DESIGN AND DEVELOPMENT OF COST EFFECTIVE DEVICE FOR FERTIGATION

A THESIS SUBMITTED TO THE

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

Er. KASARE SAMPADA KASHINATH

(Regd. No. ENDPM 2018 / 140)

B. Tech. (Agricultural Engineering)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING,

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I hereby declare that this thesis or part thereof has not been submitted

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for award of Degree or

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

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

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LIST OF SYMBOLS

Symbol	Description
%	Per cent
^{0}C	Degree Celsius
+	Plus
-	Minus
/	Division
*	Multiplication
=	Equal to
Ø	Diameter

LIST OF ABBREVATIONS

Abbreviation	Meaning
mm	Millimeter
Ml	Milliliter
cm	Centimeter
h	Hour
M	Meter
etc.	Etcetera
Fig.	Figure
No.	Number
sr.	Serial
viz.	Namely
Sec.	Seconds
Lph	Liter per hour
Min	Minute
Lit	Liter
i.e.	That is
PVC	Polyvinyl chloride
lpm	Litre per minute
l/h	Liter per hour
Kg/cm^2	Kilogram per centimeter square
PP	Polypropylene

ABSTRACT

DESIGN AND DEVELOPMENT OF COST EFFECTIVE DEVICE FOR FERTIGATION

by

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Project guide	:	**Prof. Dr. U. S. Kadam**
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The present investigation entitled, "Design and Development of cost effective device for fertigation" was carried out during the year 2019-20 in the Laboratory and the Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

The fertilizer use efficiency is very low in India. The main reason for the low efficiency is the type of fertilizer used and its method of application in Indian agriculture. There are various devices available in the market used for fertigation such as venturi injector, fertigation tank, hydraulic injection pump and electrical pump. But these devices have some limitation. Therefore, device of fertigation was developed to overcome the limitation of available devices in the market by assembling the various materials such as PVC Pipes, PVC reducers, microtube, PVC Elbow, PVC 'T' (Tee), PVC control valve, strainer and other accessories.

The six fertigation devices of size 63 x 32 mm, 63 x 25 mm, 63 x 16 mm and 50 x 32 mm, 50 x 25 mm, 50 x 16 mm were designed and developed according to design norms and criteria. The emitters of discharge 2.1 l/h were installed at a spacing

of 0.40 m and lateral were spaced at 1.75 x 1.75 m. The length of lateral was 30 m. The different operating pressures were used starting from 1.0 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2 for field testing of the developed fertigation device. The height of the device above the mainline was 70 cm. The fertigation device of size 63 x 32 mm, 63 x 25 mm and 50 x 32 mm, 50 x 25 mm do not formed suction in the field but shown good results when operated at atmospheric pressure which are also suitable for fertigation when fitted to delivery side of the pump for open channel fertigation.

The best result was found in the device of size 63 x 16 mm followed by device of size 50 x 16 mm. The maximum suction rate 73.49 l/h and 48.39 l/h were observed at 2.5 kg/cm^2 for device of size 63 x 16 mm and 50 x 16 mm respectively. The average emission rate and average emission uniformity was found maximum in the device of size 63 x 16 mm which is 3.15 l/h and 99.74 % at 2.5 kg/cm^2 operating pressure. The results of the study revealed that to create the suction, it was necessary to have the percent increase in the velocity more than 67 % at constricted section. It was also observed that when the difference of velocity at constricted section becomes half or more than half of the inlet then and then only the suction takes place. It is infered that the constricted cross section in the pipe section was inversely proportional to the velocity of flowing fluid and directly proportional to the pressure in the pipe at that point of constriction.

The cost economics was calculated by considering the different materials used for design and development of the device which was available in the market. The manufacturing cost for 63 x 16 mm and 50 x 16 mm device are Rs. 175 and Rs. 150 respectively.

The devices of size 63 x 16 mm and 50 x 16 mm are named and here after recognized as PK'S fertigation device and recommended as it fulfils most of the requirements of fertigation in the field.

I. INTRODUCTION

Geographical area of India is 328.7 mha of which 182.2 mha is arable land (Anonym, 2017). That of Maharashtra has 30.771 mha geographical area with 21.099 mha cultivable land (Anonym, 2018). This cultivable land is formerly irrigated with the traditional methods like moat, chain pump, dhekli, rahat, surface and subsurface irrigation (border and farrow irrigation system). But as the time passes the scarcity of water increases which enforces Indian farmer to use micro-irrigation system for frequent application of water directly to the root zone of the plant above or below the soil surface. Modern irrigation consists of micro-irrigation system like drip and sprinkler irrigation.

In India about 65 to 70 % agriculture land is dependent on rainfall receiving during June to September. The Productivity of irrigated land is more than two to three times than the rain-fed agriculture. As even there is no any option at present to use high valued commodity water, judiciously and precisely except micro-irrigation. The farmers are using the micro irrigation and especially drip, they have also started to apply water soluble fertilizers though it which resulted in achieving greater water use efficiency and fertilizer use efficiency. At present area under micro irrigation in India is 10.26 mha and that to in Maharashtra is 1.55 mha. Out of which 4.78 mha and 1.09 mha purely under drip irrigation in India and Maharashtra respectively. Annually as an average 26.59 MT of fertilizers are being utilized in India and 2.94 MT in Maharashtra. In general we can say that India is the big consumer of fertilizer (Anonym, 2018).

Precise scheduling of irrigation water and nutrients is required as it is directly proportional to nutrient use efficiency and inversely to the leaching of nutrient to ground water. The availability of nutrient at the appropriate time of plant’s need is very high so efficiency is more. Fertigation omits the starting and ending time of irrigation water supply. It ensures the appropriate building of differential pressure during commencement of irrigation period. The fertilizer can be injected quantitatively or proportionally (Cetin *et al,* 2013). Precise knowledge of calculation of injection rate, flow rate of water, solubility of different nutrients and different fertilizer equipment used for fertigation gives the successful fertigation result. Venturi injector is the one that, widely used in the chemigation system in small and medium size farms (Manzano Juárez J. et al, 2005). The pressure drop through a venturi will be enough to create a vacuum pressure as measured relative to atmospheric pressure. When such conditions achieve the fertilizer get injected from the tank.

Common advantages of fertigation i.e. the application of fertilizers through an irrigation system, includes 1. The considerable savings in the labor and energy costs of application. 2. Chemicals are already in solution and water-soluble form and thus immediately available to the plants in the root zone. 3. Flexibility in irrigation timing makes it easier to schedule fertilization 4. Soil compaction is minimized by avoiding heavy equipment traffic through the field 5. Small doses of chemical/fertilizers are applied when needed 6. Reducing leaching of water-soluble nutrients during periods of excessive rainfall or over-irrigation (Burt *et al.* 1998, Boman and Obreza 2002). 7. It also have some advantages like it has ability to provide protection against the drought conditions. According to the investigation of Irrigation Training and Research Center, Science & Engineering College of California, U.S.A., in normal case with fertigation in drip system, 25% fertilizer can be saved, and more labors and energies be saved (Li jiusheng et al, 2003).

Drip irrigation appropriately uses the water and fertilizers by ensuring the high crop yield. Simultaneously it ensures the healthy soil and favorable soil environment. Drip irrigation technology encircles water soluble solid and liquid minerals to pass through the drip irrigation system with irrigated water so as to supply the nutrient to the root zone of crops. For desired result of productivity and nutrients use efficiency precise management of rate of application of irrigated water and nutrients is necessary. Nutrient use efficiency is enhanced by using drip irrigation system. (Cetin *et al.,* 2013)

India is the third largest fertilizer producing and consuming country in the world. (Mane *et al.,* 2014). In India fertilizer use efficiency is very low. The types of fertilizers used and their methods of application by the farmer are mainly responsible for lowering down the fertilizer efficiency. Still there is miss conception that, more the water along with more fertilizers shall give more yield, accordingly in irrigated agriculture most of the farmer are using more fertilizers to enhance the per unit productivity which are on the other hand affects adversely to water table built up and salinity problems in the fertile soil. Therefore, it is the need of hour to deliver exact amount of fertilizers along with the required quantity of fertilizer to protect the valuable natural resources like land and water. It will also help to minimize the environmental pollution.

Further it is required to apply only the required amount of fertilizers and as per the different growth stages of the crop in the field however it is somewhat difficult task by considering the different available injectors and fertilizers their modes of operation and skill of the operator. To deliver the exact quantity of water and as per the requirements of the crop, micro-irrigation is one of the best options. In micro-irrigation system, the water-soluble fertilizers can be directly applied to root zone of the plant by using the different fertilizer applicators available in the market (Cetin *et al., 2013*). This process is considered as the fertigation and it is possible due to help of special fertilizer apparatus/devices/injectors installed at the head control unit of the system, before the filters. Several techniques are developed for application of fertilizer using pressurized irrigation system like micro-irrigation system in general and drip irrigation system in particular and many types of injectors which are available in the market. There are different types of fertilizer applicator available in the market and those are fertilizer tank, venturi, injectors/piston pump *etc.* which are either working on pressure difference or external supply with additional pressure in to the pipe network (Cetin *et al.,* 2013).

Fertilizer can be applied very precisely by drip irrigation system. The Drip irrigation technology was developed by Simcha Blass, an Israelee Engineer in early 1940. Drip irrigation appropriately uses the water and fertilizers by ensuring the high crop yield as compared to surface irrigation methods and conventional fertilizers. Drip irrigation is that type of micro-irrigation that has the potential to save water and nutrient by allowing water to drip slowly to the root zone of the plants, either from above soil surface or buried below the surface. Simultaneously it help to certain extent to ensure the healthy soil and fruitful environment. Drip irrigation technology encircles solid and liquid minerals to pass through the drip irrigation system with irrigated water so as to supply the nutrient to the root zone of crops. For desired results of productivity and nutrients use efficiency precise management of rate of application of irrigated water and nutrients are necessary. Nutrient use efficiency is enhanced by using drip irrigation system.

Drip irrigation have some advantages over the other methods which includes providing required amount of nutrient and water to the crop by maintaining high productivity. Modern drip irrigation gave the valued invention and replacing the conventional irrigation methods like surface and flood irrigation systems and helping proper utilization of water resources. Drip irrigation has more feasibility regarding design, operation and maintenance. Drip irrigation is still evolving and advancement are still being made in materials and techniques. Growers are increasingly becoming aware of how precious water is as a resource, how its efficient usage and management can assist agriculture and how drip irrigation technology can positively affect society as a whole. Drip irrigation has truly become and continue to be a benefit to all of us.

Micro-irrigation is blessed with the venturi devices for fertigation tank which helps in application of water-soluble fertilizers. The main principle on which fertigation devices are operating on differential pressure or venturi pumps. Venturi suction has limited the use of devices on large system of fertigation and where the crop required high amount of fertilizers. For higher fertigation rate parallel circuit of centrifugal pump are installed. Fertigation provides greater control over the applied nutrient over the traditional method.

For fertigation injection three different fertigation devices are used that are venturi injector, by-pass flow tank and pressure differential system or injection pump. The venturi injector works on the pressure difference principle due to constricted pipeline. It requires minimal pressure difference between inlet and outlet sides to initiate vacuum at suction port. It has simple mechanism, no moving parts, efficient and compact device, injection rate is regulated by using valves. It has drawback that has high loss of pressure, sensitive regarding pressure change which causes difficulties in precise regulation of flow. In by-pass flow tank pressurized tank is used which is connected to bypass to supply pipe of head control. It is between inlet and outlet of tank. Its dilution ratio and injection rate are unsteady, concentration at the start is high therefore it is not used in large scale. In injection pump water pressure of system plays major role which is directly installed to supply line instead of by-pass line. The system flow activates the piston then injector is operated, ejecting of fertilizer started and its rate is regulated. Centralized fertilization is possible. This system is portable. It saves the labour power and cheap in operation. But this is very expensive than venturi injectors.

Fertilizer can be injected into drip irrigation system by selecting appropriate equipment. Most injection systems are designed to accommodate other agricultural chemical such as herbicides, nematicides insecticides, *etc.* The selection of the equipment is be based on specific irrigation system. Limitations of fertigation through the fertigation devices are 1. Large loss in pumping pressure i. e. 1/3 of the operating pressure and sensitive to the change of pressure and water supply. 2. Precise regulation of flow becomes difficult due to its sensitivity. 3. It requires proper operating skills and experienced persons who should know the requirement of operation to achieve prior results. 4. It does not maintain required concentration of fertilizers throughout the fertigation. 5. Require supervision over the amount of fertilizers in tank or its storage. 6. Sometimes installation becomes complicated which is not possible to field worker and involves expensive skill personnel. 7. It may require Sometimes outside power source for operation. 8. Limited availability of water-soluble fertilizers and its high cost of application makes farmers to adopt it only for horticulture crop. 9. Price of fertigation applicators are approximately above Rs 5000/- which are not affordable for the small-scale farmers. 10. Lack of information in the form of adequate research over fertilizer application rate, amount to be applied and its frequency.

Therefore, it was felt necessary to Design and develop a cost effective, easy to operate, ready to fertigation used without or less involvement of regulating vales and regulating the pressure difference. With this background study entitled "Design and development of cost-effective fertigation applicator" is under taken at Instructional farm and Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli with the following objectives

1. Survey and study of devices for fertigation available in the market
2. Design and development of cost-effective device for fertigation
3. Performance evaluation of developed device for fertigation
4. Cost analysis

With the following hypothesis

1. The velocity of flowing fluid in the pipe line is inversely proportional the constricted cross section in the pipe section and directly proportional to the pressure in the pipe at that point of constriction.
2. The constricted cross section with diameter of fluid pressure in the pipe section decides the suction rate.
3. The different constricted cross section in the same pipe line varies the suction rate, velocity of flowing fluid and pressure at that point of constriction.

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 survey and study of different devices of fertigation available, their techniques/methods of workings etc. It also describes the different methodology and techniques for design and development of different fertigation devices their performance evaluation including mode of injection of fertilizer in to the pipeline etc. to fulfill the title of the present study and accordingly the objectives. The reviews are distinguished in four areas as given below:

1) Survey and Study of different available fertigation devices, methodology, and performance.
2) Design and development of fertigation systems
3) Performance evaluation of fertigation systems
4) Cost economics of fertigation devices

2.1 Survey and study of different available fertigation devices, methodology, and performance.

It was necessary to know which techniques and different methods are already available and are used for fertigation in the field. The work done by the earlier scientists on fertigation is described in this section.

Badr *et al.* (2006) investigated different fertigation methods and effects on water and fertilizer uniformity in drip irrigation. They conducted this experiment to compare the different fertigation methods among themselves and know the better method of fertigation in respect of water and fertilizer distribution in inline drip irrigation system under 1.5 kg/cm^2 operating pressure. To fulfill the objectives of the study they have considered and used to inject fertilizer in the pipeline were respectively, hydraulic injection pump, pressure differential tank, venturi devices and electrical centrifugal pump by fixing the length of inline lateral as 20m, 40m and 50m which were operated at 1.5 kg/cm^2. Further they studied the effect of fertigation devices under different lateral lengths on the distribution uniformity of water (D.U) and fertilization (F.D.U), in order to clarify the best fertigation device among the rest of the devices under study and accordingly best suited lateral lengths. They observed that the distribution uniformity (DU) in percentage by using the hydraulic injection pump, venturi device, pressure differential tank and electrical centrifugal pump were found to be 90, 99 and 97%, 97, 92 and 99%, 97,98 and 99% and 97, 96 and 100% for 20 m, 40 m and 50 m respectively. Further they recorded the fertilizer distribution uniformity by using the hydraulic injection pump, venturi device, pressure differential tank and electrical centrifugal pump were found to be 96, 98 and 99%, 97, 92 and 99%, 86, 88 and 96% and 97, 98 and 96 % for 20 m, 40 m and 50 m, respectively.

Fares *et al.* (2009)[1] worked on the injection and components of a venturi injector fertigation system. They said for successful fertigation precise calculation of injection rates, knowledge regarding solubility of different fertilizer components and basic of fertigation equipment. Fertigation injection devices work either on piston flow (positive displacement pumps) or on vacuum generation (suction or negative pressure, venturi-type) principles. Positive displacement pumps include proportional injectors, rotary pumps, and peristaltic pumps. The injection energy for positive displacement pumps is provided by an electric, gasoline, or hydraulic motor. Accurate chemical application and easy adaptation for automation were among the major advantages of positive displacement pumps. They provided necessary information regarding these components of fertigation system and calculated rate of injection.

Fares *et al.* (2009)[2] worked on the citrus chemigation. They used venturi injection method. They revealed about chemigation, discussed chemigation management, system component, efficiencies. They drawn observation that a chemigation system comparises an efficient irrigation system, supply tank/ reservoir, chemical injection devices and back flow prevention mechanism. In back flow prevention method they connected the supply tank to irrigation system with supply pipe line. Two small open ended tubes were connected in the supply tank. One end of small tube faces towards upstream and other one was to downstream. From upstram tube the water flows and from down stream chemical was outflow. So they got the result that when pressure increases like wise flow get adjusted so it caused management of back flow through injection tube.

Cetin *et al.*, (2013) studied application techniques of fertigation. They used fertigation tank, venturi system and hydraulic pump. All techniques for incorporating a chemical with the irrigation water create a specific level of chemical concentration during irrigation. They classified various techniques into three main groups. These were gradual decrease of chemical concentration, uniform level of chemical concentration and intermittent chemical concentration. They explained methods of fertilizer application viz. quantitative and proportional. They studied application method like Continuous application, Three-stage application, Proportional application, Quantitative application. They gave information of fertigation tank, venturi system and hydraulic pump.

Sureshkumar *et al.* (2016) stated that fertigation was the key component of precision farming. They emphasized importance of fertigation in increasing productivity with efficient and reduced consumption of water and nutrients with practically no pollution. They discussed concept of fertigation, including the concepts of wetted soil volume and the resultant root volume and their optimization. The necessity, principles, chemistry and interactive effects, advantages and limitations of fertigation were explained by them. The precautions to be taken were also enlisted by them. They reviewed hereunder response of different crops to fertigation in terms of yield, use efficiency of water and nutrients etc. and based on this they inferred fertigation was not an alternate way but the need of the hour and the best way to realize the potential yield with highest fertilizer and water efficiency and with minimum pollution with more control over factors of productivity.

Li *et al.* (2016) worked on hydraulic performance of differential pressure tanks for fertigation. They conducted Laboratory experiments to evaluate the effects of design and operation parameters on hydraulic performances of differential pressure tanks. They tested three tank volumes of 10, 30, and 65 L with respective injection orifice sizes of 10, 21.5, and 23.5 mm. In the experiments, the quantities of fertilizer applied were varied from 2 to 26 kg. Injection rate and variation of fertilizer concentration released from a tank with time were measured at several pressure differential heads ranging from 0.05 to 0.30 MPa. They inferred that the injection flow rate increased with increasing injection orifice size. The injection flow rate and pressure differential relationship can be represented by a power function with a power value of 0.5. The released concentration from a tank depends on injection orifice size, tank volume, differential pressure head, and quantity of fertilizer applied, decreasing exponentially with time. They found that the variation pattern of the released concentration was highly controlled by the injection orifice size and tank volume. They proved injection profiles can be altered by varying orifice size, tank volume, and differential pressure head.

Manzano *et al.* (2017) characterized and selected method of Venturi injectors for pressurized irrigation. They said venturi-type chemigation injectors did not require electric power and are cheap to operate. However, they also generated considerable energy losses which affect the pressure in the system. They observed correct characterization of these systems required pressures to be correctly set at the inlet, injector and outlet points in relation to main and injected solution flows. They said these analytical relationships, as described in the International Organization for Standardization's standard ISO 15873:2002, obtained theoretically, although it was recommended that the manufacturer determined the real behavior of the injector by operational tests. Based on ISO15873:2002, analytic ratios were proposed by them for injected flow, main flow range and injector operating pressures for the complete characterization of Venturi injectors. A method of commercial selection or Venturi injector design (selection abacuses) was also proposed by them which supported by the analytic, theoretical or experimental formulation. They felt for this, exact information of the irrigation subunits and the producer's fertilization program was required.

Yadav et al. (2017) reported fertigation was an efficient technique for achieving high nutrient use efficiency in crop production system. They explained, based on the crop, soil type and management practices fertigation methods has classified into two groups viz. quantitative dosing and proportional dosing. It was an efficient method of applying fertilizers, in which the irrigation system is used as the carrier and distributor of the nutrients to the crop. Fertigation system was useful in achieving higher input use efficiency, crop yield as well as net returns to the farmer. They stated different fertilizers and fertigation devices used widely in the market. They explained working principle of venturi injector and fertigation tank. Constrain regarding cost and operation were also explained by them.

Imas (2018) studied recent techniques in Fertigation of Horticultural Crops in Israel. Israel is a small country with a total land area of 21,000 km^2, from which 20% is arable land. More than half of the area of Israel has an arid to semi-arid climate.

Near half of the cultivable area (200 hectares) must be irrigated due to the lack of rain and other water resources. Approximately 80% of the irrigated area in Israel uses the method of "fertigation" that combines the application of irrigation water with fertilizers. The aim was to change them by closed systems in which the farmer must collect the leached solution and reuse it thus avoiding contamination. For proper yield he worked to capitalize on fertigation benefits, particular care should be taken in selecting fertilizers and injection equipment as well in the management and maintenance of the system back to contents by using different injection type and method of application of fertilizer. From their study it can be concluded that pump injection is accurate for fertigation but have complex structure and high cost.

Sr no.	Year	Name	Location of research	Devices or methods used	Remark
1	2006	Badr *et al.*	Cairo University	Hydraulic injection pump, venturi device, pressure differential tank and electrical centrifugal pump	It is better to use the hydraulic pump. But it is costly.
2	2009	Fares[1] *et al.*	University of Hawai'i, Manoa	Venturi device	Provided information of components of fertigation system
3	2009	Fare[2] *et al.*	University of Hawai'i, Manoa	Venturi injector device	Chemigation management and back flow prevention information is provided.
4	2013	Cetin *et al.*	Dicle university, Diyarbarkir, turkey	fertigation tank, venturi system and hydraulic pump	venturi injector have good efficiency with low cost
5	2016	Sureshkumar *et al.*	Kerala Agricultural University, Thrissur		Provided information regarding fertigation.
6	2016	Li *et al.*	Institute of Water Resources and Hydropower Research,	Fertigation tank	Injection rate depends on orifice size, tank capacity, and differential pressure head. Difference in concentration of fertilizers occurs

			China		
7	2017	Manzano *et al.*	India	Venturi injector	Venturi injector did not require external power, it is robust and cheap to run.
8	2017	Yadav *et al.*	National Dairy Research Institute, Karnal	Venturi injector and fertigation tank	Venturi injector have good performance compared to fertigation tank.
9	2018	Imas	Israel	Fertigation tank, venturi injector injection pump	Pump injection is accurate for fertigation but have complex structure and high cost.

Critique of the reviews:

In this section of survey and study of different fertigation devices and technologies available in the market some review were analyzed. It revealed that many scientist had surveyed and studied the fertigation system which were venturi injector, fertigation tank, and injection pump. They noted down working of different devices. From these review some limitation on 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 fertigation system, to maintain the proper fertigation rate, which will be resulted in enhancing the productivity and quality of crop too. Secondly, to overcome with high cost of the system and to make system user friendly the experiment entitled, “Design and Development of Cost Effective Device for Fertigation” is proposed.

2.2 Design and development of different fertigation devices:

It was necessary to know the parameter which was considered while designing the fertigation devices. The work done by the earlier scientists on designing of device of fertigation is described in this section

Huang (2009) carried CFD simulation to the flow field of venturi injector. He explained venturi injector was widely used in fertigation system due to its obvious advantages such as cheap and robust system without mobile pieces, simple structure, convenient to operation, stable performance, needless of external energy for operation etc. He observed at present, the hydraulic parameters such as suction capacity (injection rate) for the most of the Venturi injectors produced domestically were not very desirable. In this paper, CFD (Computational Fluid Dynamics) method was used by them to simulate the inner flow field of the Venturi injectors and the relationships among the structure parameters (i.e., throat length L, throat diameter D, and slot diameter Da) and suction capacity q. He analyzed the optimal structure sizes of the Venturi injector. He concluded that keeping other parameters unchanged, the suction capacity of Venturi injector increases with the decrease of throat diameter, or the decrease of throat length, or increase of the slot diameter, or increase of the inlet water pressure. It also decreases with the slot position to the right. He found results of Full Factors Experiments that the most obvious affected factor to the suction capacity was the throat diameter.

Baylar *et al.* (2009) analyzed effect of air inlet hole diameter of venturi tube on air injection rate. They observed venturi tube allows air bubbles to be inserted into flowing water from air inlet holes and so increases oxygen levels in the water. They conducted a series of experiments on venturi tubes to investigate the effect of air inlet hole diameter on air injection. They observed from the results that air inlet hole diameter on venturi tube played a significant role in air injection and there was an optimal diameter that maximizes air injection. Moreover, a multiple non-linear regression equation was obtained for venturi tubes relating air flow and water flow to Reynolds number, inlet diameter and air inlet hole diameter.

Limjuco *et al.* (2012) demonstrated model of low-cost venturi meter for understanding Bernoulli's equation. They intended to concretize Bernoulli's principle through a low-cost Venturi meter designed and constructed by them. Specifically, they aimed to improvise a device that can measure flow speeds of water both in the wide and narrow portions of a horizontal piping system for which the pressure difference was provided by a differential height revealed in the attached manometer. A mechanism which regulates volume flow rate of liquid was attached to Venturi meter to generate several trials required to establish accuracy of setup in demonstrating Bernoulli's principle. This investigation about improvisation of apparatus required experimental development method especially in assembling various components which included PVC pipe, aluminum pipe, manometer, DC pump, variable flow controller, and a plastic container as water reservoir. To determine the accuracy of the instrument, nine trials--that was three each for the three adjusted flow rates, were performed by them. They revealed that the improvised

Venturi meter can concretize Bernoulli's principle. Through this experiment they came across contraction in the size of inlet pipe causes the venturi effect.

Sun *et al.* (2012) studied the eff ects of Venturi structural parameters on its hydraulic performance, which provided theoretical basis for the design of Venturi injector. They studied method of computational fluid dynamics (CFD) , based on the an inlet diameter of 50mm, the eff ects of the structural parameters (such as throat taper, throat contraction ratio, and throat length) on their hydraulic performance (such as outlet faceted average velocity, minimum pressure, and critical pressure) under diff erent inlet pressures and pressure diff erences between inlet and outlet. They observed power function relationship existed between the mean velocity in outlet section and pressure diff erence, with an approximate flow stance index of 0.53. They inferred minimum pressure occurred in the throat inlet wall and there was a line a relationship between the minimum pressure and the pressure diff erence at the inlet and outlet. They observed throat contraction ratio was the main factor on the eff ect of Venturi injector performance, which was positively correlated with outlet velocity, negatively to critical pressure, the minimal in-tube pressure, coeffi cient of local head loss, and fertilizer absorption ratio. They said for designing Venturi injector, contraction ratio should be reasonably selected according to the coeffi cient of local head loss and fertilizer absorption ratio. They observed results which showed a negative relationship between coeffi cient of local head loss, absorption fertilizer ratio, and throat contraction ratio. So it was strongly recommended that when designing Venturi injector, contraction ratio should be reasonably selected according to the coeffi cient of local head loss and absorption fertilizer ratio.

Cetin *et al.* (2013) studied application techniques of fertigation. They used fertigation tank, venturi system and hydraulic pump. All techniques for incorporating a chemical with the irrigation water create a specific level of chemical concentration during irrigation. They classified various techniques into three main groups. These were gradual decrease of chemical concentration, constant level of chemical concentration and intermittent chemical concentration. They explained methods of fertilizer application viz. quantitative and proportional. They studied application method like Continuous application, three-stage application, proportional application, quantitative application. They gave information of fertigation tank, venturi system and hydraulic pump in this study.

Sanghani *et al*. (2016) studied the effect of Geometrical Parameters of Venturimeter on Pressure Drop. They used venturi-meter to measure the volumetric flow rate of fluids. Certain amount of pressure drop occurred in pipeline due to the reduction in flow passage in these types of flow meters. They said design of the venturi-meter depends on the minimum pressure drop. This pressure drop depends on various geometrical parameters of flow meters and properties of the fluid. They used Computational Fluid Dynamics (CFD) to investigate the effect of different geometrical parameters like convergent cone angle, divergent cone angle, diameter ratio and throat length on pressure drop in Venturimeter. They had checked effect of each parameter by varying one parameter and keeping three parameters constant at a time. They found that pressure drop fluctuates with increase in convergent cone angle, divergent cone angle and throat length while reduces with increase in diameter ratio by simulation ratio.

Degenhardt *et al*. (2016) reported the first factorial design of a micro Venturi injector completed by a simulative investigation of the device (Micro-Venturi injector: design, experimental and simulative examination). They have shown comprehensive correlation between the point of the maximum vacuum pressure generated by the Venturi nozzle and the variation of the inlet pressure. The device reported by the researcher enables a new solution for robust low-pressure generation in parallel fluidic channels. Their aim was to investigate the impact of the geometrical dimensions of the constriction on the maximum vacuum pressure at the suction inlet. They observed that the divergent angle has the greatest influence on the suction pressure. The experimental results presented in their research showed that a vacuum pressure was generated along the entire range of applied inlet pressures. In contrast, the results by their experiments showed that the vacuum pressure collapses when the inlet pressure rises above a threshold inlet pressure. They observed that the location of the minimum pressure was not fixed, but it moved with changing inlet pressure.

Scheaua (2016) encountered theoretical approaches regarding the venturi effect. In fluid mechanics there were situations when the fluid flow was carried out inside pipelines with different values of the main flow section. Based on their research they demonstrated that when the fluid passes from a larger to a smaller section an increase in flow velocity was obtained together with a decrease of fluid static pressure. This phenomenon it was known as the venturi effect. This particular effect was based on both the fluid continuity principle, but also on the principle of conservation of mechanical energy, or Bernoulli's principle. This principle showed that inside a specific flow region, a decrease in static pressure appears when it was achieved an increase in fluid velocity. They presented the theoretical foundations regarding fluid flow inside a special model called the venturi tube where the effect can be emphasized.

Khound *et al.* (2017) analyzed influence of throat length and flow parameter on a venturi as an Aerator. They stated that venturi aeration has an effective method of aeration, highly efficient, cost effective, require less than 20% pressure difference to initiate suction to evaluate the result they calculated SOTR and SAE and compared for analyzing their performance. The study involved selection of 5 different throat length each having multiple hole of 1 mm this distance from start of the throat was characterized as effective distance(ED). They observed venturi performs best when ED was less. Increasing throat value beyond certain value causes negative effect on SORT and SAE.

Yadav *et al.* (2019) worked on designed characteristics of venturi aeration system. The crucial phenomenon of air and water mixing together was called aeration. They said venturi aeration was mainly responsible to transfer air directly through the atmosphere into the flowing water attribute to its simplicity and reliability. They used water tank of 1000 litres capacity having dimensions 100 × 100 × 100 cm^3 to conduct the experiments for aeration for the purpose of studying the characteristics of venturi aeration system design. They used three section inlet, outlet and constricted where constriction in section is responsible for transfer of air into water they interpreted. On the basis of dimensional analysis, non-dimensional numbers associated with geometric, dynamic and process parameters were analysed by them. The non-dimensional geometric parameters like throat length (tl), hole distance from beginning of throat (hd), diameter (th) were optimized and additionally conducted at constant flow rate. They concluded that venturi aeration can be considered as a precise mechanism through which air is arrived into the constricted section and then towards the outlet section without any exertion. The diverging section is more responsible to create solid interaction between air entrainment and turbulent flow.

Li *et al.* (2020) did numerical and experimental study on the internal flow of the venturi injector. They conducted appropriate numerical simulation methods for venturi injectors, including the investigation of the hydraulic performance, mixing process, and the flowing law of the two internal fluids, simulations and experiments. They revealed that the cavitation model has good agreement with the experiment. They inferred that the cavitation model can exactly predict the hydraulic performance of a venturi injector. In addition, they said cavitation was a crucial factor affecting the hydraulic performance of a venturi injector. The cavitation ensured the stability of the fertilizer absorption of the venturi injector and realized the precise control of fertilization by the venturi injector, although it affected the flow stability and causes energy loss. They found that the mixing chamber and throat are the main areas of energy loss. Furthermore, the suction flow and the flow ratio increase as the pressure difference increases.

Sr No.	Year	Name	Location of research	Devices or methods used	Remark
1	2009	Haung *et al.*	Beijing, China	Venturi injector	Decreasing size of throat diameter increases the suction rate.
2	2009	Baylar *et al*.	Firat University, Elazig, Turkey.	Venturi tube	Air inlet hole diameter on venturi tube played a significant role in air injection
3	2012	Limjuco *et al.*	China	Venturi meter device	Contraction in the size of inlet pipe causes the venturi effect.
4	2012	Sun *et al.*	University of Hawai'i, Manoa	Venturi injector device	They observed throat contraction ratio was the main factor on the eﬀ ect of Venturi injector performance
5	2013	Cetin *et al.*	Dicle university, Diyarbarkir, turkey	fertigation tank, venturi system and hydraulic	venturi injector have good efficiency with low cost

				pump	
6	2016	Sanghani *et al*.	S.T.B.S. College of Diploma Engineering, Surat, India	Venturi injector	Pressure drop fluctuates with increase in convergent cone angle, divergent cone angle and throat length while reduces with increase in diameter ratio.
7	2016	Degenhardt *et al.*	Germany	Venturi injector	Divergent angle has the greatest influence on the suction pressure and the vacuum pressure collapses when the inlet pressure rises above a threshold inlet pressure.
8	2016	Scheaua	University of Galaţ i	Venturi injector	When the fluid passes from a larger to a smaller section an increase in flow velocity and a decrease in static pressure appears when it was achieved an increase in fluid velocity
9	2017	Khound *et al.*	Triguna Sen School of Technology, Silchar, Assam, India	Venturi injector	Venturi performs best when effective distance of throat was less.
10	2019	Yadav *et al.*	Assam University Silchar, Assam - 788011, India	Venturi injector	The diverging section is more responsible to create solid interaction between air entrainment and turbulent flow.
11	2020	Li *et al*	Jiangsu University, Zhenjiang China	Venturi injector	The suction flow and the flow ratio increase as the pressure difference increases.

Critique of the reviews:

In this section of design and development of device for fertigation some review were studied. It revealed that many scientist had worked on designing the fertigation device based on differential pressure, flow rate, velocity of flow, convergent and divergent angle, throat length and diameter, suction pipe diameter and contraction ratio. Designing of fertigation tank and injector pump is complex procedure. The material required for its designing is not easily available local market and it is expensive too. Comparing these two devices with venturi injector, venturi have less complexity in construction but same material is not available. Most of researcher had work on the convergent and divergent angle of device but after certain differential pressure back flow started, and it has restriction of working pressure. Some review revealed that contraction ratio of throat plays a vital role in designing the venturi injector but it also have flaws of working pressure and construction superiority. And its construction cost is becoming high considering all the fabrication process and installation accessories. Considering above fact and research conducted to date, it felt necessary to surmount limitation of the fertigation system, to maintain the proper fertigation rate, which will be resulted in enhancing the productivity and quality of crop too. Secondly, to overcome with high cost of the system and to make system user friendly the experiment entitled, "Design and Development of Cost Effective Device for Fertigation" is proposed.

2.3 Performance evaluation of fertigation systems:

It was necessary to know performance of fertigation device for developing the designed fertigation device. The work done by the earlier scientists on fertigation devices was described in this section.

Bracy *et al.* (2003) tested fertigation uniformity affected by injector type. They found difficulty to determine the fertigation uniformity when it was applied by using drip irrigation. They compared (venturi, pump, and proportional) in a greenhouse experiment with a continuous-injecting experimental plot injector for fertilizer distribution uniformity in a drip irrigation system. In a field experiment they evaluated injection rate and solution volume. Injection rate had a significant effect on fertilizer distribution uniformity. They obtained better fertilizer distribution in the greenhouse experiment with venturi and proportional injectors. In the field, better distribution was obtained with the 0.06 l/s positive displacement pump than with 0.19 l/s pump. Injection times were longer with these injectors than with the other treatments, with the exception of the continuous injector. Injectors tested in this experiment gave uniform fertilizer distribution when the injector was properly sized with the water flow rate of the system. In field situations, they encountered problem in the greenhouse with injectors not being properly sized with the water flow rates of the system is not a concern because flow rate in a field would be expected to be 10 to 50 times greater than in the greenhouse experiment.

