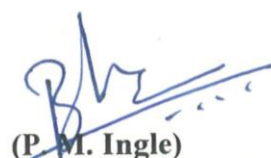
(S. T. Patil)

Assistant Professor,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology, Dapoli



(U. S. Kadam)

Professor and Head,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and
Technology, Dapoli



(P. M. Ingle)

Associate Professor,
Agricultural Engineer,
AICRP on Irrigation Water Management,
Central Experimental Station, Wakawali

October, 2020

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted
by me or any other person to any other
University or Institute
for award of Degree or
Diploma.

Place : Dapoli

Date : 27/10/2020


(Lingavale Tejas Mangesh)

Er. S. T. Patil

B. Tech. (Agril. Engg.), M. Tech. (IDE)

Research Guide,

Assistant Professor,

Department of Irrigation and Drainage Engineering,

College of Agricultural Engineering and Technology,

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712, Dist. Ratnagiri,
Maharashtra State (India)

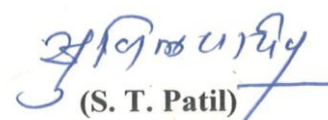
CERTIFICATE

This is to certify that the thesis entitled “**Design and Development of Cost Effective Energy Free Water Lifting Device**”, submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.) in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Irrigation and Drainage Engineering**, embodies the record of a piece of bonafied research work carried out by **Mr. Lingavale Tejas Mangesh (Regd. No. ENDPM 2018 / 141)** under my guidance and supervision and that no part of this thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place : Dapoli

Date : 27/10/2020


(S. T. Patil)

Prof. Dr. U. S. Kadam

B. Tech. (Agril. Engg.), M. Tech. (A.E.) IDE, Ph. D. (U.K.)

Professor and Head,

Department of Irrigation and Drainage Engineering,

College of Agricultural Engineering and Technology,

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712

Dist. Ratnagiri, Maharashtra (India)

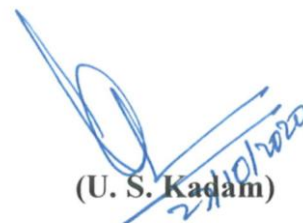
CERTIFICATE

This is to certify that the thesis entitled “**Design and Development of Cost Effective Energy Free Water Lifting Device**”, submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.) in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Irrigation and Drainage Engineering**, embodies the record of a piece of bonafied research work carried out by **Mr. Lingavale Tejas Mangesh (Regd. No. ENDPM 2018 / 141)** under the guidance and supervision of **Er. S. T. Patil**, Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri. No part of this thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place : Dapoli

Date : 27/10/2020



(U. S. Kadam)

Dr. Y. P. Khandetod

B. Tech. (Agril. Engg.), M. Tech. (PHE), Ph. D. (AGFE)

Dean,

Faculty of Agricultural Engineering and Technology,

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712

Dist. Ratnagiri, Maharashtra (India)

CERTIFICATE

This is to certify that the thesis entitled “**Design and Development of Cost Effective Energy Free Water Lifting Device**”, submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.) in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering) in Irrigation and Drainage Engineering**, embodies the record of a piece of bonafied research work carried out by **Mr. Lingavale Tejas Mangesh (Regd. No. ENDPM 2018 / 141)** under the guidance and supervision of **Er. S. T. Patil**, Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place : Dapoli

Date : 27/10/2020


(Y. P. Khandetod)

ACKNOWLEDGEMENT

*Although the words hardly suffice at this moment, I avail this opportunity to express out deep sense of gratitude and indebtedness to my research guide **Er. S. T. Patil**, Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli for his valuable inspiration, scholastic guidance, generous treatment and constant encouragement throughout this research work and help in final shaping of this manuscript in the present form.*

*I am especially indebted to **Prof. Dr. U. S. Kadam**, Professor and Head, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli for his encouragement, guidance and providing necessary facilities for prosecuting the study.*

*I take this opportunity to express sincere reverence, deep sense of gratitude and grateful thanks to **Dr. Y. P. Khandetod**, Dean Faculty of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli for his encouragement and providing necessary facilities for prosecuting the study.*

*Grateful thanks are extended to **Dr. P. M. Ingle**, Associate Professor and Member, Student Advisory Committee, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli and presently working as Agricultural Engineer, AICRP on Irrigation and Water Management, Wakawali for his timely valuable guidance, encouragement, and motivation in the research work.*

*I fall short of words in expressing my thanks to my dear friends **Sampada, Siddhesh, Shivaji, Rushikesh, Ajay, Nita** and my seniors **Sahebrao Jedhe, Madhusudan Khadtare, Govind Rawat, Prashant Dada, Vicky Dada, Uday Kaka, Aniket Dada, Shalini Kaki, Manasi Kaki** for their constant support and timely help during this project work.*

*The words are not enough to express my sincere deep respect to my beloved parents. My **Mom, Dad, Grandmother, Uncle and Aunt** have nurtured and cultured*

me by putting there all possible efforts to put me on right track and for my betterment. With their blessing and support I could complete this study.

*Also, I express my thanks to my sisters **Minal** and **Upasana** and brother **Harsh** for their support and valuable prayers.*

I express my sincere thanks to those who directly and indirectly extended help during the research work.

Place : Dapoli

Date : 27/10/2020

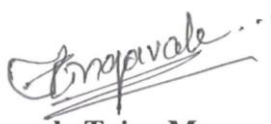

(Lingavale Tejas Mangesh)

TABLE OF CONTENTS

Sr. No.	Title	Page No.
	CANDIDATE'S DECLARATION	i
	CERTIFICATES	ii-iv
	ACKNOWLEDGEMENT	v-vi
	TABLE OF CONTENTS	vii-xii
	LIST OF TABLES	xiii-xiv
	LIST OF PLATES	xv-xvi
	LIST OF FIGURES	xvii-xviii
	LIST OF SYMBOLS	xix
	LIST OF ABBREVIATIONS	xx
	ABSTRACT	xxi-xxii
I.	INTRODUCTION	1-3
II.	REVIEW OF LITERATURE	4-34
2.1	Survey and study of different types of water lifting devices available in the market	4
2.2	Design and development of the energy free water lifting device	12
2.3	Performance evaluation of the developed energy free water lifting device	21
2.4	Cost analysis	32
III.	MATERIALS AND METHODS	35-76
3.1	Study Area	35
3.2	Location, Climate and Weather Condition	35
3.3	Survey and study of different water lifting devices available in the market	36
3.3.1	Rope and Bucket Lift	36
3.3.2	Archimedes Screw	38
3.3.3	Water Wheel	40
3.3.4	Rope pump	42
3.3.5	Suction Plunger Handpump	44
3.3.6	Direct Action Handpump	46
3.3.7	Deep-Well Diaphragm Pump	48
3.3.8	Deep-Well Piston Handpump	50
3.3.9	Hydraulic ram	53

3.3.10	Closure of the Survey and study of the water lifting devices available in the market	55
3.4	Design and development of the energy free water lifting device	55
3.4.1	Design Considerations	55
3.4.2	Design parameters of the energy free water lifting device	56
3.4.2.1	Working principle: Water hammer effect	56
3.4.2.2	Drive pipe	57
3.4.2.3	Delivery pipe	58
3.4.2.4	Supply tank	59
3.4.2.5	Supply head	59
3.4.2.6	Delivery head	59
3.4.2.7	Air chamber	59
3.4.2.8	Waste valve	59
3.4.3	Material used, shape and size of the device	60
3.4.4	Materials used for the manufacturing of energy free water lifting device	61
3.4.4.1	PVC Pipe	61
3.4.4.2	PVC Flow control valve	62
3.4.4.3	Non-return valve	62
3.4.4.4	Air Chamber (Plastic Disposable Bottle)	62
3.4.4.5	Supply and Delivery Pipe	64
3.4.4.6	PVC Male and Female Adaptors	64
3.4.4.7	PVC Elbows	64
3.4.4.8	PVC “T” (Tee)	64
3.4.4.9	Hose Clips	64
3.4.4.10	Hose Nipples	64
3.4.4.11	Reducers	64
3.4.4.12	Teflon Tape	64
3.4.4.13	PVC Solution	65
3.5	Methodology	67
3.5.1	Experimental Setup	67
3.5.1.1	Pipe Cutting	69
3.5.1.2	Assembling of the components	69

3.5.1.3	Aligning the non-return valves	70
3.5.1.4	Fixing of control valves	70
3.5.1.5	Mounting the Air chamber	70
3.5.1.6	Adjusting the supply heads	70
3.5.1.7	Delivery pipe connections	70
3.5.1.8	Setting the delivery heads	71
3.5.2	Study of hydraulic parameters of the energy free water lifting device	72
3.5.2.1	Determination of Volumetric flow rate	73
3.5.2.2	Determination of velocity of fluid	73
3.5.2.3	Calculation of Reynold's Number	73
3.5.2.4	Calculation of frictional loss	73
3.5.2.5	Determination of head loss	74
3.6	Performance of the Energy free water lifting device	74
3.6.1	Performance evaluation of the device	74
3.6.2	Efficiency of the Energy free water lifting device	75
3.7	Cost analysis	76
3.7.1	Cost of production	76
IV.	RESULTS AND DISCUSSION	77-133
4.1	Study Area	77
4.2	Survey and study of different water lifting devices available in the market	77
4.3	Design and development of energy free water lifting device	81
4.3.1	Design considerations	81
4.3.2	Water hammer	82
4.3.3	Construction of water lifting device	83
4.3.3.1	PVC pipe	83
4.3.3.2	Flow control valve	83
4.3.3.3	Non-return valve	84
4.3.3.4	Air Chamber (Plastic Disposable Bottle)	84
4.3.3.5	Supply and Delivery Pipe	84
4.3.3.6	PVC Threaded Adaptors	85
4.3.3.7	PVC Elbows	85
4.3.3.8	PVC 'T' (Tee)	85

4.3.3.9	Hose Clips	86
4.3.3.10	Hose Nipples	86
4.3.3.11	Reducer	86
4.3.3.12	Teflon Tape	86
4.3.3.13	PVC Solution	86
4.3.3.14	Schematic set up of the energy free water lifting device	87
4.4	Step by step construction procedure for energy free water lifting device	89
4.5	Determination of hydraulic parameters of the developed energy free water lifting device	92
4.5.1	Computation of volumetric flow rate	92
4.5.2	Velocity of fluid	93
4.5.3	Reynold's Number	94
4.5.4	Frictional loss	94
4.5.5	Head loss	95
4.6	Performance Evaluation of the Energy Free Water Lifting Device	95
4.6.1	Effect of supply pipe diameters and supply heads on delivery discharges and delivery heads	96
4.6.1.1	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	96
4.6.1.2	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	98
4.6.1.3	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	101
4.6.1.4	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	104

4.6.1.5	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	107
4.6.1.6	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	110
4.6.1.7	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	113
4.6.1.8	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	116
4.6.1.9	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	119
4.6.2	Efficiency of the energy free water lifting device	123
4.6.2.1	Efficiency of the energy free water lifting device at supply head of 1 m	123
4.6.2.2	Efficiency of the energy free water lifting device at supply head of 1.5 m	125
4.6.2.3	Efficiency of the energy free water lifting device at supply head of 2 m	128
4.7	Cost Estimation	131
V.	SUMMARY AND CONCLUSIONS	134-137
5.1	Summary	134
5.1.1	Design and development of energy free water lifting device	134
5.1.2	Working of the energy free water lifting device	135
5.1.3	Performance evaluation of the energy free water lifting	135

	device	
5.1.4	Maximum delivery head obtained	135
5.1.5	Efficiency of the energy free water lifting device	136
5.1.6	Cost Analysis	136
5.2	Conclusions	136
5.3	Suggestions for further work	137
VI.	BIBLIOGRAPHY	138-144
VII.	APPENDICES	145-159
	Appendix (A)	145
a)	Cost for design of the energy free water lifting device	145
b)	Cost of the Supply pipes and Delivery pipes	146
	Appendix (B)	147-149
	Observations recorded for 1 m supply head	
	Appendix (C)	150-153
	Observations recorded for 1.5 m supply head	
	Appendix (D)	154-156
	Observations recorded for 2 m supply head	
	Appendix (E)	157
	Percent reduction in discharge rates corresponding to delivery heads at 1 m supply head	
	Appendix (F)	158
	Percent reduction in discharge rates corresponding to delivery heads at 1.5 m supply head	
	Appendix (G)	159
	Percent reduction in discharge rates corresponding to delivery heads at 2 m supply head	

LIST OF TABLES

Table No.	Particulars	Page No.
4.1	Merits and Demerits of the water lifting devices available in the market	78
4.2	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	96
4.3	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 12 mm diameter of delivery pipe	97
4.4	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	99
4.5	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 16 mm diameter of delivery pipe	100
4.6	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	102
4.7	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 25 mm diameter of delivery pipe	103
4.8	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	105
4.9	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 12 mm diameter of delivery pipe	106
4.10	Effect of different supply pipe diameter and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	108

4.11	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 16 mm diameter of delivery pipe	109
4.12	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	111
4.13	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 25 mm diameter of delivery pipe	112
4.14	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	114
4.15	Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 12 mm diameter of delivery pipe	115
4.16	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	117
4.17	Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 16 mm diameter of delivery pipe	118
4.18	Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	120
4.19	Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 25 mm diameter of delivery pipe	121
4.20	Efficiency of the energy free water lifting device at 1 m supply head	123
4.21	Efficiency of the energy free water lifting device at 1.5 m supply head	126
4.22	Efficiency of the energy free water lifting device at 2 m supply head	128

LIST OF PLATES

Plate No.	Title	Page No.
3.1	Rope and Bucket Lift	37
3.2	Archimedes Screw	39
3.3	Waterwheel	41
3.4	Rope pump	42
3.5	Components of the Rope Pump	42
3.6	Suction Plunger Handpump	44
3.7	Direct Action Handpump	46
3.8	Components of the Direct Action Handpump	47
3.9	Deep Well Diaphragm Pump	49
3.10	Components of Deep-well diaphragm pump	49
3.11	Deep-Well Piston Handpump	51
3.12	Components of Deep well piston pump	51
3.13	Hydraulic ram	53
3.14	Components of Hydraulic ram pump	53
3.15	PVC Pipe	65
3.16	Flow Control Valve	65
3.17	Brass Non-return valve	65
3.18	Actual working of flap of Non-return valve	65
3.19	Plastic Disposable Bottle used as Air Chamber	66
3.20	Supply Pipe	66
3.21	Delivery Pipe	66
3.22	Female Threaded Adaptor	66
3.23	Male Threaded Adaptor	66
3.24	PVC Elbow	66
3.25	PVC 'T' (Tee)	66
3.26	Hose Clip	66
3.27	Hose Nipple	66
3.28	Reducer	66
3.29	Teflon Tape	66

3.30	PVC Solution Container	66
3.32	Cutting the pipes for device assembly	71
3.33	Initial Connections (Fitting accessories)	71
3.34	Setup after all the connections	71
3.35	Alignment of Non-return valves	71
3.36	Final setup after total accessories assembly	72
3.37	Adjusting the supply head	72
3.38	Delivery pipe connection with the help of Hose Nipple and Hose Clip	72
3.39	Setting the Delivery head	72
3.40	Waste valve in working condition	76
3.41	Operation of waste valve	76
3.42	Energy Free Water Lifting Device	76
4.1	Material used for the construction of the device	91
4.2	Use of Teflon tape around the MTA and joining control valve to neat fitting	91
4.3	Fixing of elbow	91
4.4	Installation of the waste valve	91
4.5	Fitting of an air chamber	92
4.6	Fitting of control valve	92
4.7	Developed energy free water lifting device	92
4.8	Our Hon. HOD Prof. Dr. Kadam Sir while giving precious guidance to me	132
4.9	Visit of Director of Research, DBSKKV, Dapoli	132
4.10	Visit of Sub Divisional Agricultural Officer	132
4.11	Visit of Hon. Vice Chancellor, DBSKKV, Dapoli	133
4.12	Visit of Hon. DYSP, Ratnagiri and PI, Dapoli	133

LIST OF FIGURES

Fig. No.	Title	Page No.
3.1	Schematic set up of the energy free water lifting device	68
3.2	Materials required for the energy free water lifting device	69
4.1	Schematic set up of the energy free water lifting device	88
4.2	Designed components of the energy free water lifting device	89
4.3	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	97
4.4	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 12 mm diameter of delivery pipe	98
4.5	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	100
4.6	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 16 mm diameter of delivery pipe	101
4.7	Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe	103
4.8	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 25 mm diameter of delivery pipe	104
4.9	Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe	106
4.10	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 12 mm diameter of delivery pipe	107
4.11	Effect of different supply pipe diameter and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe	109

4.12	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 16 mm diameter of delivery pipe	110
	Effect of different supply pipe diameters and 1.5 m supply head on	
4.13	delivery discharge and delivery head when 25 mm diameter of delivery pipe	112
	Percent increase in the discharge corresponding to supply pipe	
4.14	diameters at 1.5 m supply head with 25 mm diameter of delivery pipe	113
	Effect of different supply pipe diameters and 2 m supply head on	
4.15	delivery discharge and delivery head when 12 mm diameter of delivery pipe	115
	Percent increase in the discharge corresponding to supply pipe	
4.16	diameters at 2 m supply head with 12 mm diameter of delivery pipe	116
	Effect of different supply pipe diameters and 2 m supply head on	
4.17	delivery discharge and delivery head when 16 mm diameter of delivery pipe	118
	Percent increase in the discharge corresponding to supply pipe	
4.18	diameters at 2 m supply head with 16 mm diameter of delivery pipe	119
	Effect of different supply pipe diameters and 2 m supply head on	
4.19	delivery discharge and delivery head when 25 mm diameter of delivery pipe	121
	Percent increase in the discharge corresponding to supply pipe	
4.20	diameters at 2 m supply head with 25 mm diameter of delivery pipe	122
	Efficiency of the energy free water lifting device at 1 m supply head	
4.21		125
	Efficiency of the energy free water lifting device at 1.5 m supply head	
4.22		128
	Efficiency of the energy free water lifting device at 2 m supply head	
4.23		130

LIST OF SYMBOLS

Symbol	Description
%	Per cent
°	Degree Celsius
+	Plus
-	Minus
/	Division
*	Multiplication
=	Equal to
”	Inch / second
’	Foot / minute
£	Pound Sterling
kW	Kilowatt
US \$	United States Dollar
Ø	Diameter

LIST OF ABBREVIATIONS

Abbreviation	Meaning
mm	Millimeter
m	Meter
cm	Centimeter
hr	Hour
etc.	Etcetera
Fig.	Figure
No.	Number
Sr.	Serial
viz.	Namely
Sec, s	Seconds
Rs.	Rupees
BC	Before Christ
PVC	Poly Vinyl Chloride
NRV	Non return valve
MTA	Male Threaded Adapter
FTA	Female Threaded Adapter
Lpm	Liter per minute
lit.	Liter
e.g.	For example,
et.al.	Et alia (and others)
AD	Anno Domini (Year of our Lord)

ABSTRACT
DESIGN AND DEVELOPMENT OF COST EFFECTIVE ENERGY
FREE WATER LIFTING DEVICE

by

Mr. Lingavale Tejas Mangesh

Regd. No.: ENDPM 2018 / 141

Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

Project guide : Er. S. T. Patil

Department : Irrigation and Drainage Engineering

The present investigation entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” was carried out during 2018-20 at the Instructional Farm and in the Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

Indian agriculture is the monsoon dependent. Water is flowing nearby the fields or from roof top, but there is lack of gadgets and power to lift it at desired place. Farmers using some manually operated or animal drawn devices to draw the water from the river, channel or naturally impounded water to irrigate their fields in tribal and undeveloped areas. But they have lot of limitations. Therefore, efforts were made to develop the energy free water lifting device which will operate 24×7 with little head available.

The designed device operates on the principle of water hammer to lift the part of flowing water. The main objective of the study was to provide cost effective energy free water lifting device, locally manufactured with locally available material to the society. Therefore, the 32 mm size device was constructed by using PVC pipes of 32 mm, NRV of 32 mm, control valve of 32 mm and disposable bottle of 2.25 liters which were fixed according to the schematic sketch. The hydraulic parameters and performance of the developed device was evaluated.

Performance of the 32 mm size energy free water lifting device was worked out by taking 27 different combinations which consists of three supply heads, three diameters of delivery pipes and three diameters of supply pipes. It was found that maximum discharge rate of 2.40 lpm was found at 3 m delivery head with the 40/12 mm supply/delivery combination at 2.0 m supply head. At 1.5 m supply head, 50/12 supply/ delivery combination gives discharge of 2.07 lpm at 2.5 m delivery head. At 1.0 m supply head, 50/12 supply/delivery combination gives 1.67 lpm discharge at 2.0 m delivery head. The maximum efficiency was found 71.98% at also 3 m delivery head with the 50/12 mm supply/delivery combination at 2 m supply head. The maximum delivery head at supply head of 1.0 m, 1.5 m and 2.0 m were 3.3, 3.9 and 4.0 m respectively. It was observed that the supply and delivery pipe diameters of 50 mm, 40 mm and 12 mm, 16 mm respectively were found best amongst all the three combinations of supply pipe. From the study, it was revealed that as delivery head increases, delivery discharge gradually decreases. It was also observed that if the size of the supply pipe increases, discharge rates also increases. The cost of design of the energy free water lifting device was found to be Rs.1155. The designed and developed cost effective energy free water lifting device successfully fulfilled the requirements as per the objectives.

I. INTRODUCTION

Agriculture is the backbone of Indian economy. About 70% of the rural and 10% of the urban population is directly or indirectly dependent on agriculture as their source of livelihood (Limboore *et.al.*,2015). Indian Agriculture is mostly dependent upon the monsoon received during June to September. India receives annual average precipitation of about 1190 mm. Out of which 33.8% flows in the form of surface runoff and joins to the sea (Gupta *et.al.*,2016). During monsoon, water is available in the form of runoff and flowing from higher elevation to lower elevation. However, the farmers could not lift this flowing water due to unavailability of electricity in hilly and tribal areas or suitable device to lift the runoff water from lower elevation to higher elevation to irrigate their farms.

There are various types of mechanical and electrically operated devices available in the market which can lift the water from lower elevation to higher elevation. But overviewing Indian economic scenario, the economy of the marginal farmers does not allow them to buy and to use such types of mechanically-powered lifts or electrically operated pumps to irrigate their fields. Even some population in the hilly terrain are suffering for their basic needs like food, shelter, etc. in the rural and undeveloped areas, tribal areas and remote areas. Therefore, availability of the energy and fuels is nearly impossible for them. Thus, they are using some manually operated or animal drawn devices to lift the water from water sources like river, perennial streams, naturally impounded water, springs, etc. Based on the optimum range in the height of lift, they are classified mainly under three types viz. 1. Low head lift, 2. Medium head lift and 3. High head lift.

1. Low Head Lifts: The low head lifts are the devices which can lift the water up to height of 1.2 m. The swing basket, Don, Archimedean Screw and Water wheel, etc. are low head lifts. 2. Medium Head Lifts: The Persian wheel, Leather bucket lift with self-emptying bucket, Chain pump, Circular two-bucket lift, the counterpoise-bucket lift falls under medium head water lifts and having height of lift ranging from 1.2 m to 10 m. 3. High Head Lifts: Considering the indigenous water lifts used for deep wells is only the rope-bucket lift (charasa) operated by bullocks having the lifting capacity more than 10 m categorized under high head lifts. This device may be operated singly or in multiples of two or more working simultaneously (Michael, 1978).

Since 4000 BC, various inventions had been carried out and that time water power was used for irrigation in Mesopotamia. In 2500-2000 BC, “Shaduf” or “Shadoof” was the first water lifting device invented by Minoans and Egyptians respectively. Shaduf was the simple concept. It was a wooden hand-operated device used for lifting water from a well, a river, a cistern or a canal. It was a hand operated device for lifting the water invented in ancient times India and still used in India, Egypt and some other countries to irrigate the lands. The series of shadufs were sometimes mounted one above the other. A typical water lifting rate was $2.5 \text{ m}^3/\text{day}$. A single shaduf could thus irrigate 0.1 ha of land in 12 hours. The Mesopotamians were known to lift water using the shaduf at around 3000 BC (Yannopoulos *et.al.*, 2015).

As the development progressed, various devices were invented in 800-200 BC viz. Persian shaduf, mohte, Persian wheel, zawafa, sakkia and Persian Noria. Persian wheel or *Rahat* requires one pair of bullocks or buffaloes or single camel and one man for their operation. This was animal drawn device and having optimum lift ranging from 5-10 m. Afterward the invention of water screw was done by famous Syracusan scientist Archimedes in 287-212 BC. Then various devices like force pump, chain pump and waterwheel with pots attached or compartments for the water were invented between 300-200 BC having particular discharges and lifts according to their design characteristics, performance and adaptabilities (Michael, 1978).

Some popular devices are widely used since ancient era. The historical development wasn't stopped there by developing such devices. Also, in 1200 AD, Chinese invented windmill for the irrigation. Furthermore, in 1698 AD, Thomas Avery invented a pump that operated on steam to create a vacuum to draw the water. Then in 1580, Sliding vane pump invented by Ramelli and then invention of gear pump, piston vacuum pump was done in 15th and 16th centuries by Serviere and Otto van Guericke respectively.

Now days there are various type of electrical or fuel operated pumps available in the market. Initial costs of these pumps are too high that average farmer cannot afford but then also at present there is no any option to this as the farmers buying these pumps to irrigate their fields. However, still there is serious problem in hilly terrain and in tribal areas where availability of energy is the problem to lift the water from lower elevation to the higher elevation to irrigate their fields. Also, they require skilled labours for installation. Some regions having shortage of electricity, pumps

couldn't have utilized there. These pumps require regular maintenance. Fuel supply and sites of installation are not easily accessible. During monsoon season, many times chances of electricity failure occur, that time pumps couldn't utilized. Even for the available indigenous water lifting devices, they require animal or human power for their run. Some indigenous devices are complex in nature, so construction of such devices is too lengthy and found to be very difficult. Some devices require skilled manpower for their operation so again labour charges come in existence. Even after installation of such devices, they do not give regular supply of water (Mohammed, 2007).

In Konkan region, many perennial rivers are flowing from hilly terrain to the ocean through gulf. Major area of this region is not easily accessible. Frequent problems of the electricity failure and fuel supply arise during monsoon and other seasons. The Konkan region is having 10% of the total geographical area of the state but receives about 46% of the total precipitation (Mahale *et.al.*, 2017). Most part of the precipitation gets converted to surface flow and some part infiltrates into soil. Konkan region has lateritic soil of high water draining capacity. It drains out the water very quickly. Most critical problem occurs during the monsoon season is the availability of energy or electricity. Stakeholders possessing various pumping accessories but due to unavailability of the electricity during heavy monsoon; they could not even fill their overhead tanks. Also, there are many rivers in Konkan which are freely flowing perennially.

Hence, the design and development of the energy free low weight and low cost device which can only operate by naturally available elevation head either of sloping land or rooftop and lift the water to utilize it either to irrigate or to fill the overhead tanks placed on the rooftop was felt necessary. Similarly, the device has to be locally manufactured by using available materials. So, to overcome above given limitations, it was felt necessary work on “Design and Development of Cost Effective Energy Free Water Lifting Device” which requires no any external energy or any type of fuel for its run and which will lift the flowing water from lower elevation to the higher elevation to fulfill the domestic need during monsoon and immediately after monsoon by using the velocity head of the flowing water itself with the following objectives:

1. Survey and study of different types of water lifting devices available in the market.
2. Design and development of cost effective energy free water lifting device.

3. Performance evaluation of developed energy free water lifting device.
4. Cost analysis.

II. REVIEW OF LITERATURE

This chapter deals with review of literature related and relevant to the title and objectives of the present study. This chapter describes the different water lifting devices including some indigenous lifts and the devices which requires no any external energy or fuel to lift the water and to fulfil the title of the present study and accordingly the objectives. The review is broadly classified in four section and these are:

2.1 Survey and study of different types of water lifting devices available in the market.

2.2 Design and development of the energy free water lifting device.

2.3 Performance evaluation of the energy free water lifting device.

2.4 Cost analysis.

2.1 Survey and study of different types of water lifting devices available in the market

It was necessary to know what type of different devices are already available in the market. Also, it is required to survey and study of such devices. It will help to overcome with all the limitations of previously used devices and will help to design perfect energy free water lifting device is described in this section.

Anonymous (2008) described the various types of the handpumps powered by human or animal. They said that the hand pumps are capable of lifting relatively small amounts of water from depths of up to 100 meters. Further they said that they are widely used in places where access to other potential water pumping power sources is constrained; where financial resources available for the investment, operation and maintenance are limited; and where there is a relatively limited domestic water requirement. They found that hand pumps are relatively easy to install and simple to operate making them one of the most commonly used water-lifting technologies.

Lashofer *et.al.* (2012) studied the Archimedean screw turbines, its technology and design guidelines. They said that Archimedean screw is being used for power generation for more than one decade. They also revealed that compared to other turbines, ultra-low head technology is still a niche product. They said that presented work includes a site inquiry, an operator survey, comprehensive field measurements, and extensive laboratory tests. From that, they assess the prevalence of the turbine, its application, operational experiences as well as design alternatives and design

guidelines. They said that specific investment costs range from 0.5 to 2 €/kwh and operating costs are comparatively low due to a wide screen spacing and the general robust structure. Therefore, they found the mean plant efficiencies were 69% and the six top-performing plants achieved peak efficiencies above 75%. They evaluated the concept of rotary screw turbine. They obtained the maximum efficiencies up to 94%.

Zaman *et.al.*, (2012) performed an analysis, evaluated and systematically represented the techniques of a low head micro hydropower system using a fixed water source and designing of a water wheel for the system. They said that the system makes use of a fixed amount of water stored in a lower reservoir after circulating through the turbine. They chose a water wheel as a turbine for the system. They mainly focused on design and construction of a water wheel suitable for the micro hydropower site. After study, they found that water wheels have been known since antiquity. Further they revealed that with the industrial revolution, hydraulic sciences were developed and new materials such as wrought iron became available allowing for a rational analysis and improved strength and geometry of water wheels. They conducted a detailed study of the available literature covering the engineering design of water wheel. They said further after studying reviews that the design of water wheel was dominated by the requirement for a geometry which would minimize losses, and retain the water as long as possible in the machine. At the end, they calculated the theoretical output power for a range of water flow and a graph has been plotted using the relevant values.

Kadlowec *et.al.*, (2013) modified the rope pumps to reach greater depth in Gambia. They said that the design criteria were to develop an affordable, easy to use rope pump that could be used to pump water from a depth of 30 m to a storage tank 5 m above ground with a constraint of human power by a single operator. They use MATLAB software for the design of the pump. They conducted the experimental tests and further they compared the results to theoretical predictions. They revealed that experimental results for flow rate were within 3-18% of predicted values. To meet the client's needs, they determined that a rope pump with 1.27 cm (0.5 in) diameter piping, two pistons per meter, and a belt drive with gears of ratio of 1.5:1 to increase the torque could raise water 35 m using operator under human-power. Additionally, they briefly investigated and discussed the alternative forms of power that would be available to the region as potential future work.

Waghmare *et.al.*, (2013) designed and developed the gravity assisted free energy pump. They inferred that pump did not require electricity and also not so much hard work to lift the water. They stated that it is very simple in construction and also it is very easy to handle that device. Further they described that anyone can operate that gravity assisted free energy pump. From their study it is revealed that it is very useful not only in the hilly area where electricity was not available but also the best option for farmer which were economically backward and those people who wanted the pump which was free from electricity. From the trials, they concluded that the water can be lifted with the less effort and any human could easily operate.

Maw *et.al.*, (2014) worked on the hydraulic ram pump. They found that the ram pumps were water pumping devices that were powered by falling water and no other energy needed to operate it. They designed hydram which was intended to pump the water of 1800 liters per day and to lift 15 m of delivery head. Based on the design they worked out drive pipe length was 7.2 m, supply head was 1.2 m, power was 3 W and efficiency was 48.85%. The total cost of hydram was relatively cheaper than the other type of pumps and easy to install and maintain. Furthermore, they concluded that the development of the hydraulic ram pump that would conventionally alleviate the problem of water supply to the mass populace. They tried different combination of supply and delivery heads and flow stroke length, and weight of impulse valve, length to diameter ratio of the drive pipe with an optimum size of a hydram pump in their study. They found that designed hydram could lift only small amount of water but many hydrams could be installed in parallel to pump large amount of water. Also, they inferred that installations of many hydrams were better than installation of one large hydram because large hydram needed higher supply head than many small hydrams, and they additionally concluded that parallel installation method of hydrams can provide ease of maintenance and reduce transportation and installation costs.

Sethi *et.al.*, (2015) evaluated the performance of hydraulic ram pump with rain-cum-roof water harvesting structure in a hilly terrain of North East of India. According to their observations they inferred that the people living in the hills face difficulties in raising crops to meet their daily needs due to lack of assured source of water and energy. They installed and maintained the conventional pumping systems using diesel or gasoline or other forms of energy such as solar or electrical driven pumps were usually unaffordable for poor, remote communities living in the North

East of India. To address this issue a field experiment was conducted in a hilly terrain of Assam University, Silchar to install a hydraulic ram pump with constructed polyethylene lined rain-cum-roof water harvesting structure of 26500 liters capacity and 2 m depth and evaluated the pump performance for the on-site feasibility. A hydraulic ram pump (50 mm × 25.4 mm) was installed by them in the experimental site for the land slope of about 26.39 %, drive head of 4.05 m and inclined drive pipe length of 9 m and the performance of the ram pump were evaluated with varying delivery heads. They found the highest discharge (35.395 l/min) at 2 m head from the source i.e. 1.5 times from the pump and the minimum discharge (3.563 l/min) was observed at 15 m head (i.e. 3.75 times from the pump). They found the highest efficiency of the ram pump (65.81%) at 9 m delivery head from pump or 5 m head from the source and lowest efficiency (17.17 %) at 15 m head from the source (i.e. 3.75 times from the pump). Hence, they found that it was feasible to lift water from the water source to 2-3.75 times from the level of pump for feeding overhead reservoir used for drip irrigation system in the hilly terrain. Thus, ultimately, they inferred that the hydraulic ram pump was the only alternative for the people living in the hilly terrain who were either inaccessible to energy sources like electricity and fuel and or unaffordable for it.

Diwan *et.al.*, (2016) used the Montgolfier design in which water supply or delivery pipe fed into a larger bored pipe that was turned up at the end and also necked down creating both a pinch point and a venturi effect causing the water to increase in speed and pressure at the exit. They used iron ball or cannon ball which would fit easily into the larger bored pipe but was larger enough that it could not escape out the venturi at the end of the pipe. They found that the force of the water flowing into the larger bore pipe would push the “cannon” ball down the bore and into the venturi suddenly stopping the flow of water. This sudden blockage of the delivery pipe would cause a dramatic increase in the water pressure behind the ball commonly referred to as “water hammer” which in turn forced a small amount of water through a one-way valve and into the air chamber and delivery pipe. The pressure would then dissipate and release the iron ball, it would roll back into the larger bore area and the cycle would begin all over again. In operation the water would have been delivered in short pulses under high pressure into the air chamber which would act as a buffer, smoothing out the supply of water heading into the delivery pipe and on its way to the

intended destination. From the principle, they revealed that addition of the snifter valve allowed a small amount of air to enter into the air chamber keeping the system operational for much longer periods of time between normal inspections and servicing.

Gilbert *et.al.*, (2016) studied the various water lifting devices including the rope and bucket lifting device. They found that rope and bucket lift was the water lifting device mainly used with hand-dug wells. They said that when a bucket on a rope is lowered into the water, it hits the water it dips and fills and is pulled up with the rope. They further said that animal traction is used in combination with a pulley sometimes. They said after study that improved systems use a rope through a pulley, and two buckets one on each end of the rope. They revealed that for water less than 10 m deep, a windlass with a hose running from the bottom of the bucket to a spout at the side of the well can be used. Finally, they observed that the hygiene of that system is poorer, even if the well is protected. Thus, they said that there is need to clean the environment nearby the well.

Ghosh *et.al.*, (2018) revealed that ram pump had practically no running cost and needed minimum maintenance and was simple in construction which fulfilled the required specifications. They also found that it could provide isolation village with water and as a replacement to generator driven pumps that were used by farmers to water their lands. Their study represented the analytical calculation of homemade hydraulic ram pump with design calculation. These were based on a study of hydraulic ram pump and testing of on hydraulic ramp pump model. For which they considered literatures reviews & some of them were used for the analytical calculations. After elaborating the design, dimensioning and calculations were done and the final design was constructed. The model was tested and checked thoroughly for its working. All aspects were kept in view, efficiencies plotted and optimization& analysis of the result was done. They studied the relation between efficiency, head & discharge which was modify the hydraulic ram pump. From their study, they observed that with the increase of delivery head, delivery discharge and efficiency was found decreasing. They also found that when the delivery pipe diameter was decreased compared to supply pipe diameter, the supply head and efficiency of the Hydrum was increasing. They also observed that with the increase of supply head, the delivery head and performance of the pump was increased.

Viccione *et.al.*, (2018) investigated about the hydraulic ram on primary level. After investigation they inferred that the nexus of food, energy, and water was one of the most complex issues that face society. Their experimental results of a preliminary investigation carried on a hydraulic ram pump assembled at the Laboratory of Environmental and Maritime Hydraulics of the Department of Civil Engineering, University of Salerno, Italy showed that geometric parameters as well as material properties affect its operating efficiency. The effect of the impulse valve on the pressure temporal trend was assessed by processing video recordings taken with high-speed digital cameras with a sampling rate of 1 KHz. Most of its effect was produced when the percentage of valve opening was in the range 0–20%, where correspondingly the valve coefficient K_v varied of about 80%. Unsteady pressure profiles were detected by means of pressure transducers with an acquisition of up to 1 kHz. They finally came to conclusion that the existence of a family of transient shock waves which intensity depends on the system's features.

