DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVISED WATER PUMPING DEVICE FOR URBAN APPLICATIONS

M.Tech. (Agril. Engg.) Thesis

by

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DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVISED WATER PUMPING DEVICE FOR URBAN APPLICATIONS

Thesis

Submitted to the

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by

Pankaj Sinha

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CERTIFICATE – I

This is to certify that the thesis entitled "**Development and performance evaluation of an improvised water pumping device for urban applications**" submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Raipur, is a record of the bonafide research work carried out by **Pankaj Sinha** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigations have been duly acknowledged.

Date:

Chairman

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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Member	**(Er. Neeraj Mishra)**	....
Member	**(Dr. K. K. Srivastava)**	....
Member	**(Dr. S. K. Agrawal)**	....

CERTIFICATE – II

This is to certify that the thesis entitled **"Development and performance evaluation of an improvised water pumping device for urban applications"** submitted by **Pankaj Sinha** to Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of Soil and Water Engineering has been approved by the external examiner and Student's Advisory Committee after oral examination.

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Date: 26.8.19

Major Advisor ____________________

Head of the Department ____________________ 26/08/2019

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Approved/Not approved

Director of Instructions ____________________

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Place: Raipur

Date: *(Pankaj Sinha)*

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LIST OF SYMBOLS

Symbol	Description
%	Percent
&	And
-	Minus
x	Multiple
+	Plus
Avg.	Average
et al.	Et alibi
etc.	Etcetera
i.e.	That is
Viz.	Namely
Rpm	Revolution per minute
hp	Horse power
Mm	Millimeter
Cm	Centimeter
M	Meter
Lps	Liters per seconds
Lpm	Liters per minutes
Lph	Liters per hours
S.No	Serial number
Kg	Kilogram
Kcal	Kilocalorie
Kj	Kilo joule
1/min	Litres per minute
kJ/min	Kilo joule per minute
Min	Mintues

LIST OF ABBREVIATIONS

Abbreviation	Description
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
ICAR	Indian Council of Agricultural Research
FAE	Faculty of Agricultural Engineering
Engg.	Engineering
IGKV	Indira Gandhi Krishi Vishwavidyalaya
M. Tech.	Master of Technology
IWPD	Improvised water pumping device
BMI	Body mass index
RM	Resting metabolic
HR	Heart rate
OCR	Oxygen consumption rate
EER	Energy expenditure rate
ICMR	Indian Council of Medical Research

THESIS ABSTRACT

Title of the thesis	:	Development and performance evaluation of an improvised water pumping device for urban applications
Full name of the Student	:	Pankaj Sinha
Major Subject	:	Soil and Water Conservation Engineering
Name and Address of the major advisor	:	Dr. Jitendra Sinha Associate Professor, SWE, SVCAET & RS. Faculty of Agricultural Engineering, IGKV, Raipur (CG)
Degree to be awarded	:	M.Tech. (Agricultural Engineering)

Signature of Major Advisor

Signature of the Student

Signature of Head of the Department

Date: 22.07.2019

ABSTRACT

An experiment was conducted on "Development and performance evaluation of an improvised water pumping device for urban applications" at Department of soil and water engineering, SVCEAT & RS, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G). The aim of the work is to efficiently utilize the human energy for lifting and moving the water through the improvised pedal operated water pumping system. Water plays a very significant role in both livestock and agriculture farm. Water use enables plants to be grown and livestock to be raised, which is the primary component of our diet. Traditionally there are different types of manually or animal operated pumps available for lifting and

carrying water, some of which are superior to others for various purposes. There are also a lot of scopes to improve the standard and conventional pumping system before searching for new water-lifting mechanisms.

The performance of an improvised gym cycle as a water pumping system was analyzed. This was very useful for exercising an urban area and lifting harvested water to irrigate their field. The performance of this improvised water pumping system was evaluated at the different suction head, different delivery head and at different horizontal distance. The results show that the variation in discharge with different delivery head and different horizontal pipe distance was more significantly affected as compared to the variation in the suction head. It gave the discharge of 0.58 lps (35 lpm) at 3.58 m of suction head, 0.27 m of delivery head and 10m horizontal distance which was enough to provide water for small field, open gymnasium, hostels etc..

Ergonomics is the scientific branch that looks at about the working environment of people. Its objectives to deal with the effectiveness, productivity and overall performance of human during works, also maintain the environment and workspaces to decrease the danger of harm or injury. A different physiological parameter of the male and female operator on using pedal operated cycle pump is measured and is necessary to assess the energy expenditure of human during operating water pumping device. How long they can continuously work without getting fatigued. A Subject (human) with BMI 22.2 was found under the with-out load and load condition, minimum change in heart rate (52 and 56 beats/min), oxygen consumption rate (0.59 and 0.63 1/min), energy expenditure rate (8.2 and 8.9 kJ/min) and maximum fatigue time (27 and 16 min.) under load and without pump load conditions respectively. Based on the EER operation system was graded as “light” work.