Li *et al.* (2006) derived hydraulic performance of differential pressure tanks for fertigation. They conducted laboratory experiments to evaluate the effects of design and operation parameters on hydraulic performances of differential pressure tanks. They tested three tank volumes of 10, 30, and 65 L with respective injection orifice sizes of 10, 21.5, and 23.5 mm. They revealed that the injection flow rate increased with increasing injection orifice size. The injection flow rate and pressure differential relationship can be represented by a power function with a power value of 0.5. The released concentration from a tank depends on injection orifice size, tank volume, differential pressure head, and quantity of fertilizer applied, decreasing exponentially with time. They found that the variation pattern of the released concentration was highly controlled by the injection orifice size and tank volume. They concluded injection profiles can be altered by varying orifice size, tank volume, and differential pressure head.

Li *et al.* (2007) studied field evaluation of fertigation uniformity as affected by injector type and manufacturing variability of emitters. They conducted field experiments to evaluate effects of injector types and emitters on fertigation uniformity by simultaneously measuring the distribution of water application, solution concentration and fertilizer applied within a subunit of micro irrigation system. They used three device injectors, water driven piston proportional pump, a venture device and a differential pressure tank were evaluated with three emitters. They found result which indicated that uniformity of water application was mainly dependent on emitter type. The uniformity of solution concentration was dependent on injection methods. In fertigation tank they found the continuous dilution of the solution and decrease in injection rate compared to venturi injector and pump. So they recommended to use an injector that can inject fertilizers in a constant rate to obtain uniform fertilizer distribution.

Baylar *et al.* (2009) analyzed effect of air inlet hole diameter of venturi tube on air injection rate. They said venturi tube allows air bubbles to be inserted into flowing water from air inlet holes and so increases oxygen levels in the water. They conducted a series of experiments on venturi tubes to investigate the effect of air inlet hole diameter on air injection. They observed from the results that air inlet hole diameter on venturi tube played a significant role in air injection and there was an optimal diameter that maximizes air injection. Moreover, a multiple non-linear regression equation was obtained for venturi tubes relating air flow and water flow to Reynolds number, inlet diameter and air inlet hole diameter.

Chavan *et al.* (2009) studied the hydraulic performance of manually operated drip irrigation system. They conducted the field experiment to evaluate the performance of manually operated drip irrigation system for different types of emitters. They used three different types of emitter's *viz*. 2 lph, 4 lph and 8 lph and were fitted on three laterals each of 10 m length and the operating pressures 0.4 to 1.4 kg/cm^2. They installed the experimental set up for determination of field emission uniformity. The result of their study showed that the system performed better in the range of 0.6 to 1.0 kg/cm^2 with highest emission uniformity. They state that the manually operated system thus can be used for small farms.

Yan *et al.* (2012) inferred effect of structural optimization on performance of Venturi injector. They said venturi injector is one of the main fertilization devices widely used in small and medium-sized pipe irrigation systems. They observed the pressure loss produced by it during fertilizer injection decreases fertilization quality and irrigation uniformity. The structural optimization of the Venturi injector was carried out using orthogonal experimental design and CFD technology. An injector sample with the optimal combination of structural parameters and the highest injection efficiency was processed to test the performance of the injectors before and after optimization. They concluded that injection rate, the maximum injection rate, the flow ratio of the injection rate to the outlet flow rate and other performance parameters were significantly improved while the critical pressure differential was obviously reduced, which indicated that the range of working pressure of the injector was remarkably expanded. They concluded that inlet pressure and pressure differential between the inlet and outlet were the main factors affected the injection rate. They observed performance of Venturi injector was significantly affected by the structural parameters. They found that venturi injector had a remarkable performance improvement after optimization, which also verified the validity and reliability of structural optimization design and numerical simulation.

Mukesh *et al.* (2012) conducted experiments on the commercially available venturi for injection rate under the range of operating pressures from 1.0 to 2.0 kg/cm^2 using normal irrigation water and fertilizer solution. Maximum injection rate of the venturi with irrigation water was 106.4 l/h at operating pressure of 2.0 kg/cm^2.

Maximum injection rate (105.8 l/h), when urea fertilizer dissolved in irrigation water in the ratio of 0.25:1 (urea: water) was at the upstream and downstream pressure of 2.0 kg/cm^2 and 0.1 kg/cm^2, respectively. However, for muriate of potash (MOP) dissolved in irrigation water in the ratio of 1:1 (MOP : water), minimum injection rate of venturi was 1.44 l/h at upstream pressure of 1.6 kg/cm^2 and downstream pressure of 0.5 kg/cm^2. Injection rate was observed to be inversely proportional to the concentration of the fertilizer solution.

Mohammed (2013) studied the evaluation of the hydraulic performance of drip irrigation system with multi cases. He conducted experiment at College of Engineering, University of Babylon. He studied the improvement of emission uniformity of emitters by using new system layouts instead of the traditional system. The first proposed system layout was for to improve the hydraulic performance by improving the pressure of distribution in the system by connecting the ends of the laterals together in the subunit. For further improvement in the study, a carrier (close pipe convey the water) near the source to the lateral ends has been added to the looped network to represent the second proposed system (looped with carrier network). During study he have found that hydraulic performance in the proposed (looped) network was better than the traditional network, and there was an improvement on the uniformity in the proposed (looped) network (11.38 per cent to 15 per cent). He revealed that the mean relative percentage improvement in the emission uniformity for looped with carrier network as compared with looped network was 8.35 per cent to 9.02 per cent.

Nadiya *et al.* (2013) reported that the suction rate and motive flow rate was found to vary directly with respect to the pressure drop between the inlet and outlet of the fertigation equipment. At 0.8 kg/cm^2pressure drop, the corresponding suction rate for venturi injector and dosmatic fertigation unit was observed as 0.23 l /min and 0.163 l /min. Venturi injector can be used only if the discharge rate was above 14.6 l/min. Dosmatic fertigation unit and fertilizer tank can be used if the discharge rate was above 1.1 l/min and 6.5 l/min.

Bhangare et al. (2015) evaluated the performance of venturi injector at different pressure combinations maintained at upstream and downstream side of the venturi injector. They selected different inlet pressures of 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 kg/cm^2 with different outlet pressure combinations of 0.1, 0.3 and 0.5 kg/cm^2 at the outlet of the venturi injector. Injection rate and injection efficiency calculated by them for different varying inlet and outlet pressure combinations using relationship suggested by manufacturer of the venturi injector. The maximum injection rate in case of venturi was achieved at inlet pressure of l.8 kg/cm^2 and outlet pressure of 0.1 kg/cm^2 with pressure differential of 1.7 kg/cm^2. Injection efficiency of venturi was observed maximum at 95 per cent at 2.0 kg/cm^2 inlet pressure and 0.1 kg/cm^2 outlet pressure followed by 94.4 per cent at 1.8 kg kg/cm^2 inlet pressure and 0.1 kg/cm^2 outlet pressure and 94 per cent at 1.6 kg/cm^2 inlet pressure and 0.1 kg/cm^2 outlet pressure.

Manisha *et al.* (2015) conducted a field experiment to analyze the hydraulic performance drip irrigation system on emitter discharge, coefficient of variation and emission uniformity. The objective of this study was to collect discharge rate at four different pressures are 1.5, 1.2, 0.9 and 0.7 kg/cm^2 to assess the hydraulic performance of drip irrigation system. A parameter which can be used as a measure of emitter flow variation caused by variation in manufacturing of the emitter was called the coefficient of manufacturing variation (Cv). The extent to which manufacturer was able to control variations depends not only upon manufacturing and materials quality control but also on emitter design. Emission uniformity of the system decides the uniformity distribution of discharge by each emitter or uniformity distribution of water to each crop. Result shows that the discharge flow rate of emitter is increased when the pressure was increased. The average emission uniformity coefficient observed at 1.5, 1.2, 0.9 and 0.7 kg/cm^2 pressure was 95.04, 95.95, 94.44 and 87.63 percent respectively for 4 l/h.

Dam *et al.* (2015) said aeration was the process by which the area of contact between water and air was increased, either by natural methods or by mechanical devices. They investigated pond aeration by two phase flow systems such as high head gated conduit flow systems and two phase pipe flow systems using venturi tubes. The dissolution of oxygen into the water results from the air suction downstream of high head gated conduit and venturi tube, and the rising air bubbles into pond. The concentration of dissolved oxygen is an important indicator of water quality because aquatic life lives on the dissolved oxygen in the water. Aeration can increase dissolved oxygen when levels become deficient. Hydraulic structures can significantly improve dissolved oxygen levels by creating turbulent conditions where small air bubbles are carried into the bulk of the flow. The present paper shows applications of venturi principle to water aeration systems. They achieved maximum DO concentration by using different rpm at different throat hole i.e 1 mm, 2 mm and 3 mm respectively. They found result which indicate that venturi aeration might contribute significantly to air entrainment and aeration efficiency. Therefore, venturi device can be used as highly effective aerator in aeration processes.

Scheaua (2016) achieved and analyzed three-dimensionally model of a venturi tube. The designed model can provide a solution to determine the fluid flow rate in a hydraulic or pneumatic installation using manometers mounted on different sections of the tube. They said based on different pressure values recorded can be determined the flow rate for the working fluid circulated through the respective section. Also by means of the venturi tube can be achieved the mixture of two different fluids due to the low pressure values recorded in the middle section where the fluid flow velocity values are high, and as a result a fluid (which may be a liquid or gas) may be absorbed and transported further into the hydraulic system circuit. This property of making the mixture of two different fluids was used in automobile carburetors where was realized the mixture of liquid fuel and air, or the development of the ejectors also using the mixture of the two fluids.

Madhu *et al.* (2016) worked on practical functioning of a venture-meter which allowed to utilize the flow characteristic of liquid through venturi-meter as a carrier for the mixing of liquid. To overcome problem related to the venture-meter, they had a solution in which the fertilizer is mixed with the water which was being distributed to the agriculture land with proper proportions and without any extra labor for that. It had less cost compared to the conventional method. There were many methods available to mix two fluids require external agency like human power, electric motor, for the purpose. Here they used venturi-meter. They done results and analysis in three ways namely, theoretical, experimental and CFD analysis. Venturi meter model used for various discharge and various fertilizers proportions by varying the valve that connects the venture meter and the main flow line. For less proportion of fertilizers the water flow through the venturi meter was less and it was achieved by opening valve. Similarly for more proportions of fertilizers the water flow through the venturi meter was more and it was achieved by closing the valve. For various discharges that was for different pump capacity the same venturi meter was used. From the experimentation, calculation and analysis they got successful results.

Bagatur *et al.* (2018) tested the system performance for different aerator configuration using venturi. A venturi tube or pipe part or device allows air bubbles to be inserted into flowing water from air inlet holes and so increases dissolved oxygen (DO) levels in water. Therefore, the aim the research was to evaluate system design and experimental results related to configuration of venturi tube in air vacuum and aeration process. Different aerator modules constructed using venturi tubes connected in either single or double in parallel (with single or double outlet pipe line) were evaluated and compared for their air flowrate, vacuum capacity, oxygen transfer coefficients (OTC), standard oxygen transfer rate (SOTR), and standard oxygenation efficiency (SOE) determined by clean water tests. The experimental results indicated that the double parallel design (connected to a single outlet pipe line) generally performed better than the single and double parallel (connected to a double outlet pipe line) design in terms of transferring oxygen into water. Three venturi aerator modules were evaluated, and the results indicated that better aeration efficiencies could be achieved by simply changing of venturi aerator arrangement. Among all the configurations studied, double aerators connected in parallel (connected to a single outlet pipe line) were able to bring more dissolved oxygen into water than the others.

Sobenko *et al.* (2019) carried functional test of venturi injector and dimensional analysis of injection rate of it. Their objectives of research were (1) to carry out functional tests of Venturi injectors following requirements stated by ISO 15873; and (2) to model the injection rate using dimensional analysis by the Buckingham Pi theorem. They submitted four models of Venturi injectors to functional tests using clean water as motive and injected fluid. A general model for predicting injection flow rate was proposed and validated. In their model, the injection flow rate depends on the fluid properties, operating hydraulic conditions and geometrical characteristics of the Venturi injector. Another model for estimating motive flow rate as a function of inlet pressure and differential pressure was adjusted and validated for each size of Venturi injector. Finally, an example of an application was presented by them. They selected Venturi injector size to fulfill the requirements of the application and the operating conditions were estimated using the proposed models. For all evaluated models, the injection flow rate was positive for ΔP/P in ratios higher than 20%, regardless of the inlet pressure. The injection flow rate was more sensitive to changes in the motive flow rate and the differential pressure when the Venturi injector was operated under low values of inlet pressure (i.e., 100 and 150 kPa). Generally, under inlet pressures higher than 200 kPa and for ΔP/Pin ratios higher than 60%, the injection flow rate was relatively constant.

Therrien *et al.* (2019) characterized the performance of venturi-based aeration devices for use in wastewater treatment in low-resource settings. They said low-cost aerators relying on the venturi principle to entrain air into flowing water have the notable advantage of contributing both to water mixing and oxygen transfer, making them attractive for wastewater treatment in low-resource settings. They aimed to characterize the performance of such aerators by describing the impact of different design characteristics, including water flow rate, the number of nozzles used, and the nozzle depth. They conducted test in a 200 L reactor with 2, 3 or 4 nozzles, at depths of 20, 40 or 60 cm, while circulating water through the aeration device at a rate of 400, 600 or 800 L/h. They obtained performance data which was compared to other types of aerators. Though venturi nozzles were found to be less efficient than other available technologies, it is proposed that using plunging rather than immersed venturi nozzles could increase performance to an attractive level for low-resource applications. They found that a high water flow rate combined with a low number of venturi nozzles operating in parallel generates larger oxygen volumetric transfer rates among the investigated aerator configurations.

Zheng *et al.* (2019) analyzed effect of liquid injection arrangements on injection flow rate of a laboratory-scale venturi scrubber. As the core device of a filtered containment venting system (FCVS), Venturi Scrubber is an efficient device to scrub the radioactive gases and aerosols before release into the atmosphere. They studied the injection flow rate of Venturi Scrubber in different injection arrangements. The liquid is injected horizontally and vertically to the throat at different radial position of (i) at the wall of throat, (ii) at the half radius of throat, and (iii) at the center of Venturi Scrubber throat with a nozzle of diameter 4mm. Throat gas velocities range from 0 to 190 m/s. A constant level water tank was installed to keep water level constant during the injection process. They obtained the result which showed that liquid injection modes significantly affect the injection performance. The arrangements of straight tube at center and elbow tube at center had larger injection flow rate among the others, and the injection flow rate increased as the throat gas velocity increased. The conventional wall opening (i.e., straight tube at the wall) injection method had the worst injection performance. They provided a valuable reference for the liquid injection arrangement and structural design of the Venturi Scrubber. As the throat gas velocity increases, the injection performance of the elbow tube at the center exceeds that of the straight tube at the center.

Sr no.	Year	Name	Location of research	Devices or methods used	Remark
1	2003	Barcy	Old Covington Hwy., Hammond, LA 70403.	venturi, pump, and proportional	In field the problem of injector size was encountered due to high flow rate.
2	2006	Li *et al.*	Beijing, China	Fertigation tank	The injection flow rate increased with increasing injection orifice size.
3	2007	Li *et al.*	China	water driven piston proportional pump, venture device and differential pressure tank	In fertigation tank they found the continuous dilution of the solution and decrease in injection rate compared to venturi injector and pump
4	2009	Baylar *et al*.	Turkey.	Venturi tube	Air inlet hole diameter on venturi tube played a significant role in air injection
5	2012	Yan *et al.*	China Agricultural University, Beijing, , China	Venturi injector	Pressure loss produced by venturi fertilizer injection decreases fertilization quality and irrigation uniformity. Inlet pressure and pressure differential between the inlet and outlet were the main factors affected the injection rate.
6	2012	Mukesh *et al.*	India	Venturi injector	Injection rate was observed to be inversely proportional to the concentration of the fertilizer solution.
7	2013	Nadiya et al.	India	Venturi injector, fertilizer tank	Particular range of discharge is required for proper fertigation through the devices.
8	2015	Bhangare et al.	India	Venturi injector	Suction rate is depends on inlet and outlet pressure through venturi injector.
9	2015	Dam *et al.*	India	Venturi injector	Venturi device can be used as highly effective aerator in aeration processes.
10	2016	Scheaua *et at.*	Bijing china	Venturi meter	Change in Pressure difference and velocity effects absorption

					of the liquid.
11	2016	Madhu *et al.*	India	Venturi meter	Proper opening and closing of valve is necessary for suction of the liquid.
12	2019	Sobenko et al.	Brasil	Venturi injector	The injection flow rate was more sensitive to changes in the motive flow rate and the differential pressure
13	2019	Therrien *et al.*	Canada	Venturi aerometer	They found that a high water flow rate combined with a low number of venturi nozzles operating in parallel generates larger oxygen volumetric transfer rates.
14	2019	Zheng et al	Bijing, China	Venturi injector	As the throat gas velocity increases, the injection performance at the center exceeds that of the straight tube at the center.

Critique of the reviews:

In this section of performance evaluation of different fertigation devices and technologies available in the market some review were studied. It revealed that many scientist had observed and recorded performance of different fertigation system which were venturi injector, fertigation tank, and injection pump. They noted down working principle of different devices. From these review some limitation on working, operating pressure, and costing was observed. In field the problem of venturi injector size was encountered due to high flow rate which causes back flow of liquid. In fertigation tank they found the continuous dilution of the solution and decrease in injection rate compared to venturi injector and pump. For operation of both devices particular range of discharge is required according the capacity and size of device. Hydraulic pump have high performance of fertigation compared to other devices but required great installation and operating skill. It also required external energy to operate. It's initial and maintenance cost is high. Considering above fact and experiments were conducted to date, it felt necessary to overcome limitation of the fertigation system, to maintain the proper fertigation rate, which will be resulted in enhancing the productivity and quality of crop too. Secondly, to overcome with high cost of the system and to make system user friendly the experiment entitled, “Design and Development of Cost Effective Device for Fertigation” is proposed.

2.4 Cost economics of fertigation devices

It was necessary to know cost required for designing and developing a fertigation devices. Cost estimation of fertigation devices is described in this section.

Huang (2009) carried CFD simulation to the flow field of venturi injector. They said venturi injector was widely used in fertigation system due to its obvious advantages such as cheap and robust system without mobile pieces, simple structure, convenient to operation, stable performance, needless of external energy for operation etc. They observed at present, the hydraulic parameters such as suction capacity (injection rate) for the most of the Venturi injectors produced domestically were not very desirable. In this paper, CFD (Computational Fluid Dynamics) method was used by them to simulate the inner flow field of the Venturi injectors and the relationships among the structure parameters (i.e., throat length L, throat diameter D, and slot diameter Da) and suction capacity q. They were analyzed the optimal structure sizes of the Venturi injector. They concluded that keeping other parameters unchanged, the suction capacity of Venturi injector increases with the decrease of throat diameter, or the decrease of throat length, or increase of the slot diameter, or increase of the inlet water pressure. It also decreases with the slot position to the right. They found results of Full Factors Experiments that the most obvious affected factor to the suction capacity was the throat diameter.

Sajeena (2015) reported that the cite some example system is comparatively costly and prone to clogging; hence it is necessary to introduce a low cost effective fertigation system with a performance meeting the design expectations. The fertigation tank was tested for its hydraulic performance in terms of uniformity coefficient in the field. The uniformity coefficient values of the system were found to range between 89 to 94 %. The system was also analyzed for the cost effectiveness and it was seen that the net returns obtained using the fabricated fertigation tank was greater than the venturi injector system.

Madhu *et al.* (2016) worked on practical functioning of a venture-meter which allowed to utilize the flow characteristic of liquid through venturi-meter as a carrier for the mixing of liquid. To overcome problem related to the venture-meter, they had a solution in which the fertilizer is mixed with the water which was being distributed to the agriculture land with proper proportions and without any extra labor for that. It had less cost compared to the conventional method. There were many methods available to mix two fluids require external agency like human power, electric motor, for the purpose. Here they used venturi-meter. The results and analysis were done in three ways namely, theoretical, experimental and CFD analysis. Venturi meter model used for various discharge and various fertilizers proportions by varying the valve that connects the venture meter and the main flow line. For less proportion of fertilizers the water flow through the venturi meter was less and it was achieved by opening valve. Similarly for more proportions of fertilizers the water flow through the venturi meter was more and it was achieved by closing the valve. For various discharges that was for different pump capacity the same venturi meter was used. From the experimentation, calculation and analysis they got favorable results.

Singh *et al.* (2017)[1] compared the economics of cost of production in chilli, for drip fertigation and conventional fertigation. Though the initial capital investment was high in drip irrigation system, the cumulative benefit would be greater and considering the longer life of the system. They designed experiment for the RBD with four main treatments with five replications. The four main treatments T1, T2, T3 and T4 were with fertilizer injection pump, venturi injector, fertilizer tank and control respectively. They analyzed benefit cost ratio of chilies by calculating the annual cost, cost of cultivation, seasonal total cost, yield produced, selling price, income from produce. Highest income from produce was recorded for the treatment T1 (Rs.157650.00), followed by the treatment T2 (Rs.150450.00) whereas T3 recorded (Rs.122850.00). The lowest net seasonal income was recorded for the treatment T4 (Rs.89100.00) was estimated by multiplying the total production of chilies value with prevailing market rate. They recorded benefit cost ratio of 1.49 for T1, followed by T2 (1.47) and for T3 (1.20). The least value of benefit cost ratio was recorded in T4 as 1.08. They recommended fertilizer injection pump on the basis of benefit cost ratio treatment. But initial capital investment is high.

Singh *et al.* (2017)[2] compared the economics of cost of production in maize, for drip fertigation and conventional fertigation. Though, the initial capital investment was high in drip irrigation system, the cumulative benefit would be greater and considering the longer life of the system. They designed experiment for the RBD with four main treatments with five replications. The four main treatments T1, T2, T3 and T4 were fertigated with fertilizer injection pump, venturi injector, fertilizer tank and control respectively. The benefit cost ratio of maize was analyzed, by calculating the annual cost, cost of cultivation, seasonal total cost, yield produced, selling price, income from produce. They recorded highest income from produce was, for the treatment T1 (Rs.109800.00), followed by the treatment T2 (Rs.100440.00), whereas T3 recorded (Rs.85320.00). The lowest net seasonal income was recorded, for the treatment T4 (Rs.57960.00) was estimated by multiplying the total production of maize value, with prevailing market rate. The study concluded that, for maize crop cultivation the total annual cost, for the drip fertigation system was Rs. 54351. The benefit cost ratio of 1.48 was recorded, for T1 followed by T2 (1.41) and for T3 (1.20). The least value of benefit cost ratio was recorded, in T4 as 1.15. They recommended fertilizer injection pump on the basis of benefit cost ratio treatment. But initial capital investment is high.

Sr no.	Year	Name	Location of research	Devices or methods used	Remark
1	2009	Huang	Bijing, china.	Venturi injector	Venturi injector was widely used in fertigation system as it is cheap and robust.
2	2015	Sajeena	India	Venturi injector, fertigation tank	The net returns obtained using the fabricated fertigation tank was greater than the venturi injector system.
3	2016	Madhu *et al.*	India	Venturi injector	Venturi injector had less cost compared to other conventional method.
4	2017	Singh[1] *et al.*	India	fertilizer injection pump, venturi injector, fertilizer tank	They recommended fertilizer injection pump on the basis of benefit cost ratio treatment. But initial capital investment is high.
5	2017	Singh[2] *et al.*	India	fertilizer injection pump, venturi injector, fertilizer tank	They recommended fertilizer injection pump on the basis of benefit cost ratio treatment. But initial capital investment is high.

Critique of the reviews:

In this section of cost economics of different fertigation devices and technologies available in the market some review were studied. It revealed that many scientist evaluated cost required for the fertigation device and its accessories. Cost required for fabrication is high for hydraulic injection pump but have high efficiency of fertigation. The material required for the fabrication is not easily available in the market. Similarly other devices like venturi injector and fertigation tank required high cost. To reduce the costing of material and fabrication it was need to used low cost durable and easily available material and to make system user friendly the experiment entitled, "Design and Development of Cost Effective Device for Fertigation" is proposed.

Overall Critique of the reviews:

From the review it is revealed that many scientists worked on fertigation system which were based on either injection rate, time, geometric parameters, operating pressure or climatological approach. Secondly they had reported some limitation on working, operating pressure, and costing. For operating these systems, required special skills. Considering above fact and research carried out up to date, it was felt necessary to the overcome limitation of the fertigation system /device, to maintain the proper fertigation rate, which will be resulted in enhancing the productivity and quality of crop too. Secondly, to overcome with high cost of the system and to make system user friendly the experiment entitled, "Design and Development of Cost Effective Device for Fertigation" was proposed.

III. MATERIALS AND METHODS

The experiment entitled, "Design and Development of Cost Effective Device for Fertigation" was undertaken at Instructional Farm and in 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 PVC pipes diameter and section, assembling, installation of drip laterals, etc. is described. In section methodology, survey and study of different available fertigation devices in market, design of fertigation device, and performance evaluation including cost analysis is described.

3.1 Study Area

The experiment was conducted during winter and summer season of 2019-20 on the Instructional Farm and laboratory of the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli.

3.2 Location, Climate and Weather Condition

The experiment was conducted at the Instructional Farm and laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. Geographically, the selected site is situated at 15^0 6' N to 20^0 22' N latitude and 72^0 39' E to 73^0 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 ^{0}C to 38.5 ^{0}C, respectively. The relative humidity ranges from 46 per cent to 99 per cent.

3.3 Survey and study of available fertigation devices in market

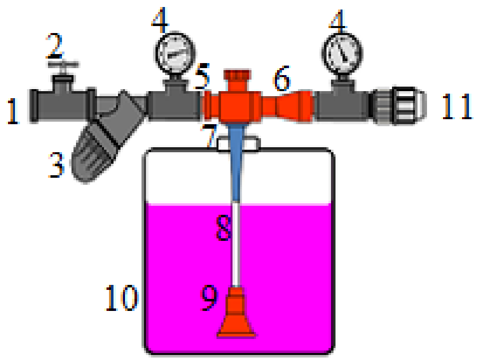
After reviewing the literature, it is revealed that there are different fertigation devices which are available in the market like venturi injector, fertigation tank, hydraulic injection pump, electric centrifugal pump, etc. Therefore, it was felt necessary to conduct the survey and then after study regarding what type of fertigation devices are available in the market, its prices, installation process, technical specification, working principle and utility in field, whether the spares of such type of fertigation devices are available in the local market or otherwise, its viability, merits and demerits, to enable, to design and development of the cost effective device for fertigation to overcome with the demerits of available devices etc. The survey and study of fertigation devices available in the market was undertaken and described as given below under different sections.

There are various fertigation devices available in the market which are as follows:

- Venturi Injector
- Fertilizer tank
- Hydraulic injection pump
- Electric centrifugal pump

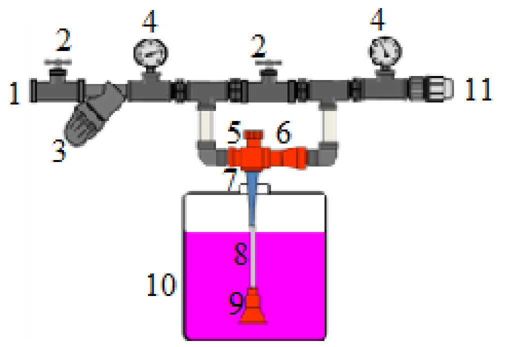
3.3.1 Venturi

This operates on venturi principle, where a flow constriction with specified entrance and exit condition on the pipeline creates a vacuum because of increased velocity of flow through constriction. This is very simple equipment. The partial vacuum is created in the system which allows suction of fertilizers in the irrigation system through venturi effect. The suction rate of venturi is 30-120 lit/hour. The Injector operates on the principle of vacuum suction created by an advanced Venturi complex. This implements the latest know-how in hydraulic technology and allows the injectors to operate at small pressure differentials. A vacuum is created as the water flows through a converging passage that gradually widens. Injection is activated at the injection inlet, when there is a pressure differential between the water entering the injectors and the water and fertilizers leaving to the irrigation system. This pressure differential can be between 15-75% according to the required injection rate (http://www.netafim.com/product-category/nutrigation). Venturi injectors can be easily connected to the irrigation system in two ways 1. In line: installed directly on the main line (typical for very low capacity systems) as shown in plate 3.1, 2. By-pass: installed as a by-pass from the main line as shown in plate 3.2. In this configuration, a manual or hydraulic pressure reducing valve is used for flow deviation through injector as shown in plate 3.3 and the complete schematic picture of venturi is shown in plate 3.4. (http://www.netafim.com/product-category/nutrigation).



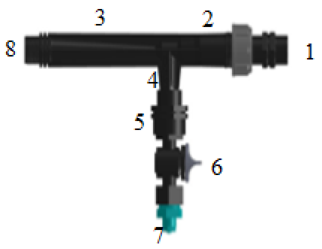
1. Inlet section 2. Control valve
3. Filter 4. Pressure gauge
5. Convergent section 6. Divergent section
7. Suction point 8. Suction tube
9. Strainer 10. Fertilizer tank
11. Outlet

Plate 3.1 A typical installation of venturi on mainline.



1. Inlet section 2. Control valve
3. Filter 4. Pressure gauge
5. Convergent section 6. Divergent section
7. Suction point 8. Suction tube
9. Strainer 10. Fertilizer tank
11. Outlet

Plate 3.2 Installation of venturi by using By-pass from the mainline.



1. Mainline flow part 2. Convergent part
3. Divergent part 4. Suction point
5. Check valve 6. Metering valve
7. Chemical flow 8. Outflow

Plate 3.3 Fitting of pressure regulating valve to the injector line

1. Mainline flow 2. Convergent section
3. Divergent section 4. Suction point
5. Outflow

Plate 3.4 A schematic picture of Venturi

A. Technical and other specifications:

a) **Material used for manufacture**: Engineering plastic

i. **Body:** Polypropylene (PP) with fiberglass fill, Reinforced Polypropylene (PP)

ii. **Internal components:** Polypropylene (PP) with fiberglass fill, Reinforced PP

iii. **Gasket:** DuPont Viton A

iv. **Spring:** Hastelloy C276

b) **Size:** Available in ¾", 1", 1¼", 1½" and 2" BSP inlet / outlet connection.
Any other size can be supplied as per advice and demand.

c) **Availability of spares:** Not available

d) **Skill manpower requirement:** Yes

B. Working principles and other implement features:

a) Vacuum is created as the water flows through a convergent passage that gradually widens

b) **Suction rate:** Ranging between 30 to 120 LPH

c) Operates at large differential pressure

d) Pressure differential can be between 15 -75 % according to the required injection rate.

e) **Fitting arrangement :** Inline and bypass

f) **Cost :** Approximate Rs.5000 /- and above

g) **Maintenance:** Frequent maintenance is required to suction portion

C. Merits:

- Does not require external force to operate.
- Its cost is relatively low compared to other fertigation devices
- Easily connected to computer system
- Excellent chemical resistance to most of the chemicals.

D. Demerits:

- Pressure loss in main irrigation line or a booster pump.
- Quantitative fertigation is difficult.
- Difficult to adjust and control valve to start the suction and suction rate
- Required skilled and experienced manpower
- Batch tank system
- Sometimes will have to face the problem of syphoning (reverse flow in fertilizers tank)
- The principle of operation includes a narrow valve causing a portion of the main line flow to be diverted through a batch tank.
- Automation is difficult.

3.3.2 Fertigation tank (Pressurized tank):

Fertigation tank is a cylindrical, epoxy coated, pressurized metal tank, resistant to the system's pressure, and connected as a bypass to the supply pipe of the head control. It operates by differential pressure created by a partially closed valve, placed on the pipeline between the inlet and the outlet of the tank. Part of the flow is diverted to the tank entering at the bottom. It mixes with the fertilizer solution and the dilution is ejected into the system. The dilution ratio and the rate of injection are not constant. The concentration of fertilizer is high at the beginning and very low at the end of the operation. However, this apparatus is still in service on a very small scale in some countries because of its low cost and easy manufacture. A pressure differential is created by throttling the water in the control head and diverting a fraction of a water through a tank containing the fertilizer solution. A gradient of 0.1 to 0.2 bar (1.02 to 2.04 kg/cm^2) is required to redirect an adequate stream of water through a connecting tube of 9-12 mm diameter. The pressurized tank is generally, made of corrosion resistant enamel coated or galvanized cast iron, stainless steel or fiberglass. This should withstand the network working pressure. The diverted water is mixed with solid soluble or liquid fertilizers in the pressure tank. Once the solid fertilizer had been fully dissolved, continuous dilution by water gradually decreases the concentration of the chemical solution.

Fertigation tank are available of 30, 60, 90, 120 and 160 litre of capacity and as shown in plate 3.5 and 3.6 as vertical and horizontal pressurized fertigation tank respectively.

A. Technical and other specification:

a) **Specifications:** The specification are shown in table No. 3.1

Table No. 3.1 Specification of fertilizer/ pressurized tank

Tank capacity(litres)	**Inlet/outlet connection(inches)**	**Height (mm)**	**Length(mm)**	**Gross weight(kg)**
30	¼”	830	285	22
60	¾”	815	500	33
90	¾”	1015	500	40
120	¾”	1120	500	48
160	¾”	1210	500	51

From Table No 3.1 it is observed that the capacity of tank in litre is ranging from 30 to 160 litre. The inlet and outlet is ranging from ¼’’ to ¾’’ and height is 830 to 1210 mm. the length is vary from 285 to 500 mm whereas its weight is shown in the range of 22 to 51 kg.

 **Components :** 1. Inlet hose 2. Outlet hose 3.Lid 4. Fertilizer tank 5. Flush valve **Plate 3.5 Vertical pressurized fertigation tank**	 **Components :** 1. Inlet hose 2. Outlet hose 3.Lid 4. Fertilizer tank 5. Flush valve **Plate 3.6 Horizontal pressurized fertigation tank**

b) **Materials used:** Mild steel, powder coated with more than 70 micron thick deep blue coloured epoxy polyester for both inside and outside for corrosion resistant, stainless steel and fibre grass

c) **Accessories :** Separate valves are provided at inlet and outlet for controlling injection rate

d) **Flush:** Drain port to flush the tank

e) **Maximum working pressure:** 10 kg/cm^2

f) **Fertigation:** The information in respect of type of fertilizers used is not available

g) **Application of water + fertilizer:** The nutrient solution is being provided through drip system which is attached to the 45 litre plastic tank

B. Working principle and other features:

a) Operates by differential pressure created by the partially closed valve.

b) **Area requirement:** Large area is required

c) **Required spares available in the market:** No

d) **Skill man power requirement:** Yes

e) **Pricing :** Approximate Rs.10000 /- (minimum and depending on the capacity)

e) **Maintenance:** regular maintenance is required.