Asvapoositkul *et.al*, (2019) assessed the possibility of using a hydraulic ram pump as a means of utilizing its energy to produce high head for pump after the determination of its performance. The performance was presented in dimensionless terms as the head ratio H or discharge head to drive head and flow-rate ratio Q or discharge flow rate to drive flow rate. They conducted an experiment on hydraulic ram pump by varying each of the following factors independently: (a) supply head, (b) air chamber pressure and (c) waste valve beats per minute. They found that increase in the supply head tended to increase the supply flow rate, delivery flow rate, delivery head, and the overall efficiency of the pump. And again, they inferred that an increase in air chamber pressure tended to decrease the overall efficiency of the pump. However, there was no significant difference on the HRP performance over a wide range of flow conditions when air chamber pressure was varied. They found an increase in waste valve beats per minute tended to decrease the supply flow rate, delivery flow rate and delivery head. But it tended to increase the head ratio, the flow rate ratio and the overall efficiency of the pump. They further revealed that the HRP characteristics were the functions of the waste valve beats per minute and the supply head.

Sr. No.	Name	Year	Location of research	Device or Method used	Remark
---------	------	------	----------------------	-----------------------	--------

1.	Anonymous	2008	-	Different types of handpumps	Range of lift is up to 100 m and costs of the handpumps is too high.
2.	Lashofer <i>et.al.</i>	2012	University of Natural Resources and Life Sciences Vienna (BOKU) and survey carried out in different countries	Archimedean screw turbines	Can be used for power generation.
3.	Zaman <i>et.al.</i>	2012	University of Dhaka, Bangladesh	Waterwheel	It can be used in design of low head micro hydropower system
4.	Kadowec <i>et.al.</i>	2013	The Gambia	Rope pump	Range of lift up to 30 m or more than 30m and a belt drive with gears of ratio of 1.5:1 to increase the torque.
5.	Waghmare <i>et.al.</i>	2013	RM CET, Devrukh	Gravity assisted free energy pump	Water lifting is possible with less effort. Useful in hilly terrain, heavy rainfall area, tribal area and where the electrical energy is not available.
6.	Maw <i>et.al.</i>	2015	Mandalay Technological University, Mandalay, Myanmar	Hydraulic Ram Pump	Parallel installation is better than that of one large ram.
7.	Sethi <i>et.al.</i>	2015	Assam University, Silchar	Hydraulic Ram Pump	Hydraulic ram was feasible to lift water from the water source to 2-3.75 times from the level of pump for feeding overhead reservoir.
8.	Diwan <i>et.al.</i>	2016	-	Hydraulic Ram Pump	Addition of the snifter valve allowed a small amount of air to enter into the air

					chamber keeping the system operational for much longer periods
9.	Gilbert <i>et.al.</i>	2016	-	Rope and bucket lift	Water can hardly lift up to 15m and also poor hygiene.
10.	Ghosh <i>et.al.</i>	2018	Durgapur Institute of Advanced Technology & Management, West Bengal	Hydraulic Ram Pump	i) Increase of delivery head causes decrease of delivery discharge and efficiency. ii) Delivery pipe diameter was decreased compared to supply pipe diameter, the supply head and efficiency of the Hydram was increasing. iii) Increase of supply head, the delivery head and performance of the pump was increased.
11.	Viccione <i>et.al.</i>	2018	University of Salerno, Italy	Hydraulic Ram Pump	The effect of the impulse valve on the pressure temporal trend was maximum when valve opening was 0-20 %
12.	Asvapoositul <i>et.al.</i>	2019	King Mongkut's University of Technology, Thonburi.	Hydraulic Ram Pump	HRP performance depends on waste valve beats and supply head provided.

Critique of reviews:

It is revealed from study that many scientists had surveyed and studied the energy free water lifting devices which were hydraulic ram pumps and one has gravity assisted free energy pump. They noted down working of different devices. From these reviews, some limitations regarding working, operating pressure and costing was observed. For operating these systems required special skills. Considering, above fact and research carried out up to date, it felt necessary to

overcome limitation of the available energy free water lifting device to reduce cost of the device and make system user friendly, so that normal person can operate it. Secondly, it should lift the water during monsoon to fulfill the overhead tanks. Therefore, experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” is proposed.

2.2 Design and Development of the Energy Free Water Lifting Device

It was necessary to know what type of different devices are already available and their design methodology as well as their design hypotheses. The work done by the earlier scientists on design methodology of energy free water lifting devices is described in this section.

Filipan *et.al.*, (2003) presented the mathematical modelling of a hydraulic ram pump system and explained the simplified working cycle of its action. They found the flow in the HRP system was unsteady; therefore, unsteady pipe-flow equations and the method of characteristics were given. They described the mathematical modelling of particular components of the HRP system. The drive and delivery pipes were modelled by a fixed grid method of characteristics and the supply and delivery tanks were the boundary conditions open reservoirs with a constant water level. Then HRP was modelled as a unit boundary condition describing the physics of its action by them. That boundary condition consists of 11 equations with 11 dependent variables and they solved equations by an iterative procedure for each time step of the computational run. Their derived model was programmed for a digital computer. They finally made a computer simulation using input data from the literature. They presented the results in the form of pressure and velocity vs time graphs.

Verspuy *et.al.*, (2010) worked on the mathematical calculations of the hydraulic ram. In their study, they found that operation of hydraulic ram system simulated with using water hammer theory. The operation of hydraulic ram installation was analyzed by considering the pressure occurring in the drive pipe. The hydraulic ram, being the source of the pressure waves was modelled as instantaneous opening and closing of two massless valves. The model showed its usefulness in a parameter variation study. They concluded finally that the pressure wave speed and friction factor were varied accordingly and the main effect of both variations was in the duration of pumping cycle which was of importance of the performance of the ram.

Sheikh *et.al.*, (2013) studied the design methodology of hydraulic ram. They inferred that the availability and cost of electric power was a great concern to common man. They also stated that conventional energy was also a great concern for environment. Therefore, more attention of designers was diverted towards use of unconventional energy or other forms of energy than convention energy. Water pump was of a more utility item. Furtherly, they said that the hydraulic ram pump was the mechanical pump which runs on kinetic energy of flowing water. According to them, though the pump was in use since long, it was not seen in common forms for lots of its performance limitations. That type of pump was a blessing to rural areas, farmers and middle class for its zero-running cost. They studied the literature available aimed to present generalized design methodology for hydraulic ram pump covering design parameters, design procedure along with the mathematical relationship used for the design work. They mathematically calculated the efficiency of the hydraulic ram pump and produced suitable design of the hydraulic ram pump.

Balgude *et.al.*, (2015) described the techniques and guidelines to successfully install the modern hydraulic ram pump. They used proposed technique which illustrated the methodology that could be used for the primary design considerations and applications in various ways. They provided the method by means of continuous water supply. They used the basic principle of working was ramming action of air inside pressure vessel. They revealed that hydraulic ram pump played an important role in areas which were not connected to national electricity grid. They concluded if this type of pump be utilized that it would greatly solve water problems for agricultural as well as domestic purpose.

Choudhary *et.al.*, (2015) had presented the basic concepts of hydram and analytical calculation using individual head losses of hydram with the related search. Their study specified individual head losses influencing the efficiency of the hydram. These were based on a systematic study of the all parameters affecting the hydram. Design of hydram was acceptable for the general uses. Considering individual losses, they found that the performance of hydram flow was drastically affected. They inferred that it will help to predict losses in complete working system which results they would try to minimize the losses in curve.

Inthachot *et.al.*, (2015) installed and studied the hydraulic ram in the stream. They allowed it to run continuously first for six and then eight weeks and then failure

was caused by heavy rain. It was running continuously first for six weeks. They revealed that as there was no professional strainer used, a lot of debris was present in the pumped water. Again, they found that the ram itself was not influenced by that and it was delivering about 1.3 liters per minute at a wastewater flow of about 6.25 liters per minute. They finally revealed that with the given supply and delivery head of 3.5 m and 9 m, that results in an efficiency of about 44%. Altogether they inferred that the hydraulic ram represented a good alternative to conventional pumping devices with lower initial financial effort.

Deo *et.al.*, (2016) designed the ram pump and worked on its methodology. They inferred that the hydraulic ram pump was simple in design but it not implemented in the remote areas of India despite of its low cost. So, they have decided to come up with the design methodology. They said that there were lot of problems they have faced during calculations and in the actual performance and then it gave the rough idea of proceeding to the calculations. They designed the hydraulic ram pump using dimensions and they were getting the efficiency up to 60 %. There were various types of losses and leakage problems that they have gone through but the problem was solved by using the PVC solvent which they have used. They found that the size of air vessel played vital role in the design of the hydram. Also, they revealed that the design of waste valve was also very much importance in that aspect too.

Girish *et.al.*, (2016) designed and fabricated the water lifting device without electricity and fuel. They stated the availability and cost of electric power was a great concern to common man. After designing the ram, they found that an impulse pump was a device which uses the energy of falling water to lift water to desired height. Hydraulic rams were relatively economical to purchase and install. Hence, they said that one can built with detailed plans and if properly installed, it will give many trouble-free years of service with no pumping costs. For these reasons, they revealed that the hydraulic ram is an attractive solution where a large gravity flow exists. They also found that the supply head was important factor which decides delivery head as well as flow rate. They concluded after checking the performance of the ram, flow rate and delivery head can be increased by using contraction in drive pipe.

Kumar *et.al.*, (2016) designed and manufactured the pollution free hydraulic ram pumps for villages in hill areas. They found that the hydraulic ram pump was water-lifting device that was powered by falling water. They found that such pumps

worked by using the energy of water falling from a small height to lift a small part of that amount of water to a much greater height. Thus, they revealed that water from a spring or stream in a valley could be pumped to a village or irrigation scheme on the hillside. For that, they designed and manufactured the hydraulic ram pump of good quality and high performance with an efficiency of 63.3%. Then after, they inferred that the main and unique advantage of hydraulic ram pumps was that with a continuous flow of water, a hydraulic ram pump operates automatically and continuously with no other external energy source be it electricity or hydrocarbon fuel. After that, they concluded that all the advantages of hydraulic ram pumps made it suitable to rural community water supply irrigation in developing countries.

Pathak *et.al.*, (2016) concluded that the development of a hydraulic ram pump that would conveniently alleviate the problem of water supply to the mass populace. They tried the different combinations of the supply and delivery heads and flows, stroke length and weight of the impulse valve, length to diameter ratio of the drive pipe, volume of the air chamber and size of the snifter valve, etc. After trying different combinations, they finally designed an optimum size of a hydram pump and revealed that hydraulic ram pump was truly a blessing to the rural areas, farmers and middle class for its zero-running cost.

Sakhare (2016) designed and fabricated the automatic hydraulic ram pump by using principle of water hammering effect. According to him, a hydraulic ram pump was a simple, motor less device for pumping water at low flow rates. He further studied on it and stated that it uses the energy of flowing water to lift water from a stream, pond, or spring to, or lower elevation to the higher elevation (storage tank) or to a discharge point. He also stated that it was suitable for use in household, garden, water supply in hilly regions. Also, it was useful where the water source flows constantly. The overall cost required for fabrication of that hydraulic ram pump was less. He found that the pump gave 450 lit/hr water discharge for maximum efficiency of 41.25%. Pump gave 98 lit/hr water discharge for minimum efficiency of 18.65%. Therefore, he concluded that if the head ratio was taken approximately 2, it attained maximum efficiency and for increasing the efficiency, it had to minimize the head ratio.

Satyanarayana *et.al.*, (2016) designed a hydraulic ram pump powered by falling water. The developed model results showed that model simulated well. They

successfully fabricated and tested the hydraulic ram pump of good quality and high performance at Visakha institute of technology & science in Visakhapatnam. They developed and tested a proven and effective methodology to identify suitable sites for hydraulic ram use. Also, they tested a locally made hydram successfully. They were recommended that ministry of water and agriculture department to establish small scale water supply schemes using hydram pumps so that it would greatly solve water problems for agricultural as well as domestic purpose. Ultimately, they concluded that to disseminate hydrams at potential sites throughout the country, there is a need to create awareness through training and seek integrated work with rural community, government institutions like water, energy and mines bureau of local region and non-governmental organizations.

Gaikwad *et.al.*, (2017) designed a recycled hydroelectric power plant by using hydraulic ram pump to transfer tailrace water from turbine to water source which was situated at higher height, which used as supply water for electricity generation. Based on the calculations performed, they believed that hydraulic ram pump was the suitable and efficient application for the given conditions. For the first step of designing, they listed and understand all the related problems. Then, they developed the specifications, criteria and evaluated the solutions. They used most suitable operational working principals for the hydraulic ram pump (hydram), turbine generator, outline of the theoretical background behind the operation and its details calculations. From their present study, they concluded that performance of hydraulic ram pump depends upon length of inlet and delivery pipes, diameters of pipes, inlet and delivery heads, flow rate available at source. They also inferred that the parameters alter with change in site selected; that also affected the size of pump required.

Hussin *et.al.*, (2017) found that the current pumping system (DC water pump) for agriculture was powered by household electricity, therefore, the cost of electricity would be increased due to the higher electricity consumption. The aim of their project was to analyse and develop the water ram pump in order to meet the desired delivery head up to 3-meter height with less operation cost. They designed hydraulic ram using CATIA software. They simulated the work by using ANSYS CFX software to validate the working concept. For that, they tested three designs in the experiment

study. The best design reached target head of 3 m with 15% efficiency and flow rate of 11.82l

min^{-1} . From the study, they concluded that the less diameter of pressure chamber and higher supply head will create higher pressure.

Mondol (2017) revealed that pump in which the momentum of a driving stream of water undergoing a small head drop was used to pump a small portion of the stream to a head considerably greater than that of the supply. In his study, he designed, manufactured and tested a hydraulic ram. He found that the hydraulic ram pump worked perfectly. Altogether, he observed that if the water in the tank decreased, the time taken between strokes increased and the pump ceased to work and shortening the stroke increased the frequency of strokes. Thus, he concluded that a certain amount of water has to be maintained in the supply tank in order to pump water via the ram pump satisfactorily.

Arude *et.al.*, (2018) fabricated and tested the prototype of high performance and good quality of hydraulic ram pump. In that, they designed and operated the waste valve successfully. They designed the waste valve in such a way that it eliminates the need of retainer springs which were not available locally. They evolved and tested a proven and effective methodology to identify suitable sites for hydraulic ram use. They successfully developed and tested locally made device. From the study, they concluded that such type of pump was truly a blessing to the rural areas, farmers and middle class for its zero-running cost.

Nair *et.al.*, (2018) designed and developed a pump called hydraulic ram pump that delivered water to higher altitudes with the use of its kinetic energy at inlet and then converting it to pressure energy. They said that unlike other pumps, that pump was based on utilization of kinetic energy of water at inlet rather than simply being operated by an electrical supply. They inferred further that people could easily pump the water to high terrains without of use of any external supply. They used simple piping equipment and was adaptable to work in various areas. They found that the amount of water delivered at the outlet was comparatively low. But as the device didn't make use of an electricity, they inferred that the process was a boon in areas where water has to be pump to greater heights without use of electricity.

Ninawe *et.al.*, (2018) analyzed and experimented on the developed hydraulic ram. They recorded and structured the actual experimental data of developed hydraulic ram as per the design of experimentation. They done various planning for making formulation of standard modeling of parameters of hydraulic ram pump. They also identified the proper implemented path of the experimentation along with various dependent and independent parameters. Accordingly, they reduce the various variables using dimensional analysis, test planning, design of experimental set-up etc.

Rajaonison *et.al.*, (2019) studied theoretically the behavior of a hydraulic ram pump with springs. They invented a new type of hydraulic ram pump, called "Raseta pump." They afterword patented and crafted that pump in Madagascar. The peculiarity of that hydram pump over conventional ones was that there was a spring in each of the waste and delivery valves. In addition, they used the usual air balloon with replacement of a balloon with 4 springs. They theoretically studied the behavior of hydram pump equipped with a system of springs. For that purpose, they developed and coded a model associated with the studied hydram pump on MATLAB Software. Then, they carried a global sensitivity analysis for identifying the most influential parameters of the model while successively considering as the surveyed model outputs: the amount of wasted water, the amount of pumped water and the efficiency of the pump. As results, they found that most dominating parameters were relatively the same as that of previous works on the conventional hydram pump without springs: height of the water column in the delivery pipe, the height of supply tank, the weight of the waste valve, and the length of the waste valve stroke. They concluded finally that if one wants to have good results for each output independently, it was necessary to act on parameters were the same for the amount of pumped and lost water which were: the supply tank height and the supply pipe radius. For the efficiency of the pump, those parameters were: the length of the supply pipe from the source to the center of the delivery valve, the length of the supply pipe from the source to the center of the waste valve, and the slope of the hydram pump relative to the horizontal. They concluded further that for the balloon containing the four springs, it had no influence on the operation of the pump and balloon used to eliminate noise of the water hammer.

Sr. No.	Year	Name	Location of research	Device or Method used	Remark
---------	------	------	----------------------	-----------------------	--------

1.	2003	Filipan <i>et.al.</i>	University of Zagreb, Croatia	Hydraulic Ram Pump	Modeling of hydraulic ram characteristics on the unsteady pipe flow equations
2.	2010	Verspuy <i>et.al.</i>	Delft University of Technology, Delft, The Netherlands	Hydraulic Ram Pump	Simulated operation of the hydraulic ram pump with water hammer theory.
3.	2013	Sheikh <i>et.al.</i>	KDKCE, Nagpur	Hydraulic Ram Pump	Mathematical calculations of the efficiency.
4.	2015	Balgude <i>et.al.</i>	Smt. Kashibai Navale College of Engineering, Pune	Hydraulic Ram Pump	Studied ramming action of the air inside air chambers.
5.	2015	Choudhary <i>et.al.</i>	K.D.K.C.E, Nagpur	Hydraulic Ram Pump	Performance of ram was affected drastically with individual losses.
6.	2015	Inthachot <i>et.al.</i>	University of Hohenheim, Stuttgart, Germany	Hydraulic Ram Pump	Efficiency of the ram was found 44 percent at supply and delivery head of 3.5 and 9.0 m respectively.
7.	2016	Deo <i>et.al.</i>	Dr. Babasaheb Ambedkar College of Engineering and Research, Wanadongri	Hydraulic Ram Pump	Air vessel and waste valve plays vital role in the design.
8.	2016	Girish <i>et.al.</i>	MITE, Moodabidri, VTU, Karnataka,	Water Lifting Device without Electricity and Fuel	Flow rate and delivery head can be increased using contraction in the drive pipe.
9.	2016	Kumar <i>et.al.</i>	Wollega University, Ethiopia.	Hydraulic ram pump	suitable to rural community water supply irrigation in developing countries.
10.	2016	Pathak <i>et.al.</i>	Dr. Babasaheb Ambedkar College of Engineering	Hydraulic ram pump	Blessings to middle class family.
11.	2016	Sakhare	Sahakar Maharshi Shankarrao Mohite-Patil	Hydraulic Ram Pump	If head ratio is approximately 2, ram attains maximum efficiency.

			Institute of Technology and Research, Akluj		
12.	2016	Satyanarayana <i>et.al.</i>	Visakha institute of technology & science, Visakhapatnam	Hydraulic Ram Pump	Disseminate the hydraulic ram at potential sites throughout the country.
13.	2017	Gaikwad <i>et.al.</i>	G.H.Risoni College of Engineering and Management, Ahmednagar, Maharashtra.	Hydraulic Ram Pump	Performance of the HRP depends upon length of inlet, delivery pipe, diameter of pipe, flow rate, inlet and delivery heads.
14.	2017	Hussin <i>et.al.</i>	University Malaysia Perlis, Malaysia	Hydraulic Ram Pump	Less diameter of pressure chamber and higher supply head creates high pressure.
15.	2017	Mondol	Heritage Institute of Technology	Hydraulic Ram Pump	Certain amount of water level maintained in the supply tank to run the ram.
16.	2018	Arude <i>et.al.</i>	Jaihind Polytechnic, Kuran, Maharashtra, India.	Hydraulic Ram Pump	Worked on suitable sites for hydraulic ram.
17.	2018	Nair <i>et.al.</i>	Hindusthan Institute of Technology, Coimbatore.	Hydraulic Ram Pump	Use of kinetic energy of water to lift it to the higher elevation.
18.	2018	Ninawe <i>et.al.</i>	KDKCE, Nagpur	Hydraulic Ram Pump	Analysis of the data with various dependent and independent parameters.
19.	2019	Rajaonison <i>et.al.</i>	University of Antananario, Antananario, Madagascar	Hydraulic Ram Pump	Provided information about new technique with spring and balloon system.

Critique of the reviews:

In this section of design and development of energy free water lifting revealed is that many scientists had worked on design of the hydraulic ram pump based on the drive-delivery ratio, waste valve construction, design of the waste valve, air chamber design, pressure chamber working, working of waste valve, strokes of the waste

valve, analytical calculations of the hydraulic ram pump, design methodology of the hydraulic ram, diameters of the supply pipe, diameters of the delivery pipe, weight of the waste valve, lengths of the pipes, volume of the air chamber, designing of the components of the hydraulic ram, etc. Designing of the hydraulic ram found comparatively complex procedure. Also, the material required for its designing is not easily available local market and it is expensive too. Also, sometimes it may require skilled labors for the installation of the hydraulic ram. Most of researcher had work on the weight of the waste valve design but it is not possible to run the device 24 hours, because operation of waste valve may stop after the excess pressure created in the system or when there found if small amount of leakage. And again, its construction cost is becoming high considering all the fabrication process and installation accessories. Considering above fact and research conducted to date, it was felt necessary to surmount limitations of the water lifting device to get the proper delivery discharge and will continuously run 24 hours whenever giving the starting torque which results in continuous supply of the water to the fields. Secondly, to overcome with the high cost of the device and to make system user friendly the experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” is proposed.

2.3 Performance Evaluation of the Energy Free Water Lifting Device

It was felt necessary to know the performance evaluation of different energy free water lifting devices. Hence the work done by the earlier scientists on the performance evaluation of energy free water lifting devices is described in this section.

Abate *et.al.*, (2002) tested the performance of ram. They inferred that the recent conventional energy crisis was leading to the exploration of alternative energy sources. And thus, the pumping of water using ram pumps was widely used in farms where electric energy was scarce or inexistent. They evaluated the performance of a hydraulic ram pump utilizing two kinds of supply pipes (PVC and steel) using three different supply heads (2.1m, 3.8m and 4.7m). They utilized the delivery head, delivery discharge, waste discharge and supply head to calculate the yield of the hydraulic ram by the equation of D'Aubussion. They obtained the maximum yield of the hydraulic ram for the PVC pipe for the 4.2 m head. And further they found the steel pipe was more efficient for heads higher than 4.2m.

Maratos (2002) checked the technical feasibility of wave power for seawater desalination using the hydro-ram. For that phenomenon, he referred the effect of water hammer could be used to create the pressure required for reverse osmosis of seawater. He concluded in the subsequent paper that it could achieve the significant cost savings as well as eliminating the need to burn fossil fuel energy for seawater desalination. It was necessary to investigate the theoretical feasibility of using hydro-ram for that purpose. A major question was whether the hydro-ram can pump the large quantities of seawater required for desalination. Thus, he reviewed the literatures in respect of the various designs and especially large designs and the theories of its operation. And then he identified the formulas for determining the output of a particular size of ram. He considered the seawater corrosion also. Then after reviewing all the necessary information he finally concluded that the system was both economically and technically feasible for that simple piece of apparatus to be used for the desalination of seawater.

Cararo *et.al.*, (2007) tested the hydraulic ram. They performed the tests at the Hydraulics Laboratory of Universidade Federal de Lavras - UFLA, Lavras, to evaluate a hydraulic ram pump built with PVC and metallic threadable connections, and a bottle made with polyethylene tereftalic. They tested the manufacturer features were: bottle size (0.6 and 2.5 L), hole size of the bottle top (5, 15 and 25 mm), bottle models (disposable and returnable) and valve positions (horizontal and vertical). They used the operational hydraulic head 4.36m and the simulated pump elevation pressures 48.39 to 483.92 kPa and 48.39 to 48.39 kPa. They found the best efficiency, the highest pumped water flow, the lowest operational water flow and the lowest waste water flow using the 0.6 L PET disposable or returnable bottle with horizontal valve position and top size of 25 mm.

Nnene *et.al.*, (2009) designed and constructed water conservation system and afterward checked its performance. They presented an automatic hydraulic system for grey water reuse. The developed system was a self-acting and almost perpetual working device which worked on the modified principles of the hydraulic ram it conserved water by recycling grey water through a sand filter and pumps it back to the water closet for reuse in flushing. They designed a system fit into the standard domestic bath found in most homes. They obtained results that the system was highly efficient and needed little or no maintenance over a long period of time with two

valves as the only moving parts. They hoped that the new system would ultimately solve some of the water problems encountered in the third world. They found some problem of supply and distribution of potable water in the world was highlighted with particular concern for the third world. They identified the water conservation as a major solution to this problem. Therefore, they designed a cheap and efficient domestic water conservation system and also inferred that the system was applicable to daily domestic living and would solve the problem mentioned.

Yang *et.al.*, (2014) tested the hydraulic performance of a novel hydraulic ram pump. They found that the hydram was a self-operating water-lifting device without other external energy, such as electricity and fossil fuel. They found the structure of a hydram body affected not only its appearance and weight, but also its hydraulic performance. They presented a novel design of the hydram body. The novel hydram body consists of a straight tee, a 90° diameter elbow and a diffuser. They not advised conical diffuser, because that leads to the asymmetric pressure distribution on the waste valve disc. They recommended the diffuse angle α is recommended between 25° and 90°. They compared it with the traditional hydram, the novel hydram body was more compact in structure, lighter in weight and less in the composite resistance coefficient. In the same material and composite resistance coefficient, they found that the weight of the new body was only about 1/ 2 times as great as that of the tradition body. From the tests for 100mm new hydram, they concluded that the supply head was 2.0m to 2.2m and the waste flow Q is 3.8 l/s to 2.0 l/s and the delivery head increases from 5.6m to 101.1m, then the efficiency η ranged from 63.9% to 26.9%; when $h < 50\text{m}$, $\eta > 53\%$.

Mbiu *et.al.*, (2015) worked on the performance testing of hydraulic ram pump. They tested for the different supply heads, delivery heads, stroke frequencies and weights on the waste valve in order to come up with an optimum size of a hydram pump. They found that the performance of the hydram was dependent on the drive head during the testing. They also noted that the optimum weights for maximum discharge at the maximum frequency. They afterword inferred that such type of hydram required at least a drive head of 0.5 m which was capable of pumping to a head of 4 m. The waste valve and discharge valve were only two moving parts and required replacement of the rubber in between due to wear and tear. They used recycled aluminum alloy which absorbs most of the noise produced in the waste valve

and the air chamber unlike hydrams fabricated from steel. Further, they highlighted on design and development of a durable and locally made hydram using inexpensive and readily available materials. For that they also fabricated the test rig and used to analyses the different parameters of the hydram. Optimizing these parameters, they ensured that the hydram performance was enhanced and as a result giving the pump a longer life. The testing projected to solve major problems encountered in the operation of the hydram i.e. tuning of the valves for best performance of the pump. Experimental and analytical modelling results were generalized in They compared performance charts to commercially available types operating characteristics. They concluded that these results will enable targeted users to be able to select appropriate sizes for their water pumping needs.

Shende *et.al.*, (2015) did the analysis on the hydraulic ram pump using Computational Fluid Dynamics (CFD). During their study, they presented the paper on the analysis of the hydraulic ram pump performance using computational fluid dynamic (CFD). Their study specified that mass flow through the waste valve of hydram was more, so to reduce it an enhancement was done and a new design was created. These were based on a systematic study of hydraulic ram pump and testing of on hydraulic ramp pump model. For which they considered literatures reviews & some of them were used for the analysis. Using CFD, they did the analysis of existing model and enhancement model. They found that the mass flow rate through the waste valve was comparatively less in enhancement model as compared to existing model. They revealed that the new design was good to get higher output as compared to the old model of hydram. They observed that the new design of hydram had gave better performance than the old one.

Carvalho *et. al.*, (2016) tested the performance of the hydraulic ram. They concluded that hydraulic ram was a device that makes use of the energy of a “water fall” to raise part of the water flow to a higher elevation by merely using the energy of the water hammer. And also said that even though a small water volume was compressed, the device may be a solution for water supply on family farms, for home use, animal drinking troughs and watering of vegetables. Their current study evaluated the performance of a hydraulic ram constructed with disposable bottles replacing the conventional air chamber model made of cast iron. Experiment was conducted at the College of Agronomic Sciences in Botucatu SP Brazil. Equipment’s

They assessed the performance by employing different volumes of air chambers (0.25; 0.6; 1.0 and 2.0 L) at the following pumping pressures: 70, 105, 140, 175, 210 and 245 kPa. They found that 0.6 and 1.0 L bottles possessing higher pressure flow.

Grygo (2016) studied the effect of the height of the delivery water on performance of water ram. He defined the mathematical relationship that allowed determination of the impact of the height of water (h_c) on the performance (V_c) of water ram. He analyzed the results obtained during the performance of the test. Then he determined the equation of variation of functions for each specified of height of delivery. He found that the first model ($h_c = 5$ m) was the most suited (99.66 percent of the explained variations) while two other models had proved to be well matched (94.69 and 98.06 percent of the explained variations). In first case, he observed the average height of water delivery (h_c) equalled 11.5 m the performance was 1.81 $\text{dm}^3/180\text{s}$. From the obtained mathematical data (regression equation) showed that by increasing the height of water delivery by 1 m reduced the performance about 0.7296 $\text{dm}^3/180\text{s}$ and would be equal to 1.08 $\text{dm}^3/180\text{s}$. In second case, he found the average height of water delivery (h_c) equalled 12.0 m the performance was 1.77 $\text{dm}^3/180\text{s}$. From the obtained mathematical dependence (regression equation) it showed that by increasing the height of water delivery by 1 m it would reduce performance of 0.4835 $\text{dm}^3/180\text{s}$ and would be equal to 1.29 $\text{dm}^3/180\text{s}$. Again, in third case, he found that the average height of water delivery (h_c) equalled 9.0 m the performance was 2.15 $\text{dm}^3/180\text{s}$. From the obtained mathematical dependence (regression equation) it showed that by increasing the height of water delivery by 1 m it would reduce the performance by 0.5358 $\text{dm}^3/180\text{s}$ and would be equal to 1.62 $\text{dm}^3/180\text{s}$. So, he concluded that as height of delivery increases, performance of the device was reduced.

Hamid *et.al.*, (2016) tested the performance of ram pump system which was developed to be applied in Kampung Sungai Dua Olak, an indigenous people settlement situated in Bentong, Malaysia, for the establishment of a sustainable rural water supply system. They aimed to be replicated across other rural communities in the tropical region. Their paper started by drawing the framework for sustainable low-cost water supply system, followed by demonstrating the methodology, testing setup, and the results of a series of seven ram pump performance tests. They found that ram pump could perform under different variations of water sources parameter. At the

laboratory scale, they found that ram pump had its potential to provide an alternative means of water supply delivery system though not as efficient as conventional supply. Throughout the study, they found the prototype ram pump was able to perform under different variations of water sources parameter. At the laboratory scale, they observed that the ram pump was found to be potential in providing an alternative means of water supply delivery system though not as efficient as conventional supply. However, they revealed that it will functioning as a sustainable water supply system for rural communities depended very much on issues other than technical and design consideration.

Lee *et.al.*, (2016) conducted the study to evaluate the applicability and efficiency of water supply using hydraulic ram pump. Study area was the Imgok-ri, Hwanam-myeon, Sanju-si, Kyeongsangbuk-do. There was an abandoned coal mine, where groundwater was discharged from its entrance with a flow rate of approximately 260 m³/day. They measured the flow rate to determine the efficiency of hydraulic ram pump at three points according to the altitude difference ($\Delta h = 19$ m (point 1), 30 m (point 2), 40 m (point 3)). They measured the flow rate at 1, 2, and 3 were about 8.6~10.8 m³/day, 3.98~4.39 m³/day, and 2.35~2.59 m³/day, respectively. According to their current results, they revealed that the hydraulic ram pump could be applicable for the water supply system in mountain areas without external power supply.

Harith *et.al.*, (2017) tested the performance of the hydraulic ram. They checked the significant effect on flow analysis and studied the simulation of improve design hydraulic pump. They inferred that the hydraulic ram pump was device that can lift water to the higher position without use of external energy. They tested by several ways to decrease the water waste rate to maximize efficiency. The purpose of their research work was to develop a new design of hydraulic pump and conduct simulation study to justify improvement of the design. They majorly added the threaded waste valve on making system in order to control the opening and closing of the valve. At the same time, they reduced the time taken for creating enough momentum and hammering effect. They revealed that with the advancement of the proposed well improve designs, the water losses at waste valve reducing about 20-30% compare to existing design across the mass flow rate of 0.10 kg/s. The min/max

velocity and pressure along the pipeline also had been increase for both open and closed condition.

Smith (2017) constructed the home-made hydraulic ram pump for livestock water and evaluated the performance of that device. During the study, he found many problems regarding the operation of hydraulic ram and thus, accordingly he draws the solutions on them. He prepared two designs of home-made hydraulic ram pump for livestock water. He said that first design was simple in construction than second one. As, second also was very similar to the first design, but that design incorporated a home-made “snifter” valve that allowed a small amount of air to be added to the air chamber with each pumping cycle, which eliminated the need for an inner tube in the air chamber. The advantage of that design was that if the snifter hole was sized correctly, the pump should never become waterlogged due to a leaking inner tube in the air chamber. The disadvantages were the trial-and-error approach to obtaining the correct hole size, the need for additional support for the pump’s increased vertical height, and the possibility that the snifter hole, being very small, may freeze over and closed in cold weather.

Fatahi-alkouhi *et.al.*, (2018) determined the efficiency of hydraulic ram-pumps. They found that the frequent opening and closure of the valves established a pulsatile flow which in turned results in pumping water to a higher level. The aim of the research was to develop an equation using experimental data to determine the efficiency of the ram pump. They compared results with the artificial neural network (ANN) results. They found that the proposed equation was better than the ANN to estimate the efficiency of the ram pump. Therefore, they revealed that the presented equation was a simple and the precise equation was recommended to estimate the efficiency. In that equation, they took the value of RMSE and R^2 were 0.0341 and 0.69 respectively. Afterword, they compared the error functions of the proposed equation and artificial neural network. They developed ANN in compared with experimental results predict the efficiency 13.14% more, while the proposed equation in compared with experimental results estimated the efficiency 11.92% more. Then they concluded that, the ANN performed better than the proposed equation in the modeling efficiency and correlation coefficient.

Januddi *et. al.*, (2018) developed and then tested the hydraulic ram pump (Hydram). The purpose of their paper was to study the effectiveness of hydram

implementation and the effect of the stroke valve design towards flow rate of water being delivered. They used three methods in their study; (i) experimental evaluation of hydam; (ii) experimental evaluation of adjustable waste valve; and (iii) computational simulation of adjustable waste valve. For that, they designed, fabricated adjustable waste valve for experiment and modelled it for simulation. The adjustable waste valves also gave huge advantage to the hydam, where it could increase the flow rate of water at discharge pipe. They found that most of existing hydam were using a swing waste valve which its stroke couldn't be controlled. They also found that the adjustable waste valve provided variety of stroke length. The most optimum length of stroke valve was 13 mm which it could discharge 1.2 l/min of water at high 2 m. After that, they concluded that the implementation of hydam as a pump system for high hill water supply was relevant. They found that it could supply the water above the height of inlet water. They also inferred that device was environmentally friendly and needed minimal cost of fabrication and maintenance. Therefore, they suggested that the hydam could be installed in remote area to supply water in between different altitude at constant flow rate.

Kimaro (2018) checked the influence of air vessel volume on the delivery flow rate and efficiency of a hydam water pumping system. He studied both the theoretical and experimental phenomena to investigate the existing relationship between an air vessel size and the delivery flow rate and even the system efficiency while using a standard size of a known hydam size. Also, he tested different air vessel specimens whose capacity sizes V_s ranged from 0.12 to 19.6 liters with a 40 mm size conventional hydam. Then after, he found that an air vessel size V_s was affecting the delivery flow rate q and hence the system efficiency E_{vf} of a hydam pump. Accordingly, he revealed that when V_s was too small nearing a zero volume, the system efficiency became poor and as V_s was increased beyond a value above zero there was a corresponding gradual increase in the efficiency E_{vf} until a certain critical value was attained whereby a further increase in V_s had only an insignificant increase in the efficiency E_{vf} . He tested air vessel specimens experimentally showed better efficiencies of $E_{vf} \geq 60\%$ when the ratio (V_s / V_d) ranged between 50 and 500. And hence, he concluded that in order to acquire a better hydam output performance leading to the higher system efficiencies where $E_{vf} \geq 60\%$, the ratio of (V_s / V_d) was supposed to be in between the range of 50 and 500.

Mishra *et.al.*, (2018) tested the performance of hydraulic ram by studying the effect of water hammer. During their study, they found that the impulse valve frequencies had a major impact on the discharge of a hydraulic ram pump. They also revealed that when impulse valve frequency increased from 65 beats / minute to 76 beats per minute, the quantity of waste water increased 47.20% but the quantity of useful water decreased by 74.50 %. Finally, they concluded that hydraulic ram pump had a maximum efficiency of 51.49 % (D'Aubussion's efficiency) and a minimum of 32.00% occurring at discharge of $0.134 \times 10^{-4} \text{ m}^3/\text{sec}$ and $0.046 \times 10^{-4} \text{ m}^3/\text{sec}$ respectively. However, they found that the pump has a maximum discharge of $0.263 \times 10^{-4} \text{ m}^3/\text{sec}$. And the pump also has an optimum no. of strokes of 68 beats per minute. Therefore, they ultimately revealed that as the impulse valve frequency increases the discharge also increases up to an optimum point beyond which the discharges begin to decrease.

Suarda *et.al.*, (2018) investigated on characterization of waste valve to optimize the hydraulic ram pump performance. In their study, they carried an experimental work on hydraulic ram pump model with variation of all parameters of the waste valve. They found that all of the waste valve design parameters for instance valve orifice and disc diameter, valve mass and valve stroke significantly influenced the performance of hydraulic ram pumps such as pumping discharge and total efficiency of the hydraulic ram pump system. Furthermore, they proposed procedures in determining the waste valve diameter and its stroke and for that they proposed a simple formula for estimating the optimal mass of waste valve that can deliver the best hydraulic ram performance. Then after they revealed that the optimal diameter of the valve orifice is 0.68 times the pump body diameter or about 1.35 times the drive pipe diameter if the pump body diameter is twice the diameter of the drive pipe.