Improvised water pumping device was tested under different BMI of operator for effective operation, BMI 22.2 was found best for operating the improvised device.

शोध सारांश

थीसिस का शीर्षक	:	शहरी अनुप्रयोगों के लिए एक तात्कालिक जल पम्पिंग उपकरण का विकास और प्रदर्शन मूल्यांकन
छात्र का पूरा नाम	:	पंकज सिन्हा
प्रमुख विषय	:	मृदा और जल संरक्षण इंजीनियरिंग
प्रमुख सलाहकार का नाम और पता	:	डॉ. जितेन्द्र सिन्हा एसोसिएट प्रोफेसर, एसडब्ल्यूई, एसवीसीएईटी और आरएस कृषि अभियांत्रिकी संकाय, आईजीकेवी, रायपुर (छत्तीसगढ़)
सम्मानित किया जाने वाला डिग्री	:	एम.टेक (कृषि अभियांत्रिकी)

छात्र का हस्ताक्षर

प्रमुख सलाहकार का हस्ताक्षर

दिनांक 22-07-2019

विभाग के प्रमुख का हस्ताक्षर

सारांश

मिट्टी और जल इंजीनियरिंग विभाग, में "शहरी अनुप्रयोगों के लिए एक तात्कालिक जल पम्पिंग उपकरण के विकास और प्रदर्शन मूल्यांकन" पर एक प्रयोग किया गया था। हमारे काम का उद्देश्य कामचलाऊ पैडल संचालित वॉटर पंपिंग सिस्टम के माध्यम से पानी को उठाने और स्थानांतरित करने के लिए मानव ऊर्जा का कुशलतापूर्वक उपयोग करना है।पशुपालन और कृषि कार्य दोनों में जल बहुत महत्वपूर्ण भूमिका निभाता है। जल के उपयोग से पौधों को उगाया और पशुओं को पाला जाता है, जो हमारे आहार का प्राथमिक घटक है। अधिकांश किसान अपने कृषि कार्य और पशुपालन के लिए निकटतम नदी और भूजल पर निर्भर रहते हैं जल के बिना, किसान फसलों को

उगाने की क्षमता नहीं रख सकता, जिसका अर्थ है कि उनके खेत से होने वाली आय का पूरा नुकसान। परंपरागत रूप से जल उठाने और ले जाने के लिए विभिन्न प्रकार के मानव या पशु संचालित पंप उपलब्ध हैं, जिनमें से कुछ विभिन्न प्रयोजनों के लिए दूसरों से बेहतर हैं। नए जल उठाने के तंत्र की खोज करने से पहले मानव और पारंपरिक पंपिंग प्रणाली में सुधार करने के लिए बहुत सारे विकल्प हैं। इस कामचलाऊ पानी पंपिंग प्रणाली के प्रदर्शन का मूल्यांकन अलग-अलग चूषण सिर, अलग-अलग वितरण सिर और अलग-अलग क्षैतिज दूरी पर किया गया था।

वॉटर पंपिंग सिस्टम के रूप में एक तात्कालिक जिम चक्र के प्रदर्शन का विश्लेषण किया गया था। यह एक शहरी क्षेत्र का उपयोग करने और अपने खेत की सिंचाई के लिए काटा हुआ पानी उठाने के लिए बहुत उपयोगी था। परिणाम बताते हैं कि चूषण सिर में भिन्नता की तुलना में अलग-अलग वितरण सिर और अलग-अलग क्षैतिज पाइप दूरी के साथ निर्वहन में काफी अधिक प्रभाव था। इसने 0.58 लीटर प्रति सेकंड (35 लीटर प्रति मिनट) की मात्रा 3.58 मीटर सक्शन हेड, 0.27 मीटर डिलीवरी हेड और 10 मीटर क्षैतिज दूरी पर दी, जो कि छोटे क्षेत्र, ओपन जिम्नेजियम, हॉस्टल आदि के लिए पानी उपलब्ध कराने के लिए पर्याप्त था। पेडल-संचालित साइकिल पंप का उपयोग करने पर पुरुष और महिला ऑपरेटर का एक अलग शारीरिक पैरामीटर मापा जाता है और ऑपरेटिंग वॉटर पंपिंग डिवाइस के दौरान मानव के ऊर्जा व्यय का आकलन करने के लिए आवश्यक है। बिना थकान के वे कितने समय तक लगातार काम कर सकते हैं।