C. Merits:

- Large capacity to store fertilizer
- Simple to use
- Wide dilution ratio can be attained without external source of energy

D. Demerits:

- Fertilizer solution concentration cannot be maintain.
- Requires specific skill to throttle the water in the control head and diverting a portion of water through a tank containing the fertilizer solution.
- Prior to each application, the tank has to be filled with fertilizers

3.3.3 Hydraulic injection pump:

The hydraulic motor contained in unit is powered by hydraulic pressure of the irrigation system. The unit is resistant to nearly all chemicals which are used in agricultural and horticultural crop. These are piston or diaphragm pump which are driven by water pressure. Injection rate is proportional to the flow of water in the system. It is as shown in plate 3.7

Components :

1. Inlet flow 2. Suction point
3. Suction tube 4. strainer
5. Outlet flow

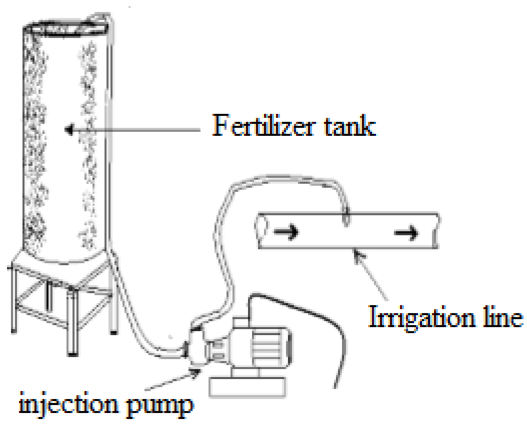


Plate 3.7 Hydrualic injection pump

A. Technical and other specifications:

a. **Materials used:** High grade engineering plastic. Parts in contact with chemicals are no corrosive to most chemicals. Seals-viton, nitrile rubber or polyurethane.
b. **Injection rate:** 10 to 320 lit/h.
c. **Working pressure:** 0.5 to 8 bar (0.51 to 8.16 kg/cm^2)
d. **Water consumption:** 3 times the quantity of fertilizers injected
e. **Gross weight:** 5 kg

B. Working principles and other important features:

a. Hydraulic motor is powered by hydraulic pressure of the irrigation system.
b. This is piston as diaphragm pump driven by water pressure.

C. Merits:

- Vast range in suction rate 10 to 320 LPH.
- Working with 0.5 to 8 bar (0.51 to 8.16 kg/cm^2).
- Light in weight

D. Demerits:

- Three times water consumption than fertilizers
- Costly than other devices.
- Spares are not easily available.

3.3.4 Electric centrifugal pump:

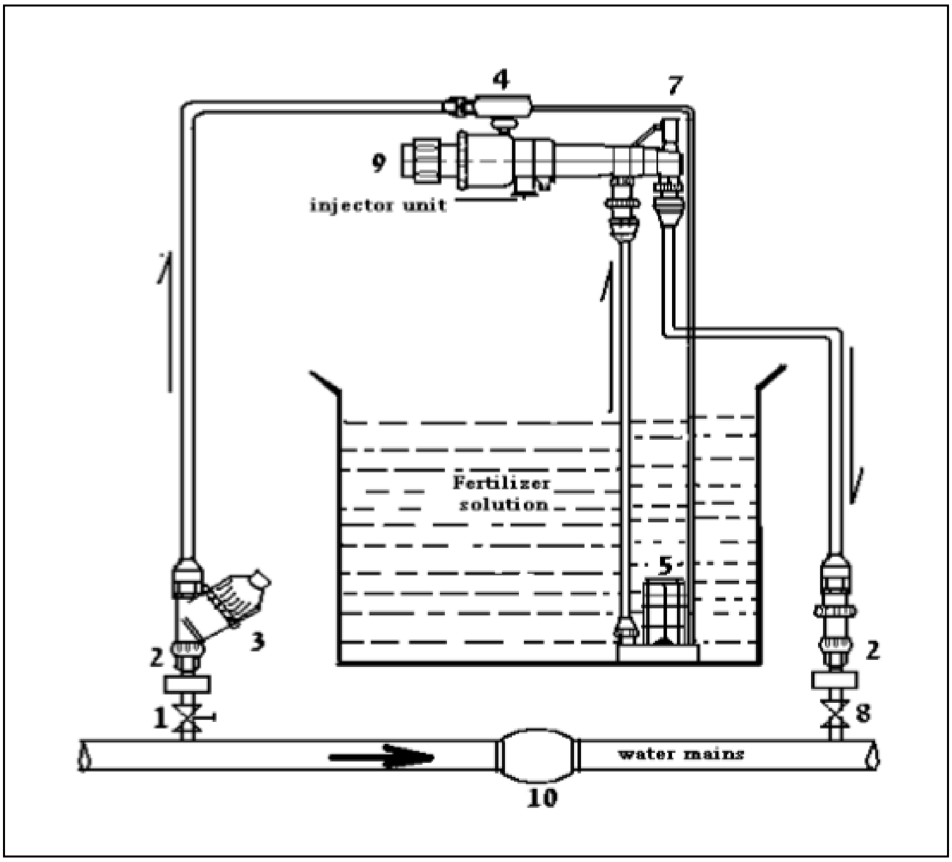
Electric pump are inexpensive and reliable. Operations cost are low. They can be readily integrated into automatic systems. A wide selection of pump is available from small low capacity to massive high capacity pump. The schematic plate is shown in plate 3.8

A. Technical and other specifications:

a. Materials used:

i. **Pump casing:** Cast iron
ii. **Rotor :** Aluminum Die cast
iii. **Motor body :** Aluminum extruded
iv. **Impeller:** Tensile brass

b. **Injection rate:** 10 to 320 lit/h.
c. **Power :** 0.5 to 1.5 hp
d. **Maximum pressure:** 5.5 bar (5.61 kg/cm^2)



1- Drive water hand valve
2- Union couple
3- Filter exhaust.
4- Automatic cut-out.
5- Suction head.
7-Air-release valve
8- Injection line hand valve.
9- Water exhaust.
10- Check valve (optional)

Plate 3.8 Electric centrifugal pump

B. Working principles and other important features:

a) Electrical centrifugal pump works on the principle of force vortex flow method.

b) It states that when quantum of liquid is rotated by an external torque, the rise in pressure head of rotating liquid takes place. In this high pressure head created which lifts the water high level.

C. Merits:

- Injection pump can be adjusted over a scope of different range to provide a continuous and uniform concentration of chemical in irrigation water.
- There is no pressure loss in system.
- The possibility to inject several tanks of nutrient stock solutions.
- Precise set up of the concentration.

- Consistent concentration and flow.
- The possibility of total automation of the system

D. Demerits:

- It is costly.
- Required skilled labour
- Complex in working
- External energy is required

3.3.5 Closure of survey and study of fertilization devices available in the, market:

The selection of devices are based on the cost of device, area to be irrigated and then after fertigation, crops to be taken and types of irrigation. i. Limitations of the existing fertigation devices are high initial cost, ii. Pressure drop, iii. Non-uniformity in distribution, iv. Requirement of skilled man power, v. Difficult to assemble and automation, vi. Difficult to maintain the uniform concentration of fertilizers and regulate the suction rate and requires continuous supervision over the amount of fertilizers in tank or its storage, vii. Sometimes installation becomes complicated and farmers finding difficulties to assemble it to their irrigation system. Viii. There is minimum further development in developing such type of fertigation devices and minimum or lack of adequate research.

Therefore, considering the above limitation there is scope to design and development of fertigation device which will i. cost effective, ii. Easy to operate, iii. Minimum fitting requirement, iv. Energy free and ready to fertigation, v. Minimum involvement of regulating valve to create pressure difference and to get high velocity, etc.

3.4 Design and development of device for fertigation:

After carrying out the exhausting survey for collecting the detailed technical information, working principles, merits and demerits of the available fertigation devices in the market and as farmers were being used and further critically studied the different fertigation devices it is revealed that, there is vast scope for design and development of cost effective fertigation device.

- **Design consideration**

For design, development and actual manufacturing the cost effective device following considerations were made;

i. The device should be low cost so that marginal farmer can afford the cost of that device for fertigation

ii. The material required for development and further manufacturing of device should be available in the local market so that cost will be minimum

iii. It should be easy to install and operated by farmer.

iv. No requirement of skilled manpower

v. It should operate at specific operating pressure to reduce pressure loss

vi. It should be user friendly.

vii. The spares should be easily available for its easy maintenance.

viii. The neatly designed and developed fertigation device should have wide range of application and adoption with affordable price.

3.4.1 Methodology:

The different approaches are considered for designing and development of user friendly device which is described in section 3.4. To design and development of cost effective fertigation device, the Bernoulli's principle, venturi effect, pressure and velocity relation at constricted/ throat portion, different operating pressure, different inlet pipes diameter are considered and accordingly the methodology is considered, tested and suggested in this section.

3.4.1.1. Bernoulli's Principle:

It is an idea of fluid dynamics. It says that as speed of the liquid increases, pressure decreases. So any change in a fluid speed must be matched by change in the pressure. Bernoulli in year 1738 to 1752 saw that while the fluid moved more quickly in the smaller point of the inlet the pressure become less.

Bernoulli's equation states that, "The sum of all forms of energy in a fluid flowing along an enclosed path is the source at any two points in that path(or streamline)", when cross sectional area of flow is reduced, it creates pressure difference between different areas of flow. It is formulation in the simplistic hypothesis of incompressible flow and fluid motion with negligible change in density as shown in equation No. 3.1

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = constant \qquad (3.1)$$

Where:

v : fluid velocity along the streamline (m/s)

g : acceleration of gravity on Earth (m^2/s)

p : pressure along the streamline (kg/cm^2)

z : Elevation of point above reference line (cm)

ρ : Density of the fluid at all point in the fluid (kg/m^3)

The Functioning scheme of velocity, pressure relation and formation of suction is shown in fig 3.1

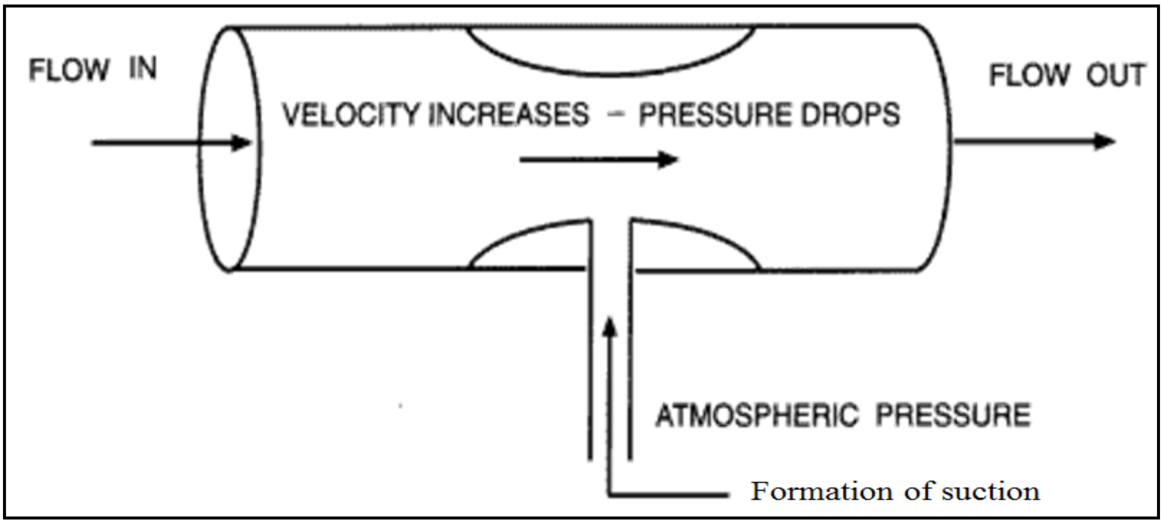


Fig 3.1 Functioning scheme of velocity, pressure relation and formation of suction

3.4.1.2 Venturi effect:

The venturi effect is the reduction in fluid pressure that results when fluid flows through constricted section of pipe. Venturi effect is about flowing of water from high pressure low velocity to low pressure high velocity. This effect is named after Giovanni Battista Venturi (1746-1822), an Italian physicist. The Venturimeter works on Bernoulli's principle/equation and continuity equation. When velocity increases pressure decreases and at the injection point vacuum is created so the suction of liquid starts.

Working principle of venturi injector is to create a pressure difference due to the presence of constriction in pipeline which accelerate the flow and create a suction effect, which is used by pump to suck the fertilizer solution into mainline**.**

Principle of venturi effect works on the following Bernoulli's equation as described below and discussed in equation 3.1, further gives the total energy lines which states that;

Total energy line = Pressure energy + kinetic energy + potential energy

Pressure energy + kinetic energy + potential energy = constant

$$\frac{v^2}{2} + gh + \frac{p}{\rho} = constant$$

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = constant$$

Where:

v : fluid velocity along the streamline (m/s)

g : acceleration of gravity on Earth (m^2/s)

p : pressure along the streamline (kg/cm^2)

z : Elevation of point above reference line (cm)

ρ : Density of the fluid at all point in the fluid (kg/m^3)

3.4.1.2.1 Concept of venturi:

The concept of venturi is illustrated by schematic diagram of venturi as shown in fig 3.2

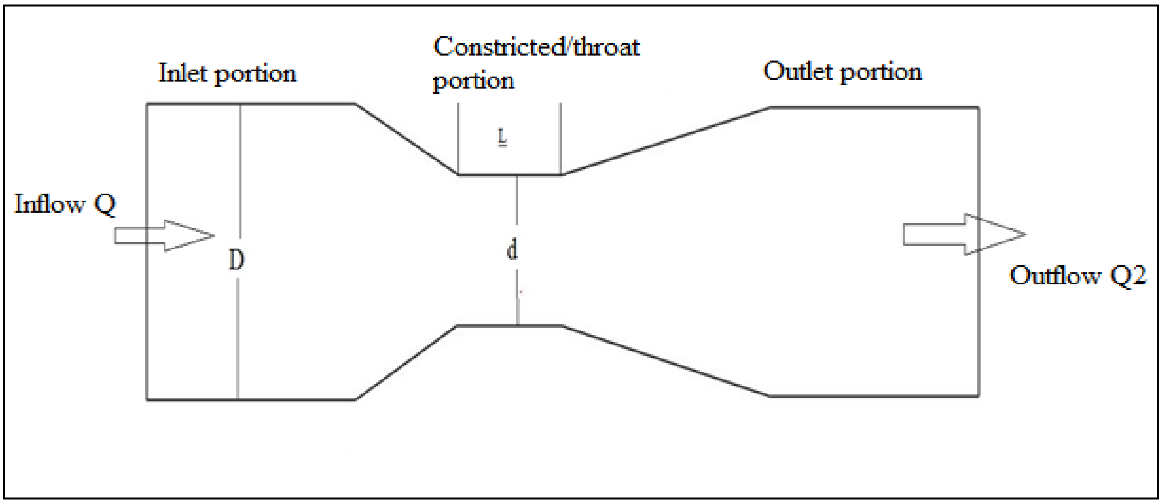


Fig 3.2 Schematic diagram of venturi

Where,

D1 = Diameter of inlet pipe (mm)

D2 = Diameter of outlet pipe (mm)

Q = Discharge of inflow (l/h)

Q2 = Discharge of out flow (l/h)

dt = Diameter of constricted portion or throat (mm)

L = length of throat (mm)

Diameter of constricted portion or throat (mm)

(dt) = length of constricted/throat portion (mm)

Bernoulli's equation which is considered as the base for design and development of cost effective fertigation device.

Where we have diameter pipe is D, diameter of throat d, p is operating pressure, v is velocity of flow of water, p_1 pressure at inlet portion, p_2 pressure at constricted/throat portion, v_1 velocity at inlet section, v_2 velocity at constricted portion from this we have the following Bernoulli's equation No. 3.2

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2 \qquad (3.2)$$

The pipe is horizontal

$$\therefore z_1 = z_2$$

$$\therefore \quad \frac{p_1}{\rho g}+\frac{v_1^2}{2g}=\frac{p_2}{\rho g}+\frac{v_2^2}{2g} \qquad (3.3)$$

Further it simplify as,

$$\therefore \quad \frac{p_1-p_2}{\rho g}=\frac{v_2^2-v_1^2}{2g}$$

$$h=\frac{p_1-p_2}{\rho g}$$

Where, h = Difference of pressure head at inlet section and constricted section (m)

So,

$$h=\frac{v_2^2-v_1^2}{2g} \qquad (3.4)$$

Modifying the equation 3.3 we will get,

$$v_2=\sqrt{\frac{2(p_1-p_2)}{\rho}+v_1^2} \qquad (3.5)$$

3.4.1.2.2 Continuity equation:

Continuity equation is actually mathematical statement of principle of conservation of mass. Continuity equation states that "if flow is steady, rate of increase of fluid mass enters within the region is equal to zero, then the rate at which the fluid mass enters the region is equal to the rate at which fluid mass leaves the region." This relation is generally used to derive the general equation of continuity.

So in other words, discharge through pipe is equal at every portion i.e. inlet, constricted and outlet portion and is as given by equation 3.6

$$\therefore\ q_1 = q_2 \tag{3.6}$$

As we know that,

q = a .v

Where, q = Discharge, m^3/s

a = cross sectional area, m^2

v = velocity m/s

$$\therefore\ a_1 v_1 = a_2 v_2 \tag{3.7}$$

As stated the device designed by using Bernoulli's as well as continuity equation which is described below.

Hence diameter of pipe is D, diameter of throat d, p is operating pressure, v is velocity of flow of water.

∴ The discharge is given by equation

$$q = av$$

Where

q = discharge, m^3/s

a = cross sectional area of pipe, m^2

v = velocity of flow of water, m/s

Hence, As per continuity equation,

$$\therefore\ q_1 = q_2 \quad \text{(From equation 3.6)}$$

$$\therefore\ a_1 v_1 = a_2 v_2 \quad \text{(From equation 3.7)}$$

We have,

$$\therefore\ v_1 = \frac{a_2 v_2}{a_1} \tag{3.8}$$

Equating Equation number 3.4 and 3.8 we can have the velocity at constricted portion

v_{2},

$$\therefore\ v_2 = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} \tag{3.9}$$

Where, h = Difference of pressure head at inlet section and constricted section (m)

Putting value of v_2 in equation 3.8

$$\therefore\ Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} \tag{3.10}$$

Above equation is termed as equation for theoretical discharge. Actual discharge will be less than the theoretical discharge.

We know that,

Actual discharge = constant (Cd) x theoretical discharge (Q_{th})

$$\therefore \quad Q_{Actual} = C_d . Q \tag{3.11}$$

$$\therefore \quad Q_{Actual} = C_d . \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} \tag{3.12}$$

So by using continuity equation it becomes possible to calculate value of actual discharge.

Where, Q = Discharge, m^3/s

C_d = coefficient of Venturimeter and its value is less than 1

h = Difference of pressure head at inlet section and constricted section (m)

3.4.1.3 Establishment of suction:

When cross-sectional area of flow is reduced it creates pressure difference between different areas of flow. As the pressure decreases velocity increases, which accelerates the flow and creates the vacuum due to which the fertilizer gets injected in flow this is refer as suction.

For achieving the suction, different sizes of pipes are used i.e. 63 mm and 50 mm which are then constricted to the different sizes i.e. 32 mm, 25 mm and 16 mm. These combinations are worked by using different operating pressure starting from 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2. The observation of injected fertilizer/suction are recorded with respect to time.

3.4.1.4 Working/operating principle is to be considered for design of device for fertigation:

Working/operating principle of venturi effect and Bernolli's theorem is to create a pressure difference due to the presence of constriction in pipeline which accelerate the flow (velocity of flow) and create a suction effect, which results in by suction the fertilizer solution into pipeline further distributed into the field**.**

For designing the cost effective fertigation device polyvinyl chloride (PVC) pipes of different diameter (Ø mm), PVC reducers of different diameters (Ø mm), and PVC elbow of different diameters (Ø mm), and ball valve are used. The reason of selecting PVC material for this device is due to the fact that it is much lighter, durable, easily available and having less cost than other material like G.I., M.S. and brass, etc. In addition to this PVC material is able to withstand the corrosive chemicals that are found in most common fertilizers. To fulfill the requirement of different sizes of devices are considered to determine the suction rate and suction of the pipe and constricted portion the suction is formed.

3.4.2 Design and development of device:

For design and development of cost effective fertigation device two different size (Ø mm) of PVC pipe, then constricted portion formed with the help of reducers and 16 number of operating pressure starting from 1 kg/cm^2 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2 were used to form the favorable suction at constricted portion

3.4.2.1 Selection of diameter of pipe for device:

Two diameter i.e. 63 mm and 50 mm are selected for design and development of pipe. As it was aimed to match this section with the existing pipeline being used by the farmer as the mainline for irrigating their fields.

- Pipe diameter – two
    - i. 63 mm Ø
    - ii. 50 mm Ø

3.4.2.2 Constricted portion:

The three constricted portion are considered and formed by using the reducers. The length of constricted portion is decided as suggested by C Herschel. Therefore the length of constricted/ throat is equal to diameter of constricted portion under consideration for each case.

A. For 63 mm pipe:
   - i. 63 X 32 mm Ø
   - ii. 63 X 25 mm Ø
   - iii. 63 X 16 mm Ø

B. For 50 mm pipe:
   - i. 50 X 32 mm Ø
   - ii. 50 X 25 mm Ø
   - iii. 50 X 16 mm Ø

3.4.2.3 Operating pressure = 16 number

To check the formulation of suction at constricted portion by using different sizes of pipe with different constricted portion 16 numbers of different operating pressure starting from 1 kg/ cm^2 to 2.5 kg/ cm^2 with an increment of 0.1 kg/ cm^2 were used. It was found that in normal course most of the micro irrigation system requires and operates may be at 1 kg/ cm^2 to 1.5 kg/ cm^2. However exceptionally it operates and required operating pressure of 1.5 kg/ cm^2 to 2.5 kg/ cm^2. That is the reason to select and consider vast range of operating pressure to match with the requirement of farmer's field. Again there are lot of chances to get available the fluctuating electrical energy which hampers the rpm of motor and pump finally results in variation in pressure on flowing fluid. Therefore an increment of 0.1 kg/cm^2 is considered for this study.

i.	1.0 kg/ cm^2	ix.	1.8 kg/ cm^2
ii.	1.1 kg/ cm^2	x.	1.9 kg/ cm^2
iii.	1.2 kg/ cm^2	xi.	2.0 kg/ cm^2
iv.	1.3 kg/ cm^2	xii.	2.1 kg/ cm^2
v.	1.4 kg/ cm^2	xiii.	2.2 kg/ cm^2
vi.	1.5 kg/ cm^2	xiv.	2.3 kg/ cm^2
vii.	1.6 kg/ cm^2	xv.	2.4 kg/ cm^2
viii.	1.7 kg/ cm^2	xvi.	2.5 kg/ cm^2

3.4.2.4 Total combination:

Total combinations = Two pipe diameter (2) X Constricted portion (3) X Operating pressure (16)

= 96 combinations

3.4.3 Material used, components, shape and size of the unit:

The different fertigation devices available in the market are surveyed and studied. The existing available devices have certain merits and demerits. Sometimes they have same operating/ working principles with different hydraulic parameters/ features while other devices under consideration have different operating/ working principle with different hydraulic parameters/ features. Based on the above observation some important design consideration are drawn and to be useful to fulfil the objectives. Therefore, for cost effective, easy to operate and with minimum pressure loss it is decided to design and develop such a fertigation device with 1. Pipes of different sizes, 2. PVC accessories of an appropriate size to reduce cost of fabrication, 3. Easy to operate, 4. Easy to manage and maintain, 5. Use different sizes of PVC pipes and accordingly the accessories, 6. Use of Bernoulli's Theorem and ventury effect and 7. Use of microtube of 6 mm outer diameter as suction pipe with strainer, etc.

3.4.3.1 Materials used for device of fertigation:

The different instruments and materials are used to design and development of the device for fertigation. The following materials are used for preparation of device:

3.4.3.1.1 PVC pipes

As per the objectives of the study i.e. cost effective; therefore for making low cost device PVC pipes of 4 kg/ cm^2 pressure rated is used. PVC pipes are locally and easily available in the market, light weight and low maintenance makes it attractiveness. It is durable. The pipes being used for irrigation system are same pipe is used for design and development of device for fertigation and shown in plate 3.20.

3.4.3.1.2 Microtubes

This is small bore polyethylene tubes of 6 mm outer diameter is used. This microtube is used as suction pipe. The flow is regulated by the inside diameter of the tube and length of tubing used. The combination of diameter and length affects the friction loss so as to manage the pressure and flow of injected water. It is flexible and have low cost. So can be used for device design. It is shown in plate 3.9

3.4.3.1.3 Strainer

This is the filters which is used to keep solid particles outside the strainer which can interrupt the flow inside the microtube of suction pipe. Using strainer at end of the microtube is used for fertigation as suction pipe restrict unwanted particles to go inside. The prepared solution of fertilizers can be filtered properly by using strainer which reduce the clogging of dripper. Strainer is shown in plate 3.11

3.4.3.1.4 Reducer

The different sizes of reducers are used which are durable, low cost and easily available in the market. Reducers reduces size of pipe from large bore to small bore which causes change in pipe diameter. Reducer refers to the fitting which causes change in pipe diameter. This change intended to meet the hydraulic flow requirement of the system due to increase in the velocity of the flowing fluid in that reduced portion and decreases the pressure at the same point. The reducer is shown in plate 3.10

3.4.3.1.5 Elbow

An elbow is installed in between length of pipe to allow a change of direction of flowing fluid. It is made up of PVC material so, it has less cost, durable and easily available in the market. Elbow is shown in plate 3.12

3.4.3.1.6 'T' (Tee)

'T' (Tee) is the most common pipe fitting used to combine and divide the fluid flow. This can connect pipe of different diameter or change the direction of pipe run. PVC 'T' (Tee) are used in installation of this device. It has less cost, durable and easily available in market and it is as shown in plate 3.13

3.4.3.1.7 Control valve/ ball-valve

Control valves are used to control fluid flow and also can adjust the discharge. A ball-valve is form of quarter turn valve which is used as hollow perforated and pivoting valve. This controls the flow through it. Ball-valve are durable, performing well after many cycles and reliable, due to PVC material it is of low cost. They are good due to chemical compatibility and different operating pressures and it is as shown in plate 3.14

3.4.3.1.7 Pressure Gauge

To determine different hydraulic parameters and to evaluate the pressure discharge relationship at various operating pressure, a pressure gauge is useful. Therefore to monitor the pressure drop/loss may be due to friction and or change of diameter of pipe i.e. constriction in the pipe section, at inlet and outlet section, the pressure gauge is installed near inlet and outlet section. Glycerin oil filled pressure gauge were used. The pressure gauges have the range of 0 to 7 kg/ cm^2 with least count 0.1 kg/ cm^2. Two pressure gauge are used in this study and it is as shown in plate 3.17

3.4.3.1.8 Grommet and take-off

Grommet is ring which is inserted in the hole to avoid the water leakages where take off or inlet side of pressure gauge is inserted in the pipe to monitor the pressure at that point. 16 mm grommet is used to connect take off. By using take off pressure gauge is inserted in the pipe to know the pressure on flow of water inside the pipe. Grommet and take of is improved method of connecting low pressure irrigation tubes. It is as shown in plate 3.15 and 3.16

3.4.3.1.9 Measuring cylinder

For measuring the amount of water through the suction pipe measuring cylinder is used. It is also necessary to measure the amount of water to be collected in catch can while determining the different hydraulic parameters, measuring cylinder is need for the purpose. The measuring cylinders of 0 to 1000 ml range is used and as shown in plate 3.18

3.4.3.1.10 Catch can

For determining various hydraulic parameter of drip irrigation system like emission rate, variation in emission rate, coefficient of variation, emission uniformity and pressure discharge relation catch cans were used to collect the water. The catch can were having diameter of 21 cm and height 7 cm and of capacity 2 liter in this study. Sixteen number of catch cans were used in this study and as shown in plate 3.19

3.4.3.1.11 Stop watch

Stop watch is used to operate the system for a particular and specific time to collect the discharge to know the pressure discharge relationship, emission uniformity, etc.

Plate 3.9 Microtube

Plate 3.10 Reducers

Plate 3.11 Strainer

Plate 3.12 Elbow

Plate 3.13 Tee

Plate 3.14 Ball-valve

Plate 3.15 Take off

Plate 3.16 Grommet

Plate 3.17 Pressure gauge

Plate 3.18 Measuring cylinder

Plate 3.19 Catch-can

Plate 3.20 PVC pipe

3.4.4 Structure/schematic diagram/plan of device for fertigation under consideration:

The schematic diagram/plan of device is prepared and as shown in diagram 3.3. The complete device is divided in three part i.e. part A, part B and Part C and described as given below:

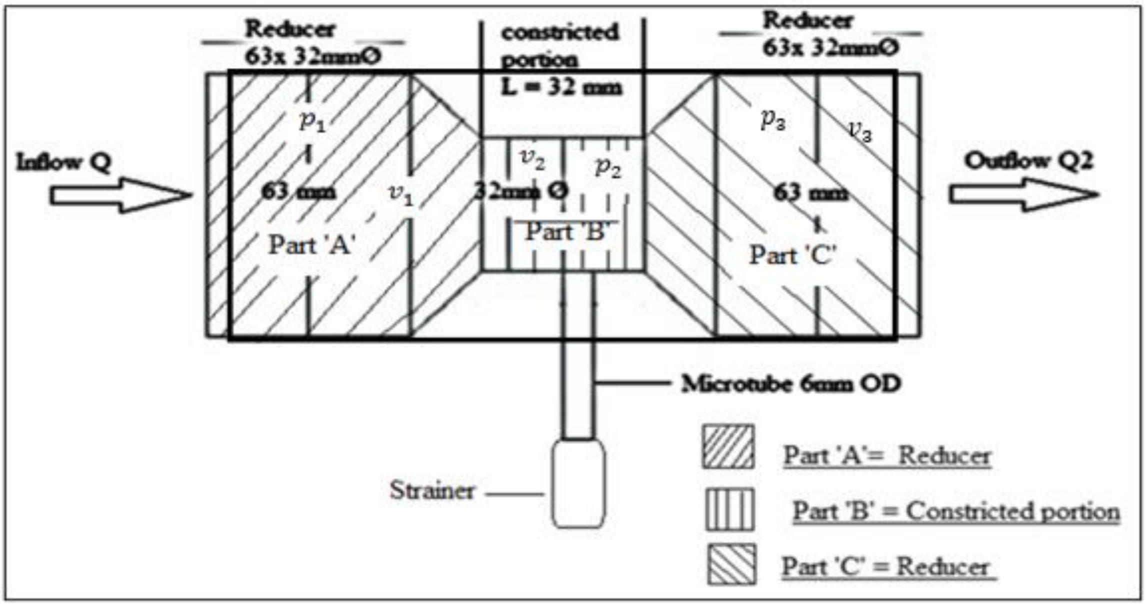


Fig 3.3 Schematic diagram of developed fertigation device

I. Part 'A':

The fluid flow in the pipe at inlet section with constant volume towards the slightly convergence part, which changes the flow rate according to the Bernoulli`s principle. It state that within a specified flow field, the pressure decreases condition occurs when there is velocity increase condition. Often slightly convergent part or the constriction section reduces its cross section gradually according to design and function. The operation and design of this part is to lower down the temporarily static pressure of the fluid applied and enhance the velocity of the fluid due to its shape and size. So that the outcome of that the ongoing pressure to the constricted/throat part will still lower down and high velocity will be generated. This will be results in sudden increase in the velocity at that point/portion with sudden drop of pressure later ultimately will help to form the suction.

II. Part 'B"

This is the middle part which generates the pressure effect at the constricted/throat portion, also is the narrowest part in the whole device of the fertigation device. The pressure difference at this section depends on the structural design of the slightly convergent section which allows the drop of pressure at the inlet part of the constricted/throat portion. This part is then a partially diverging portion by which the velocity undergoes the transformation back to pressure friction loss and then to its original condition with very marginal variation. Hence, the increasing velocity of the throat portion will influence the pressure drops under atmospheric pressure which facilitates the formation of suction at constricted/throat portion and the liquid fertilizer from the fertilizer concentrated storage tank to be injected through suction hole connected with microtube, At this portion shows that the applicability of the suction pipe diameter for fertigation process and the suction capacity mostly influenced by the throat diameter, thus the suction capacity decrease as the throat diameter increase when the suction diameter of microtube is fixed. The diameter of throat is ¼ to ¾ of the diameter of inlet pipe, mostly it is considered as ½ of the inlet pipe. (Anonym 2019)

III. Part 'C'

The fluid flow rate will decrease in this section due to the structural design. Therefore the flowing velocity of flow at this portion will be lowered at divergence section which will cause the pressure recovering to start and will be almost of its initial size. Hence the pressure difference at this point is the most important factor in this section.

The different schematic diagram/plan of prepared device is shown in fig 3.3 to 3.8. The different sizes of the pipes and throat section are taken into account as described in 3.4.3.