Dhaiban (2019) studied experimentally the performance of ram water pump. He found that the device was simple content from fittings, tank, pipes, pressure vessel and valves. He used three inlet diameters (1/2, 3/4 and 1 in) at inlet pipe and three level of tank water supply (1.9, 1.8 and 1.65 m) for study. Also, he used three ways to change the pressure in the vessel. His aim was to study the effect of change of inlet diameter and water level at the height and flow rate at the exit. Altogether, he studied the efficiency of the test device. Additionally, he found the maximum efficiency was 29 % at 1.9 m tank height and 0.5 in diameter. The experimental results showed

inversely relationship between the head and flow rate at the exit and the pressure in the vessel was not affected to the head and exit flow rate. During the study, he found the problem of amount of wastewater and noise of work. So, at the end, he suggested that the problem can be solved by using techniques in system design to collect and return the waste water to the tank.

Fatahi-Alkouhi *et.al.*, (2019) worked on the measurement of ram-pump power by changing in water hammer pressure wave energy. They evaluated the energy and power changes of hydraulic ram pumps using the combination of analytical model and experimental results. For that purpose, they constructed a ram pump of two-inch internal diameter. They got results which indicated that the ram pump power such as relative useful power (P_d/PT) and relative waste power (P_w/PT) were depended to length to diameter ratio of drive pipe (L/D), the relative energy due to steady flow velocity and impulse valve features (E_a/E_i), and the ratio of required pumping energy to maximum energy of water hammer (E_p/E_m). Ultimately, they concluded that the ram pump used in the study had good executive capabilities for use in field applications, and in compared with commercial pumps such as Wilcox's ram, it had a simpler and cheaper structure.

Sr. No.	Year	Name	Location of research	Devices or Methods used	Remark
1.	2002	Abate <i>et.al.</i>	Piracicaba, SP	Hydraulic Ram Pump	Maximum yield obtained at 4.2 m head. PVC pipe can be used for lower head and steel for higher head.
2.	2002	Maratos	University of Salford	Hydram	It eliminates the need to burn fossil fuels and can be used for sea water.
3.	2007	Cararo <i>et.al.</i>	Hydraulics Laboratory of Universidade Federal de Lavras - UFLA, Lavras	Hydraulic ram	Plastic bottle of capacity 0.6 lit., horizontal valve and 25 mm inlet can give better result.
4.	2009	Nnene <i>et.al.</i>	University of Nigeria Nsukka, Enugu State, Nigeria.	Hydraulic ram	Developed self-acting system.

5.	2014	Yang <i>et.al.</i>	China Institute of Water Resources & Hydropower Research, Beijing	Novel Hydram	Designed Novel hydram with efficiency of 63.9 %.
6.	2015	Mbiu <i>et.al.</i>	JKUAT	Hydraulic Ram Pump	Drive head and optimum weights affect the performance of the device.
7.	2015	Shende <i>et.al.</i>	K.D.K.C.E, Nagpur, India	Hydraulic Ram Pump	Mass flow rate was less in enhancement model.
8.	2016	Carvalho <i>et.al.</i>	College of Agronomic Science in Botucatu, SP, Brazil.	Hydraulic Ram Pump	0.6 and 1.0 lit. pressure chamber bottle produces optimum results.
9.	2016	Grygo	University of Warmia and Mazury, Olsztyn	Hydraulic Ram Pump	As delivery head increases, performance of the device reduced and vice versa.
10.	2016	Hamid <i>et.al.</i>	Kampung Sungai Dua Olak, Bentong, Malaysia	Hydraulic Ram Pump	Sustainable water supply system for rural communities.
11.	2016	Lee <i>et.al.</i>	Imgok-ri, Hwanam-myeon, Sanju-si, Kyeongsangbuk-do, South Korea	Hydraulic Ram Pump	Can be used in the mountains without any external power supply.
12.	2017	Harith <i>et.al.</i>	University Malaysia Pahang, Malaysia	Hydraulic Ram Pump	Improved design reduced the water waste rate can be reduced up to 20-30 %.
13.	2017	Smith	Clemson University	Hydraulic Ram Pump	Snifter eliminates the working of inner tube to draw the air in the chamber.
14.	2018	Fatahi-alkouhi <i>et.al.</i>	Jundi-Shapur University of Technology, Dezful, Iran	Hydraulic Ram Pump	Used Artificial Neural Network (ANN) for simulation.
15.	2018	Januddi <i>et.al.</i>	University Kuala Lumpur, Malaysian Institute of Industrial Technology, Johor, Malaysia	Hydraulic Ram Pump	Adjustable waste valve is profitable over the regular waste valve.
16.	2018	Kimaro	University of Dar es Salaam, Tanzania.	Hydraulic Ram Pump	Ratio of Vs/Vd should ranges between 50 to 500.
17.	2018	Mishra <i>et.al.</i>	College of Agricultural Engineering Pusa Samastipur, Bihar.	Hydraulic Ram Pump	As an impulse valve frequency increases the discharge also increases up to an

					optimum point beyond which the discharges begin to decrease.
18.	2018	Suarda <i>et.al.</i>	Udayana University, Badung-Bali, Indonesia	Hydraulic Ram Pump	The optimal diameter of the valve orifice is 0.68 times the pump body diameter, or about 1.35 times the drive pipe diameter if the pump body diameter is twice the diameter of the drive pipe.
19.	2018	Dhaiban	Dijlah University College, Al-Massafi str., Baghdad, Iraq	Hydraulic Ram Pump	Inversely relationship between the head and flow rate at the exit and the pressure in the vessel.
20.	2019	Fatahi-Alkouhi <i>et.al.</i>	Jundi-Shapur University of Technology, Dezful, Iran	Hydraulic Ram Pump	Ram has good executive capabilities for use in field applications.

Critique of the reviews:

In this section of performance evaluation of different energy free water lifting devices and technologies available in the market revealed that many scientists had observed and recorded performance of energy free water lifting devices like hydraulic ram. They noted down working principle of hydraulic ram. From these reviews, some limitations on working, operating characteristics, lifting characteristics and costing was observed. During the actual working, it was found that it requires starting torque to operate the hydraulic ram. Sometimes, there may be chances of large amount of waste water flow through waste valve altogether the no discharge or minimum discharge at the delivery side. Sometimes, there may found difficulties in the lifting of water to the considerable height. Many times, strokes of the waste valve fall off intermediately causing zero output at the delivery. As devices made from the costly materials, it can't be affordable to average people. Also, sometimes maintenance cost of such devices is also high. Considering above fact and experiments were conducted to date, it was felt necessary to overcome limitations of lifting the water during monsoon at the time of energy failure which will lift the water at the time of scarce of energy too. Secondly, to overcome with high cost of the device and to make the device user friendly the experiment entitled, "Design and Development of Cost Effective Energy Free Water Lifting Device" is proposed.

2.4 Cost Analysis

It was felt necessary to know the economic feasibility of different energy free water lifting devices. Hence, the work done by the earlier scientists on cost analysis of energy free water lifting device is described in this section.

Mohammed (2007) designed and fabricated the hydraulic ram pump (Hydram). He found that it could lift the water from a depth of 2 m below the surface with no other external energy source required. Based on the design, he obtained that the volume flow rate in the pipe was $4.5238 \times 10^{-5} \text{ m}^3/\text{s}$ (2.7 l/min), Power was 1.273 kW which results in an efficiency of 57.3%. He found the overall cost of fabrication of that hydram showed that the pump was relatively cheaper than the existing pumps.

Engel *et.al.*, (2011) designed a low cost, self-operating hydraulic ram pump for water retention and lifting in developing country Haiti. Their overall goal was to help to alleviate clean water problems in Haiti. The specific objectives of their project were to: (1) design low cost hydraulic ram pumps based on available prototypes; (2) conduct a comprehensive feasibility study for the product installation; and (3) implement the proposed design in communities in Haiti. These objectives be accomplished by a team of interdisciplinary engineering students through Engineering Projects in Community Service and Global Engineering Program (GEP) Design Teams. During Phase I of the project, a group of students team installed two prototypes in Haiti and conducted a country feasibility analysis in collaboration with the North Haiti Christian Mission. The purpose of the trip was to collect site information in order to improve the design, build improved prototypes and install these during a subsequent visit. During Phase I, they constructed and tested different prototypes. They constructed an improved design by studying theoretical calculations and experimental testing. They revealed that final prototype was economically feasible and more efficient than earlier designs which costs approximately \$100.00 excluding the inlet and outlet pipes.

Johannes *et.al.*, (2015) designed the low-cost hydraulic ram. They tested different valves in the lab under varying elevations of the water column in the driver pipe. They recorded the pumping pressure and water flow in the supply pipe for determining the ram's efficiency. They found an off-the-shelf clap check valve most reliable with an acceptable efficiency of over 30%. They installed one unit of a hydraulic ram at a foothill location at Ban Ha, Samoeng District, Chiang Mai

Province, and connected it to an automatic low-pressure irrigation system to irrigate a small plot of coffee trees. With that they monitored the soil moisture. They operated the hydraulic ram maintenance free and fully automatic over six weeks, supplying the field sufficient quantities of water during that period at a pumping efficiency of 44%. They also revealed that the cost of the system was too less than any other pumping systems.

Sr. No.	Year	Name	Location of research	Devices or Methods used	Remark
1.	2007	Mohammed	Federal University of Technology, Minna, Nigeria	Hydraulic Ram Pump	Relatively cheaper design was made.
2.	2011	Engel <i>et.al.</i>	Haiti	Hydraulic Ram Pump	Designed low cost hydraulic ram for water retention.
3.	2015	Johannes <i>et.al.</i>	Ban Ha, Samoeng District, Chiang Mai Province	Hydraulic Ram Pump	Hydraulic ram with low pressure irrigation system was successfully installed with less cost.

Critique of the reviews:

In this section of cost analysis of different energy free water lifting devices and technologies available in the market, some reviews were studied. It revealed that many scientists evaluated cost required for hydraulic ram and its accessories. Cost required for fabrication is high for hydraulic ram but have high efficiency of lifting the water. The material required for the fabrication is not easily available in the market. Therefore, to reduce the costing of material and fabrication it is needed to use low cost durable and easily available material and to make the device user friendly the experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” is proposed.

Overall Critique of the reviews:

From the reviews, it is revealed that many scientists worked on the water lifting devices which were based on either drive-delivery pipe ratio, drive-delivery pipe sizes, discharge rates, waste valve strokes and its working, construction, modification, Air chamber modification, lengths of pipes, operating and working characteristics approach, etc. Secondly, they had reported some limitations on working, operating difficulties and costing. It requires special skills to design, develop

and fabricate the hydram. Very few scientists or nil worked on the costs, materials availability in the local market, alternative to energy, device-user-friendliness, etc. Considering the above facts and research carried out up to date, it was felt necessary to overcome the limitations of the existing water lifting device to get continuous supply of water during monsoon whenever problem of electricity failure occurs continuously. Secondly, to overcome with high cost of the device and to make the device user friendly the experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” was proposed.

III. MATERIALS AND METHODS

The experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device” was undertaken at Instructional Farm and in the Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering, Dapoli. This chapter describes the material required and methodology adopted, considering the review of literature and to fulfill the objectives of the present study. Under the material section, selection of suitable inlet and outlet pipe sections, assembling of pipes, cutting of pipes, valves and their arrangement of valves, arrangement of air chamber, etc. is described. In section methodology, survey and study of different manually operated, animal drawn and some energy free water lifting devices available in the market, design and development of the energy free water lifting device, different combinations of supply and delivery pipes used based on the surveyed and studied energy free water lifting devices, performance evaluation of the energy free water lifting device and cost analysis is systematically described and discussed in this chapter.

3.1 Study Area

The experiment was conducted during monsoon and winter season of 2018-2020 at the Instructional Farm and in the Laboratory of the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli (M.S.), India.

3.2 Location, Climate and Weather Condition

The experiment was conducted at the Instructional Farm and in the Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. Geographically, the selected site is situated at 15° 6' N to 20° 22' N latitude and 72° 39' E to 73° 48' E longitudes. The altitude of the site is 250 m. The region has humid climate. Its climatic conditions are typically coastal (hot and humid) with average annual rainfall of 3500 mm. The average minimum and maximum temperatures are 7.5 °C to 38.5 °C, respectively. The relative humidity ranges from 46 per cent to 99 per cent (DBSKKV Diary, 2019).

3.3 Survey and study of different water lifting devices available in the market

After reviewing the literature, it is revealed that there are different types of water lifting devices available in the market. Some of them are being used by the different stakeholders. From the review, it is observed that, as there are different water lifting devices are designed and developed by the different researchers according to their local need, requirement, physical and climatological condition. Some of them or may be some additional new (manufactured) locally are available in the market. Therefore, according to requirement of the present study and objectives, it was necessary to know, what are the different types of water lifting devices including local one are available in the market, whether they are somewhat matching with the reviewed one or having some modifications with their making, etc. It was also necessary to know whatever the different water lifting devices are available in the market, what are their technical specifications, materials used for assembling or fabrication and manufacturing, working principles, type of energy used, their costs, discharge rates, etc. Therefore, it was felt necessary to conduct the survey and study the different water lifting devices available in the market. It was also necessary to know the design specifications, material availability in the market, etc. So that, it will help to describe the design considerations for the design and development of the energy free water lifting device in the Konkan region. The survey and study of different water lifting devices available in the market was undertaken and described as given below under different sections.

The available water lifting devices are further classified according to their technical and other specifications, working principles and other important features, merits and demerits are described as given below.

3.3.1 Rope and Bucket Lift

Rope and Bucket is the simplest and cheapest method of lifting groundwater remains a rope and bucket in a wide, shallow well. The well can operate up to a depth of 100 metres, although they rarely exceed 45 metres. The rope and bucket lift can be operated by humans or animals. Human operated rope and bucket lifters typically raise 10-15 litres/min from depths of 10-15 metres whereas an animal operated water lifter can raise 150 litres/min from 15 metres. Sometimes, a self-emptying container or moth (mohte) can be used in place of the bucket. The moth (mohte) system consists of a leather container, shaped like a funnel. Such an arrangement can discharge about 130 litres/min at depths of up to 9 metres.

The rope and bucket lift can also be adapted to include two buckets which are raised and lowered alternately. This device can lift about 230 litres/min from depths of up to 5 metres.

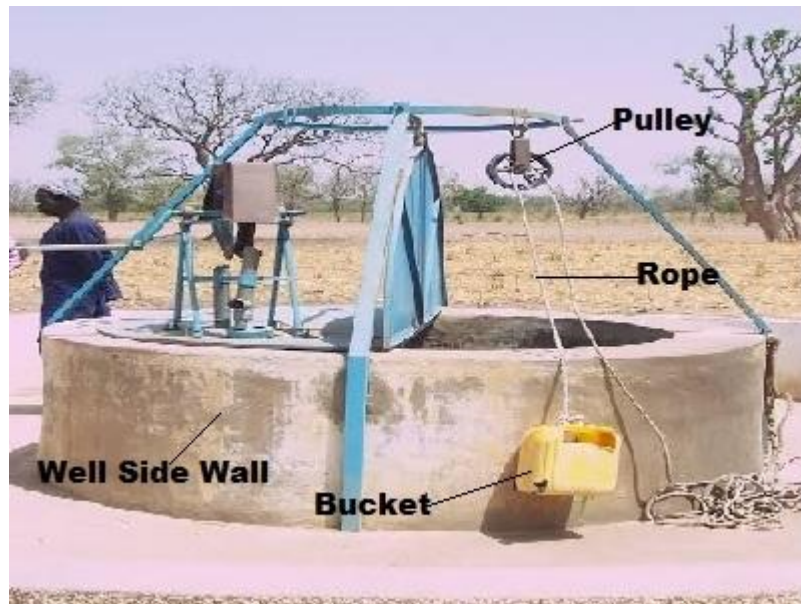


Plate 3.1 Rope and Bucket Lift

A. Technical and Other Specifications:

- a) **Initial cost:** From Rs. 77.76 for a plastic bucket and 5 m of rope to Rs. 1944 with a windlass, hose and closed superstructure, in Liberia (Milkov, 1987).
- b) **Range of depth:** 0–15 m (or more sometimes).
- c) **Yield:** 0.25 litres/s at 10 m.
- d) **Area of use:** All over the world.
- e) **Material availability (in local market):** Available
- f) **Skill manpower requirement:** Yes
- g) **Maintenance:** Frequent greasing to pulley to minimize the friction and for smooth operation is required. Rope and bucket should be replaced by every after 2 years to avoid any further accident.

B. Working Principle and Other important features:

Rope and bucket lift is mainly used with the hand-dug wells. A bucket on the rope is lowered down into the water. When the bucket hits the water it dips and fills, and then it is pulled up with the rope placed over the pulley. The rope can hold by hand, run through a pulley, or wound on a windlass. Animal traction is used

sometimes in combination with the pulley. In the improved systems, rope is used through a pulley, and two buckets in that one on each end of the rope. For the depth of water less than 10 m, a windlass with a hose running from the bottom of the bucket to a spout at the side of the well can be used. However, the hygiene of this system is somewhat poorer, even if the well is protected.

C. Merits:

- i. Useful to lift the water in the convenient way, where other means are not available.
- ii. Easy to lift the water up to some depth.
- iii. Less force required to lift the water due to pulley action.
- iv. One person can lift the water and no more persons required.

D. Demerits:

- i. Poor-quality rope deteriorates quickly.
- ii. The bucket can fall into the well.
- iii. Hose can break frequently in windlass-and-hose systems.
- iv. Poor hygiene created, especially when the rope or bucket touches users' hands or the ground.
- v. Communal wells tend to become more contaminated than family-owned wells and the latter should require be promoted whenever possible.
- vi. Only suitable for limited depths.

3.3.2 Archimedes Screw

The physicist and mathematician Archimedes (287-212 BC) is assumed to have invented the screw pump in the 3rd century BC, therefore why it is referred to as the "Archimedes screw". It is used to elevate water for irrigation as well as drainage purposes (Lashofer *et.al.*, 2012). The water screw, popularly known as the Archimedes' screw and also known as the screw pump. Archimedean screw or Egyptian screw is a machine used for transferring water from a low-lying body of water into irrigation ditches. The Archimedes screw consists of a screw (a helical surface surrounding a central cylindrical shaft) inside a hollow pipe. The screw is usually turned by windmill, manual labor, cattle, or by modern means, such as a motor. The Archimedes Screw is basically a large helix, open at both ends and encased within a watertight cylinder. It operates with the cylinder somewhat tilted from vertical. When the open lower end of the cylinder is placed in water and the

screw is turned, water trapped between the cylinder and the threads of the screw rises. Successive revolutions will raise the water thread-by-thread until it emerges at the top of the cylinder.



Plate 3.2 Archimedes Screw

A. Technical and Other Specifications:

- a) **Initial cost:** £ 5655 / Rs. 421636.8 (Paul Parker/Michael Moreno *et.al.* 2009)
- b) **Range of depth:** less than 1.2m
- c) **Useful Life:** more than 20 years.
- d) **Yield:** Screw of 1 metre diameter and can pass 250 litres/second.
- e) **Area of use:** Egypt and some other countries, some region of India also.
- f) **Material availability (in local market):** For maintenance, not available easily.
- g) **Skill manpower requirement:** Yes
- h) **Maintenance:** maintenance of wooden or metal drum required according to device use.

B. Working Principle and Other important features:

The Archimedes screw is a form of positive-displacement pump. A positive-displacement pump traps fluid from a source and then forces the fluid to move to a discharge location. The Archimedes screw is made up of a hollow cylinder and a spiral part. One end is placed in a low-lying fluid source or water and the other end is

tilted up into a higher discharge area. To move water, it is required to rotate the screw. As the screw moves it scoops up a small amount of water into the first pocket. On the next turn of the screw the first pocket of water moves to the second pocket, and a new scoop of water enters the first pocket. This motion continues, and eventually the first scoop of water comes out at the other end.

C. Merits:

- i. It is simple to construct.
- ii. It has longer life.
- iii. Especially use to raise irrigation water and for land drainage.
- iv. Used to move water that contains mud, sand, or gravel.

D. Demerits:

- i. It has less range of lift.
- ii. It requires persons to operate.
- iii. Somewhat skilled man required to install it.
- iv. Cost of such device is comparatively high as compared to its range of lift.

3.3.3 Water Wheel

A water wheel consists of a wheel (usually constructed from wood or metal) with a number of blades or buckets arranged on the outside rim forming the driving car. Water wheels were still in commercial use well into the 20th century but they are no longer in common use. Probably the oldest type of water-raising waterwheel was known as the tympanum to the Romans and tympanon or tympanion to the Greeks (i.e., drum or tambourine). (<http://www.romanaqueducts.info/technicalintro/waterlifting.html>). Although this type of waterwheel could lift a large volume of water, it could raise it less than half the diameter of the wheel. Consisting of a hollow wooden framework enclosed in a skin of planks like a drum, the interior was usually divided into eight wedge-shaped compartments, the walls of which were sealed with pitch or wax to prevent leaks. The wheel rotated in the vertical plane and was mounted on a heavy horizontal axle. The heavy construction of this type of waterwheel meant that it had to be powered by men (normally low-grade slaves or condemned criminals) treading on its perimeter or by beasts of burden harnessed to right-angled gearing (known as a saqiya gear in Arabic).

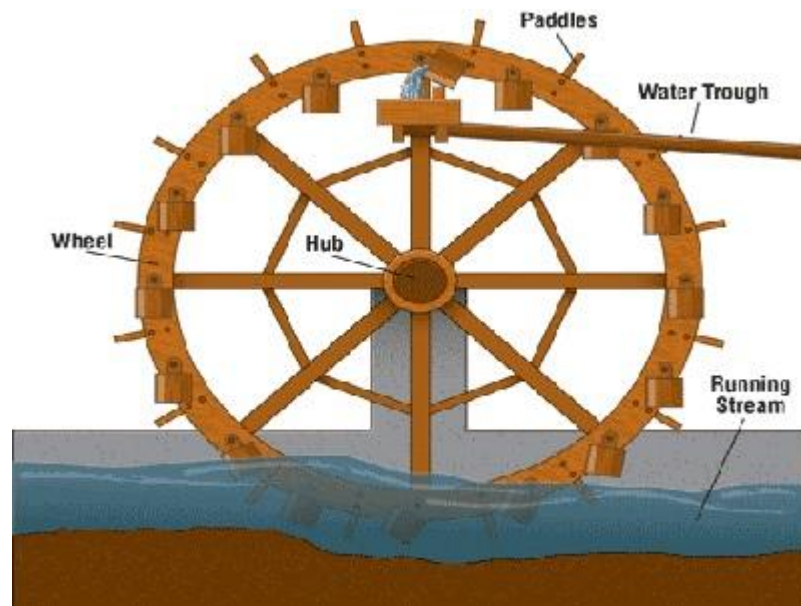


Plate 3.3 Waterwheel

B. Technical and Other Specifications:

- a) **Initial cost:** Generally, estimate for steel wheels over 10 ft: \$ 1290.00 (Rs.96,659.57)/foot in diameter. Price based on a two-foot-wide wheel (<http://www.waterwheelfactory.com/price.html>)
- b) **Range of depth:** less than 1.5 m. (Michael A.M.).
- c) **Yield:** Generates between 37 kW and 200 kW of electricity from a 20 m³ of waterflow with a head of 1 to 3.5m.
- d) **Area of use:** Europe, North America, China and Some regions of India also.
- e) **Material availability (in local market):** For maintenance, not available easily.
- f) **Skill manpower requirement:** Yes.
- g) **Maintenance:** Fortnightly maintenance required.

B. Working Principle and Other important features:

The waterwheel consists of compartments. In waterwheel, as successive compartments when immersed in the water at the wheel's base, they are filled through equidistant slots in the wheel's rim. When each compartment reaches the horizontal level of the axle, the water emptied into a trough through a circular hole located in the axle of the wheel at the terminus of the compartment's side walls.

C. Merits:

- i. In ancient time, it was used to lift the water from the water source.
- ii. With the lifting of water electricity also get generated.
- iii. The water discharges a few centimeters above the center shaft and therefore increases the useful head in relation to the diameter.

D. Demerits:

- i. Range of lift is less.
- ii. Whenever water get lifted through scoops or compartments, there found chances of spoilage of water when speed of the wheel is slow.
- iii. Design of the structure is complex.
- iv. Skilled manpower required to install.
- v. Installation as well as maintenance cost of the device is comparatively high.

3.3.4 Rope pump

A rope pump is a type of pump of which consists of most visible component is a continuous piece of rope, in which the rope plays an integral role in raising water from a well. Rope pumps are mostly used in developing areas, the most common design of which uses PVC pipe and a rope with flexible or rigid valves. These are cheap to build and easy to maintain. One design of rope pump using a solar-powered rope pump having ability to pump 3,000 litres to 15 meters per day using an 80watt solar panel. Rope pumps can be run by low speed gasoline/diesel engines, electricity, human energy, wind and solar energy.



Plate 3.4 Rope pump

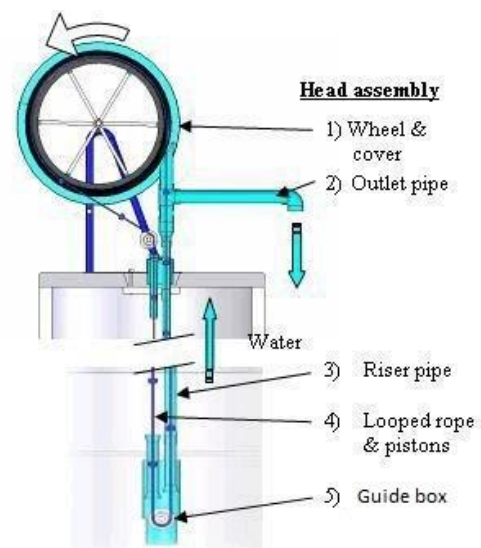


Plate 3.5 Components of the Rope Pump

B. Technical and Other Specifications:

- a) **Initial cost:** US \$ 15-35 / Rs.486.45- Rs.1135.05 for a traditional model and US \$ 90/ Rs.2918.7 for a commercial model with piping (1995 data, Nicaragua).
- b) **Range of depth:** 0–50 m.
- c) **Yield:** 0.6 litres/s at 10 m, 0.15 litres/s at 50 m.
- d) **Area of use:** In rural and periurban areas of Nicaragua, Bolivia, Indonesia, Ghana, Burkina Faso and other countries.
- e) **Construction:** Local manufacturers/artisans.
- f) **Material availability (in local market):** Available
- g) **Skill manpower requirement:** Yes.
- h) **Maintenance:** Weekly greasing required, Yearly change the rope, two yearly change the washers, six yearly replace the tubes and occasionally repair the frame structure.

B. Working Principle and Other important features:

The rope pump consists of the basic parts: a pulley wheel above the well, a riser pipe from under the water level to an outlet just under the wheel, and a rope with rubber or plastic washers. In this system, the rope comes up through the pipe, over the wheel, back down into the well and into the bottom of the pipe and completing the loop. Whenever the wheel is turned, the washers move upwards and lift water into the pipe towards the outlet. Some other important parts are an underwater rope guide which directs the rope and washers back into the pipe, and a frame that holds the pulley wheel. The device can be made at village level using local material like wood, rope and PVC tubing (or bamboo canes with the centers bored out).

In Nicaragua, local industries developed an improved type of rope pump that has a metal wheel and frame, industry-made washers and a guide block of concrete with ceramic and PVC tubes. That is some advance material is used by them. Nearly about 25,000 of these pumps have been installed in Nicaragua by them. Water can be lifted from nearly 50 m depth and raised to 5 m above ground level. Special models

with 3-inch boreholes, also powered by windmills, bicycles, animal traction, electric motors or small gasoline engines, give good results and lift the water more efficiently.

C. Merits:

- i. Up to 50 m, water can be lifted efficiently.
- ii. Materials can be easily available.
- iii. Local artisans can construct such type of device.

D. Demerits:

- i. Rope becomes worn after some interval because it is exposed to the sun.
- ii. The installation of the rope pump if poorly done then its performance become suboptimal.
- iii. The pulley wheel malfunctions.
- iv. The pistons, frame and guide block are of poor quality and thus do not function properly.
- v. The traditionally used rope pumps having a lift of only about 10 m.
- vi. Users need to exercise care when using the pump as it is susceptible to contamination.

3.3.5 Suction Plunger Handpump

Suction pumps are relatively easy to maintain. Most of the moving parts are above the ground level. Maintenance can normally be done by a village caretaker or by the users themselves, using simple tools, and basic spare parts and materials. Most suction handpumps can be easily operated by men, women and children. Preventive maintenance consists of greasing the bearings every week, inspecting the interior of the pump stand once a month, and inspecting the whole pump stand once a year. Most of this work can be done by one or two people, but more people may be needed when pump parts have to be lifted out of the well or borehole. Many suction handpumps are family pumps and are cared for by one family. For communal pumps, the user group or community will need a local committee to organize operational and maintenance tasks including making major repairs.

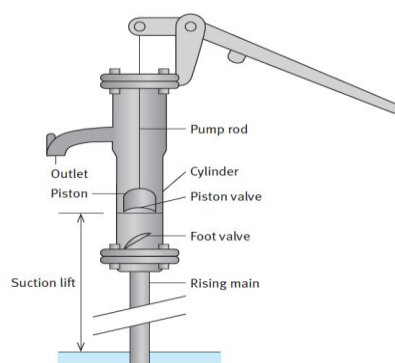


Plate 3.6 Suction Plunger Handpump

A. Technical and Other Specifications:

- a) **Initial cost:** From US \$ 35/ Rs.432.95 (Thailand, 1985), including 10 m galvanized iron drop pipe and a foot valve to US \$ 185/ Rs. 2288.45 for a Wasp pump in India (1983 price without a suction pipe) (Arlosoroff *et al.*, 1987).
- b) **Range of depth:** 0–7 m.
- c) **Yield:** 0.4–0.6 litres/s at 7 m.
- d) **Area of use:** Rural and low-income periurban areas where groundwater tables are within 7 m of the surface.
- e) **Trademarks:** AID Suction; Bandung, Inalsa Suction; Jetmatic Suction; Lucky, New No.6; Rower, SYB-100; Wasp, etc.
- f) **Material availability (in local market):** For maintenance, not available.
- g) **Skill manpower requirement:** Yes.
- h) **Maintenance:** Weekly greasing required, annually checking of the entire pump required.

B. Working principle and Other important features:

A suction plunger handpump consists of cylinder and plunger (or piston) fixed above the water level, usually within the pump stand itself. These pumps needed to be primed by pouring water on the plunger. In this type of pump, on the up-stroke of the plunger, the pressure inside the suction pipe is reduced and atmospheric pressure on the water outside pushes the water up into the pipe and on the down-stroke, a check valve at the inlet of the suction pipe closes and water passes the plunger through an opened plunger valve. Again, with the next upstroke, the plunger valve closes and the water is lifted up by the plunger and flows out at the top of the pump, while next

water flows into the suction pipe. The operational depth of suction plunger handpump is limited by barometric pressure and the effectiveness of the plunger seals to about 7 m at sea level and also less at higher altitudes.

C. Merits:

- i. Most of the parts are above the ground surface and thus easily accessible.
- ii. Less maintenance required i.e., maintenance involves replacement of seals and valves only.
- iii. Operations that can be easily performed with few tools.
- iv. It is easy to operate so that even children can also operate it.

D. Demerits:

- i. Washers, cupseals and bearings get worn out early.
- ii. Excessive corrosion that causes pump rods to break and leaks to appear in the rising mains.
- iii. Many pumps are of poor quality.
- iv. The biggest drawback of suction pumps is that they can lift water to only about 7 m, and if the water table falls below that level, the pump becomes inoperable and must be replaced with a deep-well pump.
- v. Contaminated water is often used to prime suction pumps.
- vi. Most pumps are designed for family use and are not sturdy enough for communal use.

3.3.6 Direct Action Handpump

Direct action handpumps are usually made of PVC and other plastics, and are installed on boreholes of limited depth. A plunger is the main component which attached to the lower end of a pump rod, beneath the groundwater level. The mechanical simplicity, low cost and lightweight construction makes these pumps well equipped to meet operational and maintenance objectives at the village level. Direct pump is operated by moving a handle up and down. As the plunger is located underwater, no priming is needed. Adults and even children can pump the water, although if the water table is below 5 m, this may be difficult for children. The pump stand and site must be kept clean to avoid contamination.



Plate 3.7 Direct Action Handpump

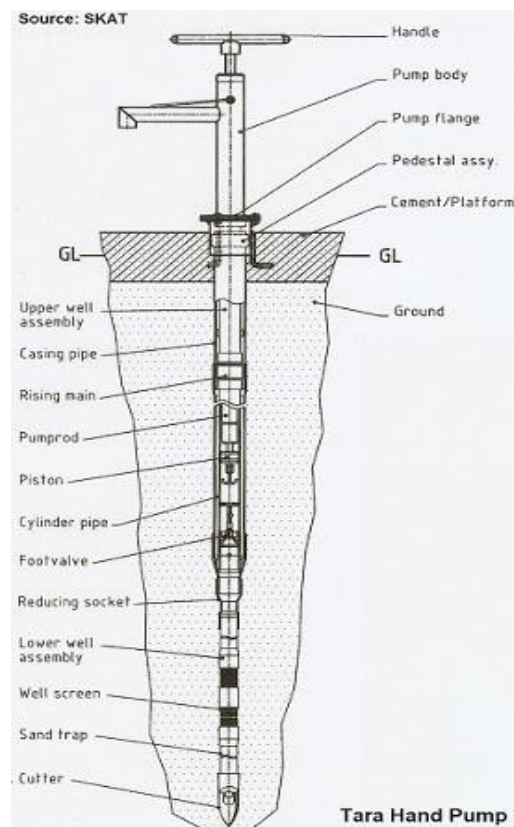


Plate 3.8 Components of the Direct Action Handpump

A. Technical and Other Specifications:

- a) **Initial cost:** From about US \$ 100/ Rs.1237 to over US \$ 900/ Rs.11133 (1985 prices) (Arlosoroff *et. al.*, 1987). Models suitable for village level operation & maintenance cost less than US \$ 150/ Rs.1855.5.
- b) **Range of depth:** 0–12 m.
- c) **Yield:** 0.25–0.42 litres/s at 12 m depth.

- d) **Area of use:** Rural and low-income periurban areas, where groundwater tables are within 12 m of the surface.
- e) **Trademarks:** Blair; Ethiopia BP50; Malawi Mark V; Nira AF85; Tara; Wavin
- f) **Material availability (in local market):** Not available easily.
- g) **Skill manpower requirement:** Yes
- h) **Maintenance:** Occasionally repair of cupseals, washers, pump rods, pump handle required, annually entire checking of pump required.

B. Working Principle and Other important features:

The working principle of this pump is that the person who use it requires to move the pump rod in an up-and-down motion, using a T-shaped bar handle. Same as like suction plunger handpump, on the up-stroke, the plunger lifts water into the rising main and the replacement water is drawn into the cylinder through the foot valve. And on the downstroke, the foot valve closes, and water passes through a one-way valve in the plunger and is lifted on the next up-stroke. Because this type of pump having no mechanical advantage like the lever or flywheel of a deep-well handpump, it can only be used to depths from which an individual can physically lift the column of water (about 12 m).

C. Merits:

- i. Easy to operate, children also can operate.
- ii. No priming is needed.
- iii. Maintenance is somewhat less.

D. Demerits:

- i. Washers, plungers and foot valve parts get worn early.
- ii. An abrasion of the seal on the PVC cylinder and between the pump rod and rising main takes place.
- iii. Sometimes there may be chances of broken or damaged the handles cause damage.
- iv. The maximum lift is limited to 12 m.

- v. The force needed to pump the water may be too great for children, especially if the water table is below 5 m.

3.3.7 Deep-Well Diaphragm Pump

Deep-well diaphragm pump consists of cylindrical pump body. At the bottom of the well inside a cylindrical pump body, a flexible diaphragm is located which shrinks and expands like a tube-shaped balloon, taking the water in through an inlet valve and forcing it out through an outlet valve. Also, body of cylindrical pump is connected to a flexible hose which deliver the water to the surface. Diaphragm movement is affected by a separate hydraulic circuit which consists of a cylinder and piston in the pump stand and a water-filled pilot pipe which is also a flexible hose. The principle of the deep-well pump is attractive because it allows thin flexible hoses to be used, making the pump easy to install or remove without the need for special tools or equipment. Replacing spares of this type of pump is usually easy; only the replacement of the diaphragm may need the assistance of a skilled mechanic. Many times, it is possible to install several pumps in a single well or borehole.



Plate 3.9 Deep Well Diaphragm Pump

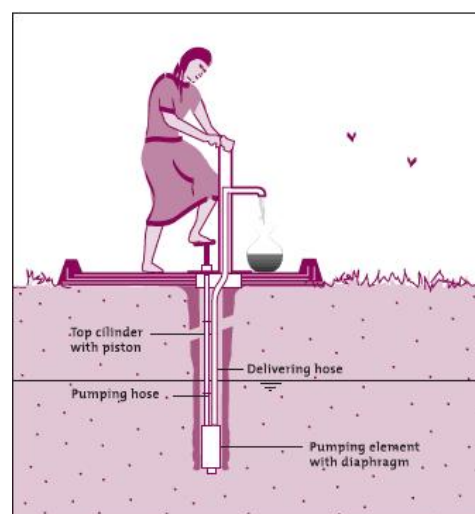


Plate 3.10 Components of Deep-well diaphragm pump

A. Technical and Other Specifications:

- a) **Initial cost:** In 1986, a complete pump that operated to a depth of 30 m cost US \$ 860/ Rs.10844.6 (CIEH, 1990). In Burkina Faso and Benin in 1993, a Vergnet model pump cost US \$ 1460–1820 / Rs.44515.4 - Rs.55491.8 (including 10% VAT), depending on the installation depth (Baumann, 1993b).
- b) **Range of depth:** 10–70 m.

- c) **Yield:** 0.50 litres/s at 10 m depth; 0.32 litres/s at 30 m; and 0.24 litres/s at 45 m.
- d) **Useful life:** Eight years.
- e) **Area of use:** Burkina Faso, Cameroon, Ghana, Liberia, Mali, Mauritania, Niger.
- f) **Trademarks:** Vergnet; ABI-ASM (no longer in production).
- g) **Material availability (in local market):** For maintenance, not available easily.
- h) **Skill manpower requirement:** Yes
- i) **Maintenance:** Daily clean the site, weekly greasing and monthly checking of entire pump is required.