एर्गोनॉमिक्स वैज्ञानिक शाखा है जो लोगों के काम के माहौल के बारे में देखती है। कार्यों के दौरान मानव की प्रभावशीलता, उत्पादकता और मानव के समग्र प्रदर्शन से निपटने के लिए इसके उद्देश्य पर्यावरण और कार्यक्षेत्र को नुकसान या चोट के खतरे को कम करने के लिए बनाए रखते हैं। पेडल-संचालित साइकिल पंप का उपयोग करने पर पुरुष और महिला ऑपरेटर का एक अलग शारीरिक पैरामीटर मापा जाता है और ऑपरेटिंग वॉटर पंपिंग डिवाइस के दौरान मानव के ऊर्जा व्यय का आकलन करने के लिए आवश्यक है। बिना थकान के वे कितने समय तक लगातार काम कर सकते हैं। बीएमआई 22.2 के साथ एक विषय (मानव) को आउट-लोड और लोड की स्थिति के तहत पाया गया, हृदय गति में न्यूनतम परिवर्तन (52 और 56 बीट्स / मिनट), ऑक्सीजन की खपत दर (0.59 और 0.63 1 / मिनट), ऊर्जा व्यय दर (8.2 और 8.9 किलोग्राम / मिनट) और अधिकतम थकान का समय (27 और 16 मिनट) लोड के तहत और क्रमशः पंप लोड की स्थिति के बिना। ईईआर ऑपरेशन प्रणाली के आधार पर "प्रकाश" कार्य के रूप में वर्गीकृत किया गया था।

इम्प्रोवाइज्ड वॉटर पंपिंग डिवाइस का परीक्षण अलग-अलग बीएमआई ऑपरेटर के प्रभावी संचालन के लिए किया गया था, बीएमआई 22.2 इम्प्रूव्ड डिवाइस के संचालन के लिए सर्वश्रेष्ठ पाया गया। इम्प्रोवाइज्ड वॉटर पंपिंग डिवाइस का परीक्षण अलग-अलग बीएमआई ऑपरेटर के प्रभावी संचालन के लिए किया गया था, बीएमआई 22.2 इम्प्रूव्ड डिवाइस के संचालन के लिए सर्वश्रेष्ठ पाया गया।

CHAPTER – I

INTRODUCTION

The socio-economic conditions of people living in villages as well as urban areas of India including Chhattisgarh state, human muscle power can be a good way of fulfilling the energy demands for doing works like water pumping. It is also well known fact that pedaling is the most efficient way of making use of human muscles.

Like water, energy is also an important part of our living particularly in urban areas. Increasing cost and decreasing sources have compelled to look for alternative sources of energy and have become the need of present time. Apart from other renewable energy, the human muscle power is the one which is available since time unmemorable. Human generates its muscle power form the calorific contains of food they eat and a person can deliver four times more power through pedaling than hand cranking.

The lifting of water for agriculture and drinking purpose is also of great importance in rural areas. Traditionally there are different types of manually or animal operated pumps available for lifting and carrying water, some of which are superior to others for various purposes. There are always much scope for improvement in the conventional pumping system than evolving new water lifting techniques.

Several methods for lifting of water are available for small urban areas. Lifting or moving water without electricity, diesel or solar power may require muscle power. The problem is more pronounced in un-electrified and frequent power cut areas. Under such circumstances the human powered water lifting is the solution. But, from the ergonomic point of view water lifting is a drudgery operation. However, if the water lifting mechanism is made to operate in a rotary mode with gym-cycle the problem could be solved to a great extent with exercising mechanism in it.

The aim of the work is to efficiently utilize the human energy for lifting and moving the water through the improvised pedal operated water pumping system. The human effort is transferred to the wheels through pedals, cranks and chain mechanism and the same pedal power can be used for operating the centrifugal pumps.

The working of centrifugal pumps is based on the principle of forced vortex flow. It’s a type of flow in which mass of fluid is allowed to rotate through an external torque than there is a rise in pressure head of the rotating liquid takes place. This rise in pressure head is used to supply water from one place to some other. This conversion of energy from kinetic energy into pressure energy takes place inside the casing. Discharge of centrifugal pumps is mainly depended upon the RPM of the wheel and it’s directly proportional to the stamina of human during operating system. More the pedaling is done the discharge will be increased. The Overall system is the eco-friendly, portable and easiest way of converting mechanical energy into the hydraulic energy. This system is useful in that area where the electricity and fuel energy are not available or costly to use.

Pedal Operated Water Pumping device is eco-friendly and pump works on mechanical energy without electricity. The Water Pump is used to lift water from sump to water tank in city when there is no electric power supply or load shedding. When pedaling is done, then bicycle wheel start rotating, so pulley will rotate and therefore rotating the centrifugal pump shaft, creating partial vacuum, which will practically lift water from sump upto 10 metres. Using Pedal Operated Water Pump we can save energy and no pollution. Pedal Operated Water Pump can use for exercise purpose also.

Ergonomics is the scientific study of relationship between man-machine and working environment. Its objectives to deal with the effectiveness, productivity and overall performance of human during works, also maintain environment and workspaces to decrease the danger of harm or injury. A different physiological parameter of the human body on using pedal operated cycle pump is measured and also to quantify the energy expenditure rate, heart rate, blood pressure and oxygen consumption rate of a person. Pedal operated water pump performance is affected by the number of variables interaction that is mechanical, human factor and environment.