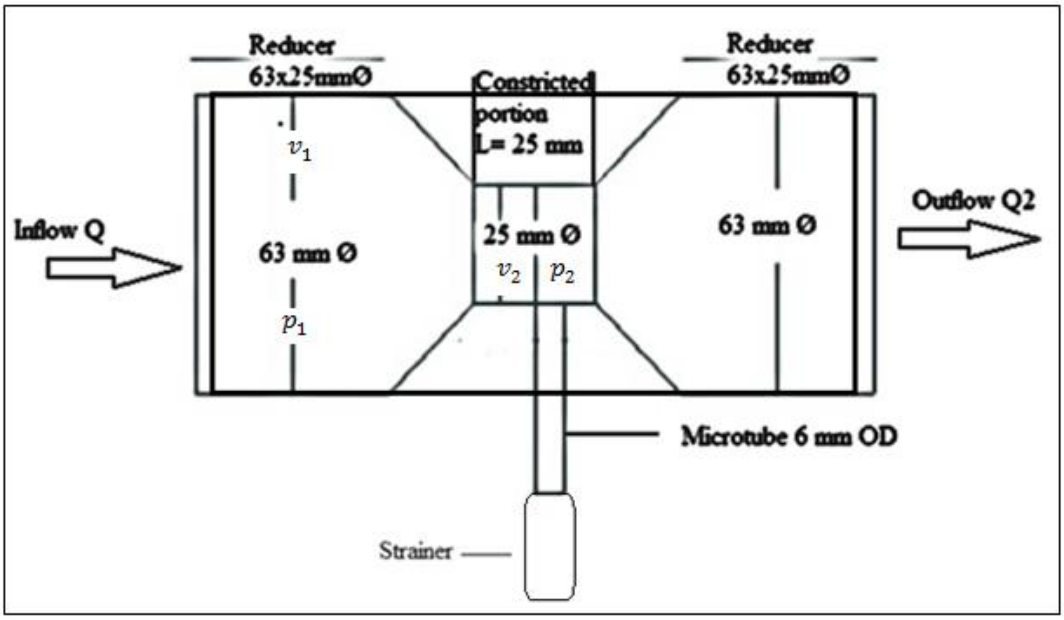


Fig 3.4 Developed device of fertigation of size 63 x 25 mm

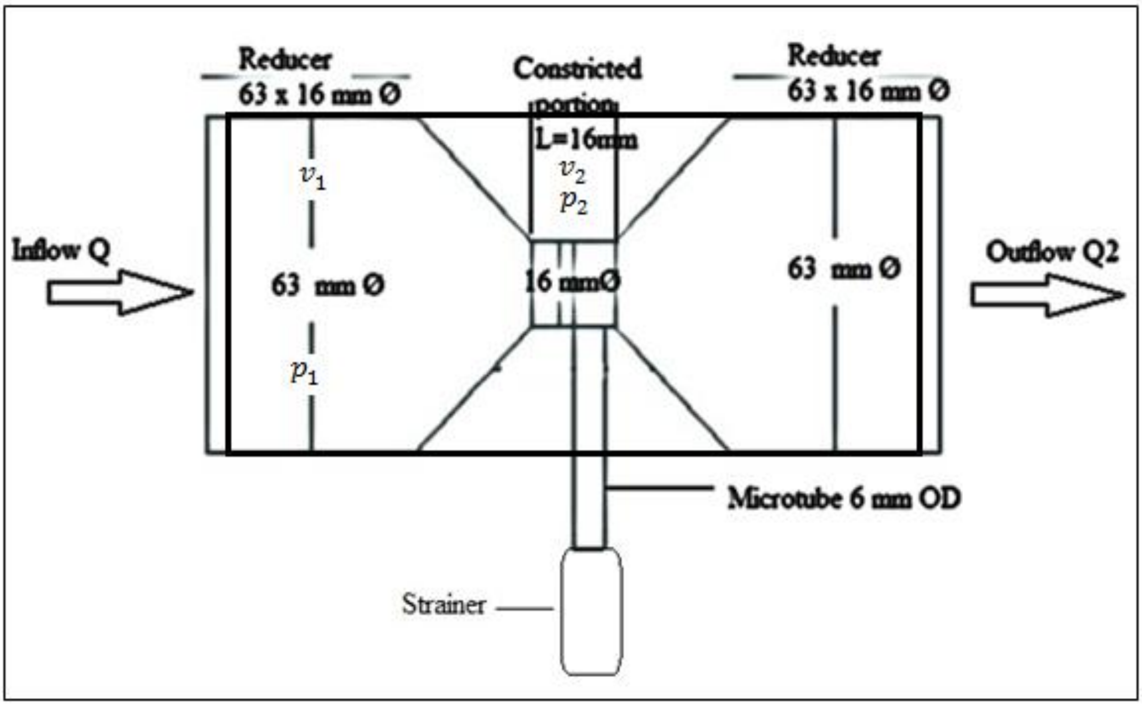


Fig 3.5 Developed device of fertigation of size 63 x 16 mm

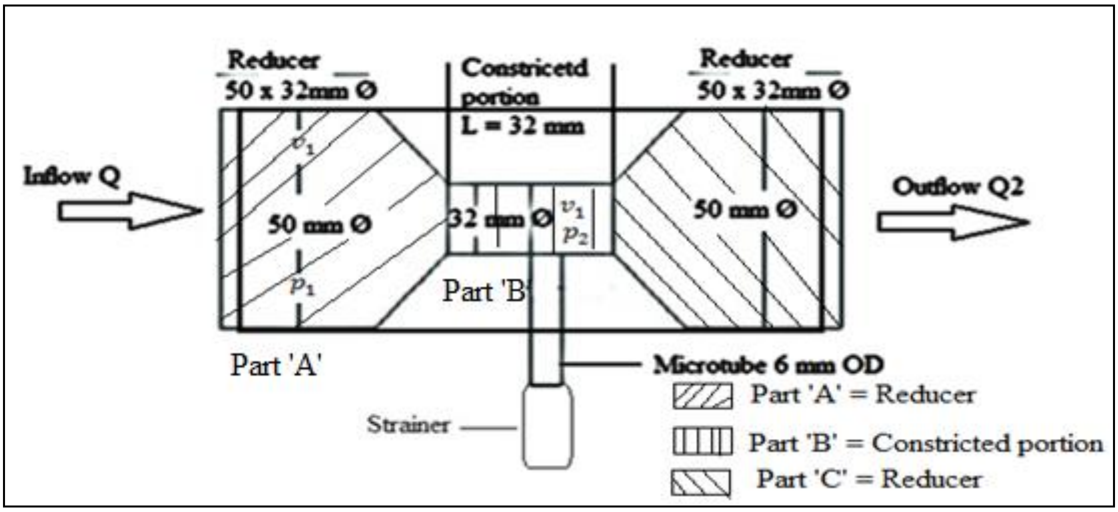


Fig 3.6 Developed device of fertigation of size 50 x 32 mm

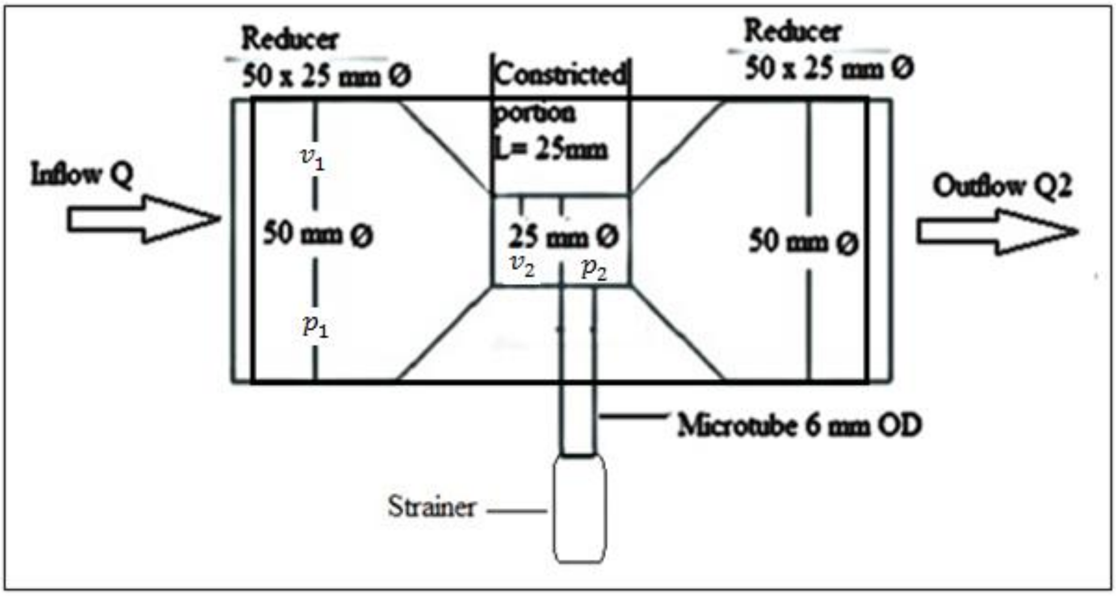


Fig 3.7 Developed device of fertigation of size 50 x 25 mm

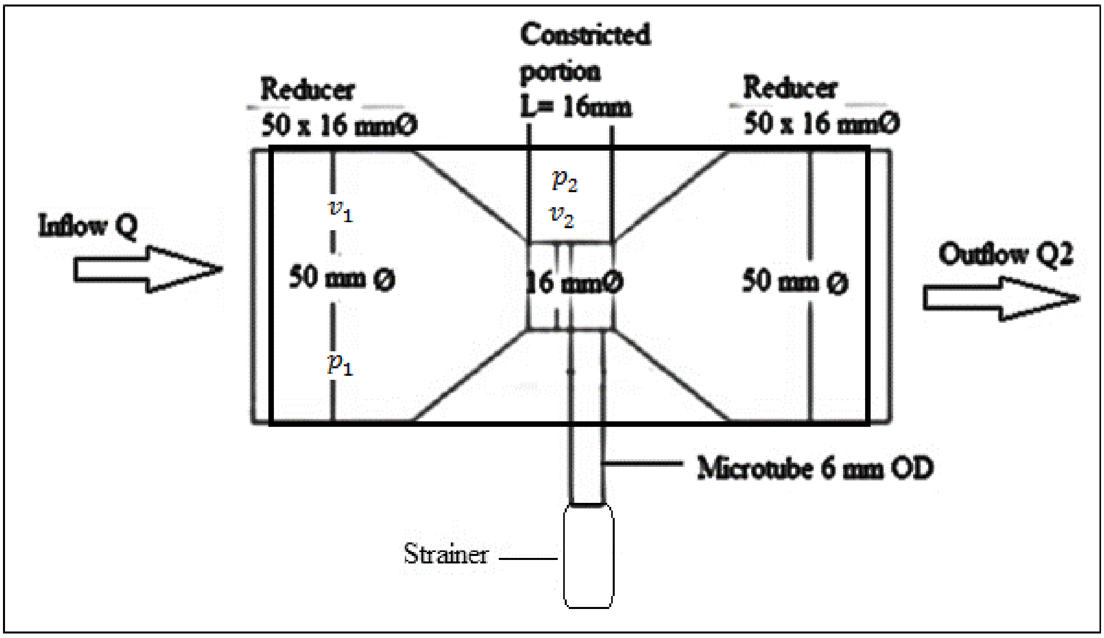


Fig 3.8 Developed device of fertigation of size 50 x 16 mm

3.4.5 Experimental setup:

The detailed experimental setup is given as shown in fig 3.9 while preparing the plan and design to develop the cost effective fertigation device. The required methodology is described in section 3.4.1 to 3.4.1.5.2. Material requirement is given in section 3.4.3.1 is considered. The operating/working principle is also taken into account along with the hypothesis made for the present study.

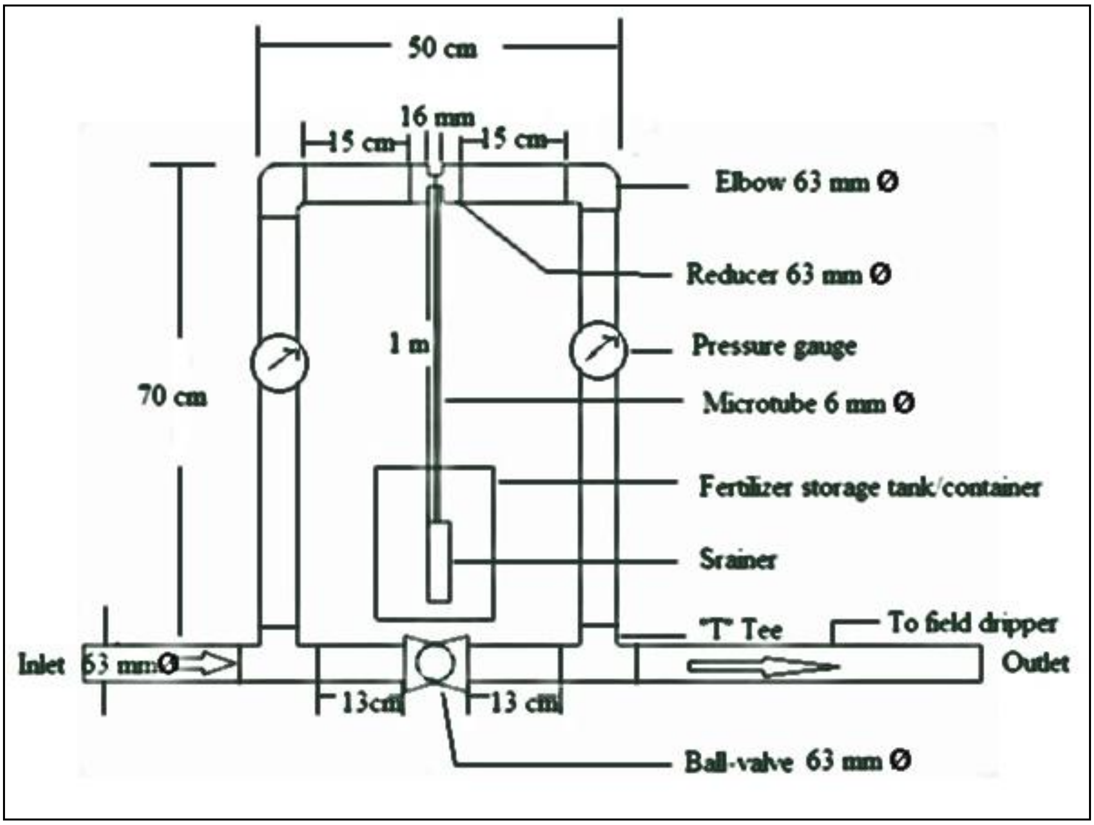


Fig 3.9 Experimental setup of developed fertigation device

As shown in Figure 3.9 which includes experimental setup, placement and fitting of all the gathering of all components of fertigation device. It includes the pipe cutting, reducer cutting, drilling hole for suction point and fixing all parts by using PVC fixing solution and installation it in irrigation system. A hand drill and hacksaw were used to cut the PVC pipes and reducer. The pressure gauge is mounted at inlet and outlet section for monitoring the pressure drop so as to determine the relation of discharge, suction ratio and pressure drop.

3.4.5.1 Pipe cutting:

The PVC pipe of different diameter are cut by the hacksaw with an appropriate length as shown in fig 3.9, required and planned for development of the device for fertigation.

3.4.5.2 Reducers cutting:

The PVC reducers of different diameter are cut by the hacksaw with an appropriate length as shown in fig 3.9, required and planned for development of the device for fertigation.

3.4.5.3 Fix the position of suction point and drilling of whole:

The suction point is considered by checking the vena contract. As suggested by Bayler in 2007 the position of suction hole should be near to the centre and toward the side of outlet. By using hand drill the required size of hole is drilled i. e. 6 mm Ø.

3.4.5.4 Fix the size of microtube and fitting:

The outer diameter of microtube is fixed 6 mm Ø as required and planned for development of the device for fertigation.

3.4.6 Suction rate:

The suction rate of fluid through the microtube is calculated by following equation and given by equation No 3.12:

$$\text{suction rate (q)} = \frac{s}{t} \qquad (3.12)$$

Where, q = suction rate (lit/h)

s = amount of injected fertilizer (lit)

t = time required for fertigation (h)

3.4.7 Calculation of velocity at different point of device:

To determine the appropriate size of pipe section along with the size of constricted or throat portion, it was needed to work out the velocity of flowing fluid at different parts of the device. Therefore the velocity is calculated by the equation 3.10 and 3.13:

3.4.7.1 Velocity at inlet i.e. part 'A' of the proposed device:

The velocity is calculated by using the equation as suggested by G H Dury and M.J Bradshaw in 1959 and given in equation 3.13.

$$V = \frac{Q}{A} \qquad (3.13)$$

Where, V = velocity through the pipe (m/s)

Q = discharge of water through the pipe (m^3/s)

A = cross sectional area of pipe (m^2)

3.4.7.2 Calculation of velocity through at constricted/throat at part 'B' of the device:

As the Bernoulli's principle venturi effect can be seen. So for achieving the high velocity the area of pipe should be contracted for starting of suction. The velocity is calculated by equation no 3.5

$$v_2 = \sqrt{\frac{2(p_1 - p_2)}{\rho} + v_1^2} \qquad \text{(from equation number 3.5)}$$

Where, V_2 = Velocity at constricted/ throat section (m/s)

P_1 = Pressure at the inlet portion of the device (kg/cm^2)

P_2 = Pressure at the constricted/throat portion of the device (kg/cm^2)

ρ = Density of the fluid (kg/m^3)

3.5 Performance evaluation of developed device for fertigation:

Before approaching to the performance evaluation of the developed device for fertigation a prototype is to be developed and the filler trial is to be conducted at the laboratory condition. Once it is confirmed that at part ‘B’ of device i.e. at constricted/throat portion the suction is occurring with a specific operating pressure along with some other flaws.

Then after considering the two pipe size i.e. of 63 mm and 50 mm as the main water line and three constricted/throat portion of 32 mm, 25 mm and 16 mm total 6 number of devices are to be made to test against the 16 number of operating pressure i. e. starting from 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2.

3.5.1 Filler trial and laboratory testing:

Filler trial and laboratory test are to be conducted to know the following parameter;

i. Whether the suction is formed with what specific operating pressure
ii. If yes then what is the suction rate at particular operating pressure at particular operating pressure
iii. Are there any flaws, if yes then further improvement in development to be undertaken.

3.5.2 Testing of device for fertigation on instructional farm pipeline by keeping the laterals ends of all laterals lines/pipe lines open to atmosphere by adjusting the control valve the following distributions are to be recorded:

i. To check whether the developed device is working satisfactorily or not.
ii. If yes then at what operating pressure it is working

iii. Are there any flaws, if yes then further development/improvement in the device are to be undertaken.

3.5.3 Testing of developed device for fertigation on instructional by keeping the laterals end open and providing valve at end of lateral to check the proportional suction rate:

In this test the lateral ends were kept open and at the end of lateral control valve was provided. The investigation was to know the number of the laterals that can be kept close and how many laterals that can kept open to atmosphere at specific flow rate in the pipe line, etc. the fallowing observation are recorded and operations are performed.

i. Preparation of the layout and fitting of drip irrigation system as shown in fig 3.10
ii. Installation of developed device as shown in fig 3.9
iii. Formation of the suction
iv. Further development if any in the designed device of fertigation
v. Testing the different sizes of device i.e. 63 x 32 mm, 63 x 25 mm, 63 x 16 mm, 50 x 32 mm, 50 x 25 mm, 50 x 16 mm,
vi. Determination injection rate w.r.t. different operating pressure to each device.
vii. Identify and select the best developed device operating best at specific operating pressure and size.
viii. Analyzing the outcome of result.

3.5.4 Testing of developed device for fertigation at the instructional farm of IDE by keeping all end of lateral close by end cap:

To check the proportionate suction to know how many lateral that can be operated at specific pressure with specific device the following observation are to be recorded along with different operation are performed.

i. Testing the different sizes of device i.e. 63 x 32 mm, 63 x 25 mm, and 63 x 16 mm, 50 x 32 mm, 50 x 25 mm and 50 x 16 mm.
ii. Determination injection rate w.r.t. different operating pressure to each device.
iii. Identify and select the best developed device operating best at specific operating pressure and size.
iv. Analyzing the outcome of result.

3.5.5 Studies on pressure at inlet of device, constricted/throat portion of the device and outlet:

The development of cost effective device for fertigation is based on Bernoulli's principle and venturi effect which latter describes that in a pipe section if the cross sectional area is constricted then at that portion/point pressure decreases and velocity increases which is also described in section 3.4.2.3. Therefore it was necessary to keep keen match on pressure rating at different suction of the developed device. Therefore the following observations are recorded to know the pressure drop at inlet and outlet portion of device.

3.5.5.1 Pressure at inlet section of device:

The pressure gauge was installed as shown in fig. 3.9 and recorded the different pressure rating observed at different combination of pipe diameter and constricted portion at different operating pressure.

3.5.5.2 Pressure at constricted section of device:

The pressure gauge was installed as shown in fig.3.9 and recorded the different pressure rating observed at different combination of pipe diameter and constricted portion at different operating portion.

3.5.5.3 Pressure drop:

The difference in the total pressure between inlet and constricted portion of a fluid carrying network is considering as pressure drop. Pressure drop occurs when frictional forces, caused by the resistance to flow act on a fluid as its flows through a pipe. The main determinants are velocity of flow and fluid viscosity. In this experiment, the study observed pressure drop between inlet section and outlet section.

Therefore pressure drop,

Pressure drop = Operating pressure at inlet – Pressure at constricted portion

3.5.6 Study on formation of suction and its rate (litre/hour):

In the fertigation it is necessary to know the suction rate of the device to decide the time of operating of irrigation system and time required for fertigation which alternately help to decide the area to be fertigated at once. Therefore is necessary to record the necessary observation on suction injection rate of device. The following procedure and obeservation are to be recorded. The fitting of microtube is done as shown in fig. 3.9. In this stud suction rate is calculated by taking ratio of amount of water injected to the time required and as given in equation 3.14.

$$\text{Suction rate (q)} = \frac{S}{t} \quad (3.14)$$

Where, q = suction rate (lit/h)

S = amount of injected volume of solution fertilizer (lit)

t = time required for fertigation (h)

Amount of fertilizer injected/ sucked by the device (litre) = Known volume of fertilizer solution (litre) - amount of fertilizers balanced in container (litre)

$$S = Kv - Bv \quad (3.15)$$

3.5.7 Effect of developed device on hydraulic parameters of the system:

Once it is confirmed that the developed device for fertigation is working properly and satisfactorily then it was felt necessary after fitting it to the existing drip irrigation system with known total area and lateral spacing and other details of the system to check any effect on the hydraulic parameter of the system like i. Emission rate ii. Emission uniformity as it is directly related to the uniform distribution of fertilizer solution in the field. For the purpose as shown in the fig. 3.9 the experimental setup was prepared. And developed device is to be tested for different operating pressure from 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2. The system was run for known time i.e for 10 min and observation was recorded. It is repeated for five times to overcome with error if any.

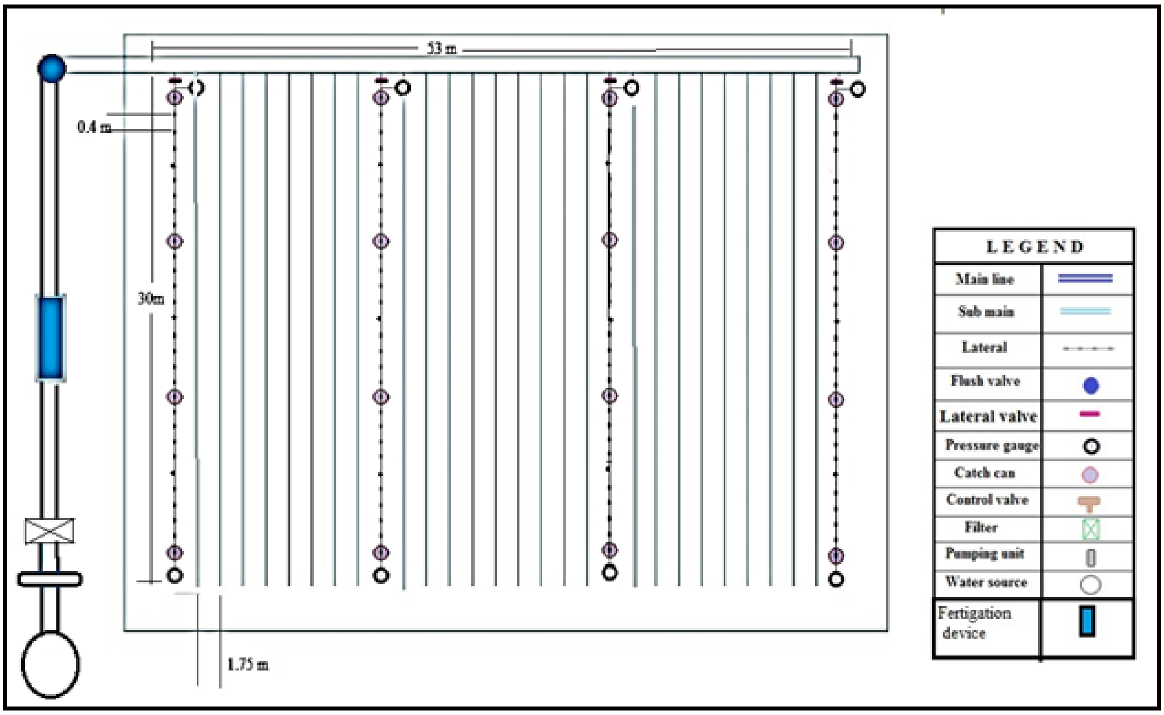


Fig 3.10 Layout of developed device for hydraulic parameters of the system:

3.5.7.1 Average emission rate

The average emission rate is the mean flow for sample number of emitters of same type tested at different operating pressure. Determination of average discharge helps in calculating the accurate discharge of emitter. For determination of emission rate the standard procedure was adopted as suggested by Keller and Karmeli, 1974. The procedure adopted to determine the average emission rate of different makes of inline laterals are described as below.

For recording the observations and collecting data, the system was run for 10 minutes with an operating pressure of 1.0 kg/cm^2. The irrigation system was run for 10 minute before recording the observation to create a real time condition. The 4 points were identified by dividing the lateral in to 3 parts, the catch can were placed below the emitter at inlet end, 1/3th down, 2/3th down, and far end. After the scheduling time, the system is turn off and the volume of water collected in catch can was measured with the help of measuring cylinder. The measuring cylinder was kept in vertical direction and then constant horizontal column level of water was observed. The collected discharge was measured using a graduated cylinder. Based on the volume of water collected in each catch can and the time taken, the discharge was calculated in lit/h.

The average emission rate of emitter was calculated by the equation 3.16 (Keller and Karmeli, 1974).

$$q_a = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad ..... (3.16)$$

Where, q_a = average emission rate (lph).

q_i = flow rate of the emitter (lph).

n = total number of emitter.

The procedure was adopted to know the average emission rate (lph) for material under testing i.e., total four makes of inline lateral and for total four inline laterals at an operating pressure of 1 to 2.5 kg/cm^2 with increments of 0.1 kg/cm^2 and replicated for five times.

3.5.7.2 Emission Uniformity (EU) %

Emission uniformity of the system guides on system's performance. It is a relative index of variability between emitters discharge. The uniform delivery of water and fertilizers by emitters is affected by elevation differences in the field, pressure drop along the lateral, clogging of emitters etc. Therefore, it is essential to determine the emission uniformity of system, which then useful to calculate the gross depth of irrigation to a particular crop. Classification of EU according to Merriam and Keller, 1978 standards are shown in Table 3.2.

Table 3.2 Classification of Emission Uniformity (EU) (Merriam and Keller, 1978)

EU range (per cent)	Classification
90 or greater	Excellent
80 to 90	Very good
70 to 80	Fair
60 to 70	Poor
Less than 60	Unacceptable

There are several methods viz. field and laboratory suggested by different research workers for estimating uniformity of water application in drip irrigation system. In the present study, emission uniformity was computed by using the standard formula suggested by Keller and Karmeli (1974) and as given in equation 3.17 and the procedure for collecting the discharge in lit/h is same as given in section 3.5.7.1 as shown in Fig.3.11

$$EU = \frac{1}{2}\left[\frac{Qmin}{Qavg} + \frac{Qavg}{Qmax}\right] x\ 100 \qquad ... (3.16)$$

Where,

EU = Field emission uniformity, (%)

Qmin = Average discharge of ¼th of emitters with least discharge, (lph)

Qavg = Average discharge of all emitters under testing, (lph)

Qmax = Average discharge of ⅛th of emitters with highest discharge, (lph)

The procedure was adopted to know the emission uniformity EU(%) for material under testing

3.6 Cost of manufacturing of developed fertigation device:

Cost of manufacturing depends on the material/spares used for developing the device and labour cost required for development. The main aim of designing and developing of fertigation system is making it low cost, easy to install and operate which will be userfriendly. The detailed cost estimation of developed cost effective fertigation device is to be calculated using different combinations of devices for fertigation by considering cost of manufacturing and labour cost required. As it was targeted to meet the need like low cost easily available material different combinations of devices was proposed in this study.

For this purpose materials as tabulated in table 3.3 and table 3.4 are required enlisted and their cost are to be considered for calculating the cost of device. The labour cost is to be added in the cost of device.

Table 3.3 Material required for developing 63 x 16 mm fertigation device:

Sr. No.	Particulars	Size	Quantity
1	PVC pipe of 4 kgf	63 mm	2.5 m
3	Elbow	63 mm	2
4	Tees	63 mm	2
5	Microtube	6 mm diameter	1 m

6	Reducer	63x 16 mm	2
7	Ball valve	63 mm	1
Total			9

Table 3.4 Material required for developing 50 x 16 mm fertigation device:

Sr. No.	Particulars	Size	Quantity
1	PVC pipe of 4 kgf	63 mm	2.5 m
3	Elbow	50 mm	2
4	Tees	50 mm	2
5	Microtube	6 mm diameter	1 m
6	Reducer	50 x 16 mm	2
7	Ball valve	50 mm	1
Total			9

Plate 3.21 Cutting of parts for designing and development of fertigation device

Plate 3.22 Assembling/ fabrication of parts for designing and development of fertigation device

Plate 3.23 Schematic picture and view of device of fertigation

Plate 3.24 Schematic picture and view of developed device for fertigation

IV. RESULTS AND DISCUSSION

The experiment entitled "Design and Development of Cost Effective Device for Fertigation", was carried out at the Instructional farm and in the laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, DBSKKV, Dapoli. The material required and the necessary procedure adopted is described neatly in Chapter 3 (Material and Methodology). This chapter deals with the survey and study of available fertigation devices in the market to decide the design consideration for design and development of the device for the present study. It also describes the design consideration based on survey and study of available fertigation devices in the market, design of device, material requirement and used, methodology adopted for design, selection of pipe sections, design of constricted portion, assembling of unit, its testing at different operating pressure, performance evaluation of developed device, cost economics is described. The necessary data is collected, analyzed and interpreted in the suitable scientific manner and presented in this chapter to fulfil the objectives of the present study.

4.1 Study area

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, Dr. Babasaheb Sawant Konkan Agriculture University, Dapoli. (MS), India during the year 2019-20.

4.2 Survey and study of available fertigation devices in market

To fulfil the first objective of the study, the survey and study of the different fertigation devices was conducted by adopting the procedure as described in section 3.3. The findings of the study are tabulated in Table 4.1.

Table 4.1 Merits and Demerits of the fertigation devices available in the market

S. N.	Name of device	Merits	Demerits
1.	Venturi injector	1. Does not require external force to operate. 2. Its cost is relatively low compared to other fertigation devices 3. It can be connected to	1. More pressure loss in main irrigation line 2. Quantitative fertigation is difficult. 3. Difficult to adjust the throttle valve to start

		computer system 4. Excellent chemical resistance to most of the chemicals. 5. Corrosion Free construction.	the suction. 4. Difficult to adjust constant suction rate. 5. Requires skilled and experienced manpower 6. The problem of syphoning (reverse flow in fertilizers tank) may arise.
2.	Fertigation tank (Pressurized tank)	1. Large capacity to store stock solution fertilizers. 2. Simple to use and operate. 3. Wide dilution ratio can be attained without external source of energy	1. Fertilizer solution concentration is reducing not constant. 2. Requires specific skill to throttle and divert portion of the water to fertilizer tank. 3. Prior to each application, the tank has to be filled with fertilizers. 4. Loss of pressure occurs due to throttling.
3	Hydraulic injection pump	1. Vast range available in suction rate from 10 to 320 LPH. 2. Working in the 0.5 to 8 bar (0.51 to 8.16 kg/cm^2) pressure range. 3. Light weight and portable. 4. Easily installed into the system.	1. Loss of pressure occurs from the mainline. 2. Costly than other devices. 3. Spares are not easily available. 4. Needs skilled person to operate.
4	Electric centrifugal pump	1. It can be adjusted over a different range to provide a continuous and uniform concentration of chemical in irrigation water. 2. There is no pressure loss in system. 3. Large range of flow settings. 4. The possibility to inject	1. It is costly. 2. Required skilled labour 3. Complex in working 4. External energy is required. 5. System is costly.

		several tanks of nutrient stock solutions. 5. Precise set up of the concentration. 6. Consistent concentration and flow. 7. The possibility of total automation of the system	

From Table 4.1, it is revealed that the different fertigation devices available in the market are having certain merits and demerits, some of them are may be working well but costing is high and require skill manpower. Some devices required frequent maintenance. Therefore, considering the flaws and according to aim of the study the deign consideration are finalized and described in the following section 4.3.

4.3 Design and development of device for fertigation

For design and development of the device, the materials used are described in section 3.4.1.1 of chapter III. The adopted methodology is as described in section 3.4.2. The following design considerations are finalized for the design and development of the device under consideration.

4.3.1 Design considerations

i. The device should be low cost so that marginal farmer can afford the cost of that device for fertigation.
ii. The material required for development and further manufacturing of device should be available in the local market so that cost will be minimum.
iii. It should be easily installed and operated by farmer.
iv. No requirement of skilled manpower.
v. It should operate at specific operating pressure to reduce pressure loss.
vi. The spares should be easily available for its easy maintenance.
vii. It should be ready to use.
viii. The device should be user friendly.
ix. Minimum fitting requirement.
x. Energy free and ready to fertigation.
xi. Minimum involvement of regulating valves to create pressure difference and to get high velocity, etc.
xii. The neatly designed and developed fertigation device should have wide range of application and adoption with affordable price.

Here an attempt is made to design cost effective fertigation device for enhancing the application of fertilizers in field and described in the section 4.4.

4.4 Methodology

As described in the section 3.4.1, the required methodology was adopted for design and development of device for fertigation. For design of the device various principle and concepts are considered and studied. Bernoulli's principle was one of the most important concept which is explained in section 3.4.1.1 which found to be most relevant and useful for the design of the device. The continuity equation was also studied and described in section 3.4.1.2.2. For further development, the venturi effect was studied and considered which helped for knowing the establishment of suction described in section 3.4.1.2 and 3.4.1.3.

4.4.1 Working/operating principle

Working/operating principle of venturi effect and Bernoulli's theorem was considered for design and development of the device,which states that the pressure difference due to the presence of constriction in pipeline which accelerate the flow (velocity of flow) and create a suction effect, further which results in the suction of fertilizer solution into pipeline for further distribution into the fieldwhich is explained in section 3.4.1.4.

4.5 Design and development of device

For design and development of the device in present study the schematic diagram was prepared as shown in Fig 4.1. For construction of the device, the PVC pipes of 4 kg/cm^2 of 63 mm Ø and 50 mm Ø were used. To form the constricted portion reducers of 63 x 32 mm, 63 x 25 mm, 63 x 16 mm, 50 x 32 mm, 50 x 25 mm and 50 x 16 mm were used. The length of PVC pipe of 63 mm Ø and 50 mm Ø were taken, for horizontal section 15 and 13 cm and for vertical section was 70 cm. By using the control valve, microtube, 'T' (Tee), and elbow the device constructed and tested for 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2 i.e. for 16 pressure rating combination. For these purposes the procedure adopted is given in section 3.4.5 and section 4.5.

4.5.1 Selection of diameter of pipe for device

The description of diameter of pipe is described in section 3.4.2.1. For designing the device, two sizes of pipes are considered as the main line/ sub main of irrigation system i.e. 63 mm and 50 mm. For further design the area of PVC pipe under consideration is required and calculated by the Equation 4.1

$$\text{Area of pipe } A = \frac{\pi}{4} \times D^2 \quad (4.1)$$

Where, D = Diameter of the pipe, cm

When diameter is 63 mm,

Then,

$$\text{Area of pipe } A = \frac{\pi}{4} D^2$$

$$= \frac{\pi}{4} \times (6.3)^2$$

Area of pipe A= 31.17cm^2

When diameter is 50 mm,

Then,

$$\text{Area of pipe } A = \frac{\pi}{4} D^2$$

$$A = \frac{\pi}{4} \times (5.0)^2$$

Area of pipe A = 19.625 cm^2

4.5.2 Design of Constricted portion

The detail description of constricted portion of pipe is described in section 3.4.2.2 and section 4.5.1. The formation of constricted portion is prepared by the reducers as explained in 4.6. The diameter and length of throat is considered for constriction as described in section 3.4.3.2. Generally, the diameter of constricted portion is considered as ¼ or ¾ of the diameter of inlet pipe. Mostly it is considered as ½ and ¼ of the inlet pipe diameter. Therefore, diameter of constricted portion under study is taken as given by equation 4.2

$$\text{Diameter of constricted or throat portion (d)} = \frac{D}{2} or \frac{D}{4} \quad (4.2)$$

Where d = diameter of constricted/throat portion, cm

Therefore, when diameter of inlet pipe is 63 mm,

Then the diameter of constricted/throat portion= $\text{d} = D/4$

d = 6.3/4

= 1.575 cm

Say d = 16 mm Ø, and considering

$$\text{d} = \frac{D}{2}$$

$= 6.3/2$

$= 3.2$ cm say 32 mm

Now when diameter of inlet pipe is 50 mm,

Then the diameter of constricted/throat portion = $d = D/4$

$$d = \frac{5.0}{4} = 1.25 \text{ cm say } 13 \text{ mm}$$

$$\text{and when} \quad d = \frac{D}{2} = \frac{5.0}{2} = 2.5 \text{ cm say } 25 \text{ mm}$$

Therefore, constricted portion for 63 mm pipe diameter were 32 mm and 16 mm and for 50 mm pipe diameter were 13 mm and 25 mm. 13 mm Ø PVC pipe is not available in the market. Therefore as it was aimed to construct with low cost and with available material in the market, for formation of the constricted portion the reducers of different sizes were used. Therefore, these sizes of constricted portion i. e. 32 mm, 25 mm and 16 mm were selected for construction of the devices which are matching with the calculated one.

4.5.3 Operating pressure

The different operating pressure starting from 1 kg/ cm^2 to 2.5 kg/ cm^2 with an increment of 0.1 kg/ cm^2 were used to test the device of different sizes to check at which range of pressure the suction is forming. The detail of description is explained in section 3.4.2.3.

4.5.4 Total combinations

For construction of device total 96 combinations were considered for designing the device.

4.5.6 Materials used for design and testing of the device of fertigation

The different materials were used in the design and development of the device for fertigation according to the specifications required. The care was taken while selection of the material that, it should be locally available cost effective and have suitable strength. The necessary and required materials were used as described in 3.4.3 and 4.5. For fitting/ construction the procedure adopted is as described in 3.4.4 and 3.4.5 and shown in Fig 4.1. The list of material required for constriction of 63 x 32 mm, 63 x 25 mm, 63 x 16 mm, 50 x 32 mm, 50 x 25 mm and 50 x 16 mm is given in the Appendix III. The following materials were used for construction of the fertigation device.

4.5.6.1 PVC pipes

The piece of PVC pipes measuring 15 cm in length (two pieces) and 13 cm in length (two pieces) of diameter 50 mm Ø and 63 mm Ø were used for horizontal sections of the fertigation device. 250 cm of PVC pipe of 63 mm and 50 mm each was required for preparation of complete unit.

4.5.6.2 Micro tubes

As described in section 3.4.3, the micro tube of 6 mm Ø outer diameter and 100 cm in length is used as suction inlet in the design and construction of the fertigation device and as shown in fig. 4.1

4.5.6.3 Strainer

The strainer was used at the suction inlet for removing out the precipitation and the impurities from nutrient solution before injecting into the system. The strainer was having at its upper portion of 6 mm Ø as outlet portion for fitting to the microtube as shown in Figure 4.1.