B. Working Principle and Other important features:

The pump is operated by pushing down on a pedal, usually by foot, but sometimes with a handle. Depressing the pedal can take a considerable effort, as much as the bodyweight of the user, and the pump must be built to withstand this. Whenever user push down the foot pedal, the piston is moved, although conventional lever handles may also be used. Whenever foot pressure is removed, the elasticity of the diaphragm forces water out of it, back up the pilot pipe, and lifts up the foot pedal.

C. Merits:

- i. Easy to install or remove without the need for special tools or equipment.
- ii. Replacing spare parts is usually easy; only the replacement of the diaphragm may need the assistance of a skilled mechanic.
- iii. It is possible to install several pumps in a single well or borehole.

D. Demerits:

- i. Pedal rod guides and plunger seals need to be replaced frequently and also the plunger guides may wear out quickly.
- ii. Drive hoses often need to be re-primed because water leaks past the plunger seals, and the foot pedal then needs to be raised by hand.
- iii. If solid dust or particle enter the downhole pumping element it must be cleaned, since this will cause the diaphragm to stop working or even rupture.

- iv. If a community cannot afford to replace the pump diaphragm, or if no skilled mechanic is available, users may be forced to return to their traditional sources temporarily.
- v. Moderate skills in steel fabrication and fitting are needed to produce a pump stand, while advanced manufacturing techniques and tight quality control are needed to produce the pumping element; in many countries, these parts will have to be imported.

3.3.8 Deep-Well Piston Handpump

In this type of handpump, the piston is placed in a cylinder below the available water level, which is usually 15–45 m below the ground. The pump consists of pump rods having special connectors that allow them to be assembled or dismantled without tools or with only very simple ones. The pumping motion by the user at the pump stand is transferred to the piston by a series of connected pumping rods inside the rising main. The connecting joints incorporate pump rod centralizers that prevent wear of the rising main. To a large extent, improved models can be maintained at village level. The pump is operated by moving the handle up and down, or by rotating the handle of a flywheel. This can be done by adults and even children, since handle forces are usually kept within acceptable limits. Preventive maintenance usually consists of checking that the pump is functioning, and cleaning the pump and pump site daily. Each week, the pump should be greased, and once a month.



Plate 3.11 Deep-Well Piston Handpump

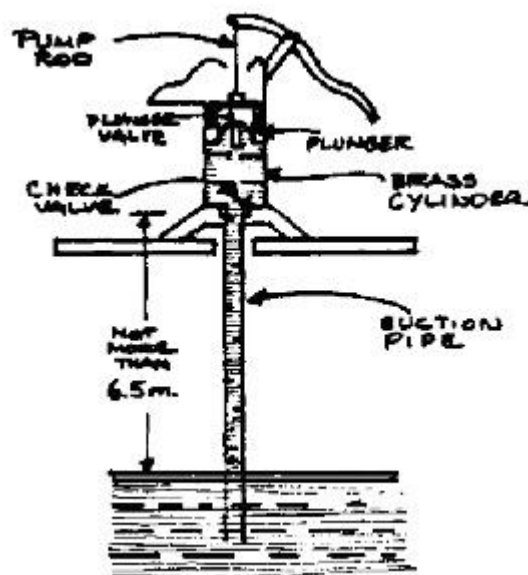


Plate 3.12 Components of Deep well piston pump

A. Technical and Other Specifications:

- a) **Initial cost:** In 1985, for a well 25–35 m deep, prices ranged from about US \$ 40/ Rs.494.8 for a cylinder, plunger and foot valve set (installed under a locally-made pump head), to over US \$ 2300/ Rs.29808 for a complete pump with stainless steel parts (Arlosoroff *et al.*, 1987). Most good pumps cost US \$ 300–500/ Rs.3888 - Rs.6480.
- b) **Range of depth:** 15–45 m, although depths of up to 100 m are possible.
- c) **Useful life:** 6–12 years.
- d) **Yield:** 0.25–0.36 litres/s at 25 m, and 0.18–0.28 litres/s at 45 m depth.
- e) **Area of use:** Rural and low-income periurban areas where groundwater tables are within 100 m (but preferably within 45 m) from the surface.
- f) **Trademarks:** Afridev/Aquadev; Bestobell Micro; Bush pump; Blair pump; India Mark II and III; Kardia; Tropic (Duba); UPM; Volanta
- g) **Material availability (in local market):** For maintenance, not available easily.
- h) **Skill manpower requirement:** Yes
- i) **Maintenance:** Monthly maintenance required.

B. Working Principle and Other important features:

In deep-well piston handpump, the motion of pumping by the user at the pump stand is transferred to the piston with the help of a series of connected pumping rods inside the rising main. On the up-stroke, the plunger lifts water into the rising main, new replacement water is drawn into the cylinder through a foot valve. On the down-stroke, the foot valve closes, and water passes the plunger and is lifted for the delivery on the next up-stroke. According to the efforts needed to lift the water to the surface, pumping get decided. Most pump cylinders having an open top. This allows the piston and foot valve to be removed through the rising main for conveniently servicing and repairs, while the rising main and cylinder having no such type of replacement.

C. Merits:

- i. In this type of handpump, the pump rods have special connectors that allow them to be assembled or dismantled without tools, or with only very simple ones.

- ii. Servicing and repairs can be easy.
- iii. Easy to lift the water.

D. Demerits:

- i. Problems with the quality control of local manufacturers, especially in African countries.
- ii. The hook-and-eye connectors of the pump rods tend to break more often than conventional connections and then there may be chances of rod bends or rod disconnection.
- iii. Corrosion is a main problem.
- iv. Sometimes, handles become shaky or broken because of worn-out bearings.
- v. As depth of groundwater increases, number of problems goes on increasing.
- vi. To reduce the number of major repairs, the rising main should be made of the highest-quality material available; otherwise chances of failure.
- vii. It may require considerable torque to start.

3.3.9 Hydraulic ram

Hydraulic ram (hydam) is the device that pump water by using the kinetic energy of a flowing water mass that is suddenly forced to stop. It has to be installed at a lower level than the surface of the water source. Source of water may be spring, stream or water channel. A part of the water from the stream or spring is pumped to the higher elevation. At the beginning of the pump cycle, water flows from the source down an inclined and rigid drive pipe into the hydram body and out through the impulse valve. When the water has accumulated enough velocity, it forces the impulse valve to close suddenly and the water in the drive pipe comes to a sudden stop. This produces a shockwave in the water mass, forcing an amount of water through the delivery valve into a buffering air chamber and from there up the delivery pipe. The air is supplied by a small air-inlet valve in the pump body. In newer designs, the buffer chamber contains a piece of compressible rubber, instead of air. After the shockwave, the pressure in the pump body drops, the delivery valve closes, and the impulse valve is opened by the force of a spring or weight. The water in the drive pipe begins to flow through the impulse valve and the pump cycle starts again. Hydam usually operate at 30–100 pumping cycles per minute. Compared to other pumps, their output is generally low, but the efficiency of newer designs has improved.



Plate 3.13 Hydraulic ram pump

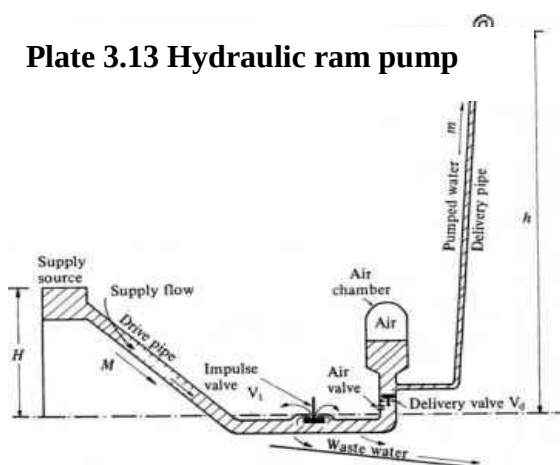


Plate 3.14 Components of Hydraulic ram

A. Technical and Other Specifications:

- a) **Initial cost:** Vary according to material used. No data available.
- b) **Pumping head:** 1–100 m (maximum is about 40 times the supply head).
- c) **Yields as percentage of inflow:** 26% for a 2 m drop and 6 m lift; 5% for 3 m drop and 30 m lift.
- d) **Expected life:** 20–30 years.
- e) **Area of use:** Rural areas where the water source falls by at least 1 m, and where little of the collected water is to be pumped higher than the water source.
- f) **Trademarks:** Blake (UK); Cecoco (Japan); Las Gaviotas (Colombia); Premier (India); Rochfer (Brazil); Sano (Germany); Schlumpf (Switzerland); and others. Hydrams are also made in workshops.

B. Working Principle and Other important features:

The principle of hydraulic ram is “Water hammer effect.” Hydraulic ram sometimes abbreviated “Hydram.” It is simple automatic device which utilizes the kinetic energy of water falling from moderate height to raise a part of it to a much greater height. Hydraulic ram pumps are generally simple devices that consist of two moving parts (the waste valve and delivery valve), an air chamber and an air valve (Taye,1998). It is operated by the opening and closing of the waste and delivery valves. When the waste valve closes, a high pressure rise is created in the drive pipe and the air valve allows air into the hydram to replace the air absorbed by the water due to the high pressures and mixing in the air chamber. It should be noted that the role of the air chamber is to maintain the continuity of the pumped water flows.

C. Merits:

- i. It lifts the water to higher elevation without electricity or external power Source.
- ii. It operates continue once torque given to it.
- iii. This device is easy to maintain.
- iv. It having long life.
- v. Effective in mountainous areas.
- vi. This is reliable.

D. Demerits:

- i. It should require comparatively higher supply head.
- ii. Initial cost of the device is comparatively high.
- iii. Parts of the device are sometimes not easily accessible.
- iv. Design of air chamber and waste valve is too complex and too lengthy.
- v. Sometimes if the velocity of the flowing water decreases, discharge getting at the delivery is comparatively very less or no discharge.

3.3.10 Closure of the Survey and study of the water lifting devices available in the market

After doing the brief survey and study regarding the different water lifting devices available in the market, their technical specifications, working principles and other important features, merits and demerits, energy requirement for their operations, it is revealed that there are certain problems with surveyed water lifting devices. Thus, the survey and study of the devices are based on the cost of the device, maximum lift by the device, discharge rates of the device or flow rates at the delivery side, area of

use, availability of electricity or fuel i.e., power requirement of the device, availability of drive head, distance of source from the device, availability of material, etc. However, limitations of existing devices are i) high initial as well as maintenance cost, ii) skilled labors requirement for installation and maintenance, iii) requirement of electricity or fuel for their run, iv) corrosion and wear and tear problem, v) unavailability of material for the maintenance as well as design, vi) Contamination and hygienic problem, etc.

Therefore, considering the above limitations, there was a vast scope to design and development of the cost effective energy free water lifting device is to be i) cost effective, ii) easy to operate, iii) simple in design and simple to construct, iv) energy free, v) with the minimum fittings, vi) made from the locally available material, vii) having less maintenance, viii) can only operate with the velocity head, energy of the flowing water in hilly terrain and high rainfall area to irrigate the field and to fill up the overhead water tank, ix) it was also revealed that the working principle of the hydraulic ram may be found suitable for the present study.

3.4 Design and development of the energy free water lifting device

After carrying out the exhausting review as described in chapter 2, section 2.1, survey mentioned under the section 3.3 for collecting the detailed technical information, working principles, merits and demerits of the available water lifting devices in the market and further critically studied the different water lifting devices it is revealed that, there is a vast scope for design and development of the cost effective energy free water lifting device.

3.4.1 Design Considerations

For design, development and actual manufacturing the cost effective energy free water lifting device the following considerations are to be made:

- i. The cost of the device should be low, so that marginal farmer can also afford that device for the lifting of water, to irrigate the small lands and for domestic purpose to fill up the overhead tanks just above up to 3 m to 4 m from the ground level.
- ii. The material required for the development and further manufacturing the device should be available easily in the local market so that the cost of that material be well minimized.

- iii. The device should be easily installed and operated by the different stakeholders.
- iv. The device should lift the water with the minimum available head.
- v. It should lift the water without electricity or fuel or any type of energy and should work in the monsoon with only velocity of the flowing water from higher elevation to the lower elevation.
- vi. Minimum or nil skilled manpower should require.
- vii. The device should be user friendly.
- viii. The spares should be easily available for its easy maintenance.
- ix. The newly design and developed energy free water lifting device should have the wide range of applications.

3.4.2 Design parameters of the energy free water lifting device

3.4.2.1 Working principle: Water hammer effect

The device works on the principle of “Water hammer effect.” The energy required to make device lift water to a higher elevation comes from water falling downhill due to gravity. This device uses the inertia of moving part rather than water pressure and operates in a cycle based on the sequences.

Water coming from the supply pipe possessing the velocity creates the water pressure. Due to that pressure surge, high pressure rise takes place in the drive pipe, flap of the check valve gets opened and at the same time pressure release at the waste valve takes place. This process occurs repeatedly like pulse, so water level in pipe rose reaching to the air chamber. Air chamber suppresses the water at the downward side, but due to placement of non-return valve water has no way to return back and it try to escape from the delivery side and water is lifted to desire height. This is the working principle of the newly developed energy free water lifting device.

Water hammer is a momentary increase in pressure inside a drive pipe caused by a sudden change of direction or velocity of the water in the pipe. Water hammer can be particularly dangerous because the increase in pressure can be severe enough to breaking of pipe or cause damage to equipment. Water hammer most commonly occurs when a valve is closed quickly and suddenly stops the flow of liquid in a pipeline. When this happens, shockwave travel back and forth through the piping system equal to the speed of sound in that liquid or water. These waves travel backward again until pressure is equalized (Maw *et.al.*, 2014). And due to this effect,

it makes way to the water or liquid to escape from the delivery side or delivery pipe. Larger is the water hammer effect, more is the water get lifted from lower elevation to the higher elevation with maximum discharge.

3.4.2.2 Drive pipe

The drive pipe is an important component of a device installation. The drive pipe must be able to sustain the high pressure caused by the closing of the waste valve. Diameters of the drive pipe were taken as 32 mm, 40 mm and 50 mm to check the device performance. Empirical relationships to determine the drive pipe length are (Kumar *et.al.*, 2016):

$$L = 2.5H \quad \dots(3.1)$$

Where, L= Drive pipe length,

H= Supply Head.

Accordingly, three supply heads were taken and corresponding length of drive pipe length decided as follows.

Case I:

Supply Head = 1m

$$\text{Length of drive pipe} = 2.5 \times 1 = 2.5\text{m} \quad \dots(3.2)$$

Thus, for supply head of 1m supports length of drive pipe of 2.5 m.

Case II:

Supply Head = 1.5m

$$\text{Length of drive pipe} = 2.5 \times 1.5 = 3.75\text{ m} \quad \dots(3.3)$$

Thus, for supply head of 1.5m supports length of drive pipe of 3.75 m.

(Justification: If excess length of pipe i.e., 3.75 m is used, discharge get at delivery is less as compared to 3.5 m. Therefore, length of drive pipe is taken as 3.5 m.)

Case III:

Supply Head = 2 m

$$\text{Length of drive pipe} = 2.5 \times 2 = 5\text{ m} \quad \dots(3.4)$$

(Justification: At 5 m length it would not getting proper discharge and proper strokes. Thus, length of drive pipe decreased and is used as 4.8 m).

Since efficiency and reliable cycling depend on water hammer effects, the drive pipe design is important. The device should have an input fitting designed to accommodate in such a way that it should get the optimum slope. Though there is difference in the diameter of the supply pipe and input fitting on the device, the drive

pipe should be of constant diameter and kept as straight as possible. Wherever bends are necessary, smooth, large diameter curves are used. PVC pipe which is flexible and cost effective is better use than steel pipe much more expensive and non-flexible. Valves were used they are of free flow type such as a flow control valve.

3.4.2.3 Delivery pipe

The diameter of delivery pipe is taken as 12 mm, 16 mm and 25 mm corresponding to the drive pipe diameter of 32 mm, 40 mm and 50 mm respectively. The delivery pipe used is much less critical since the air chamber prevents water hammer effect from traveling up it. Its overall design taken according to the allowable pressure drop based on the expected flow. Typically, the deliver pipe sizes were taken as 12 mm 16 mm and 25 mm, but for very long runs a larger size may be indicated. For the research work, it was decided to use three diameters of delivery pipes with three diameters of supply pipe at three different supply heads are categorized under three parts. i) Part A, ii) Part B and iii) Part C.

Part A: Diameters of supply pipes

- i. 32 mm
- ii. 40 mm
- iii. 50 mm

Part B: Diameters of delivery pipes

- i. 12 mm
- ii. 16 mm
- iii. 25 mm

Part C: Supply heads

- i. 1 m
- ii. 1.5 m
- iii. 2 m

(Note: It was decided that during doing changes in the diameters of supply pipes, diameters of delivery pipes and the supply heads, the size of the waste valve kept constant as 32mm to reduce the amount of waste water).

3.4.2.4 Supply tank

Supply tank of the 33 litres capacity is used for the study. Supply tank stores the water and further it conveys to the energy free water lifting device with the help of drive pipe. Supply tank is kept at a pre-decided height from the ground to develop

supply head. The supply tank is filled up to 30 litres mark to take necessary observations.

3.4.2.5 Supply head

Supply head is the vertical distance from water level in the supply tank to the ground surface. It is also known as drive head or inlet head. In some cases, supply head is also known as fall or vertical fall. Under the given study, three supply heads as 1 m, 1.5 m and 2 m are used for checking corresponding discharges and delivery heads respectively.

3.4.2.6 Delivery head

Delivery head is the very important term in the performance parameter of the energy free water lifting device. The maximum and optimum delivery head at the respective supply head are found out by operating the energy free water lifting device.

3.4.2.7 Air chamber

In design parameters, air chamber is the very important component for maintaining the continuous flow. According to the previous research, it is recommended that the volume of the air chamber be approximately 100 times the volume of water delivered per cycle (Kumar *et.al.*, 2016). Under this study, plastic disposable bottle of 2.25 litres is used for the current research. It is seen that, plastic disposable bottle of 2.25 litres volume working nicely and functioning the role of an air chamber. Due to this, cost of the device gets reduced and also it gave better results.

3.4.2.8 Waste valve

The flow area through the waste valve should equal to or exceed the cross-sectional area of the drive pipe to avoid “chocking” of the flow. The reverse non-return valve is used as waste valve in this device. Waste valve plays an important role in lifting the water by creating water hammer effect. Due to velocity of water, flap of the waste valve gets closed and further open when inside pressure releases. Thus, due to continuous opening and closing of the flap of waste valve water hammer effect is created which effect in the lifting of water. In current research, waste valve of 32 mm diameter is used and kept constant to reduce amount of waste water. The weight of 32 mm waste valve is found 98.50 g and size of the waste valve is selected corresponding to size of drive and delivery pipe.

When the waste valve is opened, water flows from the source, through the water inlet (drive) pipe and drain out through waste valve. After a short time, the

velocity of the flow is high enough to force the waste valve closed. The water, due to its inertia, wants to continue moving past the valve. The pressure inside the device will rapidly increase enough to force the check valve open. This forces some water into the air chamber, compressing the chamber's air bubble. The pressurized bubble forces that water through the delivery pipe to the point of use. The compressed air in the air chamber helps smooth out the flow on the delivery side of the device, so the flow tends to be more continuous, rather than a small spurt during each cycle. Soon after the check valve has opened, the pressure surge (generated by the waste valve closing) is spent. Flow will try to start backwards, but the check valve will close, preventing this from happening. At about this time, the pressure in the drive pipe will be low enough so that the waste valve can open, allowing water to start flowing from the source to the device, beginning a new cycle. The cycle that the device goes through can occur 70 to 130 times per minute, depending upon conditions such as head, flow rate, and the size of the energy free water lifting device.

3.4.3 Material used, shape and size of the device

The different water lifting devices available in the market are surveyed and studied. The existing available water lifting devices have found certain merits and demerits. Sometimes they have the same operating and working principles with the different hydraulic parameters which other devices under consideration have different operating and working principles with different hydraulic parameters or features. As some of the reviewed and surveyed devices are working with the working principle matching to the hydraulic ram. Therefore, for the present study, the same working principle is to be found suitable. Hence, it was decided to use the velocity head of the flowing water to run the proposed device and to lift the water from lower elevation to the higher elevation. Also, based on the above observations some important design considerations are drawn and to be useful to fulfill the objectives. Therefore, the cost effective, easy to operate, from locally available material and energy free which run without the electricity or fuel it is decided to design and develop such an energy free water lifting device which will run by velocity head of the flowing water and with the working principle which matching to the hydraulic ram. Besides, selected material for development of the device should fulfill following requirements:

- i. Selected material should be of low cost and easily available in the local market.

- ii. Pipes of the different sizes with sufficient pressure rating.
- iii. PVC accessories of an appropriate sizes and pressure rating to reduce the cost of the manufacturing.
- iv. Easy to assemble, disassemble, operate and maintenance.
- v. Accessible for use of different supply heads with corresponding different delivery heads.
- vi. Accessible for use of different diameters of supply pipe corresponding to the different diameters of delivery pipes.
- vii. Operation by use of water hammer effect.
- viii. Use of kinetic energy of the flowing water to lift the part of it to a considerably greater height.

3.4.4 Materials used for the manufacturing of energy free water lifting device

The materials for construction of the cost effective energy free water lifting device is described in the following section. It was also decided to consider the small section of pipe i.e., 32 mm may be considered for the present study and then accordingly the different accessories or components. After successfully run of the proposed study, it will enable to propose the different pipe sections for the different dead weights with the different velocity, pressure heads to lift the water to a specific height. However, considering the reviews, it was proposed to use the 32 mm diameter PVC pipes with the 12 mm, 16 mm and 25 mm diameter delivery pipes by keeping the valve size same as 32 mm diameter and accessories for the present study.

3.4.4.1 PVC pipe

For designing the energy free water lifting device polyvinyl chloride (PVC) pipes were used. The reason of selecting PVC pipe for this device is due to the fact that it is much lighter and durable. In addition, the PVC is corrosion free materials with easy availability anywhere. If the iron material is used; it will undergo corrosion after some time; because our device would be continuously in contact with water and iron is costly compared to PVC. To fulfill this requirement, 32 mm, 40 mm and 50 mm diameter pipes were selected for design the device with the 12 mm, 16 mm and 25 mm diameter delivery pipes and by keeping the valve size same as 32 mm. The 32 mm PVC pipe was cut into small pieces of 10 cm for joining. The PVC pipe used for developing energy free water lifting device is shown in the plate 3.15.

3.4.4.2 PVC Flow Control Valve

A flow control valve regulates the flow or pressure of a fluid. Control valves regulate the flow of a liquid by opening or closing internal passages. Two flow control valves, one is at inlet side to regulate flow through 32 mm, 40 mm and 50 mm diameters and another is at delivery side as well as to start and close off the device are required. Therefore, the locally available PVC control valve of 32 mm (1 inch) diameter is used for energy free water lifting device. The pictorial view of the control valve is shown in the plate 3.16.

3.4.4.3 Non-return valve

The unidirectional flow can be developed by using non return valve. A threaded non-return valve of 32 mm diameter is fitted to ensure the flow through a pipe of 32 mm, 40 mm and 50 mm diameters in the right direction without reversing the flow. The design of developed free energy pump equips two non-return valves of 32 mm (1 inch) diameter, one is placed vertically in the direction of flow to prevent reverse flow from high pressure region and another kept exact opposite in direction of flow to release water as a waste valve till sufficient pressure close it. The waste valve creates water hammer effect at the pipe end. The pictorial view of the control valve is shown in the plate 3.17 and 3.18.

3.4.4.4 Air chamber (Plastic Disposable Bottle)

The plastic disposable bottle of 2.25 lit capacity is used as an air chamber for energy free pump. The main function of the air chamber is to absorb the water hammer pressure that will occur in the energy free water lifting device. Water continues to flow into the air chamber until the unbalanced force caused by the difference between supply and delivery pressures reduces the velocity to zero. The plastic disposable bottle transforms the high intermittent pumped flows into a continuous stream of flow. The valves allow air into the device to replace the air absorbed by the water due to the high pressure and mixing in the air chamber. The use of the plastic bottle will allow the design to be cost effective as well as enhances its portability due to weight reduction. The detailed pictorial view of the disposable bottle is shown in the plate 3.19.

3.4.4.5 Supply and Delivery pipe

As shown in the plate 3.20 and 3.21 for conveying water from supply tank or water source to the device, drive pipes are used and for conveying part of lifted water

to the delivery tank delivery pipes are used. Various pipe diameter combinations for drive and delivery sides are used and accordingly the performance is evaluated. At drive side 32 mm, 40 mm and 50 mm pipes are decided to use and at delivery side 12 mm, 16 mm and 25 mm pipes are decided to use corresponds to respected drive pipes. The combine effect of the drive and delivery pipe on the performance of the energy free water lifting device is having paramount importance for selection of pipes.

3.4.4.6 PVC Male and Female Adaptors

Adaptors, sometimes called reducing couplings, are a versatile fitting. These fittings are designed to change the end type of a pipe, allowing it to connect to fittings and pipes of many sizes. They can have threaded or slip socket ends to connect to an endless variety of pipes and fittings. Adaptors can be either male or female-threaded, as well as socket or spigot as shown in the plate 3.22 and 3.23. Female Threaded Adaptors has internal threads and Male Threaded Adaptors has external threads. Male Threaded Adaptor is also called as MTA and Female Threaded Adaptors is called as FTA.

3.4.4.7 PVC Elbow

Elbows are used to change the direction of flow of the flowing fluid. Elbows are generally available with an angle of 22.5° , 45° and 90° angle which can be selected according to the requirement. If pipes are of same diameter then normal elbows are used otherwise reducer elbows are used. The elbows of the different sizes, angles help for accurate assembling of various components of the device. The detailed pictorial view of the elbow is shown in the plate 3.24. For the present study, the elbow of 90° angle was used.

3.4.4.8 PVC “T” (Tee)

PVC ‘T’ (Tees) are a fitting with three ends; two in a straight line and one on the side at a 90-degree angle. ‘T’ (Tee) allows a line to be split into two separate lines with a 90-degree connection. Also, ‘T’ (Tee) can connect two lines into one main line. They are also often used for PVC structures. ‘T’ (Tees) are available in different sizes as well as reducing ‘T’ (Tees) can also be used as per requirement. It will help for easy combining or separating the flow lines. The pictorial view of the ‘T’ (Tee) is shown in the plate 3.25.

3.4.4.9 Hose Clips

A hose clamp or hose clip or hose lock is a device used to anchor or seal a hose onto a fitting such as a barb or nipple. Hose clamps are commonly used in the agriculture industry are made from a combination of steel and iron or plastic. They are plated to prevent rust and corrosion during use. The size of the hose clamp is selected according to the pipe size requiring anchorage and strength of the clamp is decided according to the pressure it has to withstand. The sample pictorial view of the hose clip is shown in the plate 3.26.

3.4.4.10 Hose Nipples

There is a specialty nipple called a “hose nipple” for processes which require connection to tubing. That fitting features a male threaded connection on one end and a hose barb on the other. The hose barb may be the same size as the pipe connection or it may be reduced. The required size of the hose nipple is used for joining the hose pipes with the energy free pumping device. The pictorial view of the hose nipple is shown in the plate 3.27.

3.4.4.11 Reducers

A reducer reduces the pipe size from a larger to a smaller bore (inner diameter). Alternatively, reducer may refer to any fitting which causes a change in pipe diameter or it reduces diameter. This change may be intended to meet hydraulic flow requirements of the system or adapt to existing piping of a different size. The length of the reduction is usually equal to the average of the larger and smaller pipe diameters. Although reducers are usually concentric, eccentric reducers are used as needed to maintain the top- or bottom-of-pipe level. A reducer can also be used either as a nozzle or diffuser, depending on the Mach number of the flow. Here in our study, reducers are used of size 32 mm × 16 mm, 32 mm × 25 mm i.e., 1×1/2”, 1×3/4” respectively. The pictorial view of the reducer is shown in the plate 3.28.

3.4.4.12 Teflon Tape

Plumber's tape, also called as Teflon tape, helps to get a watertight seal on threaded pipe joints. It also helps lubricate the connection, making the threading a bit smoother, and it helps to prevent pipes from sticking when want to disassemble the joint. The pictorial view of the Teflon tape is shown in the plate 3.29.

3.4.4.13 PVC Solution

A PVC pipe adhesive joining solution is used to join the PVC pipes to the accessories and make the connections leak-free. PVC solution is the very important

component in the accessories required to construction of the device. The pictorial view of the PVC solution container is shown in the plate 3.30.



Plate 3.15 PVC pipe



Plate 3.16 Flow control valve



Plate 3.17 Brass non-return valve

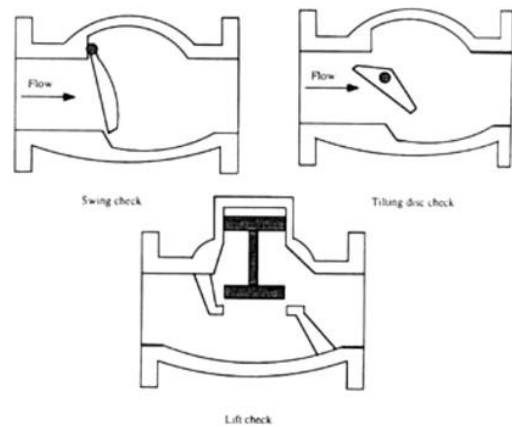


Plate 3.18 Actual working of flap of non-return valve



**Plate 3.19 Plastic Disposable Bottle
used as Air Chamber**



Plate 3.20 Supply pipe



Plate 3.21 Delivery pipe



**Plate 3.22 Female Threaded
Adaptor (FTA)**

**Plate 3.23 Male Threaded
Adaptor (MTA)**



Plate 3.24 PVC Elbow



Plate 3.25 PVC 'T' (Tee)



Plate 3.26 Hose Clip



Plate 3.27 Hose Nipple



Plate 3.28 Reducer



Plate 3.29 Teflon tape



Plate 3.30 PVC Solution Container

3.5. Methodology

The hypothesis of the study is to develop energy free water lifting device which could operate without use of any external energy but itself on the hydraulic pressure developed due to elevation difference or by kinetic energy of the falling or flowing water. The different approaches considered for designing and development of cost effective energy free water lifting device is described in the section 3.5.1 and 3.5.2. The major components needed for energy free water lifting pump are described under the section 3.4. To design and develop the cost effective energy free water lifting device the principle of water hammer effect along with different drive pipe to delivery pipe ratios, different supply head to delivery heads ratios, waste valve alignment and other parameters are important and considered under the methodology.

3.5.1 Experimental Setup

The experimental setup is given as shown in the Fig 3.1. While proposing the plan and design to develop the cost effective energy free water lifting device the required methodology described in the section 3.5 and material required given in the section 3.4 is considered. The operating and working principle are also taken into account along with the hypothesis made for the present study. As shown in the Fig. 3.2 given below, experimental setup includes the placement and fitting of all the components of the energy free water lifting device. This includes following process: pipe cutting, joining the pieces of the pipes in pre-decided manner, fitting of accessories, alignment of non-return valves, mounting of air chamber, fitting of control valves, etc.

The schematic sketch of the experimental setup of energy free water lifting device with the necessary legend is described below neatly. This shows the actual alignment of valves, direction of valves, direction of delivery, direction of the supply pipes and other details in prescribed manner. After that, the various processes which

comes under the manufacturing of the energy free water lifting devices are given in details below the schematic sketch of the energy free water lifting device is as shown in Fig. 3.1 and materials required for the manufacturing of the device are shown in the Fig. 3.2.

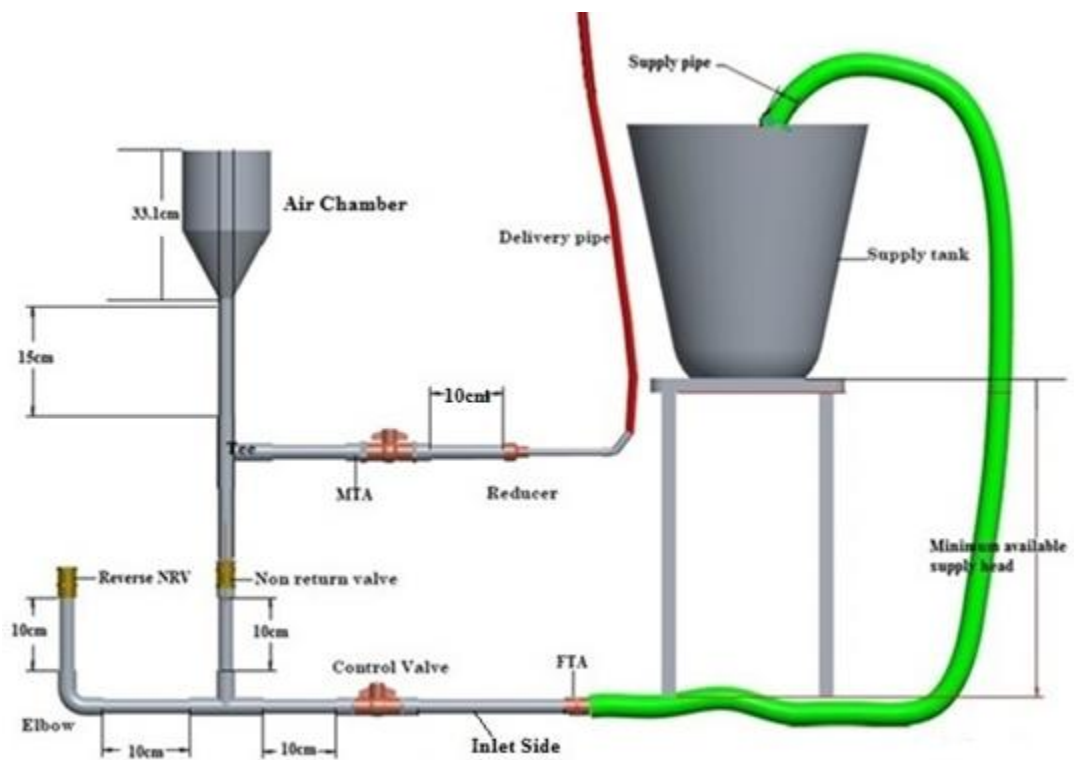


Fig. 3.1 Schematic set up of the energy free water lifting device

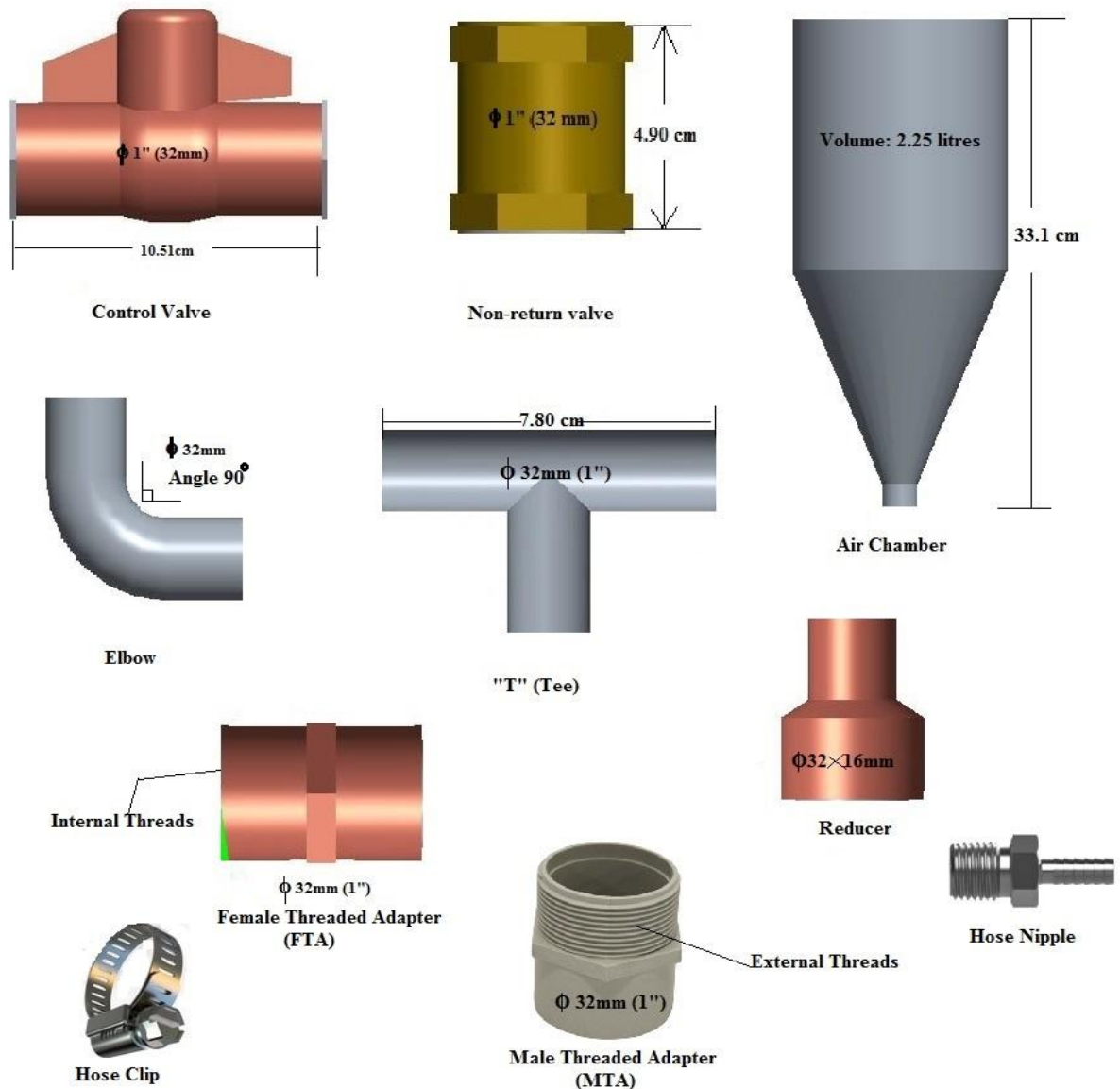


Fig. 3.2 Materials required for the energy free water lifting device

3.5.1.1 Pipe Cutting

The PVC pipe of 32 mm diameter is used for construction of the energy free water lifting device. As shown in the plate 3.32, PVC pipe is cut by the hacksaw with the appropriate length of 10 cm pieces as required and planned for the development of the energy free water lifting device.