Ergonomic evaluation is necessary to assess the energy expenditure of human during operating water pumping device. How long they can continuously work without getting fatigued. With consideration over ergonomic aspects, the performance of human powered machines can be significantly improved. Therefore, to quantify the water pumping device, there is an urgent need to study the ergonomic aspects in details. Ergonomic analysis along with mechanical evaluation helps us to make a comparison between with and without the load of work. The system will be tested in the current research, which provides better discharge, less power consumption, lower energy expenditure rate and more safety and convenience.

The BMI (Body Mass Index) is a measure of relative weight based on an individual's mass and height. Nowadays the BMI is commonly used to classify underweight, overweight and obesity. It is calculated by dividing individual's weight in kilograms by his height in meters, then dividing the answer by his height again.

$$\textbf{BMI (kg/m}^2\textbf{) = Body weight (kg) / Height (m}^2\textbf{)}$$

In urban area many people use pedal gym-cycle to burn calorie, can we improvise it as a water lifting device and utilize this energy for some useful work?

Currently the focus of Chhattisgarh government is on 4 aspects, namely: Narwa (Water Resource Management), Garuva (Cattle Management), Ghurva (Composting Mangement) and Badi (Nutritional Management). This study entitled **"Development and performance evaluation of an improvised water pumping device for urban applications**" might be of some use for the Narwa (Water Resources Management) programme which leads to Badi (Nutritional Mangement) programme in remote/un-electrified areas. If a common gym cycle can be improvised to operate a centrifugal pump, it might be useful in hostel, open gymnasium, schools with Poshan-Vatika etc. for lifting and carrying water without using electricity in and environment and health friendly manner.

Keeping in view the above facts, the present study has been undertaken with the following objectives:

1. Improvisation of a common Gym bicycle as a water pumping device.
2. Performance evaluation of improvised water pumping device.
3. Ergonomic analysis of improvised water pumping device.

CHAPTER – II

REVIEW OF LITERATURE

This chapter deals with the previous comprehensive reviews of research work done on different aspects of water lifting device in different countries of the world including India. The all research work was to provide useful information related to this topic in past years. This chapter was further described in the following sub-headings:

1. Pedal-operated devices for agriculture purpose.
2. Ergonomics analysis of different agriculture operation.

1. Pedal-operated devices for agriculture purpose

Sahu (2018) developed pedal operated Pumping system by utilizing rim of a common bicycle with chain sprocket mechanism, a frame for supporting all other parts, power transmission mechanism and 1 hp centrifugal pump without any electrical connections. The human pedal power was capable of pedaling at 50 RPM which was enhanced to 2.5 times when reached to rim of bicycle. Further the rim is connected with the pump pulley and gave speed up of 13 times. This way the system was capable of generating 1625 RPM at the pump pulley for lifting harvested water and operating a gravity drip system of irrigation. The results show that the variation in discharge with suction head is not much prominent as compare to the variation in delivery head. It has been seen that pumping system is useful in water supply for a very small area without electricity and with optimum effort. It give a discharge of 0.65 lps at 3.85 m of suction head and 0.65 m of delivery head which is enough to irrigated small area efficiently. Gravity drip system of irrigation is a cheap, efficient and precise way of providing irrigation water for the kitchen garden

Vanjari *et al.* (2017) had a pedal-operated water pump tested that is used to lift the sump water. The system was tested under different rpm and successfully lifted water at 20 feet to 30 feet. The system was used in a remote area where the source of electricity is not available for irrigation and also use for the purpose of the exercise.

Dorathi *et al.* (2017) were fabricated water pumping device which is driven by bicycle. The system consists of a centrifugal pump and dynamo which is fixed with the rear wheel of the bicycle. There is some pulley arrangement which converts the manual Power into rotary motion which is used to lifting water as well as Power generate. Human operate system in which their power is transferred to the rear wheel of the bicycle through pedals, crack and chain mechanism. They find that pump and dynamo output is increased with person weight is increased. The pump output is highest at 68 kg i.e. 36.8 lpm and dynamo output is highest at 60 kg i.e. 0.6 amperes. This system is useful in a rural area for lifting water and power generation.

Rao and Naidu (2016) conducted an experiment on the design and fabrication of the pedal operator centrifugal pump which can be developed utilizing nearby materials and ability. It operates by generating negative pressure in the tube on the basis of compression and sudden release of a tube, and this generated vacuum attracts water from the sump. This bicycle pedal-operated a pump to lift water at from wells and boreholes up to 23 feet depth at 25-30 litres per minute. It provides water to irrigates and drinks where there is no electricity available.

Sharma *et al.* (2016) conducted an experiment to utilize human physical energy to lift water from the water source through the gym cycle. It creates a simple and efficient way of lifting water by utilizing human power for communities where electricity is unavailable or impractical. The outcomes showed that the higher discharge was obtained at 3800 rpm i.e. 1.53 lit in 0-15 sec.