4.5.6.4 Reducers

` The different sizes of reducers were used to construct the fertigation device and the constricted portion which is described in section 3.4.2.2 and shown in Fig 4.2. For a single unit two reducers of same size are used. Therefore, considering two sizes of PVC pipes and three constricted portions of following types of reducers are used and shown in Fig 4.2. The selection of the reducers for the 63 mm and 50 mm Ø size of the fertigation device is shown in Fig. 4.1 and given below.

The reducers required for 63 mm Ø Fertigation Device are;

iv. Reducers of 63 X 32 mm Ø – 2 numbers.
v. Reducers of 63 X 25 mm Ø – 2 numbers.
vi. Reducers of 63 X 16 mm Ø – 2 numbers.

The reducers required for 50 mm Ø Fertigation Device are;

i. Reducers of 50 X 32 mm Ø – 2 numbers.
ii. Reducers of 50 X 25 mm Ø – 2 numbers.
iii. Reducers of 50 X 16 mm Ø – 2 numbers.

4.5.6.5 Elbow

Two elbows of same size were used for construction of device i.e. for 63 mm and 50 mm of each. The description of elbow is given section 3.4.3 and shown in Fig 4.1.

4.5.6.6 'T' (Tee)

Two 'T' (Tee) of same size were used for the construction of device i.e. for 63 mm and 50 mm of each. The description of 'T' (Tee) is given section 3.4.3 and shown in Fig 4.1.

4.5.6.7 Control valve/ ball-valve

Same size of a ball-valve was used for the designing a device i.e. for 63 mm and 50 mm. The description is given section 3.4.3 and shown in Fig. 4.1.

4.5.6.8 Pressure Gauge

The pressure gauges was used for this experiment have the range of 0 to 7 kg/ cm^2 with least count 0.1 kg/ cm^2. Two pressure gauges was used in this study which is described in section 3.4.3 and shown in Fig 4.1.

4.5.6.9 Grommet and take-off

Grommet of 16 mm diameter was used to connect take off. By using take off, pressure gauge is inserted in the PVC pipe to know the pressure of flow of water inside the pipe as described in section 3.4.3 shown in plate 3.15 and 3.16.

4.5.6.10 Measuring cylinder

The measuring cylinder of 1000 ml capacity was used in this experiment and shown in plate 3.18.

4.5.6.11 Catch can

The sixteen number of catch can were used with diameter of 21 cm and height of 7 cm and capacity 2 litres in this study. The description is given section 3.4.1 and shown in plate 3.19.

4.6 Design of Fertigation Device/ Construction of Fertigation Device

For design and development the device for fertigation the design considerations are considered which are described in section 3.4. The material used for construction of the device is properly enlisted and described under sections 3.4.3.1.1 to 3.4.3.1.12. The methodology adopted for construction of the device is described in section 3.4.1 to 3.4.2.

For construction of the device, preliminary it was decided to construct device of size 63 mm x 32 mm. The device was divided in to two sections for neat understanding i.e.

1) Horizontal section

2) Vertical section and as shown in Fig 4.1

The horizontal section again subdivided in to two sections i.e.

i) At main/sub main line.

ii) Parallel to main/submain lines (i) at height of 50 cm above and (ii) at height of 70 cm .

The horizontal section (1) as shown in Fig. 4.1 comprises of the following material/components;

a) 63 mm ‘T’ (tee) – 2 Nos.

b) 63 mm PVC pipe pieces of 13 cm – 2 Nos.

c) 63 mm control valve – 1 No.

The horizontal section (2) as shown in Figure 4.1 comprises the following components;

a) Reducer of 63 mm x 32 mm – 2 Nos.

b) 63 mm PVC pipe pieces of 15 cm – 2 Nos.

c) 32 mm PVC pipe of 32 mm in length - 1 Nos.

The vertical section (2) and as shown in Figure 4.1 is comprises of the following components.

a) 63 mm PVC pipe pieces of 70 cm – 2 Nos.

Each component is depicted in Fig. 3.3 to 3.8

The fittings were made by adopting the following step by step procedure and shown in Fig 4.1

4.6.1 Fitting at main/submain line

i. Two pieces of 13 cm in length of 63 mm PVC pipes were taken.
ii. These two pieces were fitted in the ‘T’ (tee) of 63 mm independently as shown in Fig 4.1
iii. These two ‘T’ (tees) of 63 mm fitted with 63 mm PVC pipe pieces were inwardly connected to the control valve of 63 mm as shown in Fig. 4.1 by taking care that vertical outlet of those two ‘T’ were kept in vertical direction.
iv. The assembly of T and control valve was fitted to main/submain line of 63 mm pipe line.

v. Two pieces of 70 cm in length of 63 mm PVC pipes were fitted in those two T' (tees) by keeping the position perfectly upright as shown in Fig. 4.1

vi. The elbows of 63 mm were fitted by keeping their other end in inward direction as shown in Fig. 4.1

vii. The two small pieces of 15 cm of 63 mm PVC pipe were fitted in the reducer as shown in Fig. 4.1

viii. The reducers of 63 mm x 32 mm were fitted to the pieces of 15 cm of PVC pipe of 63 mm as shown in Fig. 4.1

ix. The constructed portion was prepared and the micro tube was inserted by drilling a hole towards the forward directions of flow and at close to centre of the constricted portion for sucking the fertilizer in to main pipe line and a strainer was fitted to other end of the that micro tube as shown in Fig. 4.1.

x. All fittings were made with PVC solvent cement.

xi. The same procedure was adopted for construction of 63 mm x 25 mm, 63 mm x 16 mm, 50 mm x 32 mm, 50 mm x 25 mm and 50 mm x 16 mm devices and shown in Fig 3.3 to 3.8 and tested for different for operating pressures starting from 1.0 to 2.5 kg/m^2 with an increment of 0.1 kg/cm^2.

4.7 Construction of the device

In section 3.4.4 structure/schematic diagram/plan of device and as shown in Fig 4.1 for fertigation under consideration is explained. For making these devices, for two inlet pipe size of 63 mm and 50 mm Ø, 6 pairs of reducers of respective size viz. 50 x 32 mm, 50 x 25 mm and 50 x 16 mm, 63 x 32 mm, 63 x 25 mm and 63 x 16 mm were used. These reducers were cut at throat section as described in section 3.4.5.2 with the length equal to throat diameter (16 mm, 25 mm, and 32 mm). These reducers were connected with help of pipe section by using PVC binding solution. For injection of fertilizer a hole of diameter 6 mm is made by using hand drill as described in 3.4.5.3 and 3.4.5.4 near the centre of the throat towards 'C' part shown in Fig 4.2. In that hole the microtube of 6 mm diameter is inserted of required length of 100 cm.

4.7.1 Experimental setup Assembling and fitting

The different components used and assembled to form the device and appropriate procedure is adopted and explained in section 3.4.5 section 4.5 and as shown in Fig 4.1. The following part/components were used to construct the device considering 63 mm Ø of inlet pipe and 50 mm Ø and as reported in Table 4.2 and Table 4.3.

Table 4.2 Different components for construction of fertigation device when size of inlet pipe was of 63 mm.

S.N.	Components	Quantity	Remark
1.	'T'(Tee) of 63 mm	02 no	Connecting device to mainline/Sub main line.
2.	Elbow of 63 mm	02 no	For fitting of device to upper horizontal section of the device.
3.	Control valve 63 mm	01 no	To regulate the flow.
4.	Piece of PVC pipes of 63 mm Ø = 13 cm	02 no	To connect control valve and T
5.	Piece of PVC pipes of 63 mm Ø = 15 cm	02 no	To connect elbow and reducer.
6.	Piece of PVC pipes of 63 mm Ø = 70 cm	02 no	Vertical section
7.	Reducers of 63 x 32 mm	02 no	Constricted portion
8.	Reducers of 63 x 25 mm	02 no	Constricted portion
9.	Reducers of 63 x 16 mm	02 no	Constricted portion
10.	Microtube – 6 mm Ø	100 cm	Suction line
11.	Strainer	01 no	To filter impurities.

Table 4.3 Different components for construction of fertigation device when size of inlet pipe was of 50 mm.

S.N.	Component	Quantity	Remark
1.	'T'(Tee) of 50 mm	02 no	Connecting device to mainline/Submain line.
2.	Elbow of 50 mm	02 no	For fitting of device to upper horizontal section of the device.
3.	Control valve 50 mm	01 no	To regulate the flow.
4.	Piece of PVC pipes of 50 mm Ø = 13 cm	02 no	To connect control valve and T
5.	Piece of PVC pipes of 50 mm Ø = 15 cm	02 no	To connect elbow and reducer.
6.	Piece of PVC pipes of 50 mm Ø = 70 cm	02 no	Vertical section
7.	Reducers of 50 x 32 mm	02 no	Constricted portion
8.	Reducers of 50 x 25 mm	02 no	Constricted portion
9.	Reducers of 50 x 16 mm	02 no	Constricted portion
10.	Microtube – 6 mm Ø	100 cm	Suction line

11.	Strainer	01 no	To filter impurities.

4.7.2 Reducers cutting

For construction of constricted portion/ throat of the device the reducers are used as described in section 4.6.1. To match the length of the constricted portion/ throat the either reducers were cut equal at reduced portion by using the hacksaw. This is shown in Fig 3.3 to 3.8.

1. The two reducers of size 63 x 32 mm were cut 8 mm from reduced size of each reducer.
2. The two reducers of size 63 x 25mm were cut 12.5 mm from reduced size of each reducer.
3. The two reducers of size 63 x 16 mm were cut 16 mm from reduced size of each reducer
4. The two reducers of size 50 x 32 mm were cut 8 mm from reduced size of each reducer.
5. The two reducers of size 50 x 25 mm were cut 12.5 mm from reduced size of each reducer.
6. The two reducers of size 63 x 16 mm were cut 16 mm from reduced size of each reducer.

4.7.3 Fixing of the position of suction point and drilling of whole

As suggested by Bayler (2007) the position of suction point is decided which is explained in section 3.4.5.3. By using hand drill the required size of hole is drilled i.e. 6 mm Ø near the centre of constricted portion towards the ‘C’ part as shown in Fig. 4.2.

4.7.4 Microtube and fitting

The diameter of microtube is fixed as 6 mm Ø outer diameter as required and planned for development of the device for fertigation which is explained in point 3.4.5.4 and shown in Fig 4.2.

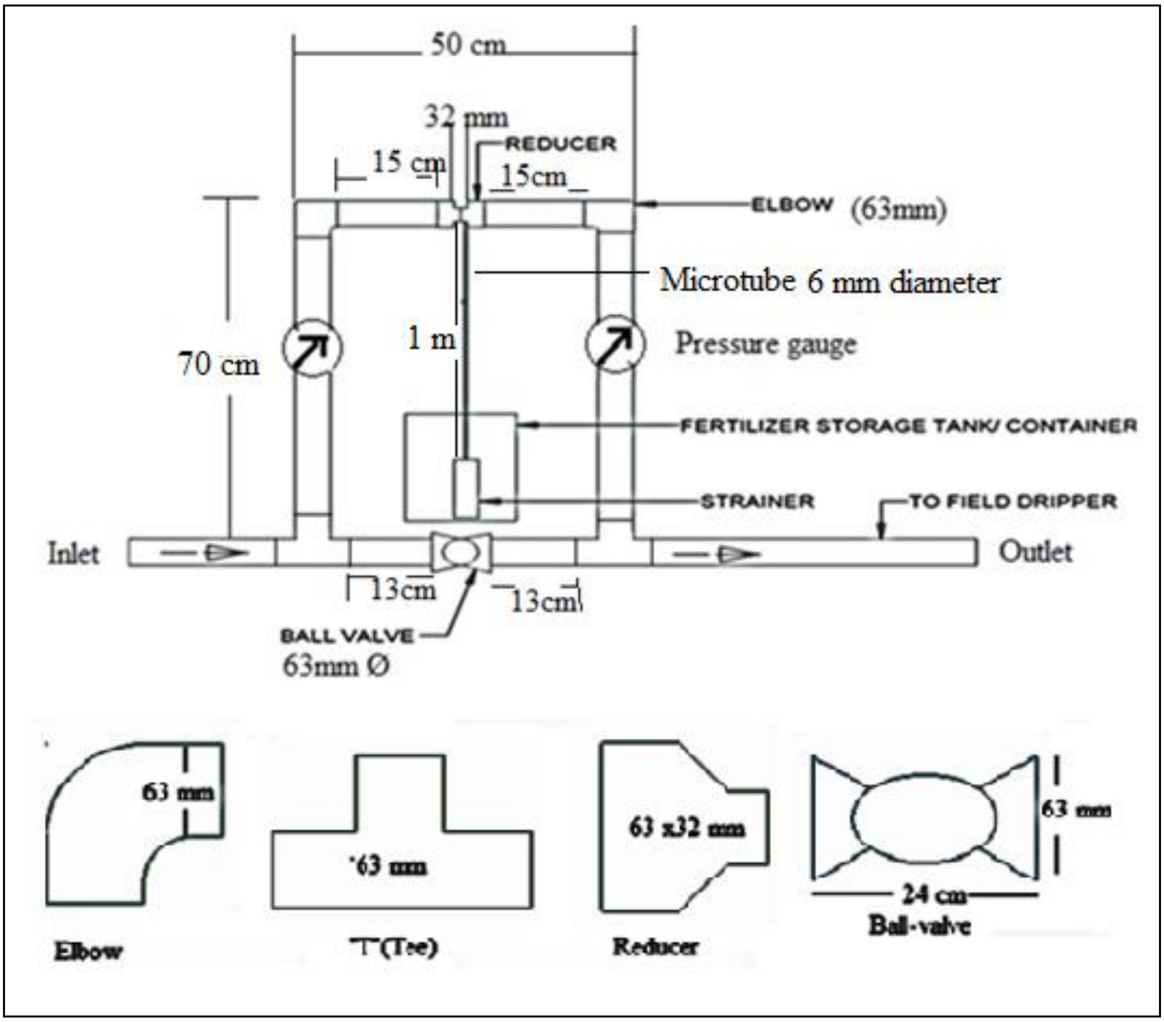


Fig 4.1 Structure/Schematic diagram/ plan of fertigation device

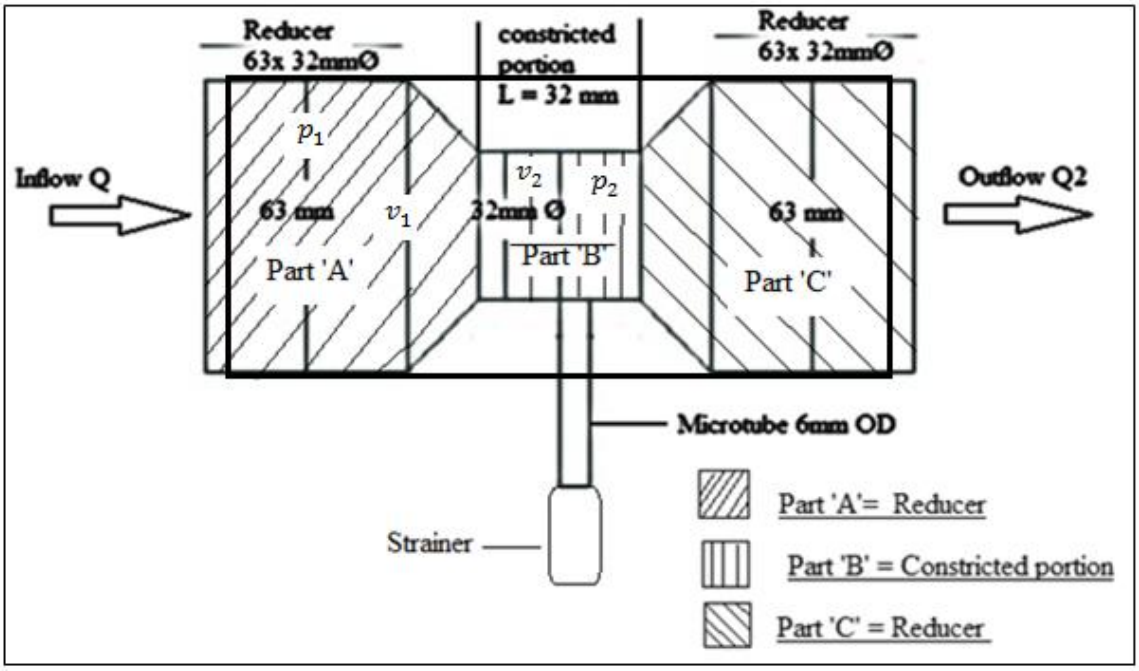


Fig 4.2 Developed device of fertigation of size 63 x 32 mm

4.8 Hydraulic study of developed device

To know the viability, feasibility of the device the study of different parameter like suction rate, velocity of flowing water at different sections, pressure discharge relationship, pressure at different section, average discharge, emission uniformity, etc. are determined.

4.8.1 Suction rate

Initially the suction rate and performance was worked out for 63 mm Ø of inlet pipe and 50 mm Ø with constricted portion of 32 mm and 25 mm to check whether the suction is forming or not when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 50 cm and 70 cm above the mainline. While recording the observation the height of device was maintain as 50 cm and 70 cm from ground level. The necessary data was recorded and tabulated in Table 4.4 to 4.11. The relation between different operating pressure and suction rate for height of device and for each operating pressure is also studied and as shown graphically in Fig 4.3 to 4.16.

4.8.1.1 Suction rate of device for fertigation for size of 50 x 32 mm at 50 cm height

The suction rate and performance was worked out for 50 mm Ø of inlet pipe with constricted portion of 32 mm when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 50 cm. The observations are reported in Table 4.4.

Table 4.4 Suction rate of device for fertigation for size of 50 x 32 mm at 50 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator above ground (cm)	Operating pressure kg/cm^2	Outlet pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet l/h
50	1	0	1	83.67	10870
	1	0.1	0.9	65.89	10790
	1	0.2	0.8	46.97	10680
	1	0.3	0.7	36.16	10600
	1	0.4	0.6	31.54	10530
	1	0.5	0.5	11.76	10510
50	1.25	0	1.25	87.98	10970
	1.25	0.1	1.15	75.04	10890

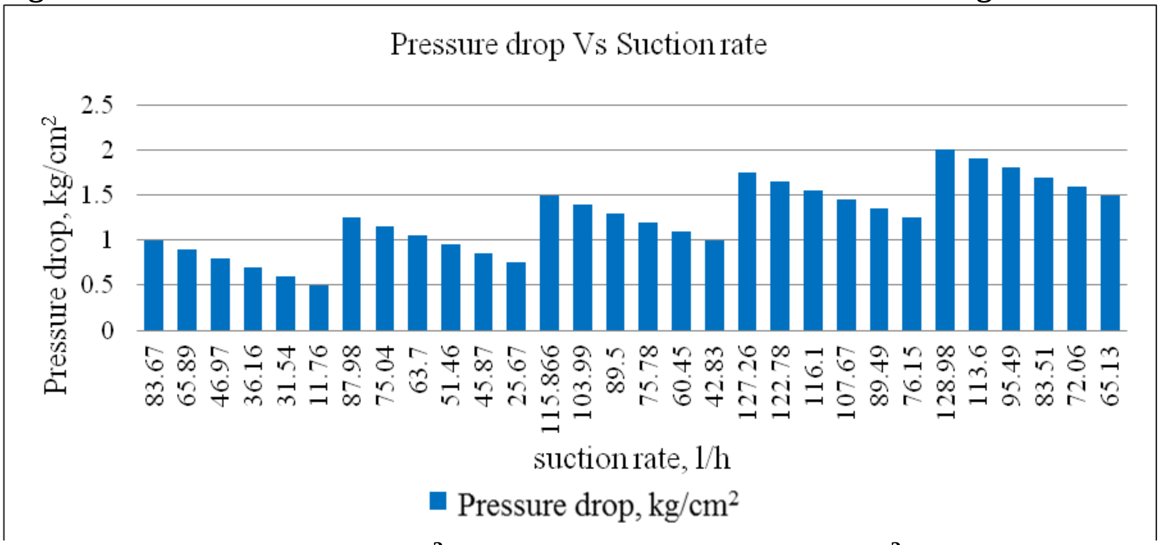
	1.25	0.2	1.05	63.7	10800
	1.25	0.3	0.95	51.46	10750
	1.25	0.4	0.85	45.87	10690
	1.25	0.5	0.75	25.67	10620
50	1.5	0	1.5	115.86	11100
	1.5	0.1	1.4	103.99	11000
	1.5	0.2	1.3	89.5	10980
	1.5	0.3	1.2	75.78	10920
	1.5	0.4	1.1	60.45	10830
	1.5	0.5	1	42.83	10850
50	1.75	0	1.75	127.26	11320
	1.75	0.1	1.65	122.78	11260
	1.75	0.2	1.55	116.1	11200
	1.75	0.3	1.45	107.67	11150
	1.75	0.4	1.35	89.49	11000
	1.75	0.5	1.25	76.15	10900
50	2	0	2	128.98	11400
	2	0.1	1.9	113.6	11320
	2	0.2	1.8	95.49	11270
	2	0.3	1.7	83.51	11200
	2	0.4	1.6	72.06	11130
	2	0.5	1.5	65.13	11090

From Table 4.4 and as depicted in Fig. 4.3 and 4.4, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 83.67 l/h, 87.98 l/h, 115.86 l/h, 127. 26 l/h and 128.98 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

The same trend was observed for the all the devices under study i.e. 50 mm x 25 mm, for 50 and 70 cm height 63 mm x 32 mm for 50 and 70 cm height and for 63 mm x 25 mm, for 50 and 70 cm height which are reported in Table 4.5 to Table 4.11 and depicted in Figure 4.3 to 4.18.

From the data presented in Table 4.4 to 4.11 and Figure 4.3 to 4.18, it is very important to note that for both height of device i.e. 50 cm and 70 cm the suction rate is found to be higher in 63 mm x 25 mm and 50 mm x 25 mm than 63 mm x 32 mm and 50 mm x 32 mm when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2 which is clearly indicative that again there were chances to modify the size and constricted portion to form the suction when connected this device to actual drip irrigation system and to get the desired suction rate.

Fig. 4.3 Suction rate of device for size of 50 x 32 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.



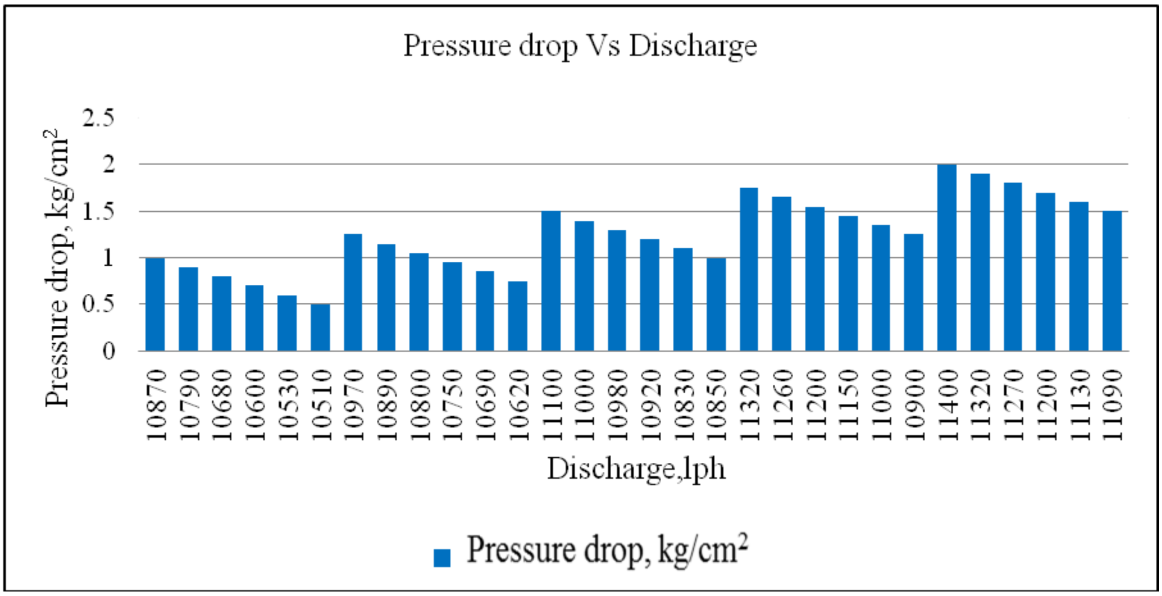


Fig.4.4 Discharge rate of device for size of 50 x 32 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.2 Suction rate of device for size of 50 x 32 mm at 70 cm height

The suction rate and performance was worked out for 50 mm Ø of inlet pipe with constricted portion of 32 mm when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 70 cm. The observations are reported in Table 4.5.

Table 4.5 Suction rate of device for size of 50 x 32 mm at 70 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator above ground cm	Operating pressure kg/cm^2	Outlet Pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet l/h
70	1	0	1	90.56	10,850
	1	0.1	0.9	76.64	10790
	1	0.2	0.8	49.08	10690
	1	0.3	0.7	41.68	10630
	1	0.4	0.6	35.72	10590
	1	0.5	0.5	14.84	10530
70	1.25	0	1.25	101.34	11120
	1.25	0.1	1.15	93.85	11090
	1.25	0.2	1.05	76.48	10900
	1.25	0.3	0.95	58.35	10850
	1.25	0.4	0.85	48.74	10800
	1.25	0.5	0.75	35.97	10740
70	1.5	0	1.5	122.67	11210
	1.5	0.1	1.4	112.24	11100
	1.5	0.2	1.3	91.4	10980
	1.5	0.3	1.2	80.54	10920
	1.5	0.4	1.1	62.78	10880
	1.5	0.5	1	41.35	10850
70	1.75	0	1.75	127.26	11320
	1.75	0.1	1.65	122.78	11280
	1.75	0.2	1.55	116.1	11220
	1.75	0.3	1.45	107.67	11150
	1.75	0.4	1.35	89.49	11000
	1.75	0.5	1.25	76.15	10970
70	2	0	2	129.08	11420
	2	0.1	1.9	127.68	11370

	2	0.2	1.8	119.17	11270
	2	0.3	1.7	112.73	11200
	2	0.4	1.6	92.45	11150
	2	0.5	1.5	87.69	11090
	2	0.5	1.5	65.13	11090

From Table 4.5 and as depicted in Fig. 4.5 and 4.6, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 90.56 l/h, 101.34 l/h, 122.67 l/h, 127.26 l/h and 129.08 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

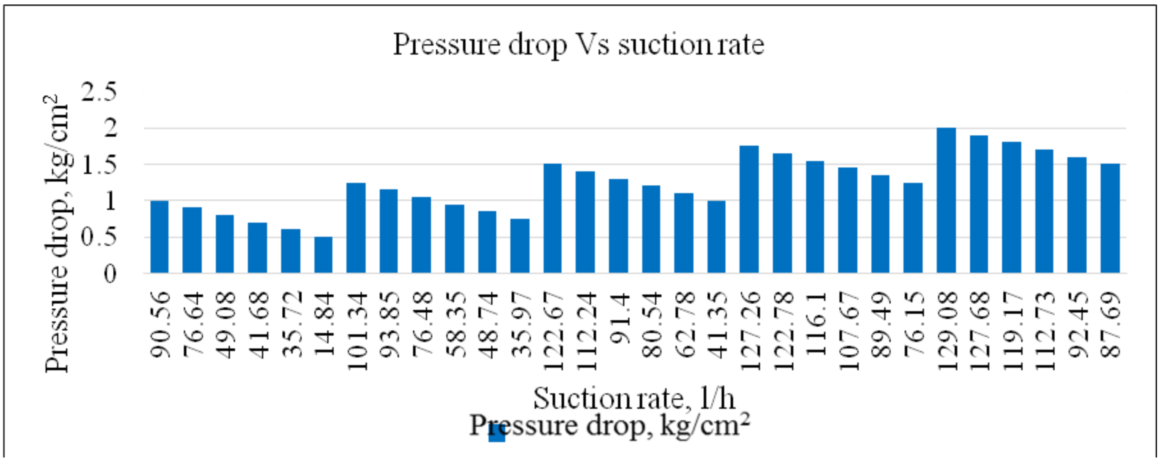


Fig 4.5 Suction rate of device for size of 50 x 32 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

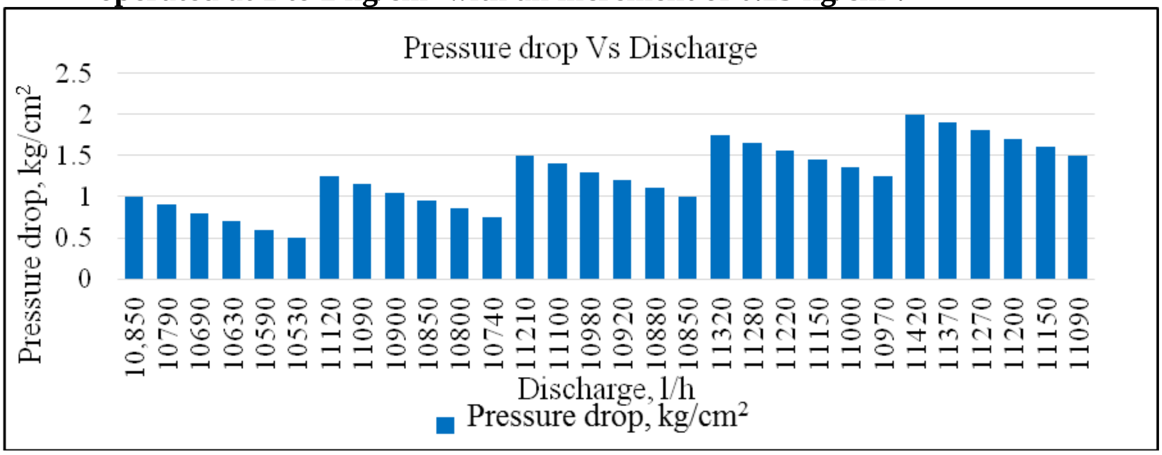


Fig 4.6 Discharge rate of device for size of 50 x 32 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.3 Suction rate of device for size of 50 x 25 mm at 50 cm height

The suction rate and performance was worked out for 50 mm Ø of inlet pipe with constricted portion of 25 mm when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 50 cm. The observations are reported in Table 4.6.

Table 4.6 Suction rate of device for size of 50 x 25 mm at 50 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator Above ground, cm	Operating pressure kg/cm^2	Outlet Pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet l/h
50	1	0	1	87.8	10,800
	1	0.1	0.9	67.93	10760
	1	0.2	0.8	48	10680
	1	0.3	0.7	39.13	10600
	1	0.4	0.6	34.95	10540
	1	0.5	0.5	13.89	10510
50	1.25	0	1.25	92.31	10980
	1.25	0.1	1.15	78.26	10860
	1.25	0.2	1.05	70.58	10800
	1.25	0.3	0.95	57.14	10740
	1.25	0.4	0.85	48	10690
	1.25	0.5	0.75	37.11	10660
50	1.5	0	1.5	116.12	11040
	1.5	0.1	1.4	105.88	11000
	1.5	0.2	1.3	90	10970
	1.5	0.3	1.2	78.26	10920
	1.5	0.4	1.1	63.15	10880
	1.5	0.5	1	43.9	10850
50	1.75	0	1.75	121.56	11090
	1.75	0.1	1.65	112.45	11030
	1.75	0.2	1.55	107.09	10995
	1.75	0.3	1.45	97.67	10800
	1.75	0.4	1.35	83.29	10760
	1.75	0.5	1.25	76.82	10720
50	2	0	2	130.34	11180
	2	0.1	1.9	113.6	11090
	2	0.2	1.8	109.12	11040
	2	0.3	1.7	100.08	11000
	2	0.4	1.6	94.08	10900
	2	0.5	1.5	86.09	10860
	2	0.5	1.5	65.13	11090

From Table 4.6 and as depicted in Fig. 4.7 and 4.8, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1.5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 87.8 l/h, 92.31 l/h, 116.12 l/h, 121.56 l/h and

130.34 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

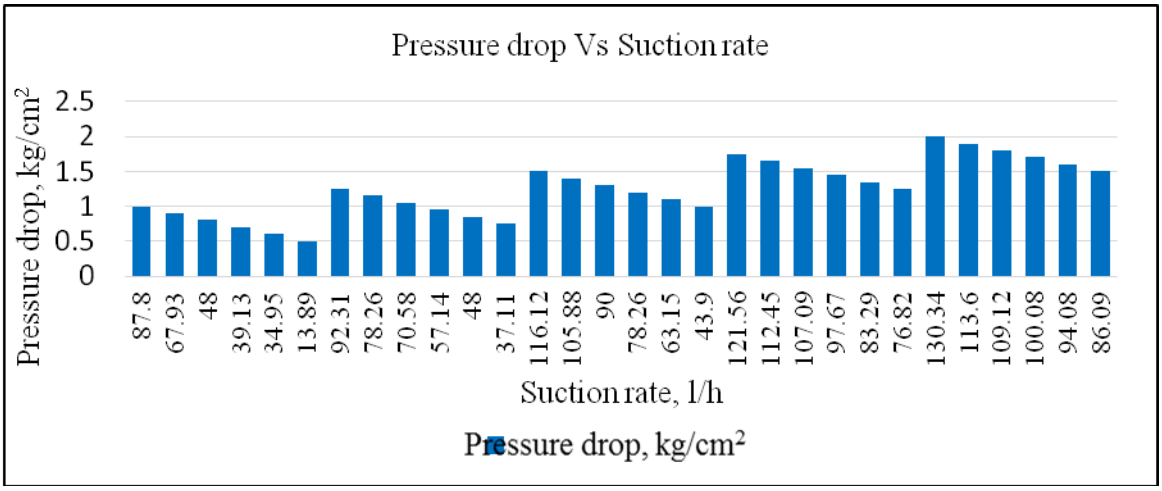


Fig 4.7 Suction rate of device for size of 50 x 25 mm at 50 cm height when operate at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

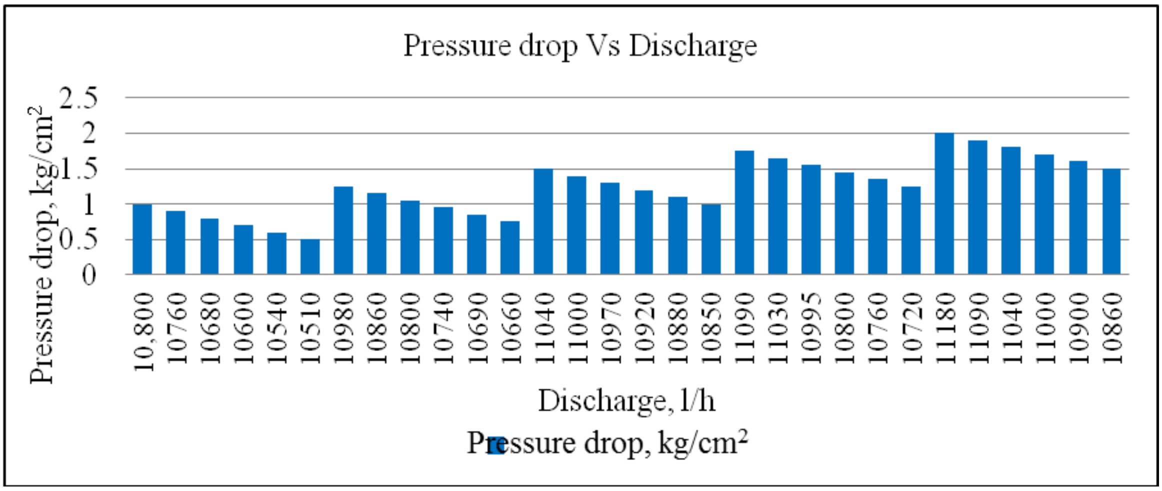


Fig 4.8 Discharge rate of device for size of 50 x 25 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.4 Suction rate of device for size of 50 x 25 mm at 70 cm height

The suction rate and performance was worked out for 50 mm Ø of inlet pipe with constricted portion of 25 mm when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 70 cm. The observations are reported in Table 4.7.