3.5.1.2 Assembling of the components

After the cutting of the pipe of size 32 mm and organizing other components, position of the various components gets fixed as shown in the schematic sketch 3.1 and plate 3.33 and 3.34. The cut pieces of PVC pipe are joined with the help of accessories according to the sketch with the help of PVC solution.

3.5.1.3 Aligning the non-return valves

The 32 mm non return valves are used as waste valve and check valve in the energy free water lifting pump. The position of the non-return valve is fixed as shown in the plate 3.35. Non-return valves fitted in a such way that the valve which will act as a waste valve placed in the reverse manner, so that downward side of it is directed towards the upper side and flap of the valve is located at the upper side. The valve which will act as a check valve and restrict the return entry of the water is placed in the straight position.

3.5.1.4 Fixing of control valves

The PVC control valves are useful for regulating flow through the pipeline. The control valves used for the energy free water lifting pump are 32 mm diameter. The fixing of control valves for energy free water lifting pump is as shown in the plate 3.33. At the inlet side and at the outlet side, control valves get fitted to control the flow of the fluid and also for regulating the strokes of the waste valve.

3.5.1.5 Mounting the air chamber

The plastic disposal bottle of 2.25 lit. capacity is used as air chamber in the energy free water lifting pump. After the all connections, plastic disposable bottle which will act as an air chamber mounted after the check valve and delivery line is connected in between check valve and air chamber as shown in the plate 3.36. With the help of cutter, the middle portion of bottle's lid removed and then the whole bottle with the lid get stuck as the air chamber with the help of cut piece of the PVC pipe and PVC solution.

3.5.1.6 Adjusting the supply heads

After joining all connections, inlet or supply of the water was connected to the device by adjusting decided supply heads. The performance of the device was evaluated for three supply heads. This is shown in the plate 3.37.

3.5.1.7 Delivery pipe connections

After the completion of the setup of the device, the device was fixed on the wooden plank with the help of small clinch nails for the better support whenever device is in working condition. Delivery pipe is connected to the device with the help of hose nipple and hose clip as outlet of the water. Care must be taken that the delivery pipe diameter should always be less than that of inlet pipe diameter. This is shown in the plate 3.38.

3.5.1.8 Setting the delivery heads

The delivery head is set according to the head and discharge developed by the device. Delivery heads were increased gradually corresponding to the discharge rates and optimum performance of the device is determined. The measurement and setting of the delivery head are shown in the plate 3.39.



Plate 3.32 Cutting the pipes for device assembly



Plate 3.33 Initial Connections (Fitting accessories)

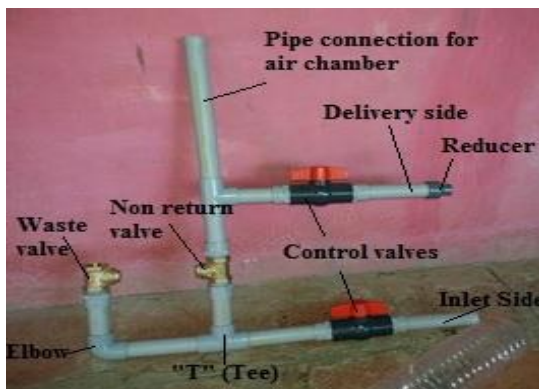


Plate 3.34 Setup after all the connections



Plate 3.35 Alignment of Non-return valves

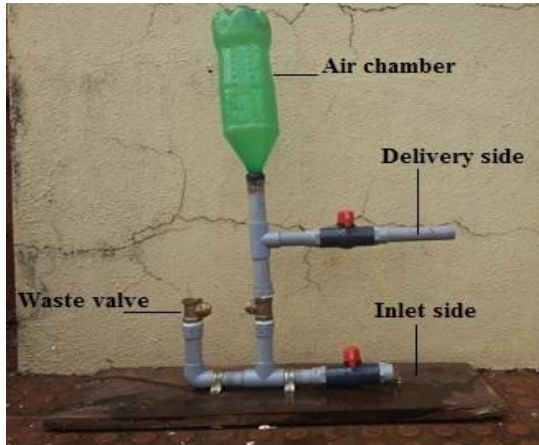


Plate 3.36 Final setup after total accessories assembly



Plate 3.37 Adjusting the supply head

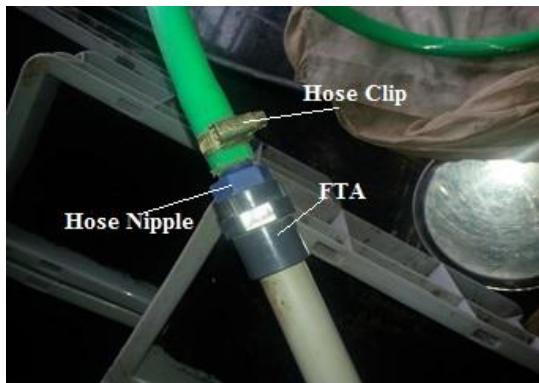


Plate 3.38 Delivery pipe connection with the help of Hose Nipple and Hose Clip

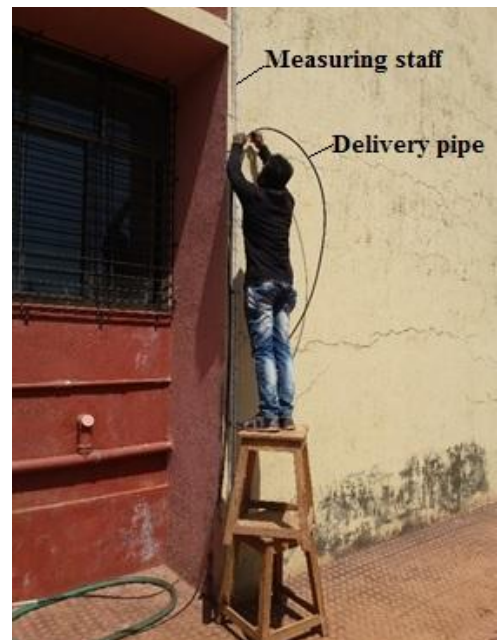


Plate 3.39 Setting the Delivery head

3.5.2 Study of hydraulic parameters of the energy free water lifting device

A hydraulic parameter needs to be considered while designing energy free water lifting device (Hussin *et.al.* 2017). These parameters include volumetric flow rate (Q), velocity of the fluid flow (V), and the system efficiency (η). (Hussin *et.al.* 2017). The hydraulic parameters are determined by using following procedure:

3.5.2.1 Determination of Volumetric flow rate

The volumetric discharge from the drive pipe of the energy free water lifting device is calculated by using equation given in 3.5. The calculated volumetric flow rate is further used in next calculation of velocity.

$$Q = \frac{\pi r^2 L n}{60} \quad \dots(3.5)$$

Where, Q= Volumetric flow rate, lpm

r = radius of the pipe, mm

L = length of the pipe, m and

n= number of strokes

3.5.2.2 Determination of velocity of fluid

The velocity of fluid flow in the drive pipe is given by

$$V = \frac{Q}{A} \quad \dots(3.6)$$

Where, V = velocity of fluid, m/s

Q = fluid volumetric flow rate, lpm and

A = area of the pipe, mm²

3.5.2.3 Calculation of Reynold's Number

In order to ascertain the nature of the flow (that is whether laminar or turbulent), the Reynolds number is determined by using following equation.

$$Re = \frac{Vd}{\nu} \quad \dots(3.7)$$

where, V = velocity of fluid flow, m/s

d = pipe diameter, mm and

ν = kinematic viscosity, m²/s.

3.5.2.4 Calculation of frictional loss

If the flow found turbulent, it is required to calculate frictional loss which is computed by following formula

For Turbulent flow,

$$f = \frac{0.316}{Re^{0.25}} \quad \dots(3.8)$$

where, f = frictional factor of the pipe and

Re = Reynolds number.

3.5.2.5 Determination of head loss

The Darcy–Weisbach formula is the basis of evaluating the loss in head for fluid flow in pipes and conduits and is given by

$$\text{Head Loss} = \frac{fLV^2}{2gd} \quad \dots(3.9)$$

where, g = acceleration due to gravity, m/s^2

L = length of the pipe, mm

V = fluid velocity, m/s and

d = pipe diameter, mm.

3.6. Performance of the Energy free water lifting device

Before approaching to the performance evaluation of the developed energy free water lifting device a prototype is developed and the filler trial is conducted at the laboratory conditions. Once it is confirmed that device prototype is working properly, then combinations of the supply and delivery pipes are decided with the corresponding supply heads and furthermore efficiency of the energy free water lifting device is calculated.

3.6.1 Performance evaluation of the device

While determining the performance of the designed device, delivery discharges and flow rates at the delivery side are recorded with respect to corresponding delivery heads. Observations were taken for 1 m, 1.5 m and 2 m supply heads and with respect to them different delivery heads were taken were described in details in result and discussion chapter. The volume of water passed through supply pipe in unit time were recorded. The volume of water delivered at delivery side is recorded and flow rates at the inlet and flow rates at the delivery side were calculated. With the help of recorded observations and putting them into the formula, efficiency of the energy free water lifting device was calculated.

The performance evaluation of the device is conducted to know the following parameters:

- i. At particular supply head, how much water is to be lifted.
- ii. Any significant effect of increment in delivery head on the performance of the device.
- iii. Is there any significant effect occurs if the diameters of the supply pipe will get varied?
- iv. By keeping same size of waste valve, up to how much diameter of supply pipe can we used and if such cause any problem to the working of the device?

- v. If the delivery head increases, will there any difference in the delivery discharge?
- vi. By using such a device, up to how much efficiency will it lift the water at particular head?

These were the main purposes of the performance evaluation of the energy free water lifting device. The performance of the designed system is done for combinations of supply pipe, delivery pipe and supply heads from which delivery discharge, delivery head and efficiency of the device is worked out. At optimum performance, corresponding delivery discharge, delivery head and efficiency are worked out.

3.6.2 Efficiency of the Energy free water lifting device

After design and development of the energy free water lifting device it was required to check the performance of the device. So that, the working of the energy free water lifting device and lifting performance was checked. In that, delivery discharges with corresponding delivery heads were checked. From the performance of the energy free water lifting device, efficiency of the energy free water lifting device is checked by using formula given by Hussin *et.al.* 2017:

$$\eta = \left(\frac{H \times Q_{out}}{h \times Q_{in}} \right) \times 100 \quad \dots(3.10)$$

Where, H = Delivery head, m

Q_{out} = Flow rate at delivery pipe, lpm

h = Supply head, m and

Q_{in} = Flow rate at inlet pipe, lpm.

η = Efficiency of the device, %.

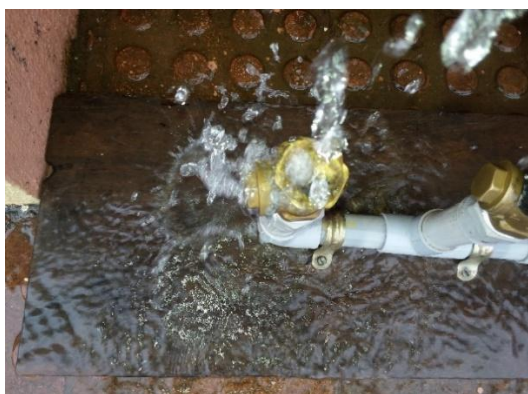


Plate 3.40 Waste valve in working condition

Plate 3.41 Operation of waste valve

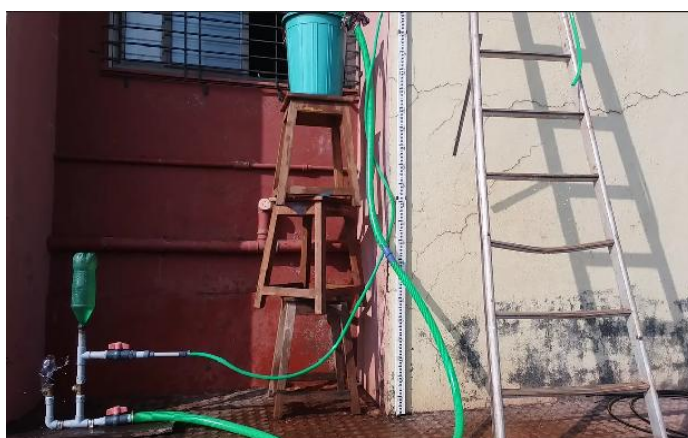


Plate 3.42 Energy Free Water Lifting Device

3.7 Cost analysis

Cost analysis includes cost of production that is cost required to manufacture the energy free water lifting device are as follows:

3.7.1 Cost of production

The cost of production was worked out by calculating the seasonal fixed cost which comprises cost of material used including accessories. The total operating cost includes variable cost and fixed seasonal cost.

IV. RESULTS AND DISCUSSION

The experiment entitled, “Design and Development of Cost Effective Energy Free Water Lifting Device”, was carried out at Instructional farm and in the Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. The appropriate and required materials and methodology were used and adopted as discussed and described in Chapter 3 (Materials and Methods) section 3.1 to section 3.7. Accordingly, all the necessary observations were recorded. The survey conducted regarding the different devices available in the market, their advantages and disadvantages; design and performance of the existing and developed device are presented, interpreted and discussed under the following sections and sub-sections of this chapter to draw the specific conclusions. This chapter concludes about pros and cons of the different existing water lifting devices, design considerations to overcome flaws in the existing devices, design and development of the energy free water lifting device, various components of the designed device, performance evaluation and cost estimation of the designed and developed energy free water lifting device. Thus, all the necessary data is collected, analyzed and interpreted in the scientific manner to draw the neat conclusion of the study.

4.1 Study Area

The experiment was conducted during 2018-2020 at the Instructional Farm and in the Laboratory of the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli (M.S.), India as described in section 3.1.

4.2 Survey and study of different water lifting devices available in the market

The survey to know the different water lifting devices available in the market was conducted by following the proper procedure as described in section 3.3 of chapter 3 materials and method. Collected the information by approaching the different suppliers, farmers and studied those water lifting devices in details. The findings of the study of the different water lifting devices available in the market are as given below in Table 4.1.

Table 4.1 Merits and Demerits of the water lifting devices available in the market

Sr. No.	Name of the device	Advantages	Disadvantages
1.	Rope and Bucket Lift	i. Simple technology. ii. Inexpensive to build and maintain. iii. Operated at depths of up to 100 m. iv. Water Delivery of 200 lpm and 15 lpm for animal and human operated Rope and Bucket Water Lift respectively.	i. Needs human or animal power. ii. Animals need to be maintained all year even when irrigation is not necessary. iii. Relatively low efficiency for traditional human and animal operated designs (10-40%).
2.	Archimedes Screw	i. It is simple to construct. ii. It has longer life. iii. Especially use to raise irrigation water and for land drainage. iv. Used to move water that contains mud, sand, or gravel.	i. It has less range of lift. ii. It requires 1human power to operate. iii. Skilled labours required to install. iv. Cost is comparatively high considering its range of lift.
3.	Waterwheel	i. Ancient device to lift the water from the water source. ii. Besides lifting of water electricity also get generated. iii. The water discharges a few centimeters above the center shaft and therefore increases the useful head in relation to the diameter. iv. It has high degree of efficiency even with only partially-full buckets or scoops.	i. Range of lift is less. ii. Spoilage of water when speed of the wheel is slow. iii. Design of the structure is complex. iv. Skilled manpower required to install. v. Installation as well as maintenance cost of the device is comparatively high. vi. Heavy weight and large space requirement. vii. The losses due to height and suspension.
4.	Rope pump	i. Water can be lifted up to 50 m efficiently. ii. Easily available. iii. Local artisans can construct such type of device.	i. Rope becomes worn after some interval because it is exposed to the sun. ii. The installations of the rope pump if poorly done then its performance become suboptimal. iii. The pulley wheel

			malfunctions. iv. Regular maintenance of pistons, frame and guide block require. v. The traditionally used rope pumps having a lift of only about 10 m. vi. Users need to exercise care when using the pump as it is susceptible to contamination.
5.	Suction Plunger Handpump	i. Most of the parts are above the ground surface and thus easily accessible. ii. Less maintenance required i.e., maintenance involves replacement of seals and valves only. iii. Operations can be easily performed with few tools iv. It is easy to operate.	i. Washers, cup seals and bearings get worn out early. ii. Excessive corrosion that causes pump rods to break and leaks to appear in the rising mains. iii. Many pumps are of poor quality. iv. The biggest drawback of suction pumps is that they can lift water to only about 7 m, and if the water table falls below that level, the pump becomes inoperable.
6.	Direct Action Handpump	i. Easy to operate. ii. No priming is needed. iii. Maintenance is somewhat less.	i. Washers, plungers and foot valve parts get worn early. ii. An abrasion of the seal on the PVC cylinder and between the pump rod and rising main takes place. iii. Problem of damage to handle. iv. The maximum lift is limited to 12 m. v. The force needed to pump the water may be too great for children, especially if the water table is below 5 m.
7.	Deep-Well Diaphragm Pump	i. Easy to install or remove without the need for special tools or equipment. ii. Replacing spare parts is usually easy; only the replacement of the diaphragm may need the assistance of a skilled mechanic. iii. It is possible to install	i. Pedal rod guides and plunger seals need to be replaced frequently and also the plunger guides may wear out quickly. ii. The drive hoses often need to be re-primed because water leaks past the plunger seals, and the foot pedal then needs to be raised by hand.

		several pumps in a single well or borehole.	iii. If solid dust or particle enters the downhole pumping element it must be cleaned, since this will cause the diaphragm to stop working or even rupture. iv. Needs skilled manpower to repair, install or replace. v. Technically sound knowledge and equipment are needed to manufacture.
8.	Deep-Well Piston Handpump	i. Assembled or dismantled without tools, or with only very simple ones. ii. Servicing and repairs can be easy. iii. Easy to lift the water.	i. Problems with the quality control of local manufacturers ii. More chances of breakage of parts. iii. Corrosion is a main problem. iv. Problem of worn-out bearings. v. Hard to handle as depth of groundwater increases. vi. The rising main should be made of the highest-quality material vii. It may require considerable torque to start them.
9.	Hydraulic ram	i. It lifts the water to higher elevation without electricity or external power source. ii. It operates continue once torque given to it. iii. This device is easy to maintain. iv. It having long life. v. This is reliable. vi. Effective in mountainous areas.	i. It should require comparatively higher supply head. ii. Initial cost of the device is comparatively high. iii. Parts of the device are sometimes not easily accessible. iv. Design of air chamber and waste valve is too complex and too lengthy. v. Sometimes if the velocity of the flowing water decreases, discharge getting at the delivery is comparatively very less or no discharge.

From the Table 4.1, it is observed that some of the existing devices require power to operate, costly installation, needs skilled manpower for repair and maintenance. These devices are not designed for specific purpose and hence not easy to operate. Their size, shape, weight is also one of the constraints in their use according to specific need and local conditions. Therefore, to overcome the problems

associated with the different existing water lifting devices under study; the design considerations were made for the design and development of the cost effective energy free water lifting device and are presented under the section 4.3.

4.3 Design and development of energy free water lifting device

Considering the limitations of the available water lifting devices which were surveyed and studied and described in the section 4.2 and on the basis of basic considerations as given in material and methods under section 3.4.1 following points were considered for designing the energy free water lifting device as;

4.3.1 Design considerations

- i. All the material of construction should be available in the local market.
- ii. The cost of the construction material should be affordable.
- iii. The device should lift the water without any external energy source such as human, animal, electricity and fuel etc.
- iv. No requirement of skilled manpower.
- v. It should operate at low supply head.
- vi. The spares should be easily available for its easy maintenance.
- vii. The device should be user friendly.
- viii. Minimum fitting requirement.
- ix. Construction and design of the energy free water lifting should not be complex. It should be such that, normal person can easily understand and construct at his/her own.
- x. It should give continuous optimum discharge.
- xi. Energy free water lifting device is to be operated by using the velocity (hydropower) head of that flowing water.
- xii. The device should have less corrosion attacking parts, so that life of the device becomes longer as possible.
- xiii. The device should work continuously at its own once started and should not in need to supervise.
- xiv. Once started, it should run continuously.
- xv. The energy free water lifting device should have less wear and tear problems and if such type of problems occurs, any person can replace it or repair.

- xvi. The design of the energy free water lifting device should be cost effective, so that common person can also afford the cost of that device.

Therefore, an attempt was made to design and develop the cost effective energy free water lifting device from locally available material which is to be used in remote areas as an alternative to the electrical and mechanical pumping devices where the unavailability of energy or fuel and to fill the overhead tanks and even to meet the requirements of irrigations of small upland fields during dry spell during monsoon to meet the domestic needs of the people by using kinetic energy of the flowing water.

From the survey and study of the different water lifting devices available in the market and design considerations made there on. It was decided to use the working principle of hydraulic ram and water hammer effect by using the locally available material to minimize the cost and to serve the purpose.

4.3.2 Water hammer

Considering the design approach of the energy free water lifting device, the effect of water hammer was considered which is described in the section 3.5.2.1 in chapter 3 materials and method. The water hammer effect is the result of sudden stoppage of the water with high velocity. By allowing water to flow with the velocity and sudden stoppage could result in water hammer effect at the waste valve. Water hammer effect creates rise in pressure in the device, results in lifting of water up to the air chamber. Air chamber possesses air which get suppressed due entry of water and again expands once pressure outside lowers down and water gets lifted.

As it was aimed to use the water hammer effect to push the water to a desired height i.e., 3 to 4 m (up to a roof top) to fill the water into the overhead tanks during monsoon due to absence or failure of electricity in the Konkan region. It was also aimed that it should be energy free i.e., only use of hydropower and not with mechanical, electrical or any other source of energy. The use of hydropower was from flowing water/ water current with specific grade. It was decided to have the cost effective device, user friendly and made of locally available material. Therefore, initially as described in section 4.3, the materials were used and procedure was adopted to construct the energy free water lifting device. After construction, the trial was taken of that device as shown in Fig. 4.1 and plate 4.7, whether there occurs the water hammer effect or otherwise. Once, it was confirmed that when by simply adjusting the direction of non-return valve (NRV) i.e., one in forward direction while

another was in opposite direction, the purpose was serving and device is lifting the water up to a certain height with the water hammer effect due to non-return valve (NRV) only.

After confirmation, it was necessary to know by changing the inlet size of pipes and corresponding size of the delivery pipes by keeping the size of control valve and non-return valve (NRV) constant as described in the section 4.3.2.3, what is happening in getting the height of water lift. Accordingly, it was tested for different combinations and in total 27 combinations as described in section 4.3.2.5.

Therefore, further by adopting the following step by step procedure, the device was constructed as shown in Fig 4.1 and Plate 4.7. Preliminary the device was constructed for 32 mm inlet pipe with 32 mm diameter of non-return valve (NRV) and control valve and for 16 mm of delivery pipe. The device was operated for 1 m. The same procedure was adopted for all the combinations i.e., for supply pipe of diameters 32 mm, 40 mm and 50 mm and delivery pipes of diameters 12 mm, 16 mm and 25 mm when supply heads were 1 m, 1.5 m and 2 m.

4.3.3 Construction of water lifting device

The different parts and accessories required with their functions to design and develop the cost effective energy free water lifting device according the design considerations are discussed in the section 3.4.3 and 3.4.4 of chapter 3 materials and method. In this section, actual material used for the fabrication with their dimensions is described and actual material used is shown in Plate 4.1 and Plate 4.2.

4.3.3.1 PVC pipe

The details of the PVC pipe are given in section 3.4.4.1. For designing the cost effective energy free water lifting device, 32 mm PVC pipe was used. The pieces of PVC pipes of 10 cm length were used to design the device. The PVC pipe is locally and easily available, corrosion free and low-cost material. Required pieces of the PVC pipe were cut and used for assembling the energy free water lifting device as shown in Fig. 4.1 and Plate 4.1. The selection of the PVC pipe was done to fulfill the requirements as reported in section 3.4.4.

4.3.3.2 Flow control valve

The details of the flow control valve are described in section 3.4.4.2. The 32 mm flow control valve was used to control the entry of water which is coming from the supply tank through the supply pipe as shown in Fig 4.1, Fig 4.2 and Plate 4.1. Thus, it

regulated the strokes of the waste valve and ultimately it helped to lift the water with better discharge. The selection of the PVC control valve was done to fulfill the requirements as reported in section 3.4.4.

4.3.3.3 Non-return valve

The details of the non-return valve are discussed in section 3.4.4.3. The 32 mm brass non return valve with the brass flap was used for energy free water lifting device. Two numbers of non-return valves were used as shown in Fig. 4.1, Fig 4.2 and Plate 4.1. One NRV was placed in straight position to restrict backwater while another one was placed in reverse direction to create water hammer effect. The selection of the brass non-return valve was done on the basis of working principle of hydraulic ram and as suggested by Mishra *et.al.* (2018).

4.3.3.4 Air chamber (Plastic Disposable Bottle)

Design of an air chamber in the existing devices was found to be very costly which was needed to put an air pressure on water lifted due to water hammer effect and compel to move it through the delivery pipe in forward direction. Thus, it was replaced by the plastic disposable bottle of 2.25 litres volume. It is very interesting to note that the purpose was served nicely and the plastic bottle of 2.25 litres capacity working as an air chamber perfectly and sustain the pressure created from the water hammer action. The required size of an air chamber i.e., of plastic bottle was considered to minimize the cost of the device and also by considering amount of water to be lifted at a certain height which is explained neatly in the section 3.4.4.4 and shown in Fig. 4.1, Fig 4.2 and Plate 4.5.

4.3.3.5 Supply and Delivery pipe

The three different diameters of pipes i.e. 32 mm, 40 mm and 50 mm were used as supply pipes and three different diameters of delivery pipes i.e. 12 mm, 16 mm and 25 mm were used as delivery pipes. It was necessary to know the maximum lifting head with the minimum waste water through the waste valve. Therefore, total 9 combinations of the supply and delivery pipes were taken with 3 different supply heads i.e. 1 m, 1.5 m and 2 m. Therefore, there were total 27 combinations were considered to find the most suited combination and to suit the purpose as described in the section 3.4.4.5. Diameters of supply pipes, diameters of delivery pipes and supply heads are categorized into three parts as:

Part A: Diameters of supply pipes used:

- i. 32 mm
- ii. 40 mm
- iii. 50 mm

Part B: Diameters of delivery pipes used:

- i. 12 mm
- ii. 16 mm
- iii. 25 mm

Part C: Supply heads taken:

- i. 1 m
- ii. 1.5 m
- iii. 2 m

(Note: By keeping the size of the waste valve constant as 32 mm (1-inch), necessary modifications were done in the diameters of supply pipes, diameters of delivery pipes and supply heads.)

4.3.3.6 PVC Threaded Adaptors

The details of the threaded adaptors are given in section 3.4.4.6. Male and female threaded adaptors of size 32 mm (1 inch) were used to fix the control valves, NRVs with the help of Teflon tape which are also main accessories in the fittings. The selection of the threaded adaptors was done to fulfill the requirements reported at section 3.4.4 and shown in Fig. 4.1, Fig 4.2 and Plate 4.1.

4.3.3.7 PVC Elbows

The details of the elbow are described in section 3.4.4.7. PVC elbow were used to divert the flow and was used to fix the reverse-NRV as a waste valve. For design, 32 mm (1 inch) elbow with 90° angle was used. Non-return valve in the reverse direction was fixed with the help of MTA by using piece of PVC pipe. The selection of the PVC elbow was done to fulfill the requirements reported at section 3.4.4 and shown in Fig. 4.1, Fig 4.2 and Plate 4.1.

4.3.3.8 PVC ‘T’ (Tee)

The details of the ‘T’ (Tee) is given in the section 3.4.4.8. For design, two numbers of PVC ‘T’ (Tee) were used as shown in Fig. 4.1. One PVC ‘T’ (Tee) was used after the control valve and before the elbow, whose one end connected to inlet

side, other end connected to the waste water side and vertical end connected to the NRV. Another 'T' (Tee) was used at upper side, in that lower end was connected to the NRV, upper end is connected to the air chamber and perpendicular end connected to the delivery side. The selection of the PVC 'T' (Tee) is done to fulfill the requirements reported at 3.4.4 and shown in Fig. 4.1, Fig 4.2 and Plate 4.1.

4.3.3.9 Hose Clips

The details of the hose clip are given in the section 3.4.4.9. Hose clips were used to tighten the supply pipe connection. Also, it was used to tight the delivery pipe to the hose nipple. Different hose clips used are 16 mm (1/2 inch), 32 mm (1 inch), 40 mm (1-1/4 inch), 50 mm (1-1/2 inch), etc. shown in Fig. 4.1. The selection of the hose clips was done to fulfill the requirements reported at 3.4.4 and shown in Fig. 4.2.

4.3.3.10 Hose Nipples

The details of the hose nipple are given in the section 3.4.4.10. Hose nipples were used to connect hose barb and male threaded end. These were used to connect PVC pipe to the supply pipe. For design of cost effective energy free water lifting device, 32 mm (1 inch) cast iron hose nipple was used. The selection of the hose nipple was done to fulfill the requirements reported at 3.4.4 and shown in Fig. 4.2.

4.3.3.11 Reducer

The details of the reducer are described in the section 3.4.4.11. PVC reducers of 32 mm×16 mm (1 to ½ inch), 32 mm × 25 mm (1 to ¾ inch) were used at the delivery side to connect 1" PVC pipe to the respective small PVC pipe. The selection of the reducer was done to fulfill the requirements reported at 3.4.4 and shown in Fig. 4.1, Fig 4.2 and Plate 4.1.

4.3.3.12 Teflon Tape

The use of the Teflon tape is explained in the section 3.4.4.12. Teflon tape was used to make connections leak-proof. Teflon tape was used to make connections water-tight. So that, at the delivery side proper discharges is obtained and there shouldn't any effect on the efficiency of the device and as shown in the Plate 4.2.

4.3.3.13 PVC Solution

The application and use of the PVC solution is given in the section 3.4.4.13. PVC solution was used for the joining the all components of the device which were

plain and having no threads. By applying PVC solution all the accessories were also get fixed and shown in Plate 4.3.

4.3.3.14 Schematic set up of the energy free water lifting device

According to the proposed methodology and design considerations, schematic sketch of the setup of energy free water lifting device was made which is shown in the Fig. 4.1 and for that required materials and accessories are shown in the Fig. 4.2. By taking necessary dimensions of the materials required, schematic sketch of the energy free water lifting device was made. Furthermore, according to the schematic sketch, actual construction of the device was done by involving various processes as described in the section 4.4.

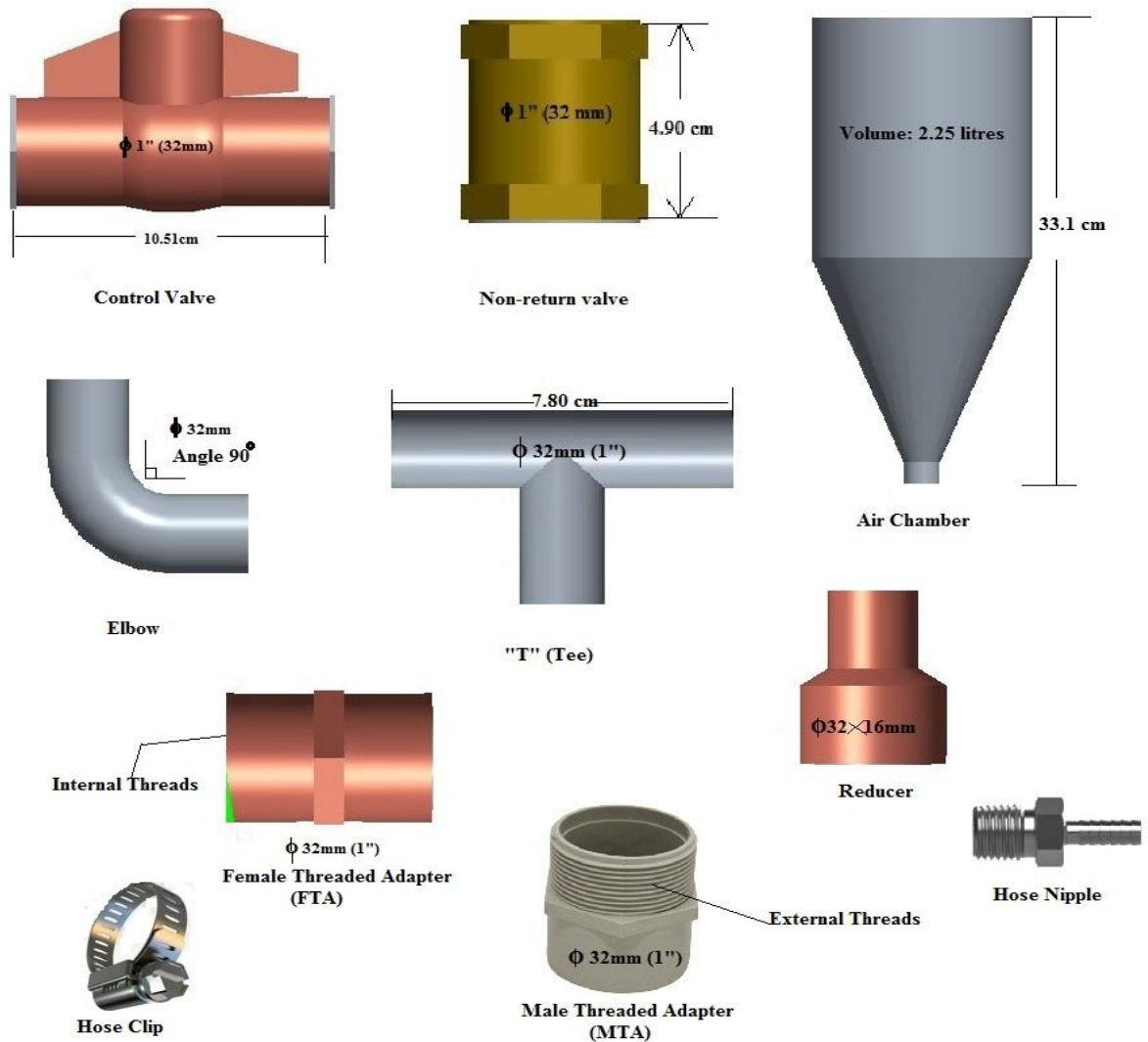


Fig. 4.2 Designed components of the energy free water lifting device

4.4 Step by step construction procedure for energy free water lifting device

1. The required material as considered in section 4.3.3 and shown in Fig. 4.2 and Plate 4.1 was bought and collected from the market.
2. To withstand the device in proper position. The plank of size 80 cm × 27 cm was used and as shown in Fig. 4.1 and Plate 4.7.
3. The horizontal section was constructed by using piece of PVC pipe of 10 cm (two pieces) and 20 cm of 32 mm diameter.
4. The piece of 10 cm and 20 cm PVC pipe were fitted to the control valve by using PVC solvent cement as shown in Fig. 4.1 and Plate 4.6.

5. The 'T' (tee) of 32 mm was fitted to the one end of 10 cm PVC pipe which was fitted to control valve by keeping the position at upright and shown in Fig.4.1 and Plate 4.7.
6. The piece of 10 cm PVC pipe of 32 mm diameter was fitted to the horizontal end of 'T' (tee) of 32 mm and other end of that 10 cm piece of PVC pipe was fitted to elbow of 32 mm and shown in Fig. 4.1 and Plate 4.4.
7. At the vertical section, at vertical end of that elbow, one end of 10 cm piece of PVC pipe was fitted while another end to the NRV of 32 mm in reverse direction and as shown in Fig. 4.1 and Plate 4.4.
8. One end of 10 cm piece of PVC pipe was fitted to 'T' in vertical direction as shown in Fig. 4.1 and another end to NRV of 32 mm.
9. To the other vertical end of that NRV, a piece of 10 cm PVC pipe of 32 mm was fitted and another end of that pipe was fitted to 'T' of 32 mm as shown in Fig. 4.1 and Plate 4.7.
10. The vertical end of the 'T' was fitted to 15 cm PVC pipe of 32 mm and other end of that pipe was fitted to 2.25 liters of bottle as an air chamber and as shown in Fig. 4.1 and Plate 4.5.
11. Below the air chamber and at horizontal 'T', one end of piece of PVC pipe of 32 mm and 10 cm in length was fitted to 32 mm MTA and then 32 mm of control valve as shown in Fig. 4.1 and Plate 4.6.
12. Further, supply tank head was maintained i.e., 1 m, 1.5 m and 2 m as shown in Fig. 4.1 and Plate 3.37 in chapter 3 materials and methods and accordingly the supply pipe was fitted to the inlet pipe by FTA of 32 mm.
13. The different sizes of delivery pipes were taken and fitted along with different sizes of supply pipes and the procedure was repeated for all the sections and combinations.
14. According the required data of lifting head to different dimensions of supply and delivery pipes corresponding to supply heads was recorded and tabulated in the scientific manner.
15. The completed device is as shown in Plate 4.7.