Dixit *et al.* (2016) were design portable irrigation pump for the marginal farmer. The result was showed that the average flow rate was varied between 27 to 40 lit/min for a different suction head of 0 to 5m. The maximum discharge was 40 lit/min at 0 m head while the minimum discharge was 22 lit/min at 5 m head respectively collected.

Mogaji (2016) was studied on the development of pedal water pump system for rural use. They used a reciprocating pump for lifting water powered by manual pedaling. The system results showed that discharge at 20 m head was 0.0016 m^3/s with a driving power of 29.5 Nm with an estimated performance of 90%.

Wadgure *et al*. (2015) studied on the centrifugal pump which is operated by bicycle as a water-lifting device which was reduced the human and electric power. The mechanism of the system consists of a single centrifugal pump which shaft was driven by pedal power. The results showed the pump successfully lift water up to 15 feet in depth. It was used for both irrigating and cycling can do simultaneously

Onmuka *et al.* (2015) studied on a double pedal-operated piston pump. They were found that pump gives the average discharge vary from 1.60 to 10.1 lpm against the suction head of 0.35 to 2.1 m the rate of the discharge depends upon the operator effort applied on the pedal system. The pump efficiency was 57 per cent against a 0.35 suction head.

Sreejith *et al.* (2014) investigate on working of a pedal-powered centrifugal pump which provides drinking water supply and irrigation in remote areas. The experiment was performed at different rpm and the result shows that discharge about 0.0025m^3/sec and 0.00007 m^3/sec can be obtained at 140rpm and 8m head respectively. It's not just only eco-friendly yet in addition provide healthy exercise.

Garg *et al.* (2013) carried out an experiment on the design and experiment setup of a pedal operated water pump. They can use locally available material to construct their system and which is easily adapted to local people. This system is lift the water up to 23 feet depth at 2-3 gallons per minute from the water source. Water Provides for irrigation and drinking purpose where electricity is not available. This system is free of cost for the user and they use anywhere in rural areas, also pollution free system and health benefit.

Sermaraj (2010) conducted an experiment on the design and fabrication of the pedal operator reciprocating water pump. They would use the foot pedal pump to lift the water from a head range of seven meters i.e. 22.96 feet. A person who can work on the foot pedal pump by pedalling can generate 4^{th} time more power than hand operated pump. At present day pedal power are used for bicycling at high power range while in agriculture purpose lower power range is required. This system is useful in those areas wherein electrical and another source of power is not available otherwise very expensive.

Zakiuddin *et al.* (2010) studied a pedal-operated flywheel application for fodder chopper. A generalized empirical model for fodder-cutting would be established. For the continuous operation on fodder-cutting, the flywheel motor could be used as a source of energy for process unit and had a higher limit of concerning 3 hp. Such an advanced source of energy had tremendous usefulness in energizing several rural-based machines in a location where there is no electricity

Islam *et al.* (2007) designed the low-lift irrigation system which is operated by pedal power and use in small project areas of irrigation. For this purpose, different kinds of check valves and piston valves were made and tested at totally different suction heads within the laboratory to evaluate their performances. They constructed a different type of piston and check valves under that piston valve type-II and check valve type-III found were to be appropriate. The pump average discharge showed that range varies from 93.27 to 53.27 l/m against 0.60 to 2.0 m suction head respectively. One adult man can operate pedal pump more than 2 hours continuously without fatigue and 46.53 per cent efficiency against a head of 1.65 m noted

2. Ergonomic analysis of different agriculture operation

Choudhary *et al.* (2018) reported the energy expenditure of 10 male agricultural works for pedal operated maize de-husker Sheller. There were 139(± 22.01) beats/min for heart rate, 1.40 (± 0.20) l/min for oxygen consumption rate and 6.83 (± 1.07) kcal/min for energy consumption rate. Based on the energy expenditure rate, the machine comes under the 'Heavy' work category

Kadam *et al.* (2015) studied on ergonomically evaluation of pedal operated cashew nut de-sheller on six women from different age group. The procedure adopted for this evaluation was as follow: - each subject was given 30 min rest before starting of works and taking 5 min rest after each trail. Each subject asked to perform for 20 min after resting. The mean value of working heart rate (93.56 bpm), ∆HR (10.54 bpm), oxygen consumption (0.39 l/min), percent VO_2 (29.33 %) and energy expenditure which were less than limit of continuous performance (LCP) and operation comes under 'Moderately heavy'.

Parmanand *et al.* (2015) were analyzed ergonomic evaluation of pedal operated millet thresher. They were collected different ergonomics parameters i.e. heart rate, blood pressure, total cardiac cost of work and obtained the average working heart rate and energy expenditure rate between 116-129 beats/min and 14.00-17.8 kJ/min.

Tiwari *et al.* (2014) evaluated that the physiological response of the operator while performing the pedal operated cleaner-cum-grander for soya-bean grain. They were selected 8 agricultural workers with mean weight and stature was 54.4 kg and 168.4 cm respectively. The output was showed that mean working heart rate and work pulse during operation with original pedaling against dynapod pedaling was 114 beats min^{-1} and 108 beats min^{-1}, 35 beats min^{-1} and 29 beats min^{-1} respectively.