Table 4.7 Suction rate of device for size of 50 x 25 mm at 70 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator Above ground	Operating pressure kg/cm^2	Outlet Pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet

cm					l/h
70	1	0	1	94.736	10,770
	1	0.1	0.9	78.26	10700
	1	0.2	0.8	52.94	10690
	1	0.3	0.7	44.45	10640
	1	0.4	0.6	38.71	10560
	1	0.5	0.5	15.25	10430
70	1.25	0	1.25	105.88	10970
	1.25	0.1	1.15	97.3	10830
	1.25	0.2	1.05	80	10770
	1.25	0.3	0.95	62.07	10720
	1.25	0.4	0.85	52.18	10630
	1.25	0.5	0.75	42.35	10580
70	1.5	0	1.5	124.14	11000
	1.5	0.1	1.4	120	10970
	1.5	0.2	1.3	97.3	10840
	1.5	0.3	1.2	87.81	10790
	1.5	0.4	1.1	69.23	10700
	1.5	0.5	1	46.76	10680
70	1.75	0	1.75	127.26	11150
	1.75	0.1	1.65	122.78	11030
	1.75	0.2	1.55	116.1	10920
	1.75	0.3	1.45	107.67	10870
	1.75	0.4	1.35	89.49	10800
	1.75	0.5	1.25	76.15	10750
70	2	0	2	131.18	11280
	2	0.1	1.9	128.6	11180
	2	0.2	1.8	117.37	11100
	2	0.3	1.7	113.73	11020
	2	0.4	1.6	92.45	10890
	2	0.5	1.5	88.69	10620

From Table 4.7 and as depicted in Fig. 4.9 and 4.10, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 94.736 l/h, 105.88 l/h, 124.14 l/h, 127.26 l/h and 131.18 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

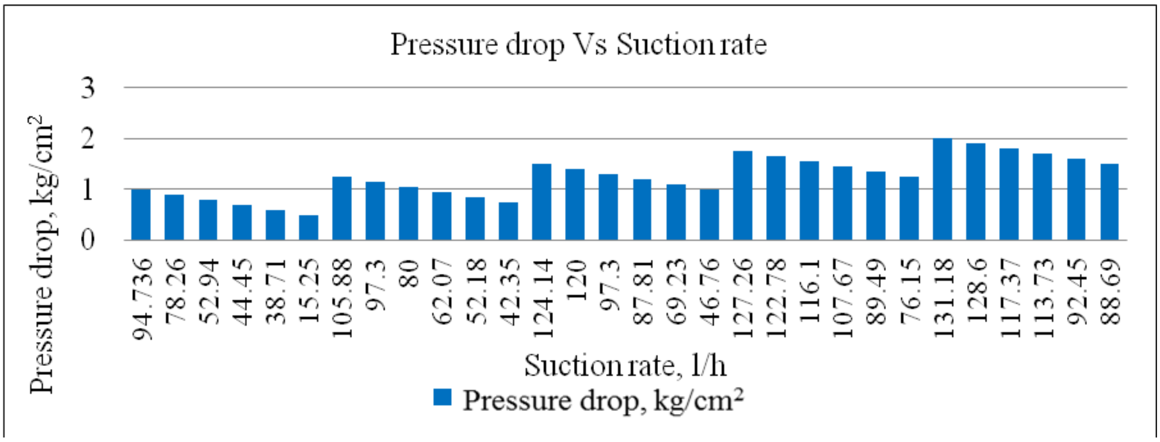


Fig 4.9 Suction rate of device for size of 50 x 25 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

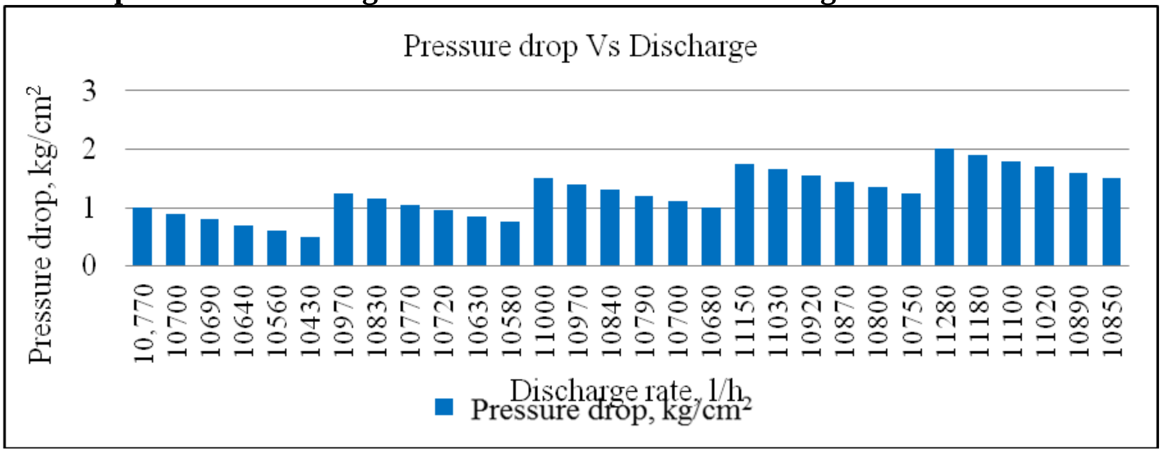


Fig 4.10 Discharge rate of device for size of 50 x 25 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.5 Suction rate of device for size of 63 x 32 mm at 50 cm height

The suction rate and performance was worked out for 63 mm Ø of inlet pipe with constricted portion of 32 mm when the outlet is allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 50 cm. The observations are reported in Table 4.8.

Table 4.8 Suction rate of device for size of 63 x 32 mm at 50 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator Above ground cm	Operating pressure kg/cm^2	Outlet pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet, l/h
50	1	0	1	105.88	13,590
	1	0.1	0.9	92.31	13460
	1	0.2	0.8	81.82	13390
	1	0.3	0.7	75	13270
	1	0.4	0.6	64.29	13180
	1	0.5	0.5	49.32	13000

50	1.25	0	1.25	120	14100
	1.25	0.1	1.15	112.5	14030
	1.25	0.2	1.05	90	13800
	1.25	0.3	0.95	83.72	13740
	1.25	0.4	0.85	70.59	13690
	1.25	0.5	0.75	55.39	13610
50	1.5	0	1.5	138.46	14430
	1.5	0.1	1.4	112.5	14370
	1.5	0.2	1.3	97.74	14200
	1.5	0.3	1.2	88.26	14140
	1.5	0.4	1.1	75.46	14030
	1.5	0.5	1	62.35	13950
50	1.75	0	1.75	140.87	15130
	1.75	0.1	1.65	118.32	15070
	1.75	0.2	1.55	108.84	14940
	1.75	0.3	1.45	89.47	14860
	1.75	0.4	1.35	81.49	14780
	1.75	0.5	1.25	73.67	14700
50	2	0	2	141.69	15670
	2	0.1	1.9	126.27	15540
	2	0.2	1.8	116.3	15490
	2	0.3	1.7	92.03	15350
	2	0.4	1.6	82.76	15200
	2	0.5	1.5	76.21	14990

From Table 4.8 and as depicted in Fig. 4.11 and 4.12, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 105.88 l/h, 120 l/h, 138.46l/h, 140.87 l/h and 141.69 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

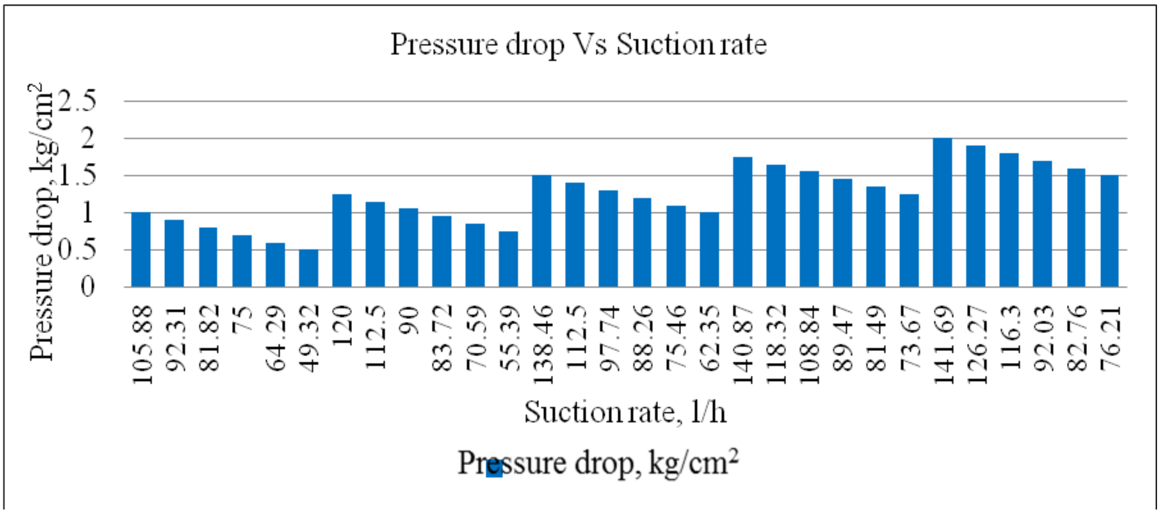


Fig 4.11 Suction rate of device for size of 63 x 32 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

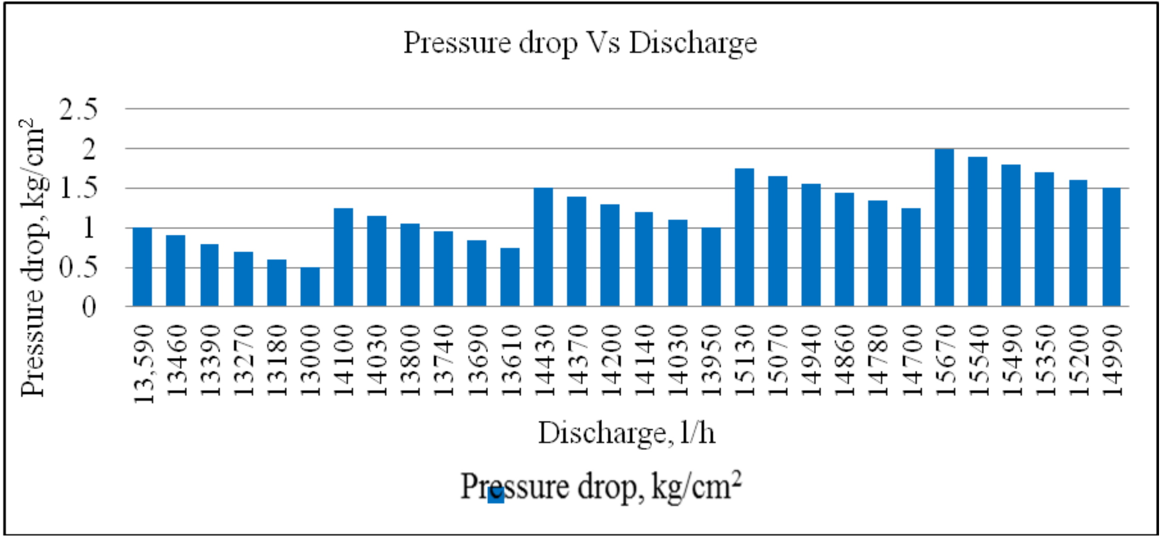


Fig 4.12 Discharge rate of device for size of 63 x 32 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.6 Suction rate of device for size of 63 x 32 mm at 70 cm height

The suction rate and performance was worked out for 63 mm Ø of inlet pipe with constricted portion of 32 mm when the outlet is allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 70 cm. The observations are reported in Table 4.9.

Table 4.9 Suction rate of device for size of 63 x 32 mm at 70 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator aboveground(cm)	Operating pressure (kg/cm^2)	Outlet Pressure (kg/cm^2)	Pressure drop (kg/cm^2)	Suction rate l/h	Discharge through outlet (l/h)
	1	0	1	124.14	13,530
	1	0.1	0.9	102.86	13420
70	1	0.2	0.8	85.72	13400
	1	0.3	0.7	75.00	13340
	1	0.4	0.6	61.01	13270
	1	0.5	0.5	52.94	13100
70	1.25	0	1.25	138.46	14000
	1.25	0.1	1.15	116.13	13970
	1.25	0.2	1.05	94.74	13880
	1.25	0.3	0.95	83.72	13740
	1.25	0.4	0.85	78.26	13690

	1.25	0.5	0.75	66.67	13610
70	1.5	0	1.5	156.52	14330
	1.5	0.1	1.4	120.00	14270
	1.5	0.2	1.3	97.30	14200
	1.5	0.3	1.2	83.72	14140
	1.5	0.4	1.1	70.59	14070
	1.5	0.5	1	57.14	13950
70	1.75	0	1.75	158.67	15100
	1.75	0.1	1.65	133.33	15010
	1.75	0.2	1.55	124.14	14920
	1.75	0.3	1.45	102.86	14810
	1.75	0.4	1.35	94.74	14760
	1.75	0.5	1.25	78.26	14700
70	2	0	2	161.64	15550
	2	0.1	1.9	134.47	15440
	2	0.2	1.8	126.30	15390
	2	0.3	1.7	111.00	15240
	2	0.4	1.6	93.63	15170
	2	0.5	1.5	87.35	14990

From Table 4.9 and as depicted in Fig. 4.13 and 4.14, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 124.14 l/h, 138.46 l/h, 156.52 l/h, 133.33 l/h and 161.64 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.8 kg/cm^2.

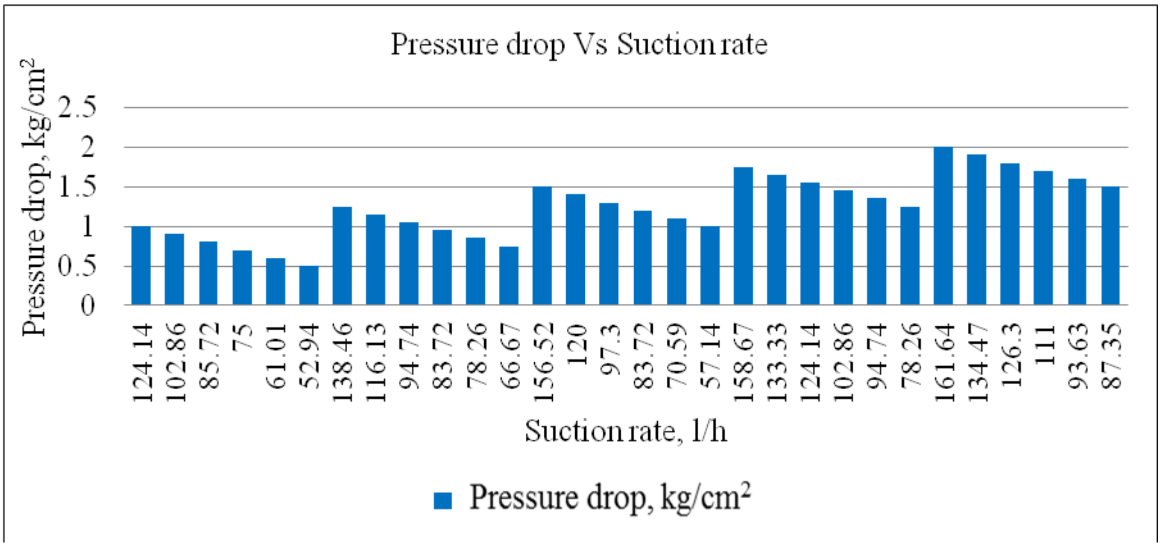


Fig. 4.13 Suction rate of device for size of 63 x 32 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

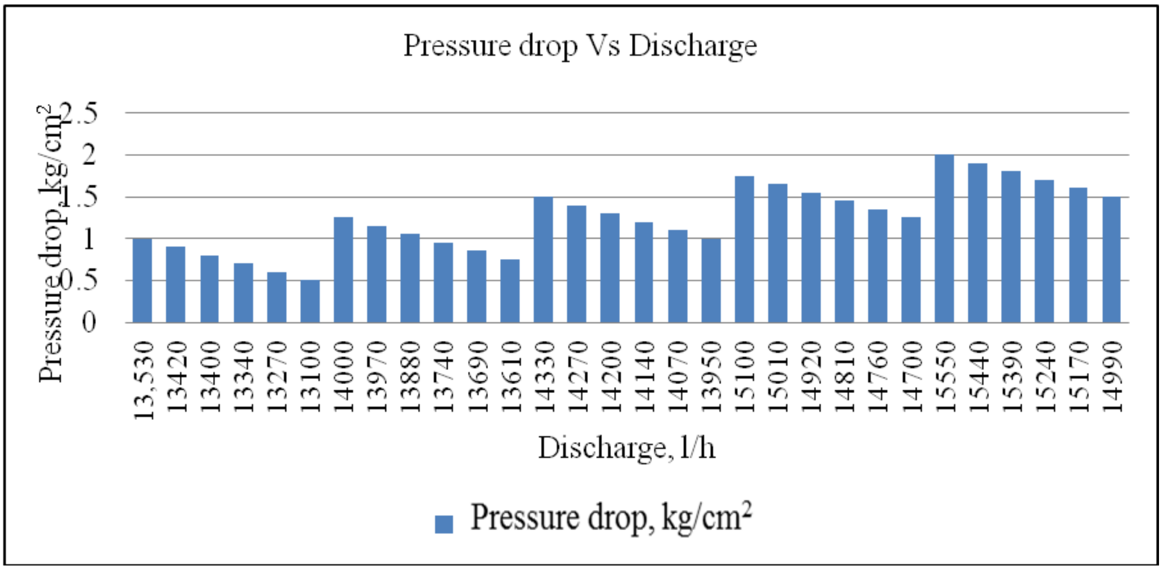


Fig. 4.14 Discharge rate of device for size of 63 x 32 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.7 Suction rate of device for size of 63 x 25 mm at 50 cm height

The suction rate and performance was worked out for 63 mm Ø of inlet pipe with constricted portion of 25 mm when the outlet was allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 50 cm. The observations are reported in Table 4.10.

Table 4.10 Suction rate of device for size of 63 x 25 mm at 50 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator Above ground cm	Operating pressure kg/cm^2	Outlet pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet l/h
50	1	0	1	116.12	13,500
	1	0.1	0.9	83.72	13420
	1	0.2	0.8	62.07	13360
	1	0.3	0.7	56.25	13240
	1	0.4	0.6	49.32	13170
	1	0.5	0.5	21.3	13040
50	1.25	0	1.25	138.46	14000
	1.25	0.1	1.15	112.5	13860
	1.25	0.2	1.05	92.3	13800
	1.25	0.3	0.95	81.81	13740
	1.25	0.4	0.85	63.93	13690
	1.25	0.5	0.75	52.94	13580
50	1.5	0	1.5	150	14430

	1.5	0.1	1.4	124.14	14290
	1.5	0.2	1.3	102.86	14200
	1.5	0.3	1.2	85.72	14120
	1.5	0.4	1.1	72	14010
	1.5	0.5	1	57.14	13900
50	1.75	0	1.75	153.67	15090
	1.75	0.1	1.65	127.3	14950
	1.75	0.2	1.55	116.5	14830
	1.75	0.3	1.45	93.58	14800
	1.75	0.4	1.35	85.67	14650
	1.75	0.5	1.25	80.12	14580
50	2	0	2	156.96	15470
	2	0.1	1.9	131	15340
	2	0.2	1.8	122.77	15290
	2	0.3	1.7	113.1	15150
	2	0.4	1.6	91.4	15000
	2	0.5	1.5	80.49	14970

From Table 4.10 and as depicted in Fig. 4.15 and 4.16, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 116.12 l/h, 138.46 l/h, 150 l/h, 153.67 l/h and 156.96 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

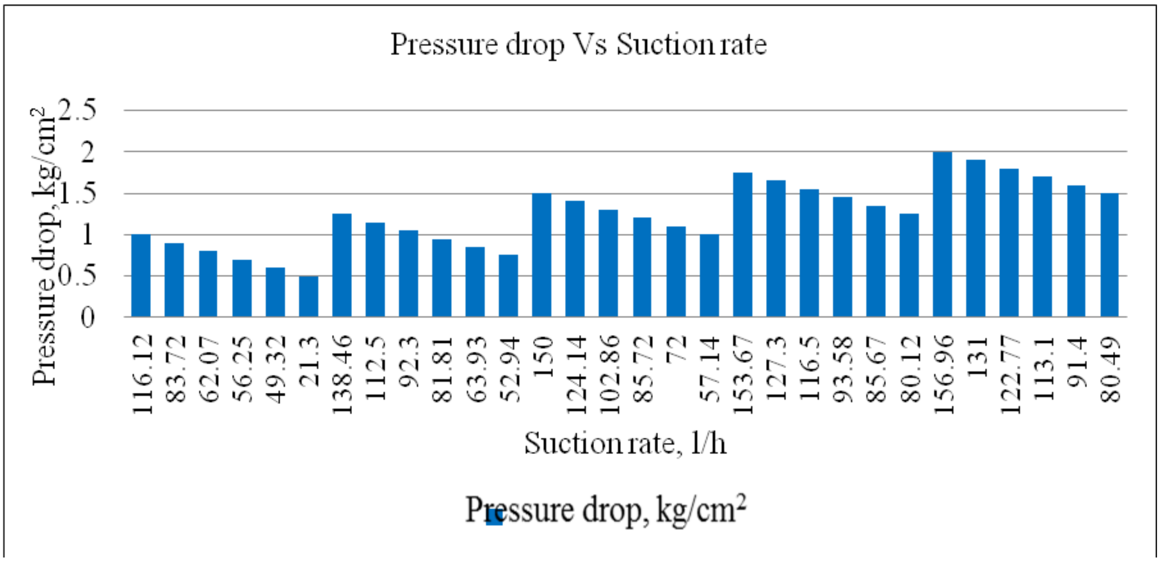


Fig 4.15 Suction rate of device for size of 63 x 25 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

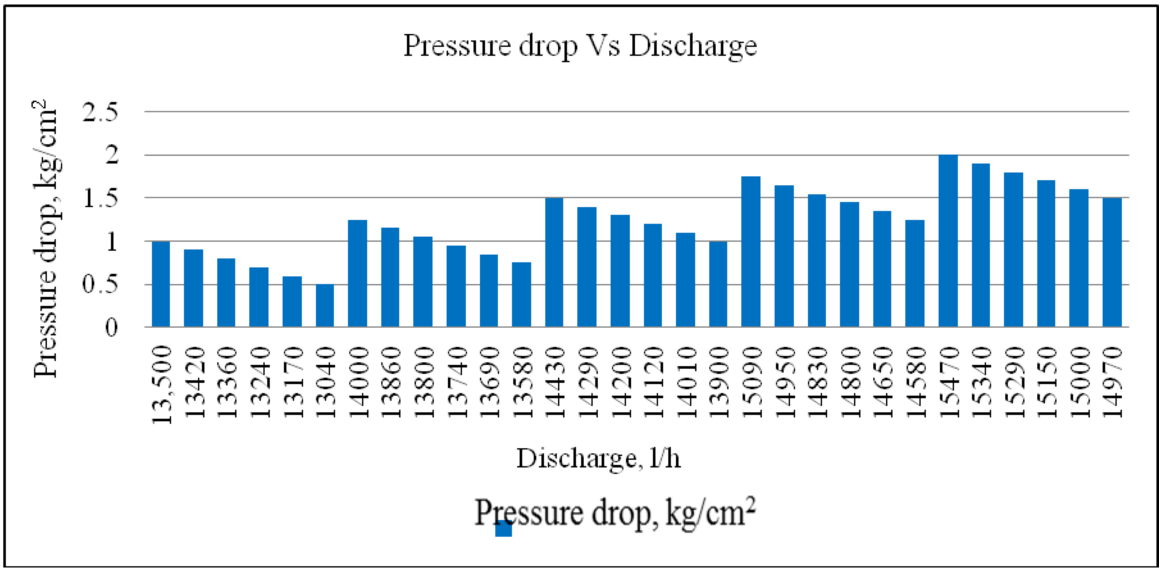


Fig 4.16 Discharge rate of device for size of 63 x 25 mm at 50 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.1.8 Suction rate of device for size of 63 x 25 mm at 70 cm height

The suction rate and performance was worked out for 63 mm Ø of inlet pipe with constricted portion of 25 mm when the outlet is allowed to deliver in atmosphere with respect to operating pressure at inlet pipe as 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 and the height of the device was maintained as 70 cm. The observations are reported in Table 4.11.

Table 4.11 Suction rate of device for size of 63 x 25 mm at 70 cm height when operated at 1-2 kg/cm^2 with increment of 0.25 kg/cm^2.

Height of applicator Above ground, cm	Operating pressure kg/cm^2	Outlet pressure kg/cm^2	Pressure drop kg/cm^2	Suction rate l/h	Discharge through outlet l/h
70	1	0	1	144	13,430
	1	0.1	0.9	100	13400
	1	0.2	0.8	85.71	13370
	1	0.3	0.7	73.47	13300
	1	0.4	0.6	64.29	13260
	1	0.5	0.5	45.57	13210
70	1.25	0	1.25	156.52	13610
	1.25	0.1	1.15	128.57	13560
	1.25	0.2	1.05	105.88	13500
	1.25	0.3	0.95	87.81	13540
	1.25	0.4	0.85	73.47	13480
	1.25	0.5	0.75	62.07	13400
70	1.5	0	1.5	171.43	14260

	1.5	0.1	1.4	138.46	14120
	1.5	0.2	1.3	116.13	14090
	1.5	0.3	1.2	92.3	13900
	1.5	0.4	1.1	80	13830
	1.5	0.5	1	63.16	13730
70	1.75	0	1.75	175.87	14900
	1.75	0.1	1.65	143.56	14850
	1.75	0.2	1.55	129.5	14800
	1.75	0.3	1.45	116.98	14750
	1.75	0.4	1.35	97.78	14690
	1.75	0.5	1.25	80.7	14590
70	2	0	2	189.08	15470
	2	0.1	1.9	146.48	15340
	2	0.2	1.8	131.67	15270
	2	0.3	1.7	126	15150
	2	0.4	1.6	94.07	14960
	2	0.5	1.5	87.91	14890

From Table 4.11 and as depicted in Fig. 4.17 and 4.18, it is observed that when the developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1. 5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2), the suction rate is found to be maximum i.e. 144 l/h, 156.52 l/h, 171.43 l/h, 175.87 l/h and 189.08 l/h respectively and reduced the suction rate when outlet pressure was increased from 0.1 kg/cm^2 to 0.5 kg/cm^2.

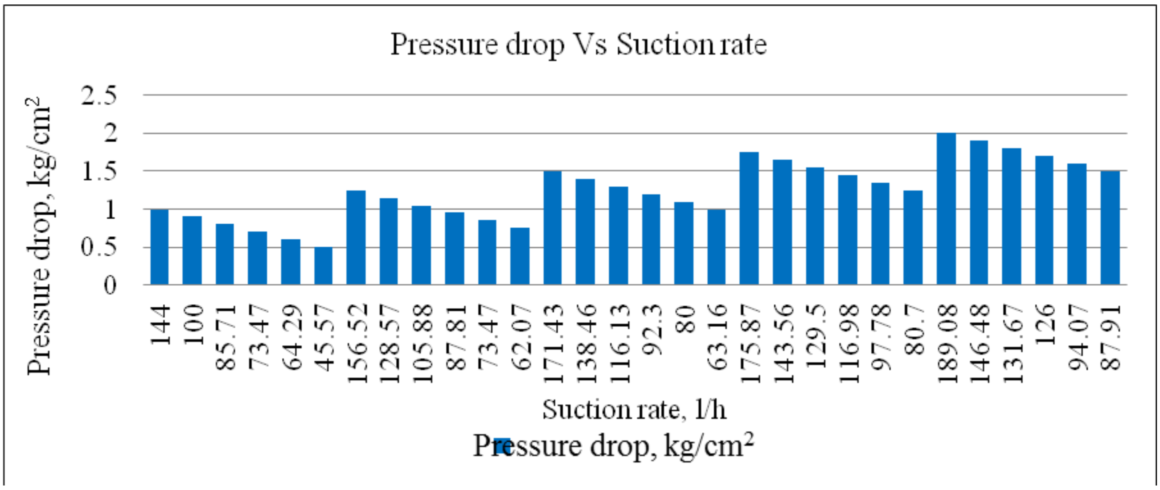


Fig 4.17 Suction rate of device for size of 63 x 25 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

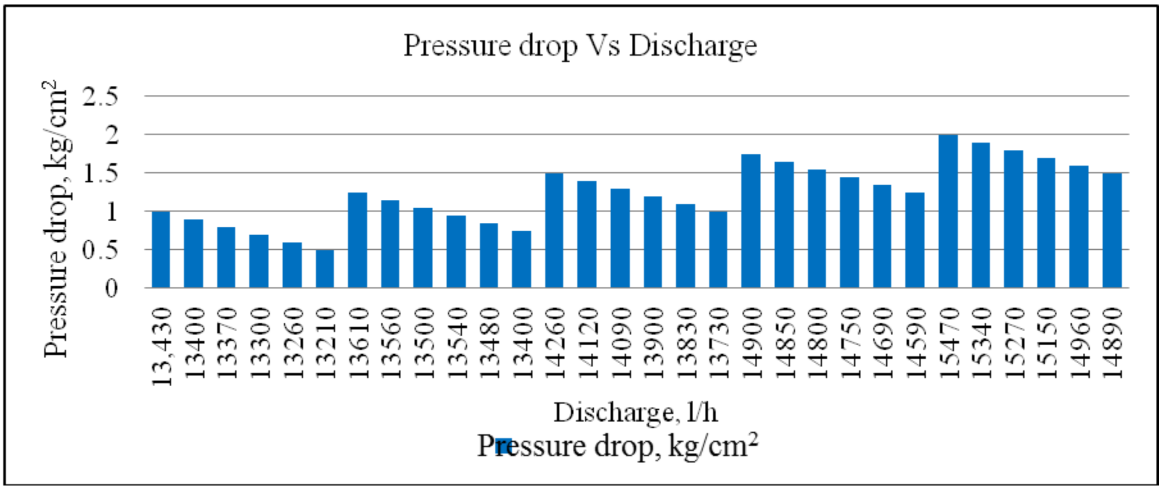


Fig 4.18 Discharge rate of device for size of 63 x 25 mm at 70 cm height when operated at 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2.

4.8.2 Testing of developed devices

The testing of initially developed devices were undertaken i.e. for 63 mm x 32 mm, 63 mm x 25 mm, 50 mm x 32 mm and 50 mm x 25 mm for an operating pressure of 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2 for 70 cm height to the existing drip irrigation set installed at instructional farm of IDE. For the purpose one by one devices was installed starting from 63 mm x 32 mm to the drip irrigation system. There were total 30 nos. of laterals of 16 mm Ø within the drip irrigation set where lateral spacing was kept 1.75 x 1.75 m. Emitter were placed at 40 cm with discharge of 2.1 l/h. The length of lateral was kept as 30 m and operated as operating pressure of 1 to 2 kg/cm^2 with and increment of 0.25 kg/cm^2. Even in the first case the lateral ends were closed and in the second case when lateral ends were kept open to the atmosphere, however in both cases the suction did not form, on the contrary there was back flow from the micro tube which was fitted to suck the fertilizer to throat or constricted portion. It is very important to note that when the developed devices were tested one by one for the operating pressure under consideration by keeping the delivery outlet in the open air i.e. at atmospheric pressure and by maintaining the outlet pressure i.e. from 0.1 to 0.5 kg/cm^2, it was observed that the suction was found in all the developed devices and the respective data is presented in Table 4.4 to 4.11. For this testing the height of the devices were maintain at 50 cm and 70 cm from G.L. (ground level).

Therefore as it is described in section 4.8.1 that there is chance to modify the constricted/throat section to form the suction to get desired suction rate with allowable pressure drop. Therefore by keeping all other components and dimensions same, modified only the constructed/throat as described in section 4.9 and it becomes 63 mm x 16 mm and 50 mm x 16 mm. These two devices were further precisely tested for the operating pressure of 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2 on instructional for with above described set of drip irrigation system.

4.9 Testing of the device on instructional farm of IDE

The devices as given in Figure 3.8 was installed for its testing and to study the hydraulic performance on the instructional farm of IDE and to existing set of drip irrigation system comprises 30 Nos. of 16 mm laterals spaced at 1.75 x 1.75 m apart. The emitter spacing was 40 cm with emitter discharge of 2.1 l/h. The length of lateral was undertaken 30 m. The size of field was 53 m x 30 m. The devices were tested at different operating pressure of 1 to 2.5 kg/cm^2 with and increment of 0.1 kg/cm^2. Therefore in all total there were 16 nos. of pressure rating combinations to know the suction rate, pressure drop, emission discharge of the drip irrigation along with the emission uniformity. Accordingly the system was run for the specific time (15 minute) for testing the devices.

4.9.1 Testing of the 50 x 16 mm fertigation device on instructional farm of IDE

Testing of device 50 mm x 16 mm was carried out by adopting the procedure as described in section 4.8 and 4.9. Accordingly the data was collected for an operating pressure of 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2 for the same set of drip irrigation system and tabulated in Table 4.12. The observations are recorded and tabulated in the Table 4.12 and also depicted in Figure 4.19 to Fig 4.22.

Table 4.12 Performance evaluation of device for fertigation for size 50 x 16 mm at 70 cm height.

Operating pressure kg/cm^2	Pressure drop kg/cm^2	Suction Rate, l/h	Percent increase in suction rate, %	Discharge of system, l/h	Average emission rate, l/h	Average Emission uniformity %
1	0.6	20.91	0	4699.69	2.09	96.46
1.1	0.7	21.03	0.57	4735.29	2.1	96.73
1.2	0.8	22.33	6.18	4678.27	2.08	97
1.3	0.9	23.74	6.31	4706.04	2.09	97.2
1.4	1	28.52	20.13	4770.86	2.12	97.49
1.5	1.1	32.9	15.36	4830.52	2.15	97.64
1.6	1.1	33.28	1.15	4783.95	2.13	97.89

1.7	1.2	34.35	3.22	4819.56	2.14	98.02
1.8	1.4	35.57	3.55	5005.72	2.22	98.19
1.9	1.425	37.65	5.85	5114.35	2.27	98.46
2	1.525	39.39	4.62	5167.29	2.3	98.73
2.1	1.6	40.63	3.15	5296.85	2.35	98.9
2.2	1.7	43.59	7.29	5491.11	2.44	99.01
2.3	1.8	46.27	6.15	5812.43	2.58	99.09
2.4	1.9	47.49	2.64	5919.04	2.63	99.13
2.5	2	48.39	1.89	5947.01	2.64	99.26

From Table 4.12 and Fig. 4.19, 4.20 and 4.21 and 4.22 it is revealed that, the maximum suction (48.39 l/h) is observed to be at operating pressure of 2.5 kg/cm^2 when pressure drop was 2 kg/cm^2. In general the suction rate is increasing with the increasing operating pressure and simultaneously increasing pressure drop. It is very interesting to note that the percent increase in suction rate drastically increases with the operating pressure form 1 to 1.4 kg/cm^2 and i.e. 7 % to 20.13%, then after even though the operating pressure increases the percent increase in the suction rate do not increases in that proportionate and on the contrary from 1.5 kg/cm^2 to 2.5 kg/cm^2 started to decrease and at even 2.5 kg/m^2 it was found to be only 1.89 % increase. There is no any specific trend observed in case of the pressure discharge relationship. However in general as the pressure increases, the discharge also increases. From the data it is observed that from an operating pressure of 1 to 1.5 kg/m^2 the discharge is found to be more or less similar.

The emission rate (l/h) and emission uniformity is increases with increases in operating pressure. The emission uniformity is found to be in the range of 96.46 to 99.26% which is in excellent zone while the emission rate is found to be in the range of 2.09 to 2.64 l/h for the operating pressure of 1 to 2.5 kg/cm^2 with and an increment of 0.1 kg/ cm^2.