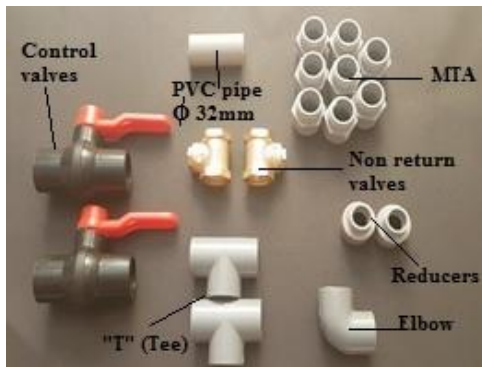


Plate 4.1 Material used for the construction of the device



Plate 4.2 Use of Teflon tape around the MTA and joining control valve to neat fitting



Plate 4.3 Fixing of elbow



Plate 4.4 Installation of the waste valve



Plate 4.5 Fitting of an air chamber

Plate 4.6 Fitting of control valve

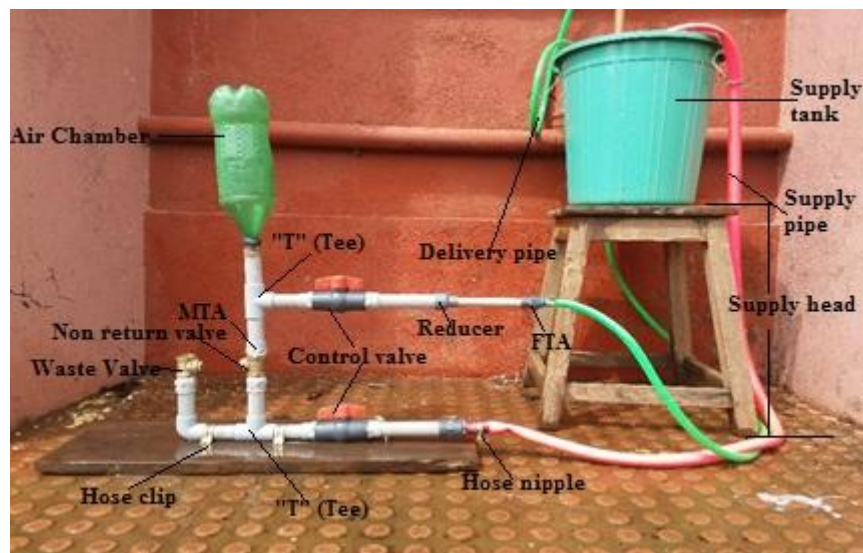


Plate 4.7 Developed energy free water lifting device

4.5 Determination of hydraulic parameters of the developed energy free water lifting device

Various hydraulic parameters of the developed energy free water lifting device is described in the section 3.5.2 of chapter 3 materials and method as suggested by Hussin *et.al.* 2017. Under this section, determination of the hydraulic parameters of designed 32 mm size energy free water lifting device are discussed in details.

4.5.1 Computation of volumetric flow rate

It was essential to understand the volumetric flow through the device. The volumetric flow rate was calculated by using equation 4.1 as suggested by Hussin *et.al.* 2017.

$$Q = \frac{\pi r^2 L n}{60} \dots \dots (4.1)$$

Where, Q=Volumetric flow rate, m³/s

d= Actual diameter of the pipe= 29.6 mm= 2.96 m=0.0296 m

r= radius of the pipe= Diameter of the pipe÷ 2= 0.0148 m

L = length of the pipe= 64 cm= 0.64 m

n= average number of strokes per minute= 99

$$Q = \frac{3.1416 \times (0.0148)^2 \times 0.64 \times 99}{60} \dots (4.2)$$

$$\therefore Q = 7.267 \times 10^{-4} \text{ m}^3/\text{s} \text{ or } 0.726 \text{ l/s} \dots (4.3)$$

From equation 4.3, it is observed that the volumetric flow through the device is found 7.267×10⁻⁴ m³/s.

4.5.2 Velocity of fluid

It was required to calculate and know the velocity of the fluid through pipe. The velocity of fluid flow in the pipe is given by

$$V = \frac{Q}{A} \dots (4.4)$$

Where, V = velocity of fluid, m/s

Q = fluid volumetric flow rate= 7.267×10⁻⁴ m³/s

A = area of the pipe, $A = \frac{\pi}{4} d^2$, m²

$\therefore$ Area of the pipe = $\frac{\pi}{4} \times 0.0296^2$

$\therefore$ Area of the pipe = 6.8813×10⁻⁴ m².

...(4.5)

Therefore, from equation 4.5, it is observed that the area of cross section of the pipe was found $6.8813 \times 10^{-4} \text{ m}^2$.

Hence, Velocity of the fluid

$$V = \frac{Q}{A}$$

$$\therefore V = \frac{7.267 \times 10^{-4}}{6.8813 \times 10^{-4}}$$

$$\therefore V = 1.056 \text{ m/s.} \quad \dots(4.6)$$

Thus, from the equation 4.6, it is observed that velocity of the fluid was found to be 1.056 m/s through 32 mm pipe.

4.5.3 Reynold's Number

Reynolds's number decides the nature of flow. Thus, it was found to be necessary to calculate the Reynolds's number. Therefore, as suggested by Hussin *et.al.* 2017, Reynolds's number was calculated by using formula 4.7

$$Re = \frac{Vd}{\nu} \quad \dots(4.7)$$

where, V = velocity of fluid flow= 1.056 m/s

d = pipe diameter= 0.0296 m

ν = kinematic viscosity= $1.787 \times 10^{-6} \text{ m}^2/\text{s}$

Hence, Reynold's number is calculated by

$$Re = \frac{Vd}{\nu}$$

$$\therefore Re = \frac{1.056 \times 0.0296}{1.787 \times 10^{-6}} \quad \dots(4.8)$$

$$\therefore Re = 17491.66 \quad \dots(4.9)$$

Therefore, from equation 4.9, it is found that Reynolds's number value is 17491.66 which is much greater than 4000 and if the value of Reynolds's number is greater than 4000. The nature of flow is said to be turbulent. Turbulent flow creates frictional losses through pipe. Therefore, it is then required to calculate frictional losses.

4.5.4 Frictional loss

For turbulent flow, frictional factor for pipe was calculated by equation 4.10 with the following formula as suggested by Hussin *et.al.* 2017

For Turbulent flow,

$$f = \frac{0.316}{Re^{0.25}} \quad \dots(4.10)$$

where, f= frictional factor of the pipe

Re = Reynolds number= 17491.66

$$\therefore f = \frac{0.316}{(17491.66)^{0.25}}$$

$$\therefore f = 0.02747 \quad \dots(4.11)$$

Therefore, from equation 4.11, it is observed that the frictional factor for pipe is 0.02747.

4.5.5 Head loss

After working on frictional loss, volumetric flow rate through pipe, velocity of water through pipe and Reynold's number, it was required to work on the head loss through pipe which plays an important role in design factor of the energy free water lifting device. Therefore, head loss through pipe was determined by equation 4.12 and as suggested by Hussin *et.al.* 2017:

$$\text{Head Loss} = \frac{fLv^2}{2gd} \quad \dots(4.12)$$

where, g = acceleration due to gravity = 9.81 m/s^2

L = length of the pipe = 0.64 m

V = velocity of fluid = 1.056 m/s .

d = pipe diameter = 0.0296 m

f = frictional loss = 0.02747

So now, by putting all the values into the equation 4.12, head loss through pipe is calculated.

$$\begin{aligned} \text{Head Loss} &= \frac{fLv^2}{2gd} \\ \therefore \text{Head Loss} &= \frac{0.02747 \times 0.64 \times 1.056^2}{2 \times 9.81 \times 0.0296} \\ \therefore \text{Head Loss} &= 0.0337 \text{ m} \quad \dots(4.13) \end{aligned}$$

Therefore, from the equation 4.13, it is found that head loss through pipe used is 0.0337 m .

Thus, from the data of energy free water lifting device, volumetric flow rate through the pipe, velocity of the water through pipe, Reynold's number to decide the nature of the flow, frictional head loss as the flow found turbulent and the head loss through the pipe were determined.

4.6 Performance evaluation of the energy free water lifting device

According to design considerations and methodology, the energy free water lifting was constructed. The performance is worked out for the total 27 combinations consisting three supply heads as 1 m , 1.5 m and 2 m , three delivery pipes i.e., 12 mm , 16 mm and 25 mm with corresponding three combinations of supply pipes i.e. 32 mm , 40 mm and 50 mm . The results of the experiment recorded are discharge rates,

delivery heads and calculated corresponding efficiencies are described in the following sections and subsections.

4.6.1 Effect of supply pipe diameters and supply heads on delivery discharges and delivery heads

The test was carried out for the total 27 combinations consisting three supply heads as 1 m, 1.5 m and 2 m, three delivery pipes of 12 mm, 16 mm and 25 mm with corresponding three combinations of supply pipes of 32 mm, 40 mm and 50 mm. The delivery heads developed and delivery discharge obtained is recorded for each supply head and supply pipe diameter. The efficiency of the energy free water lifting device was calculated by giving recorded outputs and corresponding inputs.

4.6.1.1 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe described in the section 4.6.1.1. The supply pipe of diameters 32 mm, 40 mm and 50 mm were used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.2.

Table 4.2 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)					
	2m	2.5m	3m	3.1m	3.2m	3.3m
32	0.54	0.36	0.25	-	-	-
40	1.44	0.82	0.52	0.49	0.48	0.47
50	1.67	1.13	0.82	0.79	0.72	0.60

From Table 4.2 and Fig. 4.3, it is revealed that when the supply head was maintained at 1 m height and when the diameter of delivery pipe was kept 12 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained only up to 3 m with least discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm and 50 mm diameter of supply pipe, the delivery head obtained from 2 m to 3.3 m with the decrease rate of discharge (lpm). The maximum discharge was

obtained when supply pipe diameter was 50 mm and 2 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

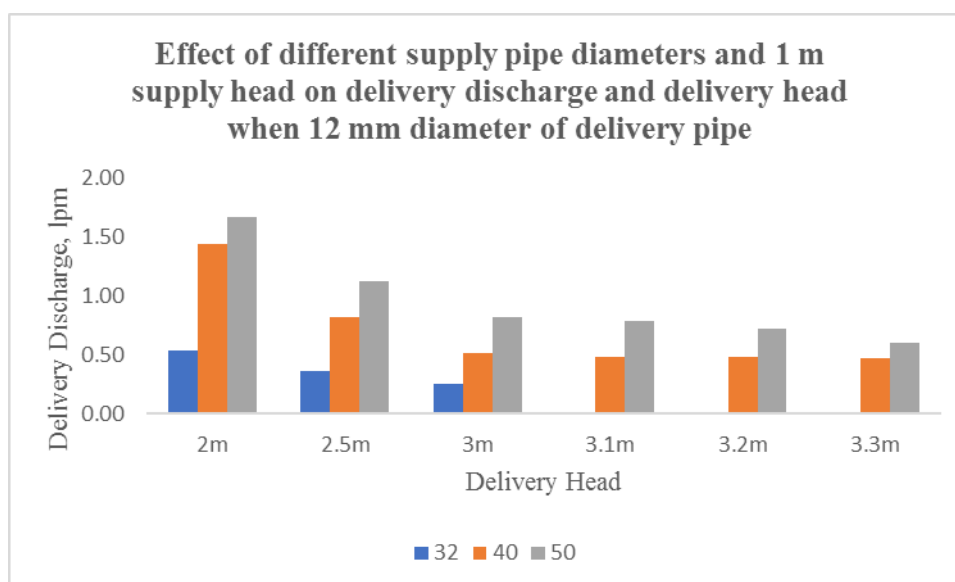


Fig. 4.3 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Table 4.3 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 12 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 12 mm diameter of delivery pipe					
	Delivery heads obtained					
	2m	2.5m	3m	3.1m	3.2m	3.3m
32 to 40	167%	128%	108%	-	-	-
40 to 50	16%	38%	58%	61%	50%	28%

It is reported from the data as shown in Table 4.3 and Fig. 4.4, the percent increase in the discharge at 2 m head with increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 167 percent and 16 percent respectively. Similarly, at supply head of 2.5 m, percent increase in the discharge for increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 128 percent and 38 percent respectively. At supply head of 3 m, percent increase in the discharge by increasing size from 32 mm to 40 mm and 40

mm to 50 mm is 108 percent and 58 percent respectively. At supply head of 3.1m, percent increase in the discharge by increasing size from 40 mm to 50 mm is 61 percent. At supply head of 3.1m, 3.2 m and 3.3 m percent increase in the discharge by increasing size from 40 mm to 50 mm are 61, 50 and 28 percent.

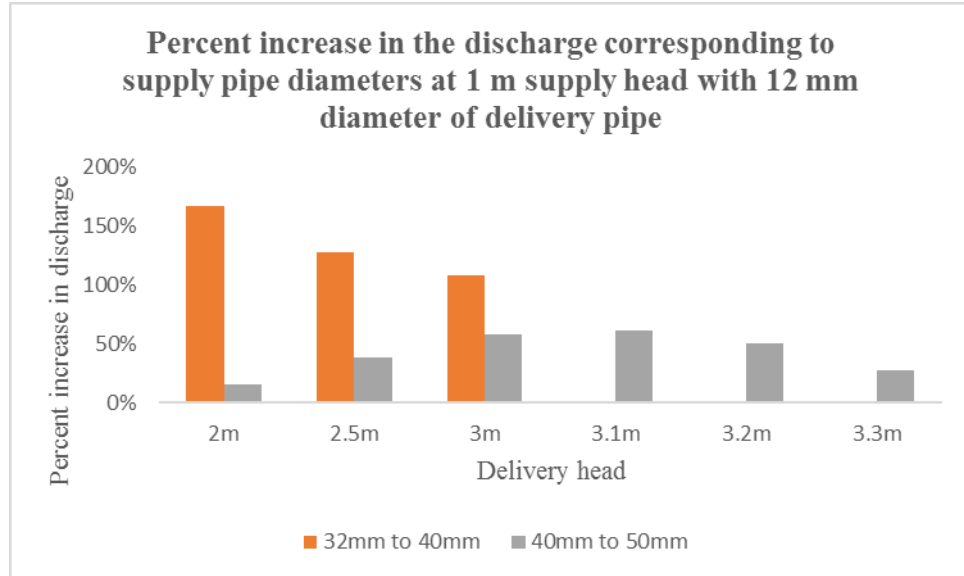


Fig. 4.4 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 12 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix E. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2 to 2.5 m and 2.5 to 3 m is 33 and 31 percent respectively. Similarly, percent reduction in discharge for 40 mm supply pipe with increasing head from 2 to 2.5 m is 43 percent, from 2.5 to 3 m is 37 percent, from 3 to 3.1 m is 6 percent, from 3.1 to 3.2 m is 2 percent and from 3.2 to 3.3 m is 2 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2 to 2.5 m and 2.5 to 3 m is 32 and 27 percent respectively. Also, from 3 to 3.1m, 3.1 to 3.2m and 3.2 to 3.3 m are 4, 9 and 17 percent respectively.

4.6.1.2 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe described in the section 4.6.1.2. The supply pipe of diameters 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.4.

Table 4.4 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)				
	2m	2.5m	3m	3.1m	3.2m
32	0.59	0.44	0.22	-	-
40	1.27	0.74	0.48	0.45	0.41
50	1.36	1.03	0.64	0.51	0.43

From Table 4.4 and Fig. 4.5, it is revealed that when the supply head was maintained at 1 m height and when the diameter of delivery pipe was kept 16 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained only up to 3 m with least discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm and 50 mm diameter of supply pipe, the delivery head obtained from 2 m to 3.2 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 2 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

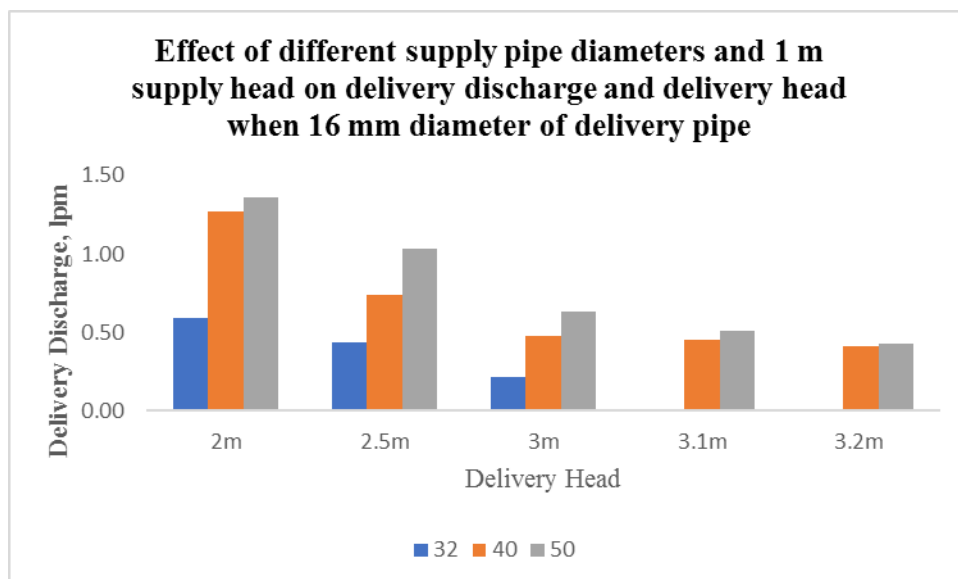


Fig. 4.5 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Table 4.5 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 16 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 16 mm diameter of delivery pipe				
	Delivery heads obtained				
	2m	2.5m	3m	3.1m	3.2m
32 to 40	115%	68%	118%	-	-
40 to 50	7%	39%	33%	13%	5%

It is reported from the data as shown in Table 4.5 and Fig. 4.6, the percent increase in the discharge at 2 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 115 percent and 7 percent respectively. Similarly, at supply head of 2.5 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 68 percent and 39 percent respectively. At supply head of 3 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 118 percent and 33 percent respectively. At supply head of 3.1 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 13 percent. At supply head of 3.2 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 5 percent.

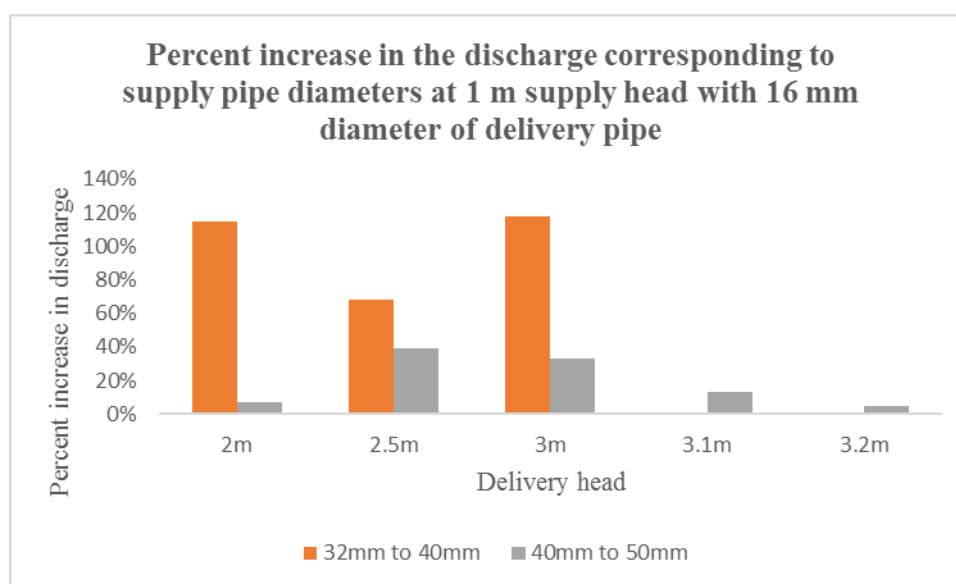


Fig. 4.6 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 16 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix E. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2 to 2.5 m and 2.5 to 3 m is 25 and 50 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 2 to 2.5 m is 42 percent, from 2.5 to 3 m is 35 percent, from 3 to 3.1 m is 6 percent and from 3.1 to 3.2 m is 9 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2 to 2.5 m and 2.5 to 3 m is 24 and 38 percent respectively. Also, from 3 to 3.1 m and 3.1 to 3.2 m is 20 and 16 percent respectively.

4.6.1.3 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe described in the section 4.6.1.3. The supply pipe of diameters 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.6.

Table 4.6 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)			
	2m	2.5m	3m	3.1m
32	0.44	0.32	0.06	-
40	1.16	0.81	0.45	0.33
50	1.30	0.92	0.49	0.26

From Table 4.6 and Fig. 4.7, it is revealed that when the supply head was maintained at 1 m height and when the diameter of delivery pipe was kept 25 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained only up to 3 m with the negligible discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm and 50 mm diameter of supply pipe, the delivery head obtained from 2 m to 3.1 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 2 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

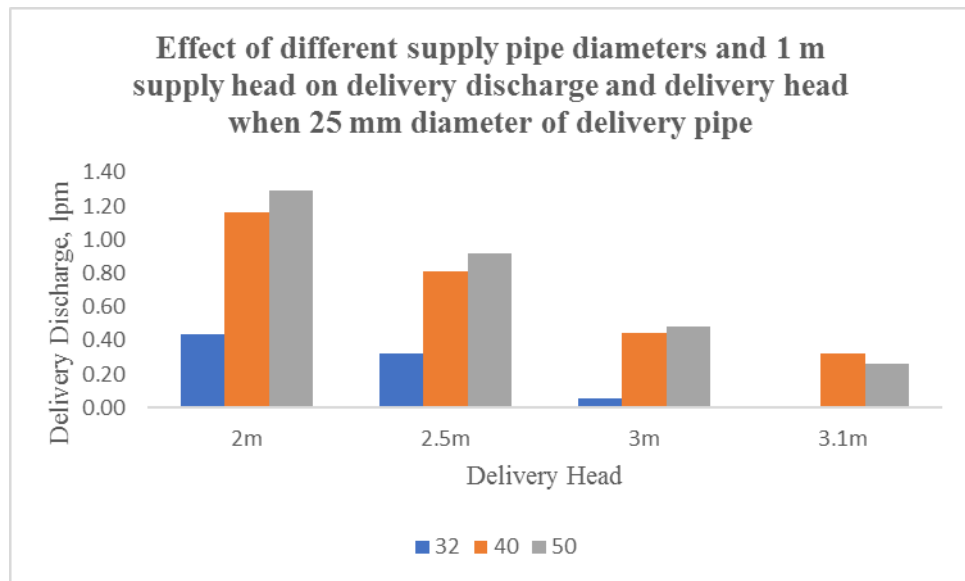


Fig. 4.7 Effect of different supply pipe diameters and 1 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Table 4.7 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 25 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 25 mm diameter of delivery pipe			
	Delivery heads obtained			
	2m	2.5m	3m	3.1m
32 to 40	164%	153%	650%	-
40 to 50	12%	14%	9%	-21%

It is also reported from the data as shown in Table 4.7 and Fig. 4.8, the percent increase in the discharge at 2 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 164 percent and 12 percent respectively. Similarly, at supply head of 2.5 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 153 percent and 14 percent respectively. At supply head of 3 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 650 percent and 9 percent respectively. At supply head of 3.1m, percent reduction occurs in the discharge increasing size from 40 mm to 50 mm is 21 percent.

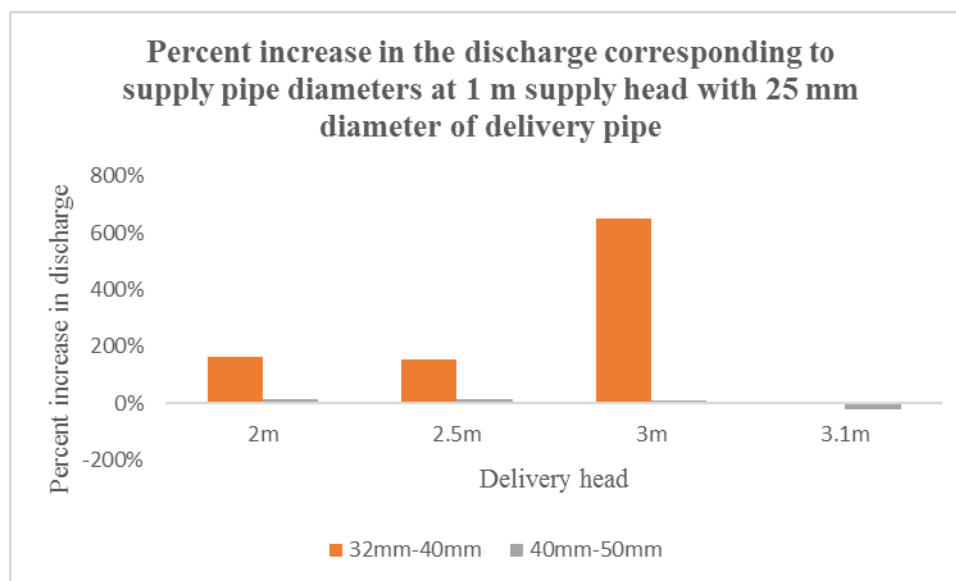


Fig. 4.8 Percent increase in the discharge corresponding to supply pipe diameters at 1 m supply head with 25 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix E. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2 to 2.5 m and 2.5 to 3 m is 27 and 81 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 2 to 2.5 m is 30 percent, from 2.5 to 3 m is 44 percent, from 3 to 3.1 m is 27 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2 to 2.5 and 2.5 to 3 m is 29 and 47 percent respectively. Also, from 3 to 3.1 m is 47 percent respectively.

4.6.1.4 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe described in the section 4.6.1.4. The supply pipe of diameters 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.8.

Table 4.8 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)			
	2.5 m	3 m	3.1 m	3.2m
32	0.81	0.59	0.39	0.37
40	1.34	1.09	1.03	0.89
50	2.07	1.39	1.05	1.03

3.5m	3.6m	3.7m	3.8m	3.9m
-	-	-	-	-
0.80	0.54	0.41	-	--
0.90	0.88	0.68	0.51	0.22

From Table 4.8 and Fig. 4.9, it is revealed that when the supply head was increased and maintained at 1.5 m height and when the diameter of delivery pipe was kept 12 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.2 m which is found to be more than in 1 m supply head for same size and with the least discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm diameter of supply pipe, the delivery head obtained from 2.5 m to 3.7 m and for 50 mm diameter of supply pipe, it was from 2.5 m to 3.9 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 2.5 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

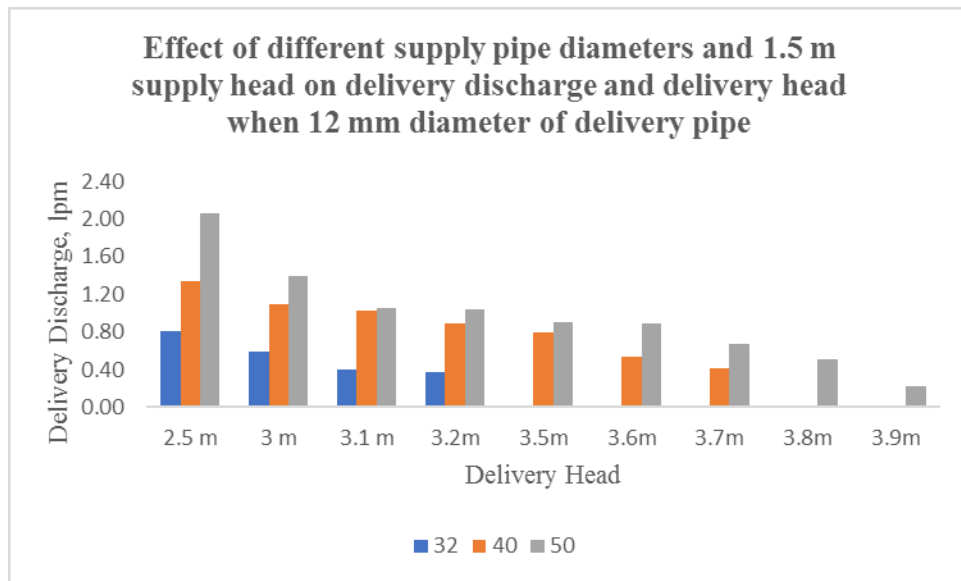


Fig. 4.9 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Table 4.9 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 12 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters with 12 mm diameter of delivery pipe								
	Delivery heads obtained								
	2.5 m	3 m	3.1 m	3.2m	3.5m	3.6m	3.7m	3.8m	3.9m
32 to 40	65%	85%	164%	141%	-	-	-	-	-
40 to 50	54%	28%	2%	16%	13%	63%	66%	-	-

It is also reported from the data as shown in Table 4.9 and Fig. 4.10, the percent increase in the discharge at 2.5 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 65 percent and 54 percent respectively. Similarly, at supply head of 3 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 85 percent and 28 percent respectively. At supply head of 3.1m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 164 percent and 2 percent respectively. At supply head of 3.2 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 141 and 16 percent respectively. At supply head of 3.5 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 13 percent. At supply head of 3.6 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 63 percent. At supply head of 3.7 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 66 percent.

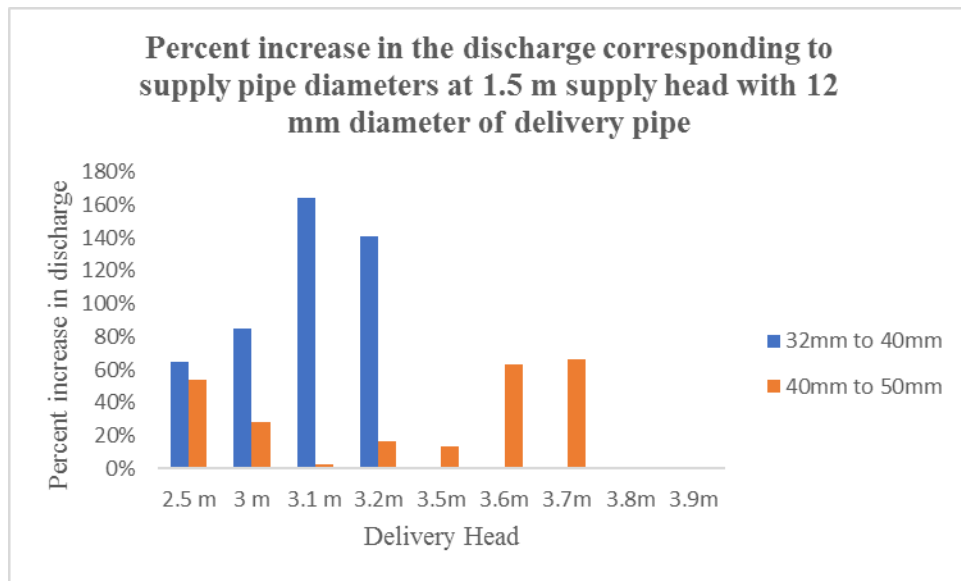


Fig. 4.10 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 12 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix F. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2.5 to 3 m, 3 to 3.1 m and 3.1 to 3.2m is 27, 34 and 5 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 2.5 to 3 m is 19 percent, from 3 to 3.1 m is 6 percent, from 3.1 to 3.2 m is 14 percent, from 3.2 to 3.5 m is 10 percent, from 3.5 to 3.6 m is 33 percent and from 3.6 to 3.7 m is 24 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2.5 to 3 m is 33 percent, from 3 to 3.1 m is 24 percent, from 3.1 to 3.2 m is 2 percent, from 3.2 to 3.5 m is 13 percent, from 3.5 to 3.6 m is 2 percent, from 3.6 to 3.7 m is 23 percent, from 3.7 to 3.8 m is 25 percent and from 3.8 to 3.9 m is 57 percent respectively.

4.6.1.5 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe described in the section 4.6.1.5. The supply pipe of 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.10.

Table 4.10 Effect of different supply pipe diameter and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)			
	2.5 m	3 m	3.1 m	3.2 m
32	0.68	0.51	0.37	-
40	1.32	1.09	1.00	0.86
50	2.04	1.39	1.05	1.03

3.5 m	3.6 m	3.8 m	3.9 m
-	-	-	-
0.68	0.40	-	-
0.90	0.80	0.43	0.17

From Table 4.10 and Fig. 4.11, it is revealed that when the supply head was increased and maintained at 1.5 m height and when the diameter of delivery pipe was kept 16 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.1 m with the least discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm diameter of supply pipe, the delivery head obtained from 2.5 m to 3.6 m and for 50 mm diameter of supply pipe, it was from 2.5 m to 3.9 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 2.5 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

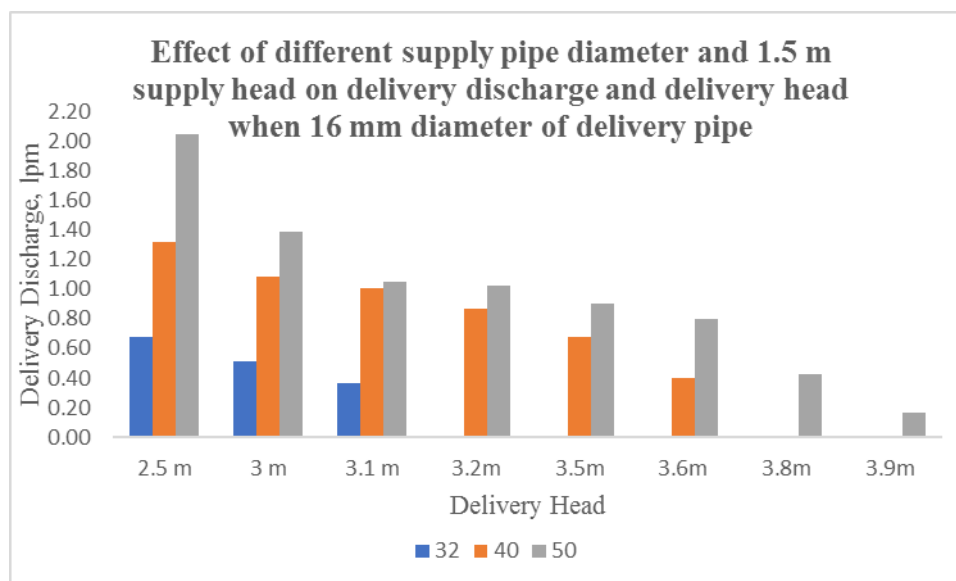


Fig. 4.11 Effect of different supply pipe diameter and 1.5 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Table 4.11 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 16 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 16 mm diameter of delivery pipe							
	Delivery heads obtained							
	2.5 m	3 m	3.1 m	3.2m	3.5m	3.6m	3.8m	3.9m
32 to 40	94%	114%	170%	-	-	-	-	-
40 to 50	55%	28%	5%	20%	32%	100%	-	-

It is also reported from the data as shown in Table 4.11 and Fig. 4.12, the percent increase in the discharge at 2.5 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 94 percent and 55 percent respectively. Similarly, at supply head of 3 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 114 percent and 28 percent respectively. At supply head of 3.1m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 170 percent and 5 percent respectively. At supply head of 3.2 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 20 percent. At supply head of 3.5 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 32 percent. At supply head of 3.6 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 100 percent.

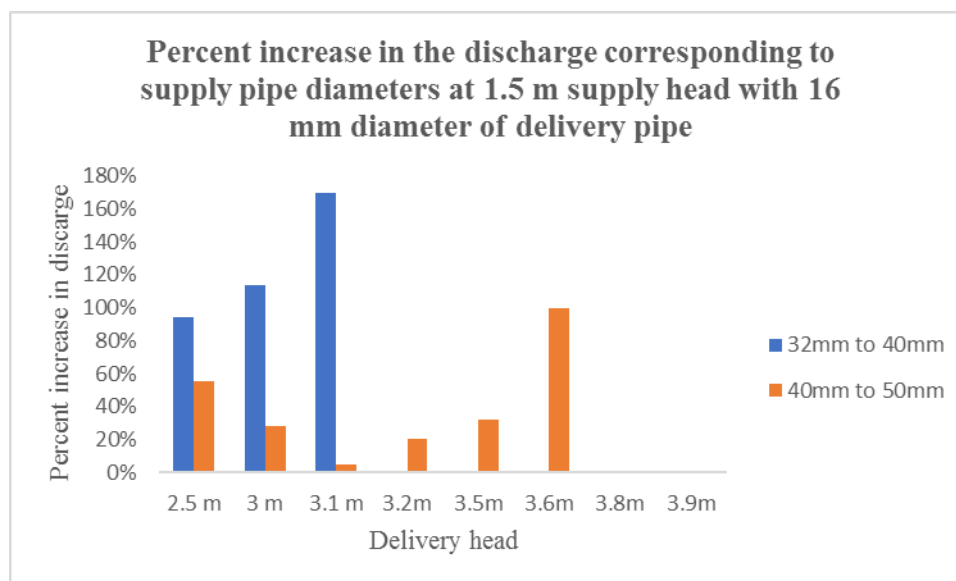


Fig. 4.12 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 16 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix F. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2.5 to 3 m and 3 to 3.1 m is 25 and 27 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 2.5 to 3 m is 17 percent, from 3 to 3.1 m is 8 percent, from 3.1 to 3.2 m is 14 percent, from 3.2 to 3.5 m is 21 percent and from 3.5 to 3.6 m is 41 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2.5 to 3 m is 32 percent, from 3 to 3.1 m is 24 percent, from 3.1 to 3.2 m is 2 percent, from 3.2 to 3.5 m is 13 percent, from 3.5 to 3.6 m is 11 percent, from 3.6 to 3.8 m is 46 percent and from 3.8 to 3.9 m is 60 percent respectively.

4.6.1.6 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe described in the section 4.6.1.6. The supply pipe of 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.12.

Table 4.12 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)						
	2.5 m	3 m	3.1 m	3.2 m	3.5 m	3.6m	3.7m
32	0.43	0.42	0.13	-	-	-	-
40	1.17	0.92	0.82	0.84	0.70	0.32	-
50	1.67	1.17	1.13	0.90	0.70	0.48	0.31

From Table 4.12 and Fig. 4.13, it is revealed that when the supply head was maintained at 1.5 m height and when the diameter of delivery pipe was kept 25 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.1 m with the least discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm diameter of supply pipe, the delivery head obtained from 2.5 m to 3.6 m and for 50 mm diameter of supply pipe, it was from 2.5 m to 3.7 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 2.5 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope to work again on size of supply pipe and supply head to obtain the maximum discharge at delivery side with optimum delivery head to fill the overhead tanks.