Tiwari *et al.* (2011) investigated the effect of power output and pedaling rpm on physiological responses. They were studied on selected 12 male workers on a bicycle at 5 levels of power output i.e. 30-90W and 7 levels of pedaling rpm i.e. 30-90 rpm. The result was indicated that the power output as well as rpm were significantly affected the physiological responses of male worker and linearly increase with them. The physiological responses in over rest condition were ∆HR= 40beats min^{-1} and ΔVO_2=0.561 min^{-1} at 60 W power output and 50 rpm.

Singh *et al.* (2008) had conducted an experiment for sustained physical activities, the aerobic capacity, i.e., maximal oxygen consumption (VO2 max) of a worker set the limit for their maximum performance. the study was carried out at fifteen farm women workers using sub maximal exercise technique on a computerized tread mill. The mean body weights of these workers of 25 to 34 year and 36 to 44 year age groups were 49.8 + 9.3 kg and 46.0 + 7.1 kg, respectively.

Corresponding mean oxygen consumption rate of farm women were 33.5 + 4.86 ml/kg/ min and 32.65 + 5.77 ml kg/min. At mean aerobic capacity of farm women for the age of 25 to 44 year of 33.18 ml kg/min, the heart rate levels of 120 beats per min or work pulse of 40 beats per min may be considered as optimal criteria, for the quick appraisal of the state of activity that may be continued for longer period with proper rest pauses A linear relationship between heart rate and oxygen consumption rate was also observed and regression equations have been suggested for estimating the oxygen consumption rate of farm women from their measured heart rate data for agricultural activities in the field and is given as

$$\text{Oxygen consumption rate (l/min)} = 0.0114 \times HR - 0.68$$

Varghese *et al.* (1994) developed a modified five point scale of perceived exertion, for determining occupational energy expenditure rate of Indian working women .The modified scale was validated with physiological workload based on heart rate and energy expenditure. The equations given by them for calculate energy expenditure.

$$\text{Energy expenditure} = 0.159 \times HR\ \text{(beats/min)} - 8.72$$

CHAPTER – III

MATERIALS AND METHODS

This chapter deals with materials used and the methodology followed for carrying out the research work. It includes study of improvisation of a common gym cycle as water pumping device.

3.1 The study area

3.1.1 Experimental site

Experiment was carried out during the year 2018-19 at field laboratory, Department of Soil and Water Engineering, SVCAET & RS, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)

3.1.2 Geographical situation

The field of Department of Soil and Water Engineering and Krishi Vigyan Kendra, Raipur, I.G.K.V., Raipur, is situated in the central part of Chhattisgarh at latitude $21^0$23’32” N and longitude $81^0$71’35” E and at an altitude of 292 m above the mean sea level.

3.2 Improvisation of a common gym cycle as water pumping device

The improvisation of a common gym cycle as water pumping device has been attempted for lifting and carrying and create efficient irrigation system for urban applications. This improvisation unit consists of mainly four parts, the first one is gym cycle, the second is centrifugal pump, third one is power transmission mechanism and the fourth one is a frame for supporting and making the unit compact. The improvised water pumping device (IWPD) ice consists of centrifugal pump which is operated by pedal power and placed in front of gym cycle wheel in such a way that the pulley of centrifugal pump is driven by the belt through the front wheel of stationary gym cycle.

The various factors considered during the improvised water pumping system are :-

i. It can be operated by a human being and suited to his body dimensions.

ii. The input force considered is the mechanical power of the operator.

iii. Design of the system is simple and it can be operated easily.

iv. Ease and quick assembling

v. Limitations in total weight to make it portable.

vi. It can be used to carry and lift water from small check dam, tank, reservoirs, river and shallow open well up to a depth of 3-4 m suction depth.

vii. No diesel or electricity is required to operate the pump or any other machine.

viii. It does not create any environmental hazards.

Since the improvised water pumping system is used mostly in urban areas, the cost of material and fabrication was another important parameter.

The material selection and the method of fabrication were made such that overall cost of the pedal operated pump is minimized so that it comes into the affordable for everyone. The pumping system was made simple by using components, which are readily available in the local market. The operations and adjustments were kept simple and easy so that human being can use it without much knowledge

3.3 Description of major components

3.3.1 Gym cycle

A stationary bicycle (also known as exercise bicycle, spinning bike, or exercise cycle) is a device used as exercise equipment. It includes a saddles pedals and some form of handle bars arranged as on a bicycle. A stationary bicycle is usually a special-purpose exercise machine resembling a bicycle without wheels. Some models feature handle bars that are connected to the pedals so that the upper body can be exercised along with the lower body. Most exercise bicycle Provide a mechanism for applying resistance to the pedals which increases the intensity of the exercise. Exercise bicycles are used for exercise, to increase general fitness, for weight loss. The exercise bicycle has long been used for physical therapy because of the low-impact, safe, and effective cardiovascular exercise it provides. The low-impact movement involved in operating an exercise bike does not put much stress on joints and does not involve sporadic motions that some other fitness equipment may require. Stationary bikes are also used for physical testing, i.e. as ergo meters for measuring speed, RPM, distance and calories. Mini-cycles offer exercisers low intensity physical activities that help burn calories, helps moderate blood pressure and sugar level and also minimize cholesterol level. This figure is shown as Plate 3.1