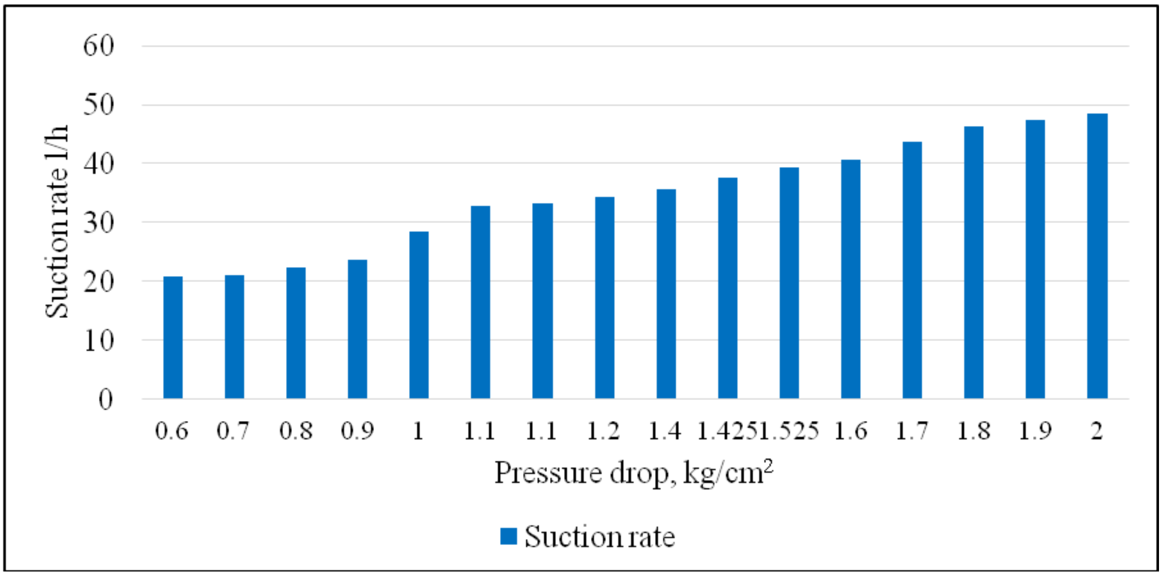


Fig 4.19 Suction rate of device for size of 50 x 16 mm at 70 cm height when operated at 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2.

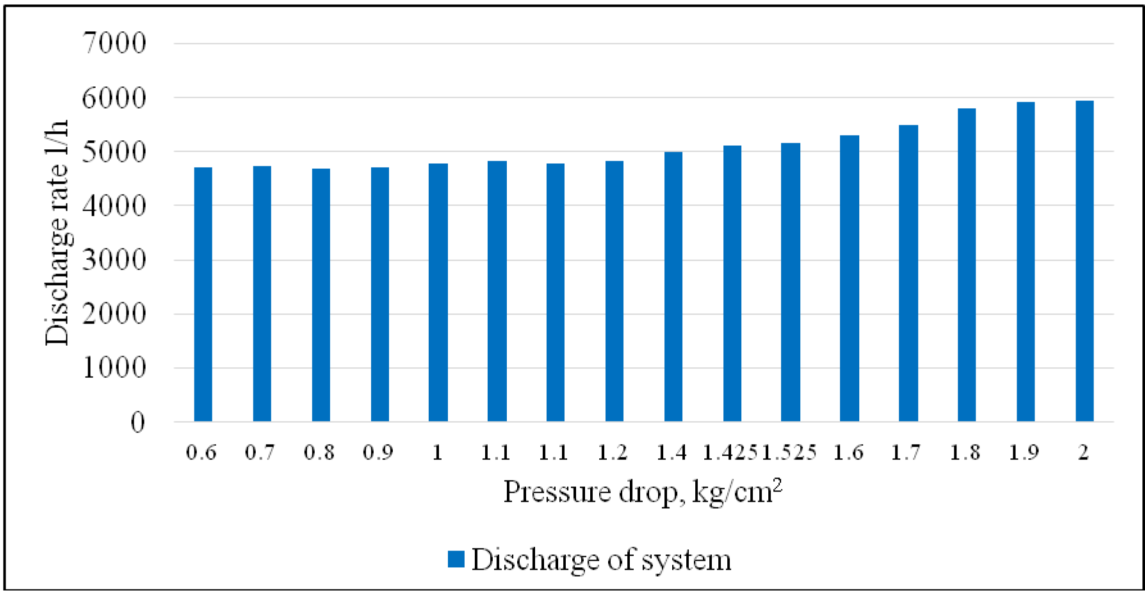


Fig 4.20 Discharge rate of device for size of 50 x 16 mm at 70 cm height when operated at 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2.

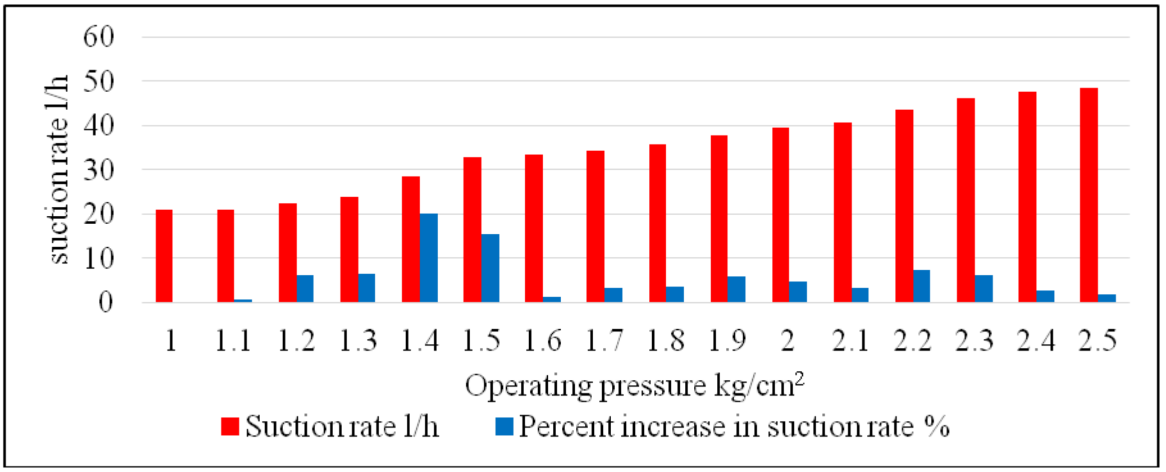


Fig 4.21 Different operating pressure Vs Percent increase in suction rate (%)

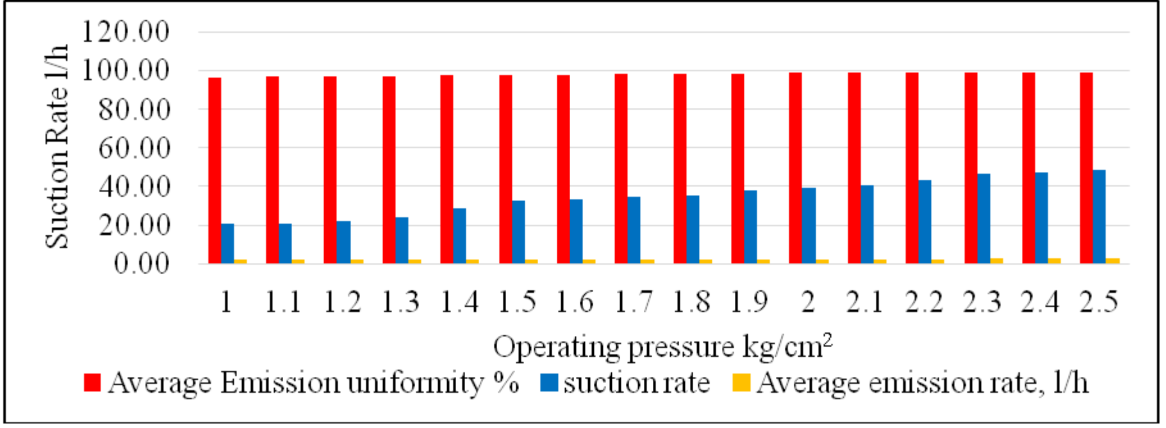


Fig. 4.22 Average emission rate (%), suction rate (lph) and emission uniformity (%) as influenced by different operating pressure.

4.9.2 Testing of the 63 x 16 mm fertigation device on instructional farm of IDE

Testing of device 63 mm x 16 mm was carried out by adopting the procedure as described in section 4.8 and 4.9. Accordingly the data was collected for an operating pressure of 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2 for the same set of drip irrigation system and tabulated in Table 4.13. It is also depicted in Figures 4.23, 4.24, 4.25 to 4.26. Surprisingly the same trends of results are obtained as observed for 50 mm x 16 mm.

Table 4.13 Performance evaluation of device for fertigation for size 63 x 16 mm at 70 cm height.

Operating pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction rate l/h	Percent increase in suction rate %	Discharge of system l/h	Average emission rate, l/h	Average Emission uniformity %
1	0.7	21.13	0	4463.44	1.98	98.34
1.1	0.8	22.31	5.58	4833.84	2.15	98.45
1.2	0.9	23.15	3.77	4707.28	2.09	98.55
1.3	0.9	24.23	4.67	4995	2.22	98.61
1.4	1	27.1	11.84	5244.47	2.33	98.74
1.5	1.1	32.22	18.89	5533.31	2.46	98.82
1.6	1.1	33.71	4.62	5634.56	2.5	98.89
1.7	1.2	37.28	10.59	5697.84	2.53	98.91
1.8	1.2	39.82	6.81	5711.34	2.54	98.99
1.9	1.3	44.89	12.73	5798.25	2.58	99.05
2	1.4	46.63	3.88	5987.25	2.66	99.13
2.1	1.5	46.87	0.53	6236.15	2.77	99.32
2.2	1.6	49.58	6.33	6220.96	2.76	99.47
2.3	1.7	55.04	11.04	6423.46	2.85	99.53
2.4	1.8	60.44	9.81	6812.43	3.03	99.61
2.5	1.9	73.49	21.59	7085.81	3.15	99.74

From Table 4.13, the minimum and maximum suction rate was found to be 21.13 l/h and 73.49 l/h for an operating pressure of 1 kg/cm^2 and 2.5 kg/cm^2 respectively. The percent increase is suction rate was drastically increased from operating pressure of 1 to 1.5 kg/cm^2 and then after slower drop down except 2.5 kg/cm^2. It is observed that there is no any specific trend in the percent increase in the suction rate for 1.6 to 2.4 kg/cm^2 operating pressure.

The pressure discharge relationship has shown increase in the discharge when pressure increases however as for 50 mm x 16 mm there is no any specific trend is observed.

The minimum and maximum values of discharge (l/h) were observed for 1.0 kg/cm^2 and 2.5 kg/cm^2 and i.e. 4463.44l/h and 7085.81l/h. The average emission rate also somewhat increasing with increase in the pressure right from 1 to 1.5 kg/cm$^{2.}$ However from 1.5 kg/cm^2 to onward it is increasing with somewhat higher rate. The emission rate (l/h) was observed to be 1.90 l/h and 3.15 l/h minimum and maximum respectively for an operating pressure of 1.0 kg/cm^2 and 2.5kg/cm^2. While the emission uniformity was observed in the range of 98.34 to 99.74 % for an operating pressure of 1 to 2.5 kg/cm^2. In general the emission uniformity increases with an increase in operating pressure and for all the operating pressure, it is observed above 98.00 % which is in the excellent zone.

In general it is concluded that the all the values of suction rate, emission rate, discharge, emission uniformity are observed to be higher for 63 mm x 16 mm with the same operating pressure of 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2 than the 50 mm x 16 mm device, it is due to the effect of large size of inlet pipe with same constricted/ throat portion.

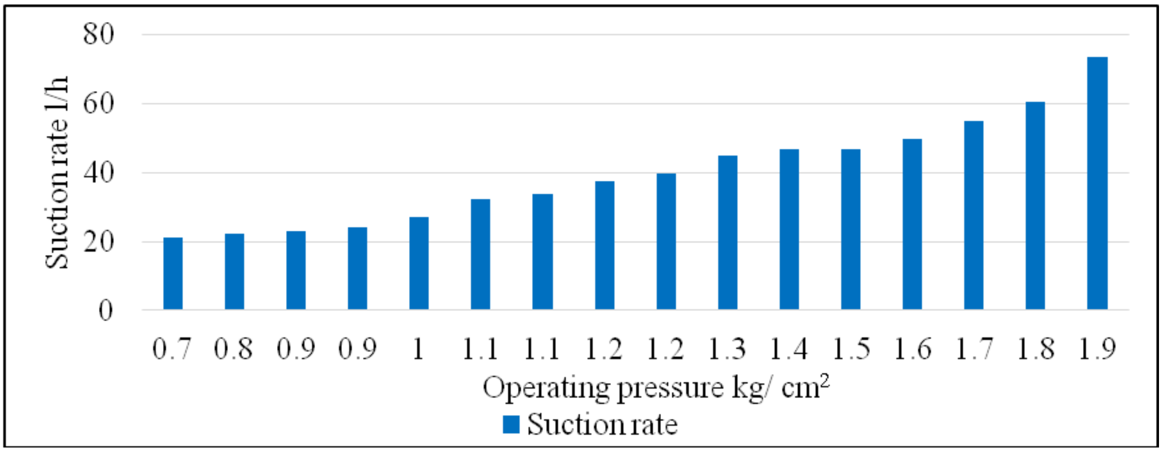


Fig 4.23 Suction rate of device for fertigation for size of 50 x 16 mm at 70 cm height when operated at 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2

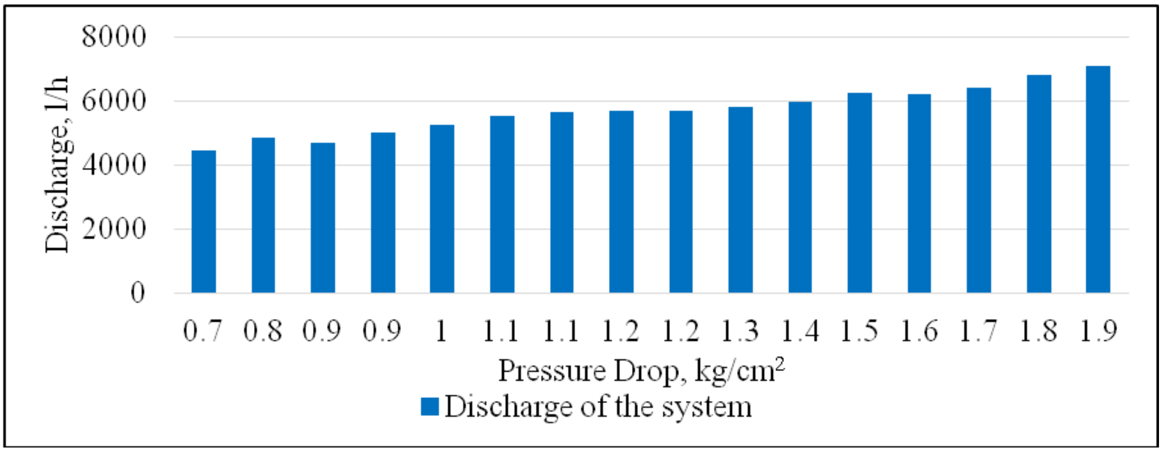


Fig 4.24 Discharge rate of device for fertigation for size of 50 x 16 mm at 70 cm height when operated at 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2

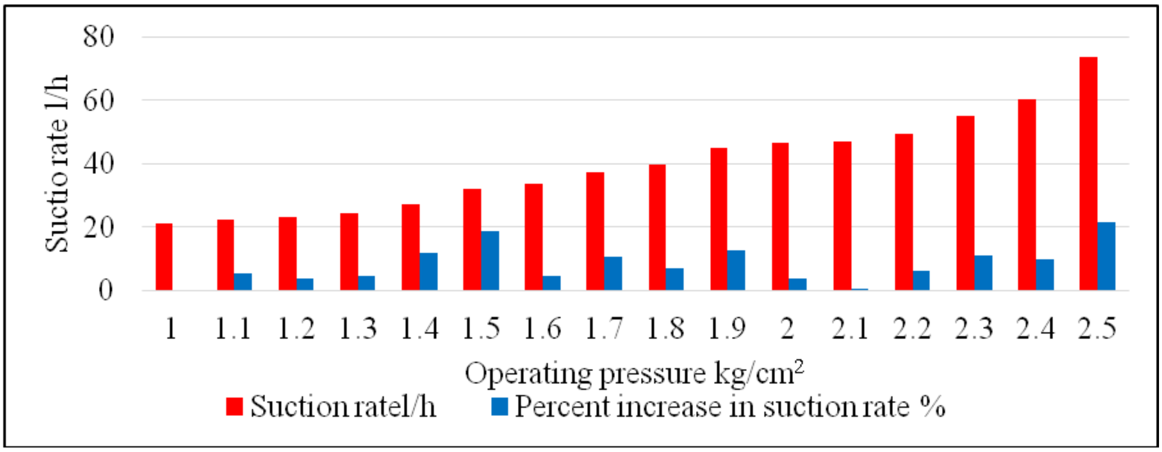


Fig 4.25 Different operating pressure Vs Percent increase in suction rate (%)

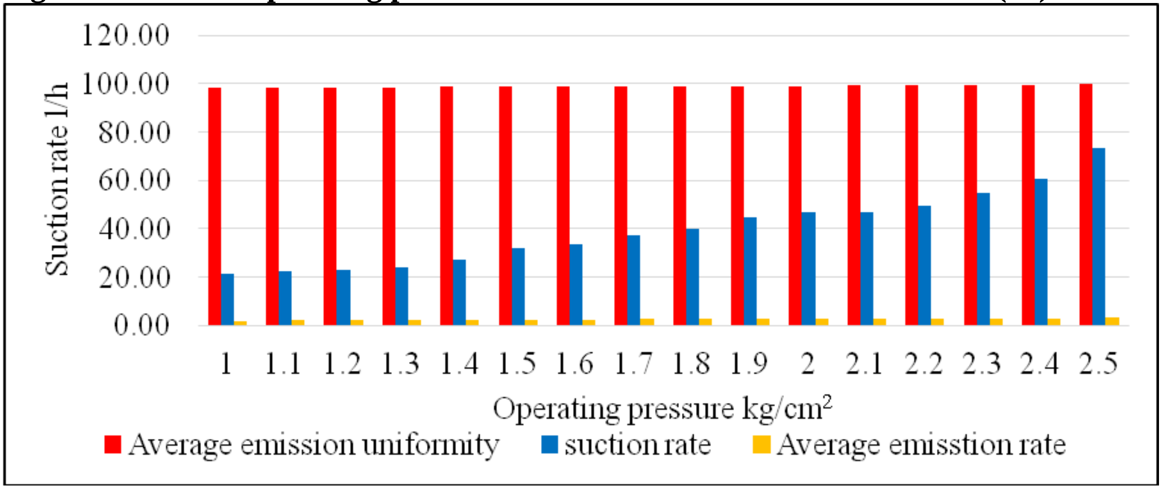


Fig 4.26 Average emission rate (%), suction rate (lph) and emission uniformity (%) as influenced by different operating pressure.

4.9.3 Study of Pressure drop and velocity at inlet and constricted portion of 50 x 16 mm device.

The pressure and velocity at different section of the device was worked out for of inlet 50 mm Ø with constricted portion of 16 mm to check whether the suction is forming or not when the operating pressure was 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2. While recording the observation the height of device was maintain as 70 cm from ground level. The relation between pressure drop and velocity at constricted/throat portion for each operating pressure is also studied and as shown graphically in Fig 4.27. Venturi effect is observed due to drop of sudden pressure and sudden increase in velocity at constricted/ throat portion of the velocity and as described in section 3.4.2.2. The method of measurement of velocity at different sections of device as described in section 3.4.7 (3.4.7.1 and 3.4.7.2). Accordingly, the observations were recorded to determine the relationship between cross section area, pressure drop, velocity at inlet section and velocity at constricted section. These observations are tabulated below in Table 4.14.

Table 4.14 Pressure drop and velocity at inlet and constricted portion of 50 x 16 mm device.

Operating pressure kg/cm^2	Pressure drop kg/cm^2	Velocity at inlet m/s	Velocity at constricted portion m/s
1	0.6	0.6652	1.1094
1.1	0.7	0.6702	1.1966
1.2	0.8	0.6622	1.2768
1.3	0.9	0.6661	1.3531
1.4	1	0.6753	1.4257
1.5	1.1	0.6837	1.4948
1.6	1.1	0.6771	1.4943
1.7	1.2	0.6822	1.5602
1.8	1.4	0.7085	1.6851
1.9	1.425	0.7239	1.7009
2	1.525	0.7314	1.7593
2.1	1.6	0.7497	1.8027
2.2	1.7	0.7772	1.8594
2.3	1.8	0.8227	1.9163
2.4	1.9	0.8378	1.9691
2.5	2	0.8418	2.0197

From Table 4.14, the minimum and maximum velocity at constricted portion was found to be 1.1094 m/s and 2.0197 m/s for an operating pressure of 1 kg/cm^2 and 2.5 kg/cm^2 respectively. The velocity at constricted portion was drastically increased as operating pressure increased from 1 to 2.5 kg/cm^2. The increasing trend of velocity with respect to the pressure drop is depicted in Fig 4.27. Increase in the velocity lowers the pressure in the constricted portion which causing suction formation and increases the suction rate

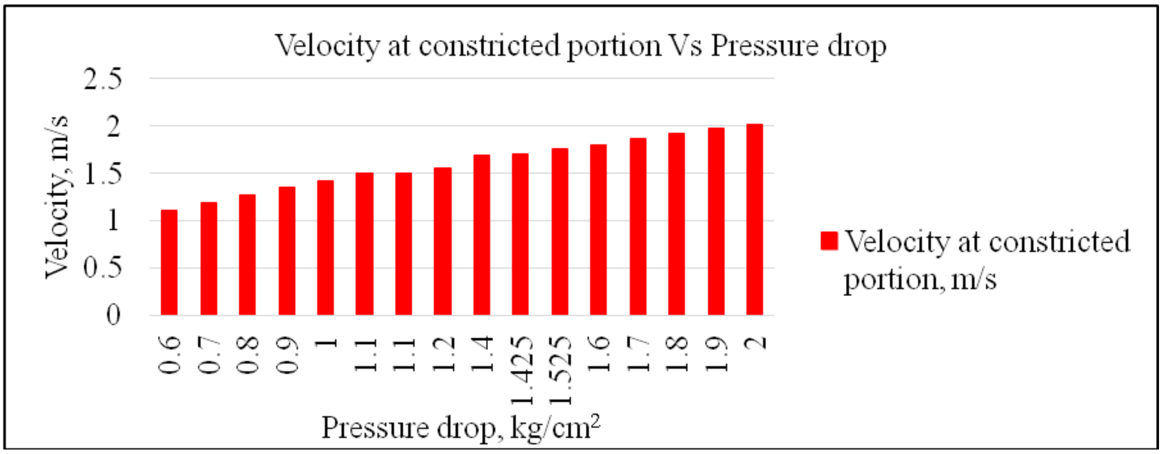


Fig 4.27 Relation between pressure drop and velocity at constricted section of 50 x 16 mm device.

4.9.4 Study of Pressure drop and velocity at inlet and constricted portion of 63 x 16 mm device.

The pressure and velocity at different section of the device was worked out for 63 mm Ø with constricted portion of 16 mm to check whether the suction is forming or not when the operating pressure was 1 to 2.5 kg/cm^2 with an increment of 0.1 kg/cm^2. While recording the observation the height of device was maintain as 70 cm from ground level. The necessary data is recorded and tabulated in Table 4.15. The relation between pressure drop and velocity at constricted/throat portion for each operating pressure was also studied and as shown graphically in Fig 4.28. Venturi effect is observed due to drop of sudden pressure and sudden increase in velocity at constricted/ throat portion of the velocity and as described in section 3.4.2.2. The method of measurement of velocity at different sections of device as described in section 3.4.7 (3.4.7.1 and 3.4.7.2). Accordingly, the observations were recorded to determine the relationship between cross section area, pressure drop, velocity at inlet section and velocity at constricted section. These observations are tabulated below in Table 4.15.

Table 4.15 Pressure drop and velocity at inlet and constricted portion of 63 x 16 mm device.

Operating pressure kg/cm^2	Pressure drop kg/cm^2	Velocity at inlet m/s	Velocity at constricted portion m/s
1	0.7	0.3978	1.2483
1.1	0.8	0.4308	1.3363
1.2	0.9	0.4195	1.4057
1.3	0.9	0.4451	1.4136

1.4	1	0.4674	1.4894
1.5	1.1	0.4931	1.5631
1.6	1.1	0.5021	1.5659
1.7	1.2	0.5078	1.6303
1.8	1.2	0.5090	1.6307
1.9	1.3	0.5167	1.6932
2	1.4	0.5336	1.7563
2.1	1.5	0.5557	1.8190
2.2	1.6	0.5544	1.8728
2.3	1.7	0.5724	1.9307
2.4	1.8	0.6071	1.9921
2.5	1.9	0.6315	2.0491

From Table 4.15, the minimum and maximum velocity at constricted portion was found to be 1.2483 m/s and 2.0491 m/s for an operating pressure of 1 kg/cm^2 and 2.5 kg/cm^2 respectively. The velocity at constricted portion was drastically increased from operating pressure of 1 to 2.5 kg/cm^2. The increase in trend of velocity with respect to the pressure drop is depicted in Fig 4.28. The same trend was observed as in developed device of size 50 x 16 mm.

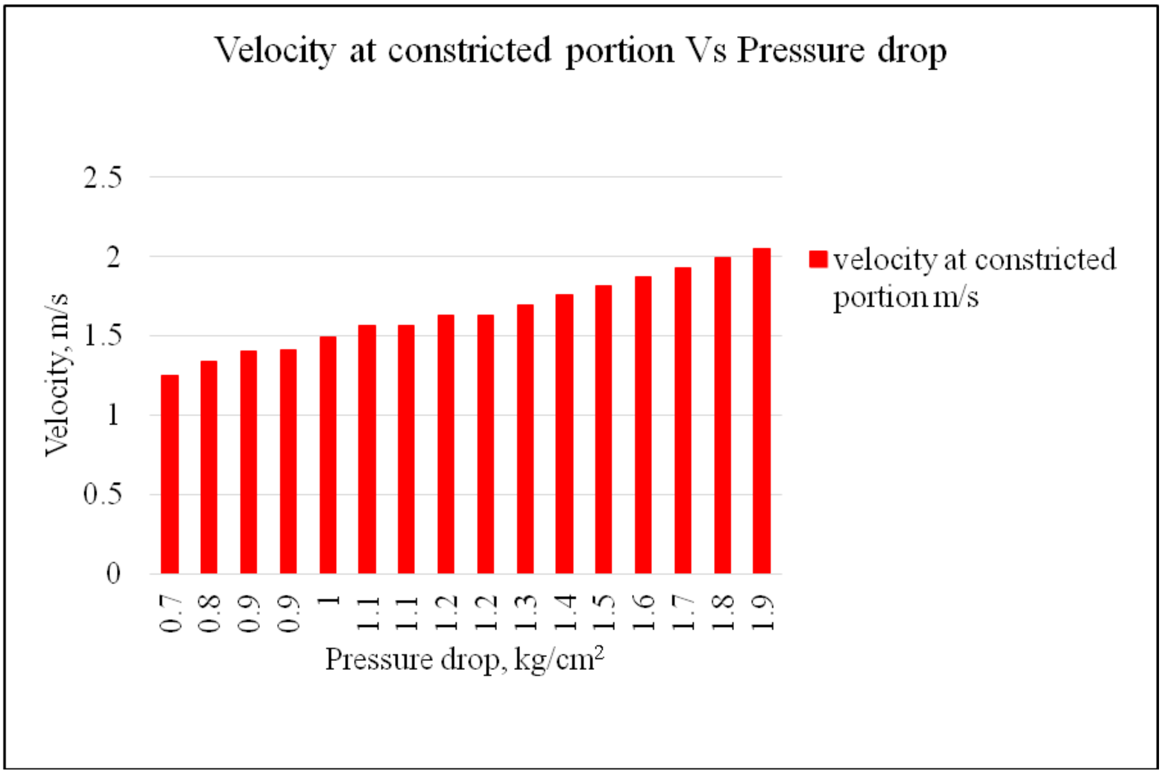


Fig 4.28 Relation between pressure drop and velocity at constricted section of developed device 63 x 16 mm

4.9.5 Study of pressure and velocity at constricted portion

Pressure drop and increase in velocity for all the devices i.e. 50 x 32 mm, 50 x 25 mm, 50 x 16 mm, 63 x 32 mm, 63 x 25 mm and 63 x 16 mm when operated at 1 to 2.5 kg/cm^2 as inlet pressure were undertaken by operating the system for particular time period (15 minutes). The heights of all the devices were kept 70 cm from G.L. The necessary data regarding operating pressure, velocities at different suction, pressure drop and difference in velocities at inlet and constricted portion was recorded and tabulated in Table 4.16 and depicted in Fig 4.29.

From Table 4.16 and Fig 4.29 and Fig 4.30 it is observed that as operating pressure at inlet increases velocity at inlet also increases and also at constricted portion. The same trend was also observed for the all devices i.e. 63 x 32 mm, 50 x 32 mm, 63 x 25 mm, 50 x 25 mm, 63 x 16 mm and 50 x 16 mm when operated at 1 to 2 kg/cm^2 operating pressure at inlet. When the device 50 x 32 mm, 50 x 25 mm and 50 x 16 mm were operated at 1 kg/cm^2 inlet pressure and as shown in Fig 4.1 the difference in velocity i. e. from inlet section to constricted section was found to be 0.32 m/s, 0.32 m/s and 0.44 m/s likewise the increasing trend was observed for 1.25 to 2 kg/cm^2.

When the devices 63 x 32 mm, 63 x 25 mm and 63 x 16 mm were operated at 1 kg/cm^2 inlet pressure and as shown in Fig 4.1 the difference in velocity i. e. from inlet section to constricted section was found to be observed 0.41 m/s, 0.35 m/s and 0.35 m/s. It is important to note that velocity difference from inlet section to throat section goes on increasing from 1 to 2.5 kg/cm^2 as similar to that of 50 x 32 mm, 50 x 25 mm and 50 x 16 mm. However it is also very interesting to note that for 63 x 32 mm and 63 x 25 mm the difference in velocity from inlet section to the throat section slowly increases and for 63 x 16 mm it drastically increases which caused to form the suction.

From Table 4.16 and Fig 4.29 and Fig 4.30 it is also observed that when the difference of velocity at constricted section becomes half or more than half of inlet then and then only the suction will takes place. Therefore, it is also very pertinent to note that from the data presented in Table 4.16 as in case 50 x 32 mm, 50 x 25 mm and 63 x 32 mm, 63 x 25 mm the difference of velocity at constricted section it is less than ½ or 50% of the inlet pressure, the suction did not take place.

Table 4.16 Comparison of the velocities at different sections of developed fertigation devices

Size of device mm	Operating pressure at inlet kg/cm^2	Pressure drop kg/cm^2	Velocity at inlet m/s	Velocity at contracted portion m/s	Difference between velocity at two section	Percent Variation in velocity, %	Size of device mm	Operating pressure at inlet kg/cm^2	Pressure drop kg/cm^2	Velocity at inlet m/s	Velocity at contracted portion m/s	Difference between velocity at two section	Percent Variation in velocity, %
50x32	**1**	0.5	1.385	1.7082	0.3232	**22.61**	63x32	**1**	0.7	1.47	1.8871	0.4171	27.00
	1.25	0.6	1.405	1.7816	0.3766	27.14		**1.25**	0.8	1.5389	1.9921	0.4532	30.00
	1.5	0.6	1.4115	1.7867	0.3752	26.24		**1.5**	0.8	1.8675	2.2556	0.3881	21.00
	1.75	0.9	1.4261	1.958	0.5319	37.32		**1.75**	0.95	2.1226	2.5309	0.4083	19.34
	2	0.9	1.4339	1.9637	0.5298	37.06		**2**	1	2.1479	2.5717	0.4238	20.00
50x25	**1**	0.7	1.1094	1.4337	0.3243	30.00	63x25	**1**	0.6	1.5279	1.88	0.3521	23.68
	1.25	0.8	1.4115	1.8954	0.4839	34.05		**1.25**	0.7	1.6173	2.0039	0.3866	24.22
	1.5	0.8	1.4371	1.9445	0.5074	35.01		**1.5**	0.9	2.0918	2.4851	0.3933	18.66
	1.75	0.95	1.4375	1.9916	0.5541	39.00		**1.75**	1	2.1428	2.5674	0.4246	19.63
	2	1	1.4393	2.0178	0.5785	39.00		**2**	1.2	2.1683	2.6649	0.4966	23.14
50x16	**1**	0.6	0.6652	1.1094	0.4442	66.67	63x16	**1**	0.7	0.3978	1.2483	0.8505	213.0
	1.25	0.8	0.6622	1.2768	0.6146	92.42		**1.25**	0.9	0.4195	1.4057	0.9862	233.0
	1.5	1.1	0.6837	1.4948	0.8111	119.00		**1.5**	1.1	0.4931	1.5631	1.07	218.0
	1.75	1.2	0.6822	1.5602	0.878	129.00		**1.75**	1.2	0.5078	1.6303	1.1225	226.0
	2	1.525	0.7314	1.7593	1.0279	139.00		**2**	1.4	0.5336	1.7563	1.2227	230.0

Therefore when these devices installed at field with existing drip irrigation set as described in section 3.5.7 those failed to suck and only form the back flow through micro tube i.e. suction line. From data depicted in Table 4.16 as the difference velocities observed to be ½ or more than ½ that of inlet in case of 50 x 16 mm and 63 x 16 mm suction took place when tested at field condition with existing drip irrigation system for the operating pressure of 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2. In general it is said that the constricted section be so designed that it should have the velocity difference ½ or more that of the inlet. Therefore hypothesis holds good.

It is also observed that from the data presented in Table 4.16 and as shown in Fig 4.29 and 4.30, that it is also very interesting to and important to take into account the percent increase in velocity from inlet section to constricted section. From that it is revealed that when all the set of devices i. e. 63 x 32 mm, 50 x 32 mm, 63 x 25 mm, 50 x 25 mm, 63 x 16 mm and 50 x 16 mm were operated at different operating pressure from 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2 with same set of conditions it is very pertinent to note that when set of 63 x 32 mm and 63 x 25 mm, 50 x 32 mm and 50 x 25 mm operated at different operating pressure from 1 to 2 kg/cm^2 with an increment of 0.25 kg/cm^2, the percent increase in velocities were found to in the range 22.61 % and 39.00 % and 27.00 % to 24.22 % respectively.

It is indicative that the percent increase in the velocities did not cross even 40 % increase at constricted section where suction did not takes place. On the other hand in case of set of device 50 x 16 mm and 63 x 16 mm when operated at 1 to 2 kg/cm^2 with increment of 0.25 kg/cm^2 the percent increase in velocities at constricted section was found to be in the range of 66.67 % to 139.00 % and 213 % to 230 % respectively when both the devices were fitted as shown in Fig 4.1 and described in section 3.4.7 with the existing drip irrigation set at Instructional farm of IDE. Therefore it is very important to state that to form the suction, it is needed to have the % increase in velocity more than 67 % at constricted portion. According to the size of constricted portion, inlet operating pressure and size of inlet pipe is to be designed and decided. Therefore the hypothesis holds good.