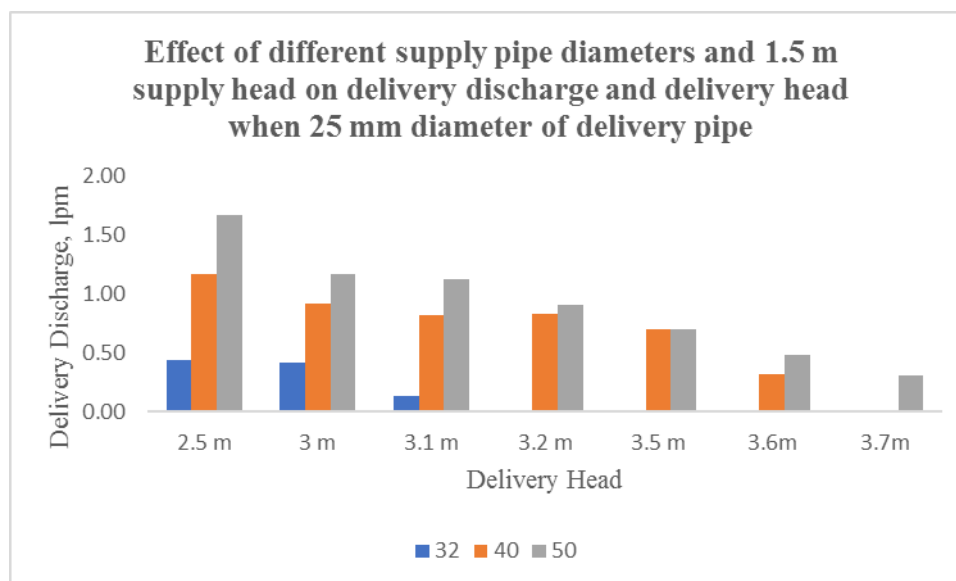


Fig. 4.13 Effect of different supply pipe diameters and 1.5 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Table 4.13 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 25 mm diameter of delivery pipe

Supply Pipe Diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters with the 25 mm delivery pipe diameter						
	Delivery heads obtained						
	2.5 m	3 m	3.1 m	3.2 m	3.5 m	3.6m	3.7m
32 to 40	172%	119%	531%	-	-	-	-
40 to 50	43%	27%	38%	7%	0%	50%	-

It is also reported from the data as shown in Table 4.13 and Fig. 4.14, the percent increase in the discharge at 2.5 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 172 percent and 43 percent respectively. Similarly, at supply head of 3 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 119 percent and 27 percent respectively. At supply head of 3.1 m, percent increase in the discharge increasing size from 32 mm to 40 mm and 40 mm to 50 mm is 531 percent and 38 percent respectively. At supply head of 3.2 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 7 percent. At supply head of 3.5 m, no percent increment in discharge found. At supply head of 3.6 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 50 percent.

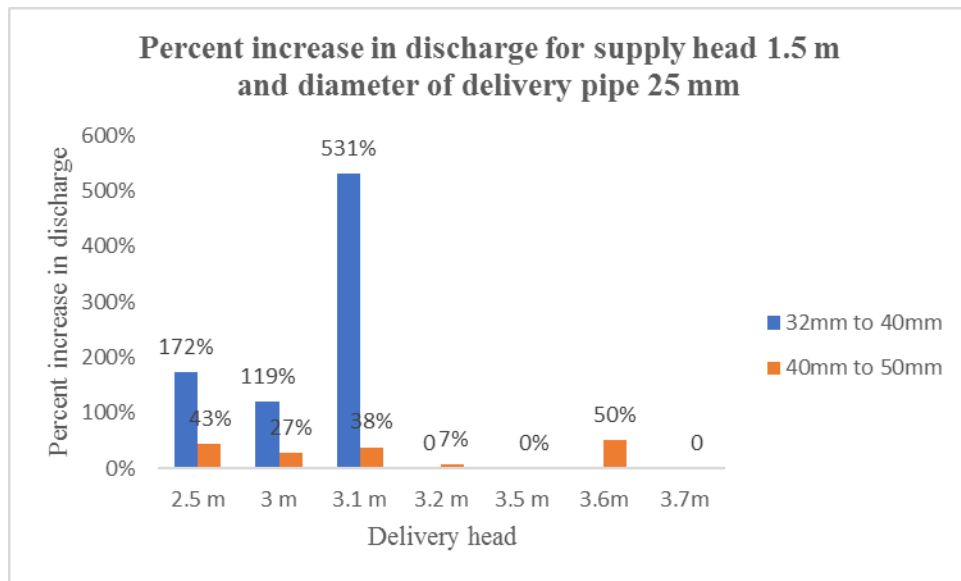


Fig. 4.14 Percent increase in the discharge corresponding to supply pipe diameters at 1.5 m supply head with 25 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix F. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 2.5 to 3 m and 3 to 3.1 m is 2 and 69 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 2.5 to 3 m is 21 percent, from 3 to 3.1 m is 11 percent but from 3.1 to 3.2m, 2 percent increase in the discharge occurs. Then, again from 3.2 to 3.5 m, 17 percent and from 3.5 to 3.6 m, 54 percent reduction in the discharge is found. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 2.5 to 3 m is 30 percent, from 3 to 3.1 m is 3 percent, from 3.1 to 3.2 m is 20 percent, from 3.2 to 3.5 m is 22 percent, from 3.5 to 3.6 m is 31 percent and finally from 3.6 to 3.7 m, 35 percent reduction in discharge occurs for 50 mm supply pipe and 25 mm delivery pipe.

4.6.1.7 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe described in the section 4.6.1.7. The supply pipe of 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.14.

Table 4.14 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)				
	3m	3.5m	3.6m	3.7m	4m
32	1.03	0.69	0.42	-	-
40	2.40	1.48	1.09	0.91	0.39
50	2.31	1.49	1.01	0.81	0.42

From Table 4.14 and Fig. 4.15, it is revealed that when the supply head was increased up to 2 m height and when the diameter of delivery pipe was kept 12 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.6 m with the significant discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm and 50 mm diameter of supply pipe, the delivery head obtained from 3 m to 4 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 40 mm and 3 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that by increasing the supply head up to 2 m, purpose is served to fill the overhead tanks placed on the roof top up to height 4 m, but there is scope again to obtain the maximum discharge at the delivery side by increasing the diameters of supply pipe.

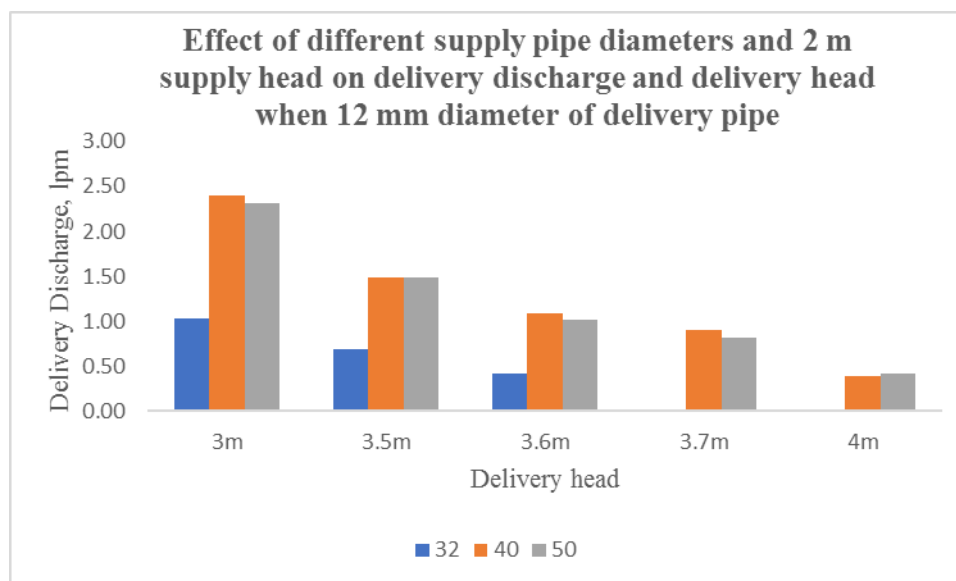


Fig. 4.15 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 12 mm diameter of delivery pipe

Table 4.15 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 12 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 12 mm diameter delivery pipe				
	Delivery head obtained				
	3m	3.5m	3.6m	3.7m	4m
32 to 40	133%	114%	160%	-	-
40 to 50	-4%	1%	-7%	-11%	8%

It is also reported from the data as shown in Table 4.15 and Fig. 4.16, the percent increase in the discharge at 3 m head with increasing size is 32 mm to 40 mm is found 133 percent. But considering the discharge at 3 m head with increasing size 40 mm to 50 mm, 4 percent reduction in discharge occurs. At supply head of 3.5 m, percent increase in the discharge with increasing size from 32 mm to 40 mm and 40 mm to 50 mm is found 114 percent and 1 percent respectively. At supply head of 3.6 m, percent increase in the discharge with increasing size from 32 mm to 40 mm is found 160 percent, but from 40 mm to 50 mm size again percent reduction in discharge occurs is 7 percent. At supply head of 3.7 m, percent reduction in the discharge occurs with increasing size from 40 mm to 50 mm is 11 percent. At supply head of 4 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 8 percent. Here, from 32 mm to 40 mm supply pipe, percent increase in the

discharge found, but from 40mm to 50 mm supply pipe, meanwhile both percent increase as well as percent reduction also occurs.

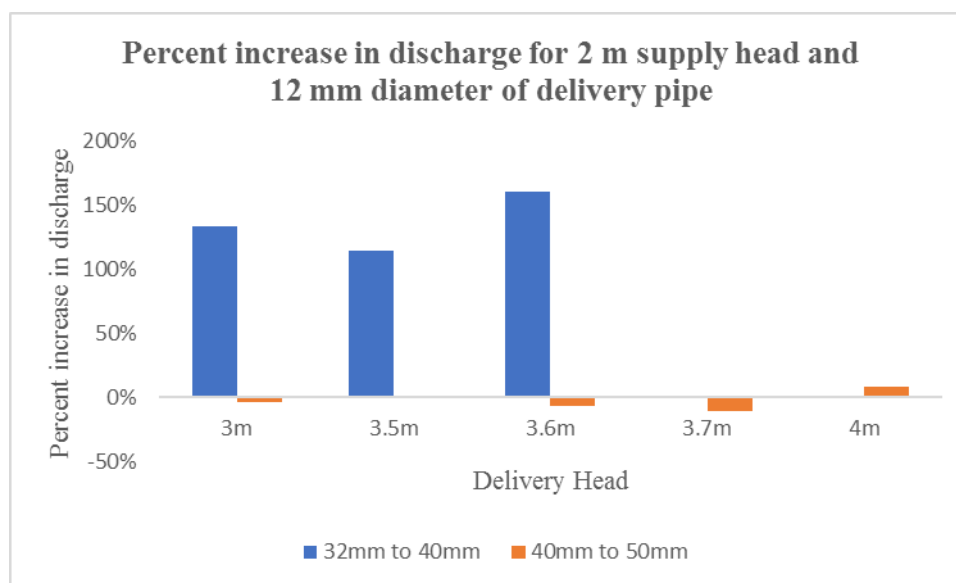


Fig. 4.16 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 12 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix G. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 3 to 3.5m and 3.5 to 3.6 m is 33 and 39 percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 3 to 3.5 m is 38 percent, from 3.5 to 3.6 m is 26 percent, from 3.6 to 3.7 m is 17 percent and from 3.7 to 4 m is 57 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 3 to 3.5 m is 35 percent, from 3.5 to 3.6 m is 32 percent, from 3.6 to 3.7 m is 20 percent and from 3.7 to 4 m is 48 percent respectively.

4.6.1.8 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe described in the section 4.6.1.8. The supply pipe of 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.16.

Table 4.16 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Supply pipe	Obtained delivery discharges (lpm) with the corresponding
-------------	---

diameter, mm	delivery heads (m)			
	3m	3.5m	3.6m	4m
32	1.00	0.63	0.41	-
40	2.21	1.47	0.83	0.29
50	2.23	1.44	0.86	0.39

From Table 4.16 and Fig. 4.17, it is revealed that when the supply head was maintained at 2 m height and when the diameter of delivery pipe was kept 16 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.6 m with the significant discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm and 50 mm diameter of supply pipe, the delivery head obtained from 3 m to 4 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 3 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that by increasing the supply head up to 2 m, purpose is served to fill the overhead tanks placed on the roof top up to height 4 m, but there is scope again to obtain the maximum discharge at the delivery side by increasing the diameters of supply pipe.

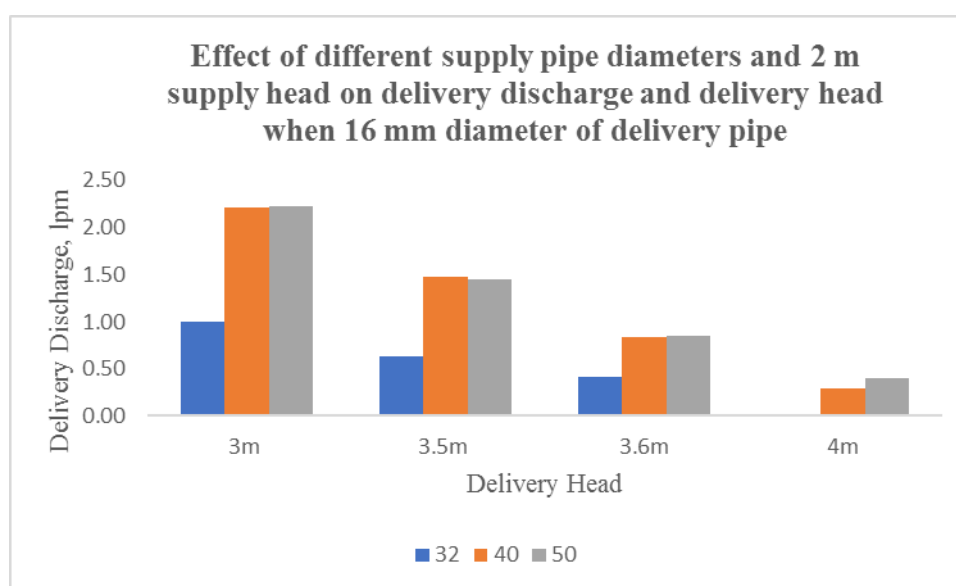


Fig. 4.17 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 16 mm diameter of delivery pipe

Table 4.17 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 16 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters with the 16 mm delivery pipe diameter			
	Delivery heads obtained			
	3m	3.5m	3.6m	4m
32 to 40	121%	133%	102%	-
40 to 50	1%	-2%	4%	34%

It is also reported from the data as shown in Table 4.17 and Fig. 4.18, the percent increase in the discharge at 3 m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 121 percent and 1 percent respectively. At supply head of 3.5 m, percent increase in the discharge with increasing size from 32 mm to 40 mm is 133 percent and percent reduction in discharge at 3.5 m delivery head occurs for 40 mm to 50 mm is found 2 percent. At supply head of 3.6 m, percent increase in the discharge with increasing size from 32 mm to 40 mm and 40 mm to 50 mm is found 102 percent and 4 percent respectively. At supply head of 4 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 34 percent.

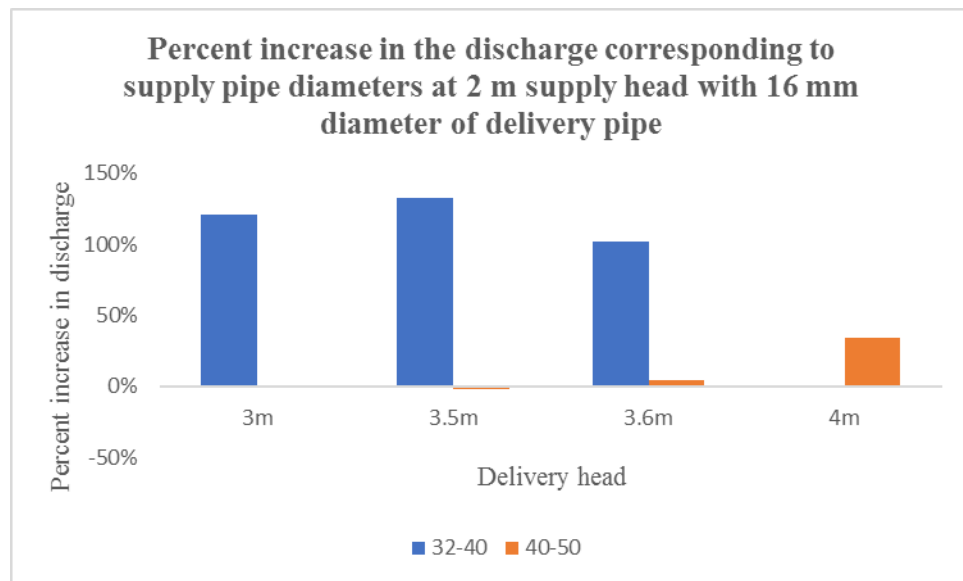


Fig. 4.18 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 16 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix G. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 3 to 3.5 m and 3.5 to 3.6 m is 37 and 35 percent respectively. Percent reduction in discharge for 40 mm supply pipe with

increasing head from 3 to 3.5 m is 33 percent, from 3.5 to 3.6 m is 44 percent, from 3.6 to 4 m is 65 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 3 to 3.5 m is 35 percent, from 3.5 to 3.6 m is 40 percent, from 3.6 to 4 m is 55 percent respectively.

4.6.1.9 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

The detailed discussion regarding effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe described in the section 4.6.1.9. The supply pipe of 32 mm, 40 mm and 50 mm are used. All the discharge rates given in litres per minute (lpm) and the results of the study are reported in the Table 4.18.

Table 4.18 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Supply pipe diameter, mm	Obtained delivery discharges (lpm) with the corresponding delivery heads (m)					
	3m	3.2m	3.5m	3.7m	3.8m	4m
32	0.81	0.61	0.32	-	-	-
40	1.48	1.22	1.10	0.46	0.35	-
50	1.74	1.30	1.23	0.50	0.40	0.32

From Table 4.18 and Fig. 4.19, it is revealed that when the supply head was maintained at 2 m height and when the diameter of delivery pipe was kept 25 mm, the discharges at delivery side increases as the diameter of supply pipes i.e., 32 mm, 40 mm and 50 mm increases. It is very important to note that when size of supply pipe was 32 mm, the delivery head was obtained up to 3.5 m with the less discharge and then after further increasing the delivery head, there was no any discharge. While for 40 mm diameter of supply pipe, the delivery head obtained from 3 m to 3.8 m and for 50 mm diameter of supply pipe, the delivery head obtained from 3 m to 4 m with the decrease rate of discharge (lpm). The maximum discharge was obtained when supply pipe diameter was 50 mm and 3 m delivery head than rest of the combinations. It is also very interesting to state that as the diameter of supply pipe increases, the discharge at delivery side increases, however decreases by increasing the delivery head. Therefore, it is very pertinent to state that there is scope again to obtain the maximum discharge at the delivery side by increasing the diameters of supply pipe.

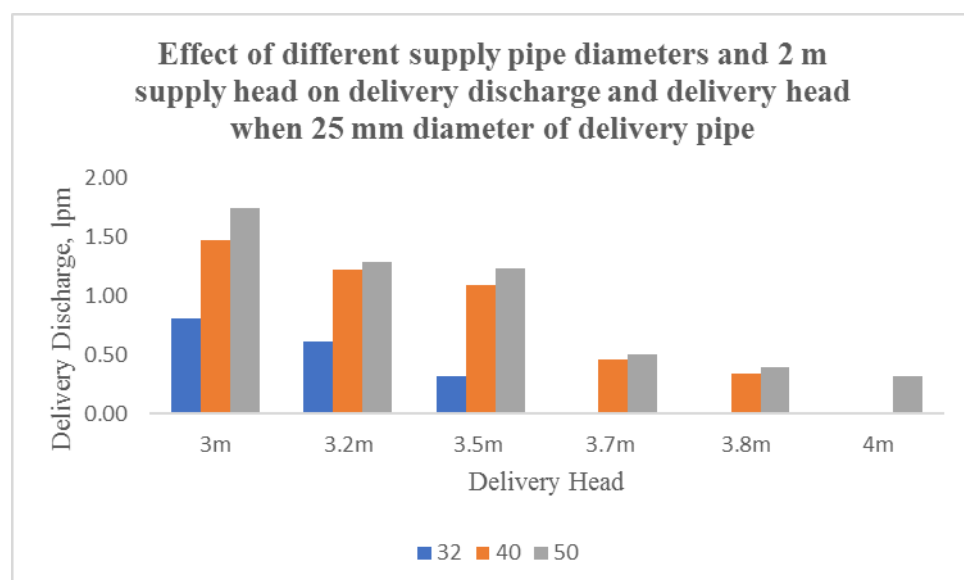


Fig. 4.19 Effect of different supply pipe diameters and 2 m supply head on delivery discharge and delivery head when 25 mm diameter of delivery pipe

Table 4.19 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 25 mm diameter of delivery pipe

Supply pipe diameter when increased, mm	Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 25 mm diameter of delivery pipe					
	3m	3.2m	3.5m	3.7m	3.8m	4m
32 to 40	83%	100%	244%	-	-	-
40 to 50	18%	7%	12%	9%	14%	-

It is also reported from the data as shown in Table 4.19 and Fig. 4.20, the percent increase in the discharge at 3m head with increasing size is 32 mm to 40 mm and 40 mm to 50 mm is 83 and 18 percent respectively. At supply head of 3.2 m, percent increase in the discharge with increasing size from 32 mm to 40 mm and 40 mm to 50 mm is found 100 and 7 percent respectively. At supply head of 3.5 m, percent increase in the discharge with increasing size from 32 mm to 40 mm and 40 mm to 50 mm is found 244 and 12 percent respectively. At supply head of 3.7 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 9 percent. At supply head of 3.8 m, percent increase in the discharge increasing size from 40 mm to 50 mm is 14 percent.

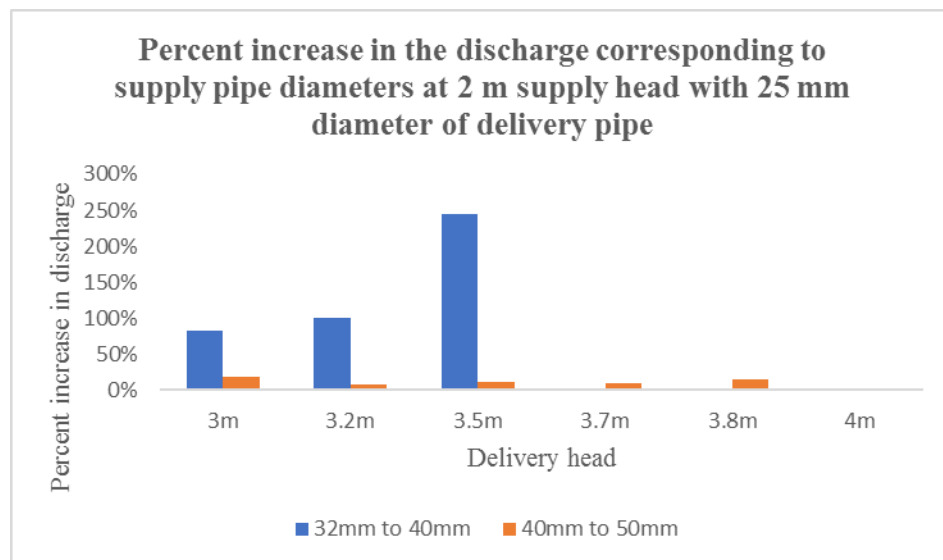


Fig. 4.20 Percent increase in the discharge corresponding to supply pipe diameters at 2 m supply head with 25 mm diameter of delivery pipe

The percent reduction in discharge corresponding to delivery head is reported in Appendix G. It is revealed from data that percent reduction in discharge for 32 mm supply pipe with increasing head from 3 to 3.2 m and 3.2 to 3.5 m is 25 and 48

percent respectively. Percent reduction in discharge for 40 mm supply pipe with increasing head from 3 to 3.2 m is 18 percent, from 3.2 to 3.5 m is 10 percent, from 3.5 to 3.7 m is 58 percent and from 3.7 to 3.8 m is 24 percent respectively. Similarly, percent reduction in discharge for 50 mm supply pipe with increasing head from 3 to 3.2 m is 25 percent, from 3.2 to 3.5 m is 5 percent, from 3.5 to 3.7 m is 59 percent, from 3.7 to 3.8 m is 20 percent and ultimately from 3.8 to 4 m is 20 percent respectively.

From Table 4.2 to Table 4.19 and Fig. 4.3 to Fig. 4.20, it is observed that the different discharge rates obtained at various delivery heads by using three supply heads i.e., 1.0 m, 1.5 m and 2.0 m with the combinations of three diameters of supply pipes i.e., 32 mm, 40 mm and 50 mm and three diameters of delivery pipes i.e., 12 mm, 16 mm and 25 mm. Therefore, results described for total 27 combinations. For 1 m supply head, the maximum discharge obtained was 1.67 lpm at 2 m delivery head with the combination of 50/12 mm diameters supply/delivery pipes followed by 50/16 mm diameters supply/delivery pipes having maximum discharge rate 1.36 lpm. For 1.5 m supply head, the maximum discharge i.e., 2.07 lpm was obtained at 2.5 m delivery head with the combination of supply/delivery pipe diameters 50/12 mm followed by supply/delivery pipe diameters 50/16 mm having maximum discharge rate of 2.04 lpm at same delivery head. For 2 m supply head, maximum discharge obtained at 3 m delivery head was 2.40 lpm with the combination of supply/delivery pipe diameters 40/12 mm followed by supply/delivery pipe diameters 50/12 having discharge rate was found to be 2.31 lpm. Combinations 32/12 mm, 32/16 mm and 32/25 mm were not found significant and the discharges obtained with these combinations were less compared to supply pipes 40 mm and 50 mm. At 1 m supply head, maximum delivery head obtained was 3.3 m. At 1.5 m supply head, maximum water was lifted up to delivery head 3.9 m and at 2 m supply head, maximum delivery head obtained was 4 m by keeping the size of the non-return valve constant as 32 mm for all the combinations.

4.6.2 Efficiency of the energy free water lifting device

The efficiency of the energy free water lifting device is the ratio of the output obtained from the device in terms of delivery discharge with the respective delivery head as the input to the inflow supply with respect to the supply head. The efficiencies of the developed energy free water lifting device at various supply pipes and delivery

pipes combinations, were calculated by using recorded data of discharges and heads and are described below in 4.6.2.1, 4.6.2.2 and 4.6.2.3.

4.6.2.1 Efficiency of the energy free water lifting device at supply head of 1 m

The efficiency of the developed energy free water lifting device was determined by the method described under section 3.6.2. For the supply head of 1 m, observations of inflows and outflows with respect to head were taken and then after, corresponding efficiencies were calculated. The efficiencies were determined from the ratio of the output obtained from the device in terms of delivery discharge with the respective delivery head of 2 to 3.3 m to the inflow supply with respect to the supply head of 1, 1.5 and 2 m respectively. All the recorded observations for 1 m supply heads of inflows and outflows to corresponding head and the calculated efficiencies are shown in the Table 4.20.

Table 4.20 Efficiency of the energy free water lifting device at 1 m supply head

Supply/Delivery Diameters of pipes, mm	Inflow(Q), Lpm	Outflow (q), lpm	Delivery Head (H), m	Efficiency, (%)
	5.54	0.54	2	19.49
32/12	5.47	0.36	2.5	16.45
	5.45	0.25	3	13.76
	5.83	0.59	2	20.24
32/16	5.49	0.44	2.5	20.04
	5.61	0.22	3	11.76
	5.79	0.44	2	15.20
32/25	5.04	0.32	2.5	15.87
	5.41	0.06	3	3.33
	5.28	1.44	2	54.55
	5.42	0.82	2.5	37.82
40/12	5.44	0.52	3	28.68
	5.64	0.49	3.1	26.93
	5.68	0.48	3.2	27.04
	5.98	0.47	3.3	25.94
	5.01	1.27	2	50.70
	5.63	0.74	2.5	32.86
40/16	5.57	0.48	3	25.85
	5.61	0.45	3.1	24.87

	5.5	0.41	3.2	23.85
	5.73	1.16	2	40.49
40/25	5.08	0.81	2.5	39.86
	5.96	0.45	3	22.65
	4.88	0.33	3.1	20.96
	5.98	1.67	2	55.85
	5.29	1.13	2.5	53.40
50/12	4.95	0.82	3	49.70
	4.99	0.79	3.1	49.08
	5.34	0.72	3.2	43.15
	5.5	0.6	3.3	36.00
	5.44	1.36	2	50.00
	5.17	1.03	2.5	49.81
50/16	5.06	0.64	3	37.94
	6.04	0.51	3.1	26.18
	7.79	0.43	3.2	17.66
	6.06	1.3	2	42.90
50/25	5.26	0.92	2.5	43.73
	4.76	0.49	3	30.88
	5.98	0.26	3.1	13.48

From the Table 4.20 and Fig. 4.21, it is observed that at 1 m supply head, maximum efficiency 55.85 % at 2.0 m supply head was obtained for the combination of 50 mm diameter of supply pipe with the 12 mm diameter of delivery pipe followed by 53.40 % under same combination. For 40 mm supply pipe with 12 mm diameter delivery pipe combination, efficiency was found to be 54.55 % at supply head of 2.0 m which was found close to the 50/12 mm supply/delivery pipe combination. For 32/16 mm supply/delivery pipe combination, the maximum efficiency obtained was 20.24% at supply head of 2.0 m for 16 mm diameter delivery pipe at 2 m delivery head. Among the three delivery pipes of diameters 12 mm, 16 mm and 25 mm, the maximum efficiencies obtained were at 12 mm diameter delivery pipe. Also, delivery discharges through the 12 mm and 16 mm diameter delivery pipe were found close to each other, but at 25 mm diameter delivery pipe efficiency was not found significant. The maximum efficiencies obtained for most of the combinations at the delivery head 2 m. At 1 m supply head, maximum water was lifted up to the delivery head of 3.3 m.

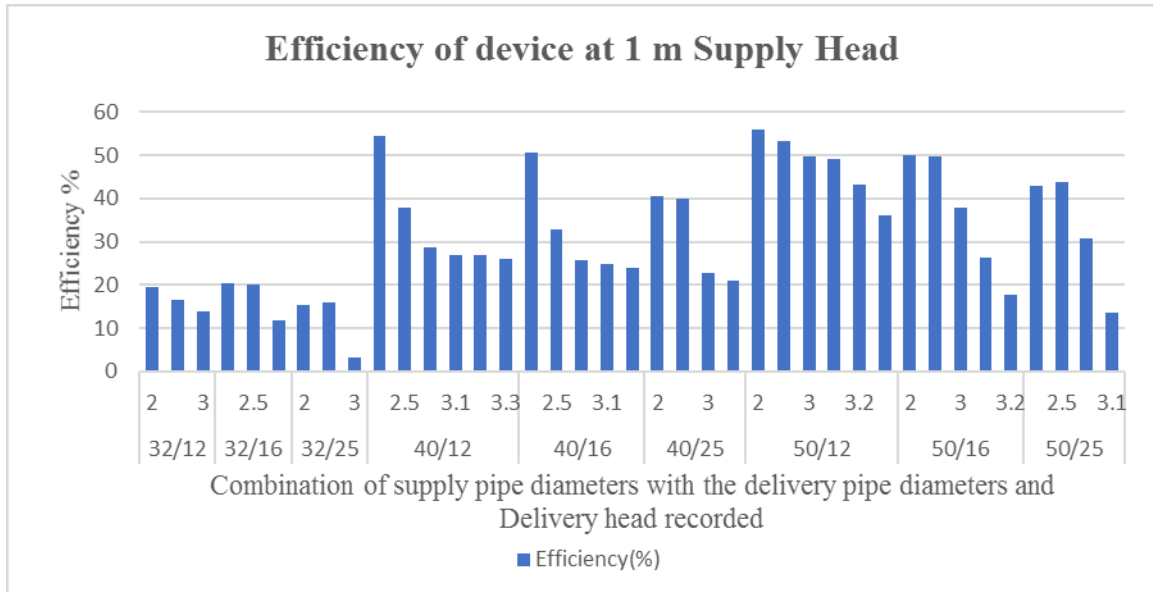


Fig. 4.21 Efficiency of the energy free water lifting device at 1 m supply head

4.6.2.2 Efficiency of the energy free water lifting device at supply head of 1.5 m

For the supply head of 1.5 m, observations of inflows and outflows with respect to head were taken and then after, corresponding efficiencies were calculated. The efficiencies were calculated from the ratio of the output obtained from the device in terms of delivery discharge with the respective delivery head of 2.5 m to 3.9 m to the inflow supply with respect to the supply head of 1.5 m. All the recorded observations for 1.5 m supply heads of inflows and outflows to corresponding head and the calculated efficiencies are shown in the Table 4.21.

Table 4.21 Efficiency of the energy free water lifting device at 1.5 m supply head

Supply/Delivery diameters of pipes, mm	Inflow (Q), lpm	Outflow (q), lpm	Delivery head (H), m	Efficiency, (%)
	5.7	0.81	2.5	23.68
32/12	5.39	0.59	3	21.89
	5.88	0.39	3.1	13.71
	5.66	0.37	3.2	13.95
	5.64	0.68	2.5	20.09
32/16	5.5	0.51	3	18.55
	5.98	0.37	3.1	12.79
	5.83	0.43	2.5	12.29
32/25	5.5	0.42	3	15.27
	4.89	0.13	3.1	5.49

	3.89	1.34	2.5	57.41
	4.02	1.09	3	54.23
40/12	4.08	1.03	3.1	52.17
	3.97	0.89	3.2	47.83
	3.85	0.8	3.5	48.48
	4.11	0.54	3.6	31.53
	4.18	0.41	3.7	24.19
	3.73	1.32	2.5	58.98
	4.11	1.09	3	53.04
40/16	4.19	1	3.1	49.32
	3.74	0.86	3.2	49.06
	3.72	0.68	3.5	42.65
	3.68	0.4	3.6	26.09
	4.01	1.17	2.5	48.63
	3.92	0.92	3	46.94
40/25	4.02	0.84	3.1	43.18
	3.93	0.82	3.2	44.51
	4.26	0.7	3.5	38.34
	4.3	0.32	3.6	17.86
	5.06	2.07	2.5	68.18
	4.73	1.39	3	58.77
50/12	3.87	1.05	3.1	56.07
	3.78	1.03	3.2	58.13
	3.72	0.9	3.5	56.45
	3.78	0.88	3.6	55.87
	3.84	0.68	3.7	43.68
	3.88	0.51	3.8	33.30
	4.3	0.22	3.9	13.30
50/16	5.13	2.04	2.5	66.28
	4.76	1.39	3	58.40
	3.76	1.05	3.1	57.71
	3.83	1.03	3.2	57.37
	3.72	0.9	3.5	56.45
	3.97	0.8	3.6	48.36
	3.92	0.43	3.8	27.79

	4.28	0.17	3.9	10.33
50/25	4.52	1.67	2.5	61.58
	4.39	1.17	3	53.30
	4.36	1.13	3.1	53.56
	4.25	0.9	3.2	45.18
	4.23	0.7	3.5	38.61
	3.99	0.48	3.6	28.87
	3.97	0.31	3.7	19.26

From the Table 4.21 and Fig. 4.22, it was observed that at 1.5 m supply head, maximum efficiency obtained for the combination of 50 mm diameter supply pipe with the 12 mm diameter of delivery pipe was 68.18% and for same diameter of supply pipe with delivery pipe diameter 16 mm, efficiency obtained was 66.28%. Maximum water lifted by maintaining 1.5 m supply head is up to 3.9 m with efficiencies 13.30% and 10.33% for 50/12 and 50/16 supply/delivery diameters pipe combination respectively. By using 32 mm supply pipe, maximum efficiency obtained was 23.68%. Supply pipe of diameter 32 mm was not found that much significant compared to 40 mm and 50 mm diameter supply pipes. Supply pipe of diameter 40 mm was given significant discharge with maximum efficiency of 58.98 % at 16 mm diameter delivery pipe followed by 57.41% under same the diameter of supply pipe with the delivery diameter 12 mm.

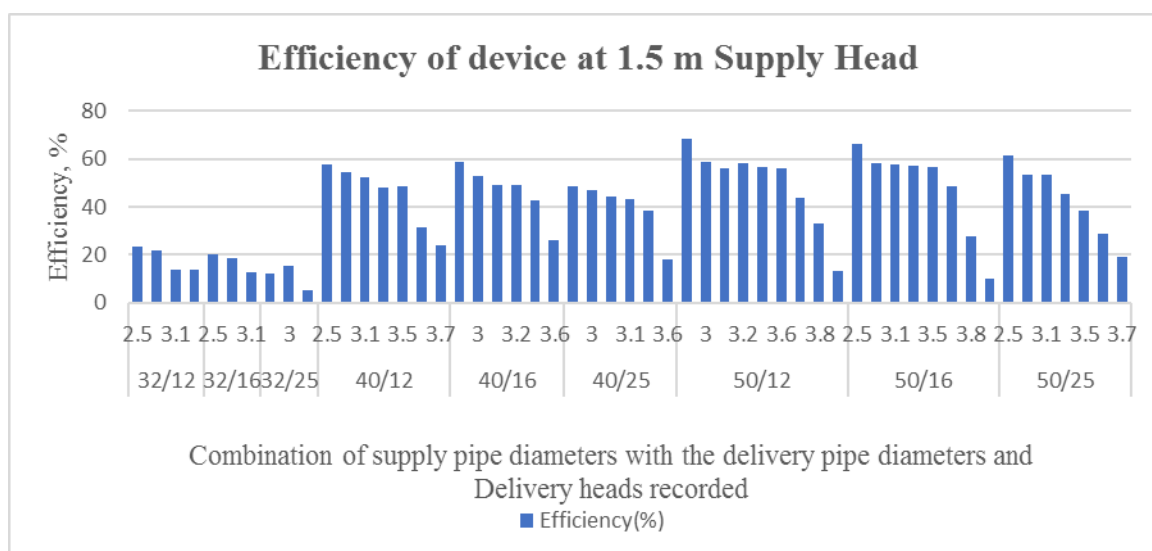


Fig. 4.22 Efficiency of the energy free water lifting device at 1.5 m supply head

4.6.2.3 Efficiency of the energy free water lifting device at supply head of 2 m

For the supply head of 2 m, observations of inflows and outflows with respect to head were taken and then after the corresponding efficiencies were calculated. The efficiencies were the ratio of the output obtained from the device in terms of delivery discharge with the respective delivery head from 3 m to 4 m to the inflow supply with respect to the supply head of 2 m. All the recorded observations for 2 m supply heads of inflows and outflows to corresponding head and the calculated efficiencies are shown in the Table 4.22.