Plate 3.1: Common gym cycle

3.3.2 Pump

The pumps work on the very simple mechanism, which converts the mechanical energy of impeller into the hydraulic energy of water. Its main components are impeller and casing. An impeller was the rotating part of the pump that rotated water inside the casing and increases pressure and velocity while the casing was the stationary part of the pump which guides the direction of water toward the outside of the casing. This figure is shown as Plate 3.2

Plate 3.2: Centrifugal pump

3.3.3 Shaft

Shaft is the central component of centrifugal pump and attached with impellers, its main function was to transmit the input power from the driver into the impeller. At the same, the shaft must maintain aligned with pulley for better power transmission. This figure is shown as Plate 3.3

Plate 3.3: Doctor Pump Shaft

3.3.4 Pulley

Pulley is a type of wheel which assembled on one end of the shaft. In this project trail was taken by two types of the pulley was used in a transmission system that's flat pulley and grooves pulley was driven by a flat belt. The size of pulley was 3 and 2 inches for more rpm 2 inches pulley was used. So finally we selected the groove pulley for transmission. The smaller the pulley would create more rpm in the shaft. This figure is shown as Plate 3.5

Plate 3.4 : Grooves pulley

plate 3.5 : Flat pulley

3.3.5 Belt

The pedal operated pumping system used belt drive to transmit the power. This type of drive is used when the power is to be transmitted from wheel to pulley which is at a distance. Pulleys are mounted on the pump shafts and an endless belt is fitted tightly over these pulleys. The frictional resistance between these pulleys and belt is the reason for the power transmission, which depends on the velocity of belt, tension of the belt and arc of contact of the belt in the smaller pulley. This figure is shown as Plate 3.6

3.3.6 Foot Valve

A foot valve is a type of check valve that is typically installed at the bottom of a pipe line. A foot valve is found at the end of a suction pipe line. They application of a check valve, but they also have a strainer affixed to their open end. It is similarity work to non-return valve. in which preventing the backward flow of water through the pipe when the water pump is stopped. Thus, in this process column of water in the pipe is maintained, and all the related issues are resolved. A foot valve is known as a check valve. The check valve is spring assisted. When the pump turn on, the pressure inside the pump column change and the valve respond by open. This figure is shown as Plate 3.7

Plate 3.6: V – Belt (A Section)

Plate 3.7: Foot Valve ($\emptyset\ 2.5\ cm$)

3.4 Pump Selection

Pump was selected on the basis of relatively low cost and less maintenance required at high speed operation, light weight and easy operated by an average human.

The following factors that influence the selection of pump for this project:

1. Nature of power supply should be a non-electric pump.
2. The pump should deliver water at uniform pressure without shocks.

3. Less power and RPM are required for pumping.
4. Low initial and maintenance cost.
5. Size of the pump should be suitable for easy handling.

In this project several trials have been made to arrive at the most suitable pump for the IWPD. Water submersible pump 18 W tullu pump (electrical pump) was tried but it is not suitable because the pump was not equipped with pulley for power transmission. Rotation was based on magnetic field. Hence, found unsuitable for pump. Self-priming centrifugal regenerative 0.25 hp pump (Electrical pump), although the average power of human is hydrokinetic that under pressure conditions it can produce more for less time . Hence, attempt was also made to run 0.5 hp pump. Self-priming monoblock 0.5 hp pump (Electrical pump) but not performed in below specified rpm. Unable to develop specified RPM through water wheel and not performing in RPM less than the Specified RPM.

3.4.1 Selection of a centrifugal pump

The most suitable pump for this project work was found to be a centrifugal pump. Because of its direct conversion of the pedal energy to rotational energy, the simplicity of design they don't require any valves, compact size, relatively low cost and less maintenance required at high-speed operation, lightweight and easy availability of spare part which makes it ideal for use in this project. The mechanism was capable of developing maximum about 1600 RPM. This pump was capable of lifting water at up to 1600 RPM also. Centrifugal pumps are a well established technology and consequently their performance is well understood.