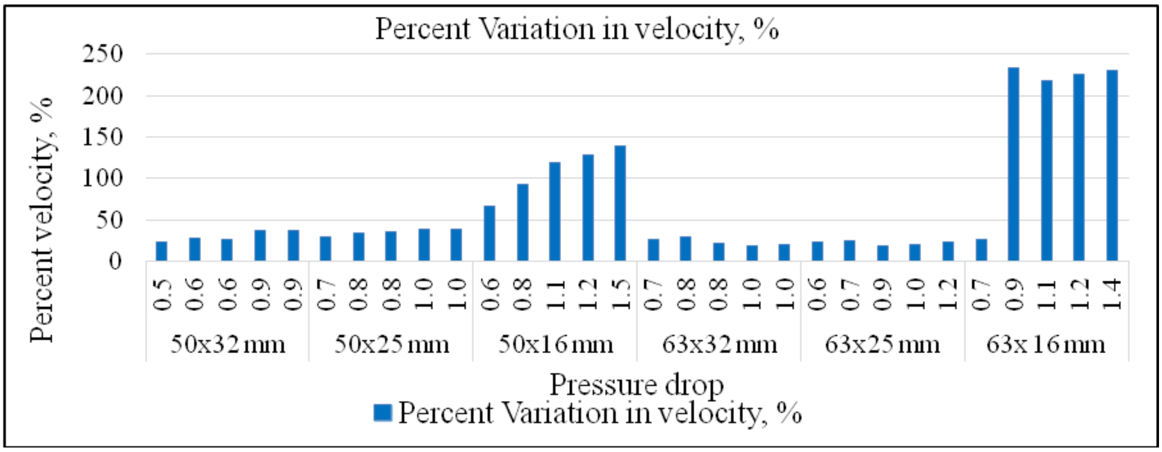


Fig 4.29 Comparison of the velocities at different sections of developed fertigation devices

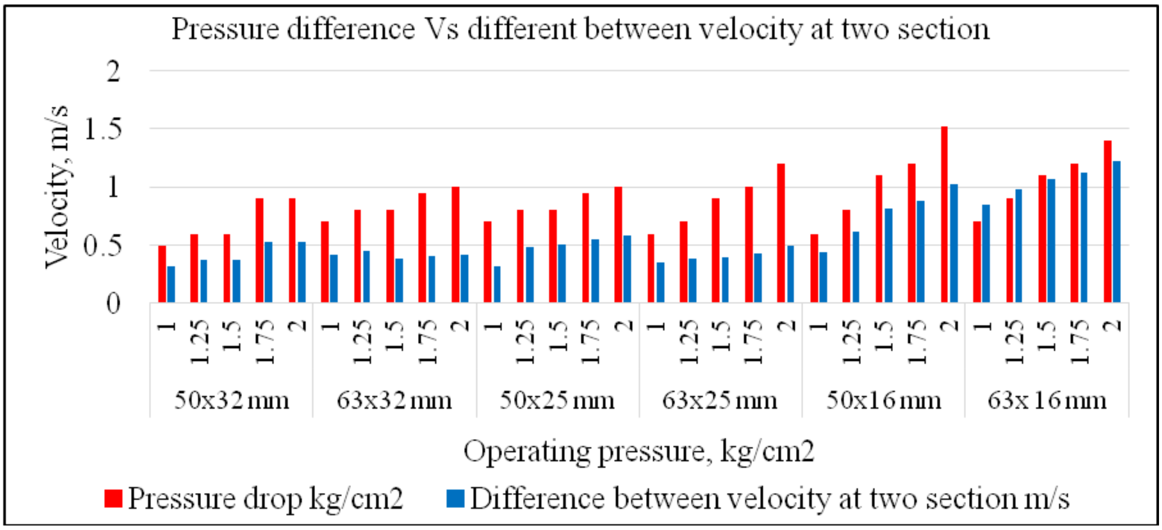


Fig 4.30 Relation between pressure drop and percent increase in velocity at constricted section of all developed device.

4.10 Cost of manufacturing of developed fertigation device

The detailed cost estimation of developed cost effective fertigation device was calculated using different combinations of devices for fertigation by considering cost of production manufacturing which is given in appendix III. As it was targeted to meet the need like low cost, easily available material different combinations of devices was proposed in this study and total cost of manufacturing was worked out.

It was observed that 63 x 16 mm and 50 x 16 mm size 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. The material used is PVC material for making it low cost. The manufacturing cost for 63 x 16 mm and 50 x 16 mm devices are Rs 175 and Rs 150 respectively.

Plate 4.1 Installation of the developed device for fertigation in the field

Plate 4.2 Testing the working of device in the field

Plate 4.3 Preparation of the field for observing effect of developed device on hydraulic parameters of the irrigation system

Plate 4.4 Demonstration of the fertigation device by of Prof. Dr. U. S.Kadam, Professor and Head and Er. S. T. Patil to the Agriculture minister Mr. Dadaji Bhuse, Hon. Vice-chancellor Dr. Sanjay Sawant and other respected members.

Plate 4.5 Demonstration to the honorable Sub-divisional Agricultural officer of Dapoli

V. SUMMARY AND CONCLUSIONS

The experiment entitled "Design and Development of Cost Effective Device for Fertigation" was carried out in Laboratory and at the Instructional Farm of Department of Irrigation and Drainage Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. The research work aimed with specific objectives of design, development and cost economics of cost effective device for fertigation 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 in the laboratory and at Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli concluded that fertilizers is to be efficiently applied in field by using developed low cost fertigation device, which is easy to install, easy to maintain, requires less technical knowledge and ready to use system. The developed system does not need any back flow protection valve which is the additional benefit over existing system.

5.1.1 Design and development of fertigation device:

The unit of the fertigation device was designed and developed by assembling the components such as PVC Pipes, PVC reducers, microtube, PVC Elbow, PVC ‘T’ (Tee), PVC control valve, strainer and other accessories. Six devices of fertigation were developed viz. device of size 50 x 32 mm, 50 x 25 mm, 50 x 16 mm, 63 x 32 mm, 63 x 25 mm and 63 x 16 mm with all design consideration. The following design considerations are applied for designing the system.

i. The PVC pipes, reducers, control valves of size 63 mm and 50 mm were used for construction of the fertigation device.

ii. The cross sectional area of the constricted section was considered as 1/3 or 1/4 of the diameter of inlet pipe. The cross sectional area of the inlet pipe was determined by standard equations. The study shown the size of constricted portion should be 32 mm, 25 mm and 16 mm.

iii. These reducers were cut at the throat section to adjust the throat length as the length equal to throat diameter (32 mm, 25 mm and 16 mm).

5.1.2 Working of device for fertigation

The main aim of the system was to apply the right amount of fertilizer at right time in low cost to fulfill the fertilizer requirement of the crop. The hypothesis which was considered worked out for designing of fertigation device. When the cross sectional area of pipe is constricted, the pressure drop at that constricted portion takes place with increase in velocity which causes suction of the fluid from fertilizer tank to the pipeline. The developed fertigation device follows the principles of the Bernoulli’s equation and continuity equation of working.

5.1.3 Installation of device for fertigation in field:

The device was installed in representative sites of field with proper care. The care was taken to get sufficient pressure for operating the fertigation device. Each part of device was fitted firmly before operating.

5.1.4 Field testing

The developed device for fertigation was tested on the field. The plot of 53 m x 30 m was selected at the Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. The emitters of discharge 2.1 l/h were installed at a spacing of 0.40 m and lateral were spaced at 1.75 x 1.75 m. The length of lateral was 30 m. The different operating pressure were used starting from 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2 for field testing of the developed fertigation device.

5.1.5 Performance evaluation

The field performance and testing of device was carried out by recording the inlet pressure, suction rate, outlet discharge and pressure drop in inlet and constricted/throat section with corresponding emission rate and emission uniformity. The performance evaluation of six devices of fertigation of size 50 x 32 mm, 50 x 25 mm, 50 x 16 mm, 63 x 32 mm, 63 x 25 mm and 63 x 16 mm were evaluated with all design considerations.

1. All the developed sizes of devices viz. device of size 50 x 32 mm, 50 x 25 mm, 50 x 16 mm, 63 x 32 mm, 63 x 25 mm and 63 x 16 mm were evaluated for different inlet operating pressure of the system from 1kg/cm^2 to 2.5 kg/cm^2 with increment of the 0.1 kg/cm^2 and for outlet pressure was used from 0 kg/cm^{2}to 1 kg/cm^2 with increment of 0.1 kg/cm^2 for performance evaluation.
2. The height of device above the mainline was 50 and 70 cm when tested for delivery in the atmosphere.
3. The developed device was operated at 1 kg/cm^2, 1.25 kg/cm^2, 1.5 kg/cm^2, 1.75 kg/cm^2 and 2 kg/cm^2 and allowed the discharge from outlet to the atmosphere (0 kg/cm^2).
4. The maximum suction rate was found to be in 50 x 32 mm fertigation device at 50 cm height was 83.67 l/h, 87.98 l/h, 115.86 l/h, 127. 26 l/h and 128.98 l/h.
5. The maximum suction rate was found to be in 50 x 32 mm fertigation device at 70 cm height was 90.56 l/h, 101.34 l/h, 122.67 l/h, 127.26 l/h and 129.08 l/h.
6. The maximum suction rate was found to be in 50 x 25 mm fertigation device at 50 cm height was 87.8 l/h, 92.31 l/h, 116.12 l/h, 121.56 l/h and 130.34 l/h.
7. The maximum suction rate was found to be in 50 x 25 mm fertigation device at 70 cm height was 94.736 l/h, 105.88 l/h, 124.14 l/h, 127.26 l/h and 131.18 l/h.
8. The maximum suction rate was found to be in 63 x 32 mm fertigation device at 50 cm height was 105.88 l/h, 120 l/h, 138.46l/h, 140.87 l/h and 141.69 l/h.
9. The maximum suction rate was found to be in 63 x 32 mm fertigation device at 70 cm height was 124.14 l/h, 138.46 l/h, 156.52 l/h, 133.33 l/h and 161.64 l/h.
10. The maximum suction rate was found to be in 63 x 25 mm fertigation device at 50 cm height was 116.12 l/h, 138.46 l/h, 150 l/h, 153.67 l/h and 156.96 l/h

11. The maximum suction rate was found to be in 63 x 25 mm fertigation device at 70 cm height was 144 l/h, 156.52 l/h, 171.43 l/h, 175.87 l/h and 189.08 l/h.
12. The 50 x 32 mm, 50 x 25 mm, 63 x 32 mm and 63 x 25 mm fertigation devices shown good results when they were operated at atmospheric pressure. These fertigation devices does not created suction when they were operated in the field with drip irrigation for closed condition
13. The 63 x 16 mm and 50 x 16 mm size devices found to be more suitable for marginal farmer as other devices were not working properly in the field with set of drip irrigation system
14. The devices of size 63 x 16 mm and 50 x 16 mm size device can fulfil requirement of fertilizer application sufficiently with low cost.

5.1.6 Hydraulic study of developed device:

For knowing the technical viability of the device various parameter were recorded like suction rate, velocity and pressure at different sections, average emission rate, emission uniformity, etc. and studied thoroughly.

5.1.7 Suction rate:

The suction rate was worked out for 63 mm Ø of inlet pipe and 50 mm Ø with constricted portion of 32 mm, 25 mm and 16 mm to check whether the suction is forming or not when the outlet was allowed to deliver fluid in the atmosphere with respect to 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2 at two height i.e. 50 and 70 cm. When it was actually tested on field suction was formed by the devices of size 63 x 16 mm and 50 x 16 mm only. The maximum suction rate was found in the device of size 63 x 16 mm at different operating pressure starting from to 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2**.**

5.1.8 Pressure and velocity at inlet of device, constricted/throat portion of the device:

Pressure and velocity are worked out at inlet and constricted portion of the device. As cross section of the pipe reduces then the pressure at constricted portion decreases and velocity increases this causes suction of fluid inside device. It is infered that the constricted cross section in the pipe section inversely proportional to the velocity of flowing fluid and directly proportional to the pressure in the pipe at that point of constriction.

5.1.9 Average emission rate, l/h:

The average emission rate obtained during experimentation was found close to the claimed by the manufacturer. So by using developed device of fertigation in the irrigation system, it's possible to supply right amount of fertilizers to the crop in the field.

5.1.10 Emission uniformity, per cent:

The maximum emission uniformity of 96.46 % and 99. 74 % was at 1 kg/cm^2 and 2.5 kg/cm^2 pressure. The similar trend was observed in case of all operating pressure starting from 1 to 2.5 kg/cm^2 with increment of 0.1 kg/cm^2. So it is observed that maximum emission uniformity 99.74 was found which falls under excellent zone in application of fertilizers which was aimed.

5.1.11 Cost economics

The material used for designing and development of cost effective device for fertigation is PVC material for making it low cost as per the objectives. The manufacturing cost for 63 x 16 mm and 50 x 16 mm devices are Rs. 175 and Rs. 150 respectively.

5.2 Conclusions

The following conclusions can be drawn from the results:

1. It was found that in overall devices, devices of size 63 x 16 mm and 50 x 16 mm worked properly in the field.
2. The other fertigation devices viz. 50 x 32 mm, 50 x 25 mm, 63 x 32 mm and 63 x 25 mm were also suitable for fertigation when fitted to delivery side of the pump for open channel fertigation. These devices are also used for aeration less pressure injection system.
3. This design of device overcome the limitation of the available fertigation devices like high cost, installation difficulties, ease of operation, maintenance cost.
4. The constricted cross section in the pipe section is inversely proportional to the velocity of flowing fluid and directly proportional to the pressure in the pipe at that point of constriction.
5. The constricted cross section and pressure drop in the pipe sections decides the suction rate.
6. The different constricted cross section in the same pipe line varies the suction rate, velocity of flowing fluid and pressure at that point of constriction which

were considered in the introduction is fulfilled with the development of device for fertigation.

7. The maximum and minimum suction rate of 48.39 l/h and 20.91 l/h at pressure drop of 2 and 0.6 kg/cm^2 were found in 50 x 16 mm fertigation device respectively. When device was operated at operating pressure of 1-2.5 kg/cm^2, the percent variation in suction rate was found in between 0 – 20.13% while emission uniformity was ranges from 96.46 to 99.26 %.
8. The maximum and minimum suction rate of 73.49 l/h and 21.13 l/h at pressure drop of 1.9 and 0.7 kg/cm^2 were found in 63 x 16 mm fertigation device respectively. When device was operated at operating pressure of 1-2.5 kg/cm^2, the percent variation in suction rate was found in between 0 – 21.59 % while emission uniformity was ranges from 98.34 to 99.74 %.
9. It was observed that when the difference of velocity at constricted section becomes half or more than half of inlet velocity then and then only the suction takes place.
10. To form the suction, it was needed to have more than 67 % increase in the velocity at constricted section.
11. The manufacturing cost for 63 x 16 mm and 50 x 16 mm devices were Rs. 175 and Rs. 150 respectively.
12. The devices of size 63 x 16 mm and 50 x 16 mm are named and here after recognized as PK'S fertigation device and recommended as it fulfils most of the requirements of fertigation in the field.
13. The following hypothesis were satisfies the conditions and holds true;
    1. The constricted cross section in the pipe section inversely proportional to the velocity of flowing fluid and directly proportional to the pressure in the pipe at that point of constriction.
    2. The constricted cross section in the pipe section decided the suction rate.
    3. The different constricted cross section in the same pipe line varies the suction rate, velocity of flowing fluid and pressure at that point of constriction which were considered in the introduction is fulfilled with the development of device for fertigation.

5.3 Suggestions for further work

1. There is still scope to work on constricted/throat section

2. With the experience of the study cited in the thesis more work required to be done evolved thesis and technology in the present study it is required to develop the device for higher suction rate with optimum operating pressure at inlet.
3. Design and development of fully automatic fertigation device, should be undertaken

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VII. APPENDICES

Appendix - I

7.1 Sample of calculations required for designing device for fertigation

I. Area of pipe of diameter 63 mm,

$$(A) = \pi r^2$$

$$(A) = \pi \times \left(\frac{0.063}{2}\right)^2$$

$$= 0.003116\ m^2$$

II. Diameter of constricted portion

When pipe diameter 63mm constricted portion,

$$(\mathrm{d}) = \frac{D}{4}$$

$$= 15.75 \approx 16mm$$

III. Velocity at constricted portion,

$$v_2 = \sqrt{\frac{2(p_1 - p_2)}{\rho} + v_1^2}$$

$$v_2 = \sqrt{\frac{2(1-0.3)}{1} + 1.4008^2}$$

$$v_2 = 1.8337\ m/s$$

IV. Suction rate at contracted portion,

$$\text{suction rate l/h} = \frac{volume\ of\ liquid\ entered\ through\ injection\ port\ (lit)}{time\ required(h)}$$

$$= \frac{1}{171} \times 3600$$

= 21.0526 l/h

V. Discharge of the system,

$$Q = Discharge\ through\ a\ dripper \times no. of\ total\ dripper\ on\ a\ lateral \times no\ of\ total\ lateral$$

$= 2.04 \times 75 \times 30$

$= 4590 l/h$

Appendix II

7.2 Performance evaluation of design and developed fertigation device

I. Performance of device for fertigation for size 50x32mm at 50 cm height.

Date	Height of applicator above ground (cm)	Operating pressure Kg/cm^2	Outlet pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time Sec/l
20-11-2019	`50	1	0	1	43.026
		1	0.1	0.9	54.637
		1	0.2	0.8	76.645
		1	0.3	0.7	99.558
		1	0.4	0.6	114.141
		1	0.5	0.5	306.122
		1.25	0	1.25	40.918
		1.25	0.1	1.15	47.974
		1.25	0.2	1.05	56.515
		1.25	0.3	0.95	69.957
		1.25	0.4	0.85	78.483
		1.25	0.5	0.75	140.242
	50	1.5	0	1.5	31.07
		1.5	0.1	1.4	34.619
		1.5	0.2	1.3	40.223
		1.5	0.3	1.2	47.506
		1.5	0.4	1.1	59.553
		1.5	0.5	1	84.053
		1.75	0	1.75	28.289
		1.75	0.1	1.65	29.321
		1.75	0.2	1.55	31.008
		1.75	0.3	1.45	33.435
		1.75	0.4	1.35	40.228
		1.75	0.5	1.25	47.275
		2	0	2	27.696
		2	0.1	1.9	31.69

		2	0.2	1.8	37.7
		2	0.3	1.7	43.109
		2	0.4	1.6	49.958
		2	0.5	1.5	55.274

II. Performance of device for fertigation for size 50x32mm at 75 cm height.

Date	Height of applicator Above ground, cm	Operating pressure Kg/cm^2	Outlet Pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time sec/l
21-11-19	70	1	0	1	39.75
		1	0.1	0.9	46.97
		1	0.2	0.8	73.35
		1	0.3	0.7	86.37
		1	0.4	0.6	100.78
		1	0.5	0.5	242.59
		1.25	0	1.25	35.52
		1.25	0.1	1.15	38.36
		1.25	0.2	1.05	47.07
		1.25	0.3	0.95	61.7
		1.25	0.4	0.85	73.86
		1.25	0.5	0.75	100.08
	70	1.5	0	1.5	29.35
		1.5	0.1	1.4	32.07
		1.5	0.2	1.3	39.39
		1.5	0.3	1.2	44.7
		1.5	0.4	1.1	57.34
		1.5	0.5	1	87.06
		1.75	0	1.75	28.29
		1.75	0.1	1.65	29.32
		1.75	0.2	1.55	31.01
		1.75	0.3	1.45	33.44
		1.75	0.4	1.35	40.23
		1.75	0.5	1.25	47.28
		2	0	2	27.89
		2	0.1	1.9	28.2
		2	0.2	1.8	30.21
		2	0.3	1.7	31.93
		2	0.4	1.6	38.94
		2	0.5	1.5	41.05

III. Performance of device for fertigation for size 50x25mm at 50 cm height.

Date	Height of applicator Above ground cm	Operating pressure Kg/cm^2	Outlet Pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time sec/l
22-11-19	50	1	0	1	41
		1	0.1	0.9	53
		1	0.2	0.8	75
		1	0.3	0.7	92
		1	0.4	0.6	103
		1	0.5	0.5	259.18
		1.25	0	1.25	39
		1.25	0.1	1.15	46
		1.25	0.2	1.05	51.01
		1.25	0.3	0.95	63
		1.25	0.4	0.85	75
		1.25	0.5	0.75	97.01
		1.5	0	1.5	31
		1.5	0.1	1.4	34
		1.5	0.2	1.3	40
		1.5	0.3	1.2	46
		1.5	0.4	1.1	57.01
		1.5	0.5	1	82
		1.75	0	1.75	29.62
		1.75	0.1	1.65	32.01
		1.75	0.2	1.55	33.62
		1.75	0.3	1.45	36.86
		1.75	0.4	1.35	43.22
		1.75	0.5	1.25	46.86
		2	0	2	28.72
		2	0.1	1.9	31.69
		2	0.2	1.8	32.99
		2	0.3	1.7	35.97
		2	0.4	1.6	38.27
		2	0.5	1.5	41.82

IV. Performance of device for fertigation for size 50x25 mm at 75 cm height.

Date	Height of applicator Above ground (cm)	Operating pressure Kg/cm^2	Outlet Pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time Sec/l
24-11-19	70	1	0	1	38
		1	0.1	0.9	46
		1	0.2	0.8	68

		1	0.3	0.7	80.99
		1	0.4	0.6	93
		1	0.5	0.5	236.07
		1.25	0	1.25	34
		1.25	0.1	1.15	37
		1.25	0.2	1.05	45
		1.25	0.3	0.95	58
		1.25	0.4	0.85	68.99
		1.25	0.5	0.75	85.01
		1.5	0	1.5	29
		1.5	0.1	1.4	30
		1.5	0.2	1.3	37
		1.5	0.3	1.2	41
		1.5	0.4	1.1	52
		1.5	0.5	1	76.99
		1.75	0	1.75	28.29
		1.75	0.1	1.65	29.32
		1.75	0.2	1.55	31.01
		1.75	0.3	1.45	33.44
		1.75	0.4	1.35	40.23
		1.75	0.5	1.25	47.28
		2	0	2	27.89
		2	0.1	1.9	28.2
		2	0.2	1.8	30.21
		2	0.3	1.7	31.93
		2	0.4	1.6	38.94
		2	0.5	1.5	41.05

V. Performance of device for fertigation for size 63x32 mm at 50 cm height.

Date	Height of applicator	Operating pressure	Outlet pressure	Pressure drop	Suction time
	Above ground	Kg/cm^2	Kg/cm^2	Kg/cm^2	Sec/l
	cm				
25-11-19	50	1	0	1	34
		1	0.1	0.9	39
		1	0.2	0.8	44
		1	0.3	0.7	48
		1	0.4	0.6	56
		1	0.5	0.5	72.99
		1.25	0	1.25	30
		1.25	0.1	1.15	32
		1.25	0.2	1.05	40
		1.25	0.3	0.95	43

		1.25	0.4	0.85	51
		1.25	0.5	0.75	64.99
		1.5	0	1.5	26
		1.5	0.1	1.4	32
		1.5	0.2	1.3	36.83
		1.5	0.3	1.2	40.79
		1.5	0.4	1.1	47.71
		1.5	0.5	1	57.74
		1.75	0	1.75	25.56
		1.75	0.1	1.65	30.43
		1.75	0.2	1.55	33.08
		1.75	0.3	1.45	40.24
		1.75	0.4	1.35	44.18
		1.75	0.5	1.25	48.87
		2	0	2	25.41
		2	0.1	1.9	28.51
		2	0.2	1.8	30.95
		2	0.3	1.7	39.12
		2	0.4	1.6	43.5
		2	0.5	1.5	47.24

VI. Performance of device for fertigation for size 63x32mm at 75 cm height.

Date	Height of applicator above ground(cm)	Operating pressure (kg/cm^2)	Outlet Pressure (kg/cm^2)	Pressure drop (kg/cm^2)	Suction time Sec/l
26-11-19	70	1	0	1	29
		1	0.1	0.9	35
		1	0.2	0.8	42
		1	0.3	0.7	48
		1	0.4	0.6	59.01
		1	0.5	0.5	68
		1.25	0	1.25	28
		1.25	0.1	1.15	26
		1.25	0.2	1.05	31
		1.25	0.3	0.95	38
		1.25	0.4	0.85	43
		1.25	0.5	0.75	46
		1.5	0	1.5	185
		1.5	0.1	1.4	27
		1.5	0.2	1.3	23
		1.5	0.3	1.2	30
		1.5	0.4	1.1	37

		1.5	0.5	1	43
		1.75	0	1.75	116
		1.75	0.1	1.65	241
		1.75	0.2	1.55	25
		1.75	0.3	1.45	22.69
		1.75	0.4	1.35	27
		1.75	0.5	1.25	29
		2	0	2	54
		2	0.1	1.9	90
		2	0.2	1.8	144
		2	0.3	1.7	24
		2	0.4	1.6	22.27
		2	0.5	1.5	26.77

VII. Performance of device for fertigation for size 63x25mm at 50 cm height.

Date	Height of applicator Above ground cm	Operating pressure Kg/cm^2	Outlet pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time sec/l
27-11-19	50	1	0	1	31
		1	0.1	0.9	43
		1	0.2	0.8	58
		1	0.3	0.7	64
		1	0.4	0.6	72.99
		1	0.5	0.5	169.01
		1.25	0	1.25	26
		1.25	0.1	1.15	32
		1.25	0.2	1.05	39
		1.25	0.3	0.95	44
		1.25	0.4	0.85	56.31
		1.25	0.5	0.75	68
30-11-19		1.5	0	1.5	24
		1.5	0.1	1.4	29
		1.5	0.2	1.3	35
		1.5	0.3	1.2	42
		1.5	0.4	1.1	50
		1.5	0.5	1	63
		1.75	0	1.75	23.43
		1.75	0.1	1.65	28.28
		1.75	0.2	1.55	30.9
		1.75	0.3	1.45	38.47
		1.75	0.4	1.35	42.02
		1.75	0.5	1.25	44.93

		2	0	2	22.94
		2	0.1	1.9	27.48
		2	0.2	1.8	29.32
		2	0.3	1.7	31.83
		2	0.4	1.6	39.39
		2	0.5	1.5	44.73

VIII. Performance of device for fertigation for size 63x25 mm at 75 cm height.

Date	Height of applicator Above ground cm	Operating pressure Kg/cm^2	Outlet pressure Kg/cm^2	Pressure drop Kg/cm^2	Suction time Sec/l
01-12-19	70	1	0	1	25
		1	0.1	0.9	36
		1	0.2	0.8	42
		1	0.3	0.7	49
		1	0.4	0.6	56
		1	0.5	0.5	79
		1.25	0	1.25	23
		1.25	0.1	1.15	28
		1.25	0.2	1.05	34
		1.25	0.3	0.95	41
		1.25	0.4	0.85	49
		1.25	0.5	0.75	58
		1.5	0	1.5	21
		1.5	0.1	1.4	26
		1.5	0.2	1.3	31
		1.5	0.3	1.2	39
		1.5	0.4	1.1	45
		1.5	0.5	1	57
02-12-19	70	1.75	0	1.75	20.47
		1.75	0.1	1.65	25.08
		1.75	0.2	1.55	27.8
		1.75	0.3	1.45	30.77
		1.75	0.4	1.35	36.82
		1.75	0.5	1.25	44.61
		2	0	2	19.04
		2	0.1	1.9	24.58
		2	0.2	1.8	27.34
		2	0.3	1.7	28.57
		2	0.4	1.6	38.27

		2	0.5	1.5	40.95

IX. Observation recorded on field for fertigation device of size 63x16mm

Date	Operating pressure kg/ cm^2	Time(sec)	Outlet pressure kg/ cm^2	Pressure at lateral end kg/ cm^2
28/02/2020	1	171	0.3	0.3
	1	175	0.3	0.3
	1	168	0.3	0.3
	1	173	0.3	0.3
	1	165	0.3	0.3
28/02/2020	1.1	170	0.3	0.3
	1.1	168	0.3	0.3
	1.1	152	0.3	0.3
	1.1	158	0.3	0.3
	1.1	160	0.3	0.3
01/03/2020	1.2	154	0.3	0.3
	1.2	164	0.3	0.3
	1.2	151	0.3	0.3
	1.2	157	0.3	0.3
	1.2	152	0.3	0.3
01/03/2020	1.3	150	0.4	0.3
	1.3	152	0.4	0.3
	1.3	149	0.4	0.3
	1.3	145	0.4	0.3
	1.3	147	0.4	0.3
01/03/2020	1.4	133	0.4	0.3
	1.4	132	0.4	0.3
	1.4	133	0.4	0.3
	1.4	134	0.4	0.3
	1.4	132	0.4	0.3
02/03/2020	1.5	109	0.4	0.3
	1.5	111	0.4	0.3
	1.5	116	0.4	0.3
	1.5	114	0.4	0.3
	1.5	109	0.4	0.3
	1.6	105	0.5	0.5
	1.6	106	0.5	0.5
	1.6	108	0.5	0.5
	1.6	107	0.5	0.5
	1.6	108	0.5	0.5
03/03/2020	1.7	100	0.5	0.5
	1.7	95	0.5	0.5
	1.7	95	0.5	0.5
	1.7	96	0.5	0.5

	1.7	97	0.5	0.5
	1.8	92	0.6	0.5
	1.8	90	0.6	0.5
	1.8	91	0.6	0.5
	1.8	89	0.6	0.5
	1.8	90	0.6	0.5
	1.9	80	0.6	0.5
	1.9	81	0.6	0.5
	1.9	81	0.6	0.5
	1.9	80	0.6	0.5
	1.9	79	0.6	0.5
04/03/2020	2	77	0.6	0.5
	2	77	0.6	0.5
	2	78	0.6	0.5
	2	77	0.6	0.5
	2	77	0.6	0.5
	2.1	77	0.6	0.5
	2.1	77	0.6	0.5
	2.1	77	0.6	0.5
	2.1	76	0.6	0.5
	2.1	77	0.6	0.5
	2.2	73	0.6	0.5
	2.2	72	0.6	0.5
	2.2	73	0.6	0.5
	2.2	73	0.6	0.5
	2.2	72	0.6	0.5
	2.3	65	0.6	0.5
	2.3	66	0.6	0.5
	2.3	65	0.6	0.5
	2.3	65	0.6	0.5
	2.3	66	0.6	0.5
05/03/2020	2.4	58	0.6	0.5
	2.4	62	0.6	0.5
	2.4	59	0.6	0.5
	2.4	61	0.6	0.5
	2.4	58	0.6	0.5
	2.5	50	0.6	0.5
	2.5	48	0.6	0.5
	2.5	48	0.6	0.5
	2.5	50	0.6	0.5
	2.5	49	0.6	0.5

X. Observation recorded on field for fertigation device of size 63 x16mm

Date	Operating pressure kg/ cm^2	Time(sec)	Outlet pressure kg/	Pressure at lateral end

			cm^2	**kg/ cm^2**
05/03/2020	1	175	0.4	0.4
	1	172	0.4	0.4
	1	171	0.4	0.4
	1	170	0.4	0.4
	1	173	0.4	0.4
	1.1	173	0.4	0.4
	1.1	172	0.4	0.4
	1.1	170	0.4	0.4
	1.1	172	0.4	0.4
	1.1	169	0.4	0.4
06/03/2020	1.2	164	0.4	0.4
	1.2	160	0.4	0.4
	1.2	159	0.4	0.4
	1.2	162	0.4	0.4
	1.2	161	0.4	0.4
	1.3	152	0.4	0.4
	1.3	151	0.4	0.4
	1.3	152	0.4	0.4
	1.3	152	0.4	0.4
	1.3	151	0.4	0.4
07/03/2020	1.4	120	0.4	0.4
	1.4	121	0.4	0.4
	1.4	129	0.4	0.4
	1.4	130	0.4	0.4
	1.4	132	0.4	0.4
	1.5	109	0.4	0.4
	1.5	110	0.4	0.4
	1.5	108	0.4	0.4
	1.5	110	0.4	0.4
	1.5	110	0.4	0.4
08/03/2020	1.6	110	0.5	0.4
	1.6	111	0.5	0.4
	1.6	108	0.5	0.4
	1.6	107	0.5	0.4
	1.6	105	0.5	0.4
	1.7	104	0.5	0.4
	1.7	105	0.5	0.4
	1.7	106	0.5	0.4
	1.7	104	0.4	0.4
	1.7	105	0.4	0.4
09/03/2020	1.8	100	0.4	0.4
	1.8	103	0.4	0.4
	1.8	101	0.4	0.4

	1.8	100	0.4	0.4
	1.8	102	0.4	0.4
	1.9	96	0.4	0.4
	1.9	95	0.475	0.4
	1.9	96	0.475	0.4
	1.9	96	0.475	0.4
	1.9	95	0.475	0.4
	2	92	0.475	0.4
	2	91	0.475	0.4
	2	92	0.475	0.4
	2	92	0.475	0.4
	2	90	0.475	0.4
	2.1	88	0.475	0.4
	2.1	89	0.475	0.4
	2.1	90	0.5	0.4
	2.1	88	0.5	0.4
	2.1	88	0.5	0.4
11/03/2020	2.2	83	0.5	0.4
	2.2	81	0.5	0.4
	2.2	84	0.5	0.4
	2.2	83	0.5	0.4
	2.2	82	0.5	0.4
	2.3	78	0.5	0.4
	2.3	79	0.5	0.4
	2.3	77	0.5	0.4
	2.3	78	0.5	0.4
	2.3	77	0.5	0.4
12/03/2020	2.4	76	0.5	0.4
	2.4	75	0.5	0.4
	2.4	77	0.5	0.4
	2.4	76	0.5	0.4
	2.4	75	0.5	0.4
13/03/2020	2.5	74	0.5	0.4
	2.5	75	0.5	0.4
	2.5	74	0.5	0.4
	2.5	75	0.5	0.4
	2.5	74	0.5	0.4
	2.6	73	0.5	0.4
	2.6	73	0.5	0.4
	2.6	73	0.5	0.4
	2.6	72	0.5	0.4
	2.6	73	0.5	0.4
16/03/2020	2.7	73	0.5	0.4
	2.7	73	0.5	0.4

	2.7	72	0.5	0.4
	2.7	72	0.5	0.4
	2.7	71	0.5	0.4
	2.8	72	0.5	0.4
	2.8	72	0.5	0.4
	2.8	72	0.5	0.4
	2.8	71	0.5	0.4
	2.8	72	0.5	0.4
17/03/2020	2.9	72	0.5	0.4
	2.9	71	0.5	0.4
	2.9	72	0.5	0.4
	2.9	70	0.5	0.4
	2.9	72	0.5	0.4
	3	69	0.5	0.4
	3	68	0.5	0.4
	3	69	0.5	0.4
	3	69	0.5	0.4
	3	69	0.5	0.4
	3.1	58	0.5	0.4
	3.1	56	0.5	0.4
	3.1	52	0.5	0.4
	3.1	58	0.5	0.4
	3.1	55	0.5	0.4

Appendix III

7.3 Cost economics of developed devices

I. Cost of materials required for 63 x 16 mm size fertigation device.

Sr. No.	Particulars	Quantity	Unit	Rate per unit (Rs.)	Total amount (Rs.)
1	PVC pipe of 4 kgf of 63 mm	0.3 m	1	60	18
2	PVC pipe of 4 kgf of 16 mm	0.1 m	1	-	4
3	Elbow	63 mm	2	25	50
4	Microtube of 6mm diameter	1 m	1	3	3
5	Reducer	63x 16 mm	2	50	100
Total					**175**

II. Cost of materials inclusive of accessories required for 63 x 16 mm size fertigation device.

Sr. No.	Particulars	Size	Quantity	Rate per unit (Rs.)	Total amount (Rs.)
1	PVC pipe of 4 kgf of 63 mm	2.5m	1	60	150
2	PVC of 4 kgf pipe of 16 mm	0.5m	1	37	18.5
3	Elbow	63 mm	2	25	50
4	Tees	63mm	2	30	60
5	Microtube of 6mm diameter	1 m	1	3	3
6	Reducer	63x32mm	2	50	100
7	Ball valve	63mm	1	220	220
9	Labour cost		2	75	150
Total					**751.5**

III. Cost of materials required for 50 x 16 mm size fertigation device.

Sr. No.	Particulars	Size	Unit	Rate per unit (Rs.)	Total amount (Rs.)
1	PVC pipe of 4kgf of 50 mm	0.3 m	1	50	15
2	PVC pipe of 4 kgf of 16 mm	0.1 m	1	-	4
3	Elbow	50 mm	2	24	45
4	Microtube of 6mm diameter	1 m	1	3	3
5	Reducer	50x16mm	2	40	80
Total					**150**

IV. Cost of materials inclusive of accessories required for 50 x 16 mm size fertigation device.

Sr. No.	Particulars	Size	Unit	Rate per unit (Rs.)	Total amount (Rs.)
1	PVC pipe of 4 kgf of 63 mm	2.5m	1	50	125
2	PVC pipe of 4 kgf 16 mm	0.5m	1	37	18.5
3	Elbow	50 mm	2	24	48
4	Tees	50mm	2	30	60
5	Microtube of 6mm diameter	2m	1	3	3
6	Reducer	50x32mm	2	40	80
7	Ball valve	63mm	1	190	190
9	Labour cost		2	75	150
Total					**674.5**