Table 4.22 Efficiency of the energy free water lifting device at 2 m supply head

Supply/Delivery diameters of pipes, mm	Inflow (Q), lpm	Outflow (q), lpm	Delivery head(H), m	Efficiency, (%)
	6.29	1.03	3	24.43
32/12	7.47	0.69	3.5	16.13
	7.50	0.42	3.6	10.07
	6.98	1.00	3	21.61
32/16	7.50	0.63	3.5	14.80
	6.14	0.41	3.6	12.11
	7.23	0.81	3	16.88
32/25	7.00	0.61	3.2	13.98
	7.47	0.32	3.5	7.61
	5.06	2.40	3	71.15
40/12	4.33	1.48	3.5	59.89
	4.28	1.09	3.6	45.75
	4.85	0.91	3.7	34.64
	3.96	0.39	4	19.59
	4.88	2.21	3	68.03
	5.10	1.47	3.5	50.57
40/16	4.09	0.83	3.7	37.67
	5.03	0.29	4	11.62
	4.40	1.48	3	50.31
40/25	4.38	1.22	3.2	44.65
	5.16	1.10	3.5	37.19
	3.91	0.46	3.7	21.65
	4.42	0.35	3.8	14.89

	4.81	2.31	3	71.98
50/12	3.91	1.49	3.5	66.61
	4.02	1.01	3.6	45.32
	4.18	0.81	3.7	35.96
	3.89	0.42	4	21.63
	4.76	2.23	3	70.13
50/16	4.62	1.44	3.5	54.77
	4.96	0.86	3.7	31.94
	4.02	0.39	4	19.57
	4.63	1.74	3	56.50
	4.09	1.30	3.2	50.65
50/25	4.30	1.23	3.5	50.29
	4.85	0.50	3.7	19.21
	4.68	0.32	4	13.66

From the Table 4.22 and Fig. 4.23, it was observed that for 2 m supply head, efficiencies were obtained for the supply pipes of diameter 50 mm and 40 mm close to each other i.e., 71.98% and 71.15%. Both the pipes had given significant readings over the supply pipe of 32 mm diameter. Also, considering the delivery pipes, the diameters of delivery pipes 12 mm and 16 mm were found significant over the delivery pipe of diameter 25 mm. Here, for supply head 2 m, maximum efficiencies were obtained amongst all the combinations. For supply head 2 m, 50 mm supply pipe with the 25 mm diameter delivery pipe has obtained maximum efficiency of 56.50% and was not found that much significant in comparison with the other two. The water gets lifted easily up to 4 m head without finding any difficulties with the significant discharge rates for supply head of 2 m and which fulfill the requirements mentioned in the section 4.3.1.

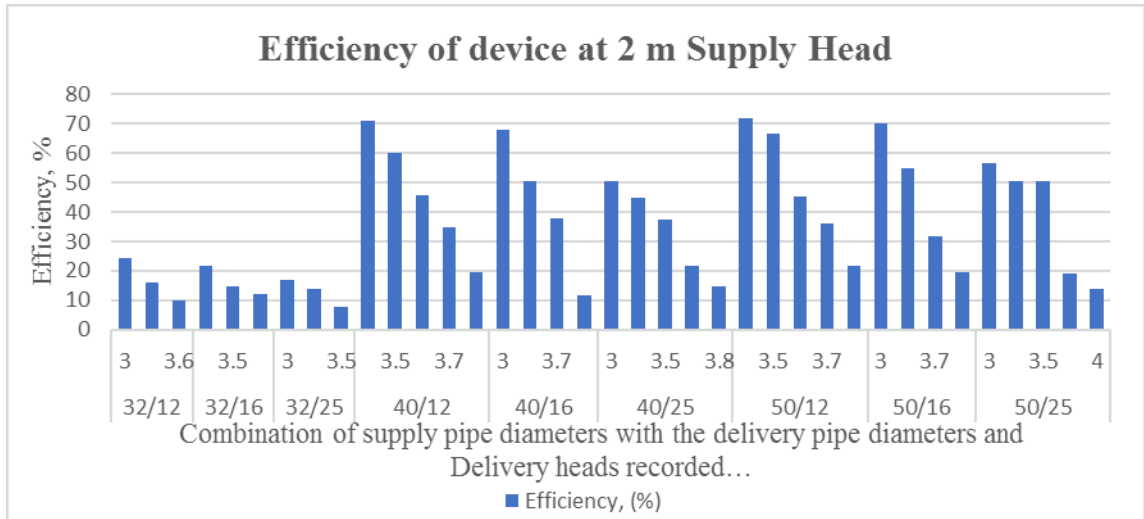


Fig. 4.23 Efficiency of the energy free water lifting device at 2 m supply head

From the data presented in Table 4.20 to Table 4.22 and also depicted in Fig. 4.21 to Fig. 4.23, it is revealed that the efficiency of the device was found to be maximum i.e., 71.98%, when the supply head was 2.0 m, diameter of supply pipe 50 mm and diameter of delivery pipe was 12 mm followed by for the same supply head i.e., 2.0 m with 40 mm diameter of supply pipe and 12 mm diameter of delivery pipe. It is very important to note that maximum efficiency i.e., 71.98% is obtained at delivery head of 3.0 m. It is very interesting to note that higher efficiencies were recorded i.e., 54.55% and 55.85% for the combinations of supply/delivery pipes of 40/12 mm and 50/12 mm respectively when the supply head of 1.0 m and with 2.0 m delivery head. Further, it is very pertinent to note that for supply head of 1.5 m and 2.0 m and diameters of supply/ delivery pipes 40/12 mm and 50/12 mm, the efficiencies were found to be highest i.e., 58.98%, 68.18% and 71.15%, 71.98% respectively. The combination of supply to delivery pipe diameters of 32 mm× 12 mm, 32 mm× 16 mm and 32 mm× 25 mm with all the supply heads i.e., 1.0 m, 1.5 m and 2.0 m was not found significant as the efficiencies recorded for these combinations are less than 50%. In general, more than 50% efficiencies were observed to be in combinations of supply/delivery diameters of pipes 40 mm/12 mm and 50 mm/12 mm for 1.5 m and 2.0 m supply heads. The combination 50 mm/12 mm supply to delivery when supply head was 2.0 m gave maximum delivery head 3.5 m when the efficiency was considered as more than 50%.

4.7 Cost Estimation

The detailed cost estimation of developed energy free water lifting device of size 32 mm was calculated by considering cost of production manufacturing which is given in Appendix A of chapter 7. As it was targeted to meet the need like low cost, easily available material in this study and total cost of manufacturing was worked out.

It was observed that 32 mm energy free water lifting device with 40 mm and 50 mm supply pipe device seemed to be better performing to use in the field. So, considering the material used for preparing these devices and cost of accessories is considered in cost estimation and given in details in section Appendices. i.e., Appendix (A). The material used for the assembly of the energy free water lifting device includes probably 90% of rigid PVC (RPVC). The material used is PVC material for making it low cost. The cost of that material plus cost of accessories were considered for the analysis. Cost incurred for the design of the energy free water lifting device which is found to be Rs.1155. Other costs are the costs of the supply pipes and costs of the delivery pipes which were equals to Rs. 2080 and Rs. 320 respectively. The cost of the device is found too less than that of the devices which are available in the market and found too much effective than other available devices in the market.



Plate 4.8 Our Hon. HOD Prof. Dr. Kadam Sir while giving precious guidance to me



Plate 4.9 Visit of Director of Research, DBSKKV, Dapoli



Plate 4.10 Visit of Sub Divisional Agricultural Officer



Plate 4.11 Visit of Hon. Vice Chancellor, DBSKKV, Dapoli



Plate 4.12 Visit of Hon. DYSP, Ratnagiri and PI, Dapoli

V. SUMMARY AND CONCLUSIONS

The experiment on “Design and Development of Cost Effective Energy Free Water Lifting Device” was carried out at the Instructional Farm and in the Laboratory of Department of Irrigation and Drainage Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, (M.S.), India. The research work aimed with specific objectives of survey and study, design, development and cost analysis of energy free water lifting device was carried out. The findings of the study are summarized under the following sections of this chapter.

5.1 Summary

The present investigation carried out at Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli concluded that by using velocity head (hydropower) of the falling water from the roof top or flowing from high to low elevation with the particular supply head was lifted to higher heads either to fill the overhead tanks placed on the rooftops of the houses or buildings to meet the domestic needs of people or by lifting the water at comparatively higher elevations to irrigate the upland fields which can be achieved by the accessories easily available with the stakeholders. With the available materials or from the available accessories one of the best cost effective energy free water lifting device by using the velocity head or hydropower of the flowing water was prepared to meet the need of remote areas which are deprive from the energy or fuel.

It could possible to use the amount of water which was totally being wasted is for the human’s welfare, and in the tribal areas where the total blind knowledge regarding the advance water lifting devices and problems to afford the high costs of the available water lifting devices.

5.1.1 Design and development of energy free water lifting device

To meet the requirements of water lifting by undertaking the cost effectiveness and considering the limitations of existing water lifting devices, energy free water lifting device of size 32 mm (1 inch) was designed and developed.

The major design parameters used are enlisted below:

- i. Waste valve was replaced by the reverse non return valve.

- ii. For the design, PVC pipe, elbow, 'T' (Tee), MTA of 32 mm size, control valve and non-return valve of 32 mm are the main components of the designed and developed energy free water lifting device.
- iii. The plastic disposable bottle of volume 2.25 liters is used as air chamber.
- iv. The volumetric flow rate, friction factor, head loss and Reynolds number were determined for designed device by using standard methods.

5.1.2 Working of the energy free water lifting device

The main aim of the energy free water lifting device is to lift the part of water up to head 3 to 4 m by using the velocity head (hydropower) of the falling water itself. The necessary design considerations were made for preparing the design of energy free water lifting device of size 32 mm. Also, the working principle of hydraulic ram i.e., water hammer effect found suitable and was used to lift the part of water by producing water hammering action.

5.1.3 Performance evaluation of the energy free water lifting device

The performance is worked out for the total 27 combinations consisting three supply heads as 1 m, 1.5 m and 2 m, three delivery pipes i.e., 12 mm, 16 mm and 25 mm with corresponding three combinations of supply pipes i.e. 32 mm, 40 mm and 50 mm. The results of the performance of water lifting device for different combinations of supply head, delivery head, supply pipe and delivery pipe is as given below:

- i. For 1 m supply head, 50 mm diameter supply pipe and 12 mm diameter delivery pipe, the maximum discharge obtained at the delivery head 2 m is 1.67 lpm and the maximum head obtained was 3.3 m with discharge rate of 0.60 lpm.
- ii. For 1.5 m supply head, 50 mm diameter supply pipe with 12 mm diameter delivery pipe, the maximum discharge obtained at delivery head 2.5 m is 2.07 lpm and the maximum head obtained was 3.9 m with the discharge rate of 0.22 lpm.
- iii. For 2 m supply head, 40 mm diameter supply pipe with 12 mm diameter delivery pipe, the maximum discharge obtained at delivery head 3 m is 2.40 lpm and the maximum head obtained was 4 m with the discharge rate of 0.42 lpm for 50 mm supply pipe with the same diameter of the delivery pipe as 12 mm.
- iv.

5.1.4 Maximum delivery head obtained

At 1 m supply head, the maximum delivery head obtained was 3.3 m. At 1.5 m supply head, the maximum delivery head obtained was 3.9 m and at 2 m supply head, the water lifted up to delivery head 4 m easily which serve the purpose and the device can also lift the water up to 4.5 to 5 m easily with the same combination by using larger size components.

5.1.5 Efficiency of the energy free water lifting device

The efficiency of the device was found maximum i.e., 71.98%, when the supply head was 2.0 m, diameter of supply pipe 50 mm and diameter of delivery pipe was 12 mm followed by for the same supply head i.e., 2.0 m with 40 mm diameter of supply pipe and 12 mm diameter of delivery pipe was 71.15%. For 32 mm diameter supply pipe, maximum efficiency obtained was 24.43% at 3.0 m delivery head with the 12 mm diameter delivery pipe and 2.0 m supply head which is not found significant.

5.1.6 Cost Analysis

The material used to design and develop the cost effective energy free water lifting device are the accessories readily available with the stakeholders consisting most of PVC material for making it low cost as per the objectives. The cost required to manufacture the 32 mm (1 inch) size energy free water lifting device is Rs.1155.

5.2 Conclusions

After serving the purpose of the present study and fulfilling the requirements of lifting the water up to 3 to 4 m, following conclusions can be drawn from the results:

1. It was found that as delivery head increases, delivery discharge gradually decreases. It is also observed that if the size of the supply pipe increases, discharge rates also increases up to certain extent by using same size of NRV and control valve.
2. It was found that the supply pipe with diameter 50 mm and 40 mm were found best amongst all the three combinations of supply pipe.
3. Delivery pipe with the diameter 12 mm and 16 mm were found best amongst all the three combinations for the delivery.
4. The waste valve of size 32 mm (1 inch) was given nice response up to 2 m supply head and above that it would not give proper strokes, stroke length and

delivery discharge. i.e., above the 2 m supply head and 50 mm supply pipe, device started to vibrate and too much pressure developed inside the air chamber causing bursting of the air chamber or either bursting of the connections like pipes, tees or elbows.

5. It was found that it would require torque to start and once started; it would run continuously as long as particular water level remains in the supply tank.
6. Supply pipe of diameter 32 mm was not found that much effective and discharge rates obtained with the corresponding delivery heads for 32 mm supply pipe were too less compared to supply pipe of diameters 40 mm and 50 mm.
7. With the help of 50 mm diameter supply pipe and 12 mm diameter delivery pipe, water lifted easily up to the delivery head of 4 m and with the discharge rate 0.42 lpm obtained. In case of 40 mm diameter supply pipe and 12 mm diameter delivery pipe, maximum head obtained was also 4 m and with the discharge rate 0.39 lpm obtained.

5.3 Suggestions for further work

Design of the waste valve should be as such that it will work better for all the diameters of supply pipe. There is a vast scope to design the waste valve. It can be designed in the such way that water which is flowing outside from the waste valve during the water hammering action can be reused by collecting it with the help of concave cup like structure. Also, waste valve can be designed in such a way that if the incoming water velocity increased then there should be an arrangement for adjusting the strokes of the valve with the hanging dead weights which can maintain the regularity in the number of strokes as well as delivery discharges.

VI. BIBLIOGRAPHY

- Abate C. and T. Botrel. 2002. Hydraulic Ram Pump Performance With Pvc And Steel Pipes. *Scientia Agricola* versão. On-line ISSN 1678-992X Sci. agric. (Piracicaba, Braz.) Vol.59(1).Piracicaba jan./mar. <http://dx.doi.org/10.1590/S010390162002000100029>.
- Anonymous. 2008. Human-Powered Handpumps for Water Lifting. *Practical Action Technology Challenging Poverty*. Tel +44(0) 1926634501 E-mail: publishinginfo@practicalaction.org.uk : <http://www.developmentbookshop.com>
- Arude H., A. Bhojane, A. Dhamale, A. Walunj and S. Shinde. 2018. Hydraulic Ram Pump, *International Journal of Advance Engineering and Research Development (IJAERD) Technophilia-2018*. Vol. 5 (04).
- Asvapoositkul W., J. Juruta, N. Tabtimhin and Y. Limpongsa. 2019. Determination of Hydraulic Ram Pump Performance: Experimental Results, *Hindawi Advances in Civil Engineering*. Vol. 2019. Article ID 9702183. 11 pages.
- Balgude R., S. Rupanavar, P. Bagul and M. Ramteke. 2015. Designing of Hydraulic Ram Pump. *International Journal of Engineering and Computer Science*. ISSN:2319-7242. Vol. 4 (5): 11966-11971.
- Cararo D., F. Damasceno, G. Griffante and L. Alvarenga. 2007. Hydraulic ram pump manufacturer features using alternative materials. *Rev. bras. eng. agríc. ambient*. Vol.11(4).
- Carvalho J., J. Saad, D. Silva, F. Cunha, M. Teixeira, M. Campos and R. Barbosa. 2016. Performance of water ram built with disposable bottles. *African Journal of Agricultural Research*. Vol. 11(34) : 3197-3202.
- Choudhary S., P. Shende, A. Ninawe. 2015. Design and Analytical Calculation for a Hydrum using Individual Head Losses. *International Journal of Science Technology & Engineering*. Vol. 2 (02): 107-111.
- Deo A., A. Pathak, S. Khune and M. Pawar. 2016. Design Methodology for Hydraulic Ram Pump. *International Journal of Innovative Research in Science, Engineering and Technology*. Vol. 5(4): 4735-4745.
- Dhaiban H. 2019. Experimental Study the Performance of Ram Water Pump, *Energy Science*, EUREKA: Physics and Engineering: Number 1, Department of

- Refrigeration and Air-Conditioning Tech. Eng. Dijlah University College Al-Massafi str., Baghdad, Iraq, 00964. PN: 22-27.
- Diwan P., A. Patel and L. Sahu. 2016. Design and Fabrication of Hydraulic ram with Methods of Improving Efficiency. *International Journal of Current Engineering and Scientific Research*. Vol.-3(4): 2393-8374.
- Engel, A. Bernard, Kujur, Birendra , Deak, Brian , Poppe, Brooke , Ahiablame, Laurent , Garner, Leah , DeNardo and Nick. 2011. Design of a Low Cost, Self Operating Hydraulic Ram Pump for Water Retention and Lifting in Developing Countries: Bringing Clean Water to Haiti. *United States Environmental Protection Agency*. Final Report, Purdue University, 610 Purdue Mall, West Lafayette.
- Fatahi-alkouhi R., B. Lashkar-ara and A. Keramat. 2018. Determine the Efficiency of Hydraulic Ram-Pumps, *Soil Structure Interaction Journal*. Vol. 3: 54-61.
- Fatahi-Alkouhi R., B. Lashkar-Ara and A. Keramat. 2019. On the measurement of ram-pump power by changing in water hammer pressure wave energy. *Ain Shams Engineering Journal*. Vol. 10: 681–693.
- Filipan V., Z. Virag and A. Bergant. 2003. Mathematical Modelling of a Hydraulic Ram Pump System. *Journal of Mechanical Engineering* 49. PN: 137-149.
- Gaikwad V., M. Gholap, R. Kadus, M. Gaikwad, A. Padekar and P. Mali. 2017. Recycled Hydro-power plant using hydraulic Ram Pump. *IJARIIIE*. Vol-3(2).
- Ghosh S., P. Sinha and B. Halder. 2018. Scope for using underutilized Hydraulic sources a Re-emphasis on the role of Hydram. *Int. Journal of Engineering Research and Application*. Vol. 8(7): 42-47.
- Gilbert S. 2016. 4.Water-lifting devices, *Linking Technology Choice with Operation and Maintenance*. <https://silo.tips/download/4-water-lifting-devices>. PP: 43-63.
- Girish L., P. Naik, H. Bhanu Prakash and M. Sunil Kumar. 2016. Design and Fabrication of a Water Lifting Device without Electricity and Fuel. *International Journal on Emerging Technologies*. Vol.7(2): 112-116.
- Grygo D. 2016. Effect of the Height of the Delivery Water on Performance of Water Ram, *Technical Sciences*. Vol. 19(2): 139–149.
- Gupta P., S. Chauhan and M. Oza. 2016. Modelling surface run-off and trends analysis over India. *J. Earth Syst. Sci.* Indian Academy of Sciences. Vol. 125(6): 1089–1102.

- Hamid Z., M. Zain, F. Hung, M. Halim, W. Bidin, I. Chatta and N. Omar. 2016. Performance Testing on Ram Pump – An Alternative Sustainable Water Supply System for Rural Communities in Malaysia. *Malaysian Construction Research Journal*. Vol. 19(2): 57-73.
- Harith M., R. Bakar, D. Ramasamy and M. Quanjin. 2017. A significant effect on flow analysis & simulation study of improve design hydraulic pump. *IOP Conf. Series: Materials Science and Engineering* 257 (2017).
- Hussin N., S. Gamil, N. Amin, M. Safar, S. Majid, M. Kazim and N. Nasir. 2017. Design and analysis of hydraulic ram water pumping system. *IOP Conf. Series: Journal of Physics: Conf. Series* 908. PN: 1-8
- Inthachot M., S. Saehaeng, J. Max, J. Müller and W. Spreer. 2015. Hydraulic ram pumps for irrigation in Northern Thailand. *Agriculture and Agricultural Science Procedia*. Vol. 5. PN: 107 – 114.
- Januddi F., M. Huzni, M. Effendy, A. Bakri, Z. Mohammad and Z. Ismail. 2018. Development and Testing of Hydraulic Ram Pump (Hydram): Experiments and Simulations. *IOP Conf. Series: Materials Science and Engineering*. Vol.440.
- Johannes F., M. Inthachot, S. Suchard, J. Muller and W. Spreer. 2015. Hydraulic ram pumps for irrigation in Northern Thailand. *Agriculture and Agricultural Science Procedia*. Vol. 5: 107 – 114.
- Kadlowec J., K. Dmitruck, J. Everett, K. Ketcho, H. Zhang, K. Pillion, T. Purdue and D. Bounieav. 2013. Rope Pump Modifications to Reach Greater Depths: A Service Project for Clean Water in The Gambia. *International Journal for Service Learning in Engineering*. Vol. 8(2): 8-23.
- Kimaro S. 2018. The Influence of Air Vessel Volume on the Delivery Flow Rate and Efficiency of a Hydram Water Pumping System. *International Research Journal of Engineering and Technology (IRJET)*. Vol. 05(05) : 1312-1320.
- Kumar H., Temesgen, T. Beyene, G. Ofgaa, M. Kaso, Shemellis, P. Rao and T. Negassa. 2016. Pollution Free Design and Manufacturing of Hydraulic Ram Pump for Villages in Hill Areas. *International Journal of Mechanical Engineering Research and Technology*. Vol. 2(2).
- Lashofer A., W. Hawle, I. Kampel, F. Kaltenberger and B. Pelikan. 2012. Study of technology and design guidelines for the Archimedes screw turbine. *Hydrology and Hydraulic Engineering*. Conference Paper, ashofer.alois@boku.ac.at

- Lee S., H. Yoon, D. Kim, E. Shin, Y. Kim, K. Ko and K. Ha. 2016. Evaluation of Field Feasibility and Efficiency of Hydraulic Ram Pump. *Korea Institute of Geoscience and Mineral Resources*. Daejeon 305-350, South Korea, *University of Science and Technology*, Daejeon 305-350, South Korea.
- Limbo N. and S. Khillare. 2015. An Analytical study of Indian Agriculture Crop Production and Export with reference to Wheat. *Review Of Research*. Vol. 4(6).
- Mandale V., D. Mahale, S. Nandgude, K. Gharde and R. Thokal. 2017. Spatio-Temporal Rainfall Trends in Konkan Region of Maharashtra State. *Advanced Agricultural Research & Technology Journal*, Vol. I(I) : 61-69.
- Maratos, D. 2003. Technical feasibility of wavepower for seawater desalination using the hydro-ram (Hydram). *Desalination*. Vol. 153 : 287-293.
- Maw Y. and Z. Htet. 2014. Design of 15 meter Head Hydraulic Ram Pump. *International Journal of Scientific Engineering and Technology Research*. Vol.03(10) :2177-2181.
- Mbiu R., S. Maranga and M. Mwai. 2015. Performance Testing of Hydraulic Ram Pump. *Proceedings of the Sustainable Research and Innovation (SRI) Conference*.PN: 6-8.
- Michael A.M. 2009. Irrigation Theory and Practice. *2nd Edition: Theory and Practice*. Vikas Publishing House Pvt Limited.
- Mishra N., I. Bhagat and Y. Jyoti. 2018. Effect of Water Hammering Action on Performance of Hydraulic Ram Pump. *International Journal of Scientific and Research Publications*. Vol. 8(12): 396-399.
- Mohammed S. 2007. Design and Construction of a Hydraulic Ram Pump. *Leonardo Electronic Journal of Practices and Technologies*. ISSN 1583-1078 (11): 59-70.
- Mondol S. S. 2017. Design, Manufacture and Test a Hydraulic ram. Stats and author profiles for this publication: <https://www.researchgate.net/publication/317031378>, Thesis May 2017.
- Nair S., P. Pranav, D. Purusothaman and V. Sivasankar. 2018. Design and Fabrication of A Hydraulic Ram Pump. *International Journal of Engineering Research & Technology (IJERT)*. ISSN: 2278-018, Published by, www.ijert.org ETEDM – 2018.

- Ninawe A., C. Handa and A. Vanalkar. 2018. Design of Experimentation for Developed Hydraulic Ram pump. *International Journal for Research in Applied Science & Engineering Technology*. Vol. 6 (VI): 1798-1804.
- Nnene O., I. Okoye and J. Agunwamba. Design and Construction of a Water Conservation System, Department of Civil Engineering, University of Nigeria Nsukka, Enugu State, Nigeria. (E-mail: o_nnene@yahoo.com; ky_sc@yahoo.com) 1-13.
- Pathak A., A. Deo, S. Khune, S. Mehroliya and M. Pawar. 2016. Design of Hydraulic Ram Pump. *International Journal for Innovative Research in Science & Technology*. Vol.2(10): 290-293.
- Rajaonison A. and H. Rakotondramiarana. 2019. Theoretical Study of the Behavior of a Hydraulic Ram Pump with Springs System. *American Journal of Fluid Dynamics 2019*. Vol. 9(1) : 1-12.
- Sakhare M. 2016. Design & Fabrication of Automatic Hydraulic Ram Pump by Using Principle of Water Hammering Effect. *International Journal of Trend in Research and Development*. Vol. 3(3): 672-674.
- Satyanarayana D., P. Syam Kumar, G. Siva and K. Tulasi Kumar. 2016. Design of Hydraulic Ram pump. *International Journal and Magazine of Engineering, Technology, Management and Research*. Vol. 3(8): 72-79.
- Sethi L., F. Panme, A. Teronpi and K. Pegu. 2015. Performance Evaluation of Hydraulic Ram Pump with Rain-Cum-Roof Water Harvesting Structure in a Hilly Terrains of North East of India. *Journal of Agroecology and Natural Resource Management*. Vol.2 (4) : 317-320.
- Sheikh S., C. Handa and A. Ninawe. 2013. Design Methodology for Hydraulic Ram Pump (HYDRAM). *International Journal of Mechanical Engineering and Robotics Research*. Vol. 2(4): 171-175.
- Shende P., S. Choudhary and A. Ninawe. 2015. Analysis and Enhancement of Hydraulic Ram Pump using Computational Fluid Dynamics (CFD). *International Journal for Innovative Research in Science & Technology*. Vol. 2(03) : 109-133.
- Smith W. 2017. Home-Made Hydraulic Ram Pump for Livestock Water. *Livestock & Forages*. LF Vol. 13 - September 2017, *Clemson Cooperative Extension Service*, Clemson University.

- Suarda M., A. Ghurri, M. Sucipta and G. Kusuma. 2018. Investigation on characterization of waste valve to optimize the hydraulic ram pump performance. AIP Conference Proceedings 1984, *International Conference on Thermal Science and Technology (ICTST) 2017*. PN: 020023-1–020023-9.
- Verspuy C. and A. Tijsseling. 2010. Hydraulic ram analysis. *Journal of Hydraulic Research*. Vol. 31(2): 267-278.
- Viccione G., N. Immediata, R. Cava and M. Piantedosi. 2018. A Preliminary Laboratory Investigation of a Hydraulic Ram Pump. *Proceedings 2018*. Vol. 2: 687.
- Waghmare S. and M. Prabhavalkar. 2013. Design And Fabrication Of Gravity Assisted Free Energy Pump. *Journal of Engineering Research and Studies*. Vol. IV(II): 12-15 and 05-08.
- Yang K., J. Li, Y. Guo, X. Guo, H. Fu, T. Wang. 2014. Design And Hydraulic Performance Of A Novel Hydraulic Ram Pump, China Institute of Water Resources & Hydropower Research, Beijing/100038, China, *City University of New York (CUNY)*, CUNY Academic Works, 11th International Conference on Hydroinformatics HIC 2014, New York City, USA.
- Yannopoulos S., G. Lyberatos, N. Theodossiou, W. Li, M. Valipour, A. Tamburrino and A. Angelakis. 2015. Evolution of Water Lifting Devices (Pumps) over the Centuries Worldwide. *Water 2015*. Vol. 7 : 5031-5060.
- Zaman A. and T. Khan. 2012. Design of a Water Wheel For a Low Head Micro Hydropower System. *Journal Basic Science And Technology*. Vol. 1(3): 1-6.

VII. APPENDICES

Appendix (A)

a) Cost for design of the energy free water lifting device:

Sr. No.	Particulars	Quantity	Unit	Rate per unit (Rs.)	Total amount (Rs.)
1.	PVC pipe, 32 mm	1.5	metre	30	45
2.	Non-return valve, 32 mm	2	inch	250	500
3.	Control valve, 32 mm	2	inch	158	316
4.	Male Threaded Adaptor, 32 mm	7	inch	15	105
5.	Elbow, 32 mm	1	inch	10	10
6.	Tee, 32 mm	2	inch	20	40
7.	Reducer (1-1/2", 1-3/4")	2	inch	30, 20	50
8.	Female-Threaded Adaptor	1	inch	20	20
9.	Plastic disposable bottle	1	litre	-	-
10.	Hose Nipple	1	inch	27.12	27.12
11.	Hose Clips (3/4", 1")	3+2	inch	6.50, 10.17	39.84 (19.5+20.34)
	Total				1152.96

b) Cost of the Supply pipes and Delivery pipes:

Sr. No.	Particulars	Quantity	Unit	Rate per unit (Rs.)	Total amount (Rs.)
	i) Supply Pipes				
1.	Hose Pipe – 32 mm	10.8	metre	47.46	512.57
2.	Hose Pipe – 40 mm	10.8	metre	70	756
3.	Hose Pipe – 50 mm	10.8	metre	75	810
	Total				2078.57
	i) Delivery Pipes				
1.	Hose Pipe – 25 mm	6	metre	24	144
2.	Hose Pipe – 16 mm	6	metre	18.64	111.84
3.	Lateral Pipe – 12 mm	6	metre	10	60
	Total				315.84

Appendix (B)

Observations recorded for 1 m supply head

i) Supply Head = 1 m

For Head= 1 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	325	2.700	302
2.5	30	329	1.600	268
3	30	330	0.700	168

For Head= 1 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	309	2.300	232
2.5	30	328	2.250	310
3	30	321	0.790	217

For Head= 1 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	311	2.100	288
2.5	30	357	1.900	356
3	30	314	0.320	333

For Head= 1 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	341	7.310	304
2.5	30	332	4.120	302
3	30	331	2.640	305
3.1	30	319	2.520	310
3.2	30	317	2.450	305
3.3	30	301	2.120	269

For Head= 1 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	359	7.200	341
2.5	30	320	3.800	310
3	30	323	2.500	313
3.1	30	321	2.380	315
3.2	30	327	2.200	319

For Head= 1 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	314	5.960	307
2.5	30	354	4.700	348
3	30	302	2.150	289
3.1	30	369	1.900	350

For Head= 1 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	301	7.980	287
2.5	30	340	6.250	332
3	30	364	4.870	357
3.1	30	361	4.650	354
3.2	30	337	3.950	329
3.3	30	327	3.150	316

For Head= 1 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	331	7.340	323
2.5	30	348	5.850	340
3	30	356	3.690	348
3.1	30	298	2.180	258
3.2	30	231	1.240	173

For Head= 1 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2	30	297	6.110	283
2.5	30	342	5.100	334
3	30	378	3.010	371
3.1	30	301	1.210	281

Appendix (C)

Observations recorded for 1.5 m supply head

ii) Supply Head = 1.5 m

For Head= 1.5 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	316	2.850	212
3	30	334	1.720	176
3.1	30	306	0.900	137
3.2	30	318	0.710	116

For Head= 1.5 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	319	2.870	254
3	30	327	2.100	248
3.1	30	301	1.100	180

For Head= 1.5 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	309	2.210	305
3	30	327	1.840	261
3.1	30	368	0.700	326

For Head= 1.5 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	463	10.200	458
3	30	448	7.810	428
3.1	30	441	7.200	419
3.2	30	453	6.510	438
3.5	30	467	6.100	459
3.6	30	438	3.810	438
3.7	30	431	2.900	426

For Head= 1.5 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	483	10.520	478
3	30	438	7.810	431
3.1	30	430	7.100	424
3.2	30	481	6.810	473
3.5	30	484	5.450	481
3.6	30	489	3.210	484

For Head= 1.5 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	449	8.700	448
3	30	459	6.740	439
3.1	30	458	6.210	453
3.2	30	448	6.100	437
3.5	30	423	4.870	419
3.6	30	419	3.120	403

For Head= 1.5 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	356	12.140	352
3	30	443	10.150	437
3.1	30	476	8.300	473
3.2	30	479	8.150	478
3.5	30	484	7.300	469
3.6	30	476	6.910	458
3.7	30	469	5.300	469

3.8	30	464	3.900	458
3.9	30	419	1.300	359

For Head= 1.5 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	351	11.880	349
3	30	433	9.700	420
3.1	30	479	8.300	476
3.2	30	470	7.890	461
3.5	30	497	7.400	491
3.6	30	453	5.980	449
3.8	30	459	3.220	451
3.9	30	421	1.000	354

For Head= 1.5 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
2.5	30	398	9.730	349
3	30	410	7.870	403
3.1	30	413	7.540	401
3.2	30	424	6.340	421
3.5	30	426	4.900	419
3.6	30	451	3.600	448
3.7	30	453	2.300	441

Appendix (D)

Observations recorded for 2 m supply head

iii) Supply Head = 2 m

For Head= 2 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	286	4.100	240
3.5	30	241	2.180	190
3.6	30	240	1.300	186

For Head= 2 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	258	4.070	243
3.5	30	240	2.220	210
3.6	30	293	1.970	286

For Head= 2 m; Supply Pipe Size= 32 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	249	3.200	236
3.2	30	257	2.540	249
3.5	30	241	1.250	231

For Head= 2 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 12mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	356	13.950	349
3.5	30	416	10.070	408
3.6	30	421	6.900	381
3.7	30	371	5.420	358
4	30	454	2.900	448

For Head= 2 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	369	13.200	358
3.5	30	353	8.350	340
3.7	30	440	5.900	425
4	30	358	1.700	349

For Head= 2 m; Supply Pipe Size= 40 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	409	9.890	402
3.2	30	411	8.210	403
3.5	30	349	6.230	341
3.7	30	452	3.450	460
3.8	30	407	2.300	398

For Head= 2 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 12 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	374	14.280	371
3.5	30	460	11.370	458
3.6	30	448	7.200	427
3.7	30	431	5.790	428
4	30	463	3.210	458

For Head= 2 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 16 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	378	13.210	356
3.5	30	390	9.100	378
3.7	30	363	4.980	349
4	30	448	2.870	438

For Head= 2 m; Supply Pipe Size= 50 mm; Delivery Pipe Size= 25 mm

Delivery Head, (m)	Vin (litre)	Time (second)	Vout (litre)	Time (second)
3	30	389	10.980	378
3.2	30	440	7.360	341
3.5	30	419	8.210	399
3.7	30	371	2.990	356
4	30	385	1.980	372

Appendix (E)

Percent reduction in discharge rates corresponding to delivery heads at 1 m supply head

For Supply Head = 1 m

a) Diameter of delivery pipe = 12 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1 m supply head with 12 mm diameter of delivery pipe				
	2 to 2.5m	2.5 to 3m	3 to 3.1m	3.1 to 3.2m	3.2 to 3.3m
32	33%	31%	-	-	-
40	43%	37%	6%	2%	2%
50	32%	27%	4%	9%	17%

b) Diameter of delivery pipe = 16 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1 m supply head with 16 mm diameter of delivery pipe			
	2 to 2.5m	2.5 to 3m	3 to 3.1m	3.1 to 3.2m
32	25%	50%	-	-
40	42%	35%	6%	9%
50	24%	38%	20%	16%

c) Diameter of delivery pipe = 25 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1 m supply head with 25 mm diameter of delivery pipe		
	2 to 2.5m	2.5 to 3m	3 to 3.1m
32	27%	81%	-
40	30%	44%	27%
50	29%	47%	47%

Appendix (F)

Percent reduction in discharge rates corresponding to delivery heads at 1.5 m supply head

For Supply Head = 1.5 m

a) Diameter of delivery pipe = 12 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1.5 m supply head with 12 mm diameter of delivery pipe							
	2.5 to 3 m	3 to 3.1 m	3.1 to 3.2m	3.2 to 3.5m	3.5 to 3.6m	3.6 to 3.7m	3.7 to 3.8m	3.8 to 3.9m
32	27%	34%	5%	-	-	-	-	-
40	19%	6%	14%	10%	33%	24%	-	-
50	33%	24%	2%	13%	2%	23%	25%	57%

b) Diameter of delivery pipe = 16 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1.5 m supply head with 16 mm diameter of delivery pipe						
	2.5 to 3 m	3 to 3.1 m	3.1 to 3.2m	3.2 to 3.5m	3.5 to 3.6m	3.6 to 3.8m	3.8 to 3.9m
32	25%	27%	-	-	-	-	-
40	17%	8%	14%	21%	41%	-	-
50	32%	24%	2%	13%	11%	46%	60%

c) Diameter of delivery pipe = 25 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 1.5 m supply head with 25 mm diameter of delivery pipe					
	2.5 to 3 m	3 to 3.1 m	3.1 to 3.2 m	3.2 to 3.5 m	3.5 to 3.6 m	3.6 to 3.7 m
32	2%	69%	-	-	-	-
40	21%	11%	-2%	17%	54%	-
50	30%	3%	20%	22%	31%	35%

Appendix (G)

Percent reduction in discharge rates corresponding to delivery heads at 2 m supply head

For Supply Head = 2 m

a) Diameter of delivery pipe = 12 mm

Supply pipe Diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 2 m supply head with 12 mm diameter of delivery pipe			
	3 to 3.5m	3.5 to 3.6m	3.6 to 3.7m	3.7 to 4m
32	33%	39%	-	-
40	38%	26%	17%	57%
50	35%	32%	20%	48%

b) Diameter of delivery pipe = 16 mm

Supply pipe Diameter mm	Percent reduction in discharge rates corresponding to delivery heads at 2 m supply head with 16 mm diameter of delivery pipe		
	3 to 3.5m	3.5 to 3.6m	3.6 to 4m
32	37%	35%	-
40	33%	44%	65%
50	35%	40%	55%

c) Diameter of delivery pipe = 25 mm

Supply pipe diameter, mm	Percent reduction in discharge rates corresponding to delivery heads at 2 m supply head with 25 mm diameter of delivery pipe				
	3 to 3.2m	3.5 to 3.5m	3.5 to 3.7m	3.7 to 3.8m	3.8 to 4m
32	25%	48%	-	-	-
40	18%	10%	58%	24%	-
50	25%	5%	59%	20%	20%