3.4.2 Specification of selected Centrifugal Pump without motor

1. Horse power – 0.5 hp
2. RPM - 2900
3. Total head - 10 m
4. Discharge - 1 lps
5. Pump efficiency - 49 %
6. Impeller Diameter - 99 mm

7. Pipe size - 25 X 25 mm

3.4.3 Working principle

In improvised water pumping system when pedal is operated by human being then human energy is transfer into mechanical energy and this energy is transfer to sprocket gear at rear side by chain, from sprocket energy is transfer to front wheel, from front wheel it is transfer to Pulley, from pulley energy is transmitted to pump by shaft. So water is sucked from sump and lifted up to 4 m. Pump is a mechanical device which converts mechanical energy into hydraulic energy. A centrifugal pump is of a very simple design. The two main parts of the pump are the impeller and diffuser. Impeller, which is the only moving part, is attached to a shaft and driven by a motor. Impellers are generally made of bronze, polycarbonate, cast iron, stainless steel as well as other materials. The diffuser (also called as volute) houses the impeller and captures and directs the water of the impeller. Water enters the centre (eye) of the impeller and exits the impeller with the help of centrifugal force. As water leaves the eye of the impeller a low-pressure area is created, causing more water to flow into the eye. Atmospheric pressure and centrifugal force cause this to happen. Velocity is developed as the water flows through the spinning at high speed. The pressure (head) that a pump will develop is in direct relationship to the impeller diameter, the number of impellers, the size of impeller eye, and shaft speed. The head and capacity are the main factors, which affect the horsepower size of the motor to be used. The more the quantity of water to be pumped, the more energy is required.

3.5 Selection of suitable low cost material for power transmission:

Selection of suitable low cost belt material for power transmission i.e. cycle tube, bike tube and elastic cloths belt and v- belt. Among these four belts, the friction resistance between the pulley and belt was the reason for the power transmission for that condition cycle tube and v-belt was found as a better power transmission material for the system. It’s easily available in market. This figure is shown as Plate 3.8 and Plate 3.9.

Plate 3.8: Cycle tube Belt **Plate 3.9: V-belt**

3.6 Pump attachment for power transmission

To improvise a common gym bicycle as water pumping device, some improvisation have been done. Initially the wheel of the gym cycle was opened and a v belt has been inserted. For attaching a centrifugal pump, a frame of mild steel plate has been fabricated and attached at the base of gym cycle with suitable fasteners. This way the wheel of gym cycle is attached with the pump pulley. These attachments were helped in easy transmission of pedal power to pump and also pumping the water from the sump. There was only little beat modification was done on the gym bicycle for portable, just an attached the foundation plate for pump was attached with the gym cycle with the help of fastener and clamped and small cutting and welding on gym cycle base. For attachment of the pump are done in several following steps:

1. V-belt is permanent attached in gym cycle wheel with the help skilled mechanics.
2. Flat plates the dimension are 30 cm x 30 cm with the hole 0.5 cm diameter was welded for attaching the pump with the help of fastener.
3. The pump was attached at the foundation plate at the base of gym cycle with the help of fastener and clamp.

3.7 Matching human capability to pump performance

Electrically powered pump heads are designed to work optimally at the specific input power that is normally provided by the pump's electric motor. It is therefore important to find a pump with a rated electrical power that matches as closely as possible with the power that a person can realistically generate on a bicycle. How the power generated by people of varying fitness levels drops as the duration of exercise increases. It is estimated that the gym cycle will be used for around 20-30 minutes for each pumping session. Reading from healthy men can expect to generate around 250 Watts when peddling for this period of time. The design specification states that the bicycle should be able to be used by men, women and children of varying sizes and fitness levels. The average power generated by the average user of the bicycle is likely to be significantly. This figure is shown as Plate 3.10

Plate 3.10: Improvised water pumping system

3.8 Performance Evaluation of Improvised Water Pumping Device

3.8.1 Measurement of suction head

The depth of static water level in the laboratory sump/any water source was measured directly by a graduated tape from centre of the eye of impeller/pump to the static water level.

3.8.2 Measurement of delivery head

The height of discharge water level in the laboratory test/field test water was measured directly by a graduated tape centre of the eye of impeller/pump to the top of the delivery pipe.

3.8.3 Determination of pump speed

The RPM of gym cycle was measured using a tachometer. Then, RPM of pump pulley was obtained through suitable conversion factor.

3.8.4 Determination of pump discharge

Volumetric method was used to measure pump discharges. It is simplest way to estimate small flow is by direct measurement of time to fill the container of known volume. The pump discharge in litre per minutes (lpm) was calculated by dividing the amount of water by the measured time. The time required to fill the container was counted with a stopwatch. The rate of flow is determined by volumetric method. The discharge is calculated as:

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

Where, Q = discharge rate, litres per minute

V =volume of container, litres

T = time required to fill, second

3.9 Testing of Improvised water pumping device

3.9.1 Performance testing

The pump was tested at different suction heads and was operated manually by an average sized man under normal operating conditions. The suction head was varied by reducing the water level. For each operation head, water was collected in a large plastic bucket for a few minutes and the collected water was measured by a plastic bucket graduated to litre marks. Each test was repeated thrice and in each case, operation period, and water volume were measured. Average discharge per second (Q) were then calculated. The results of the experimentation have been presented as a graph and each point on a graph represents an average of three discharge rate if all three were within ±10 percent of their average. This pedal operated pump system is tested at different places at different head conditions Plate 3.11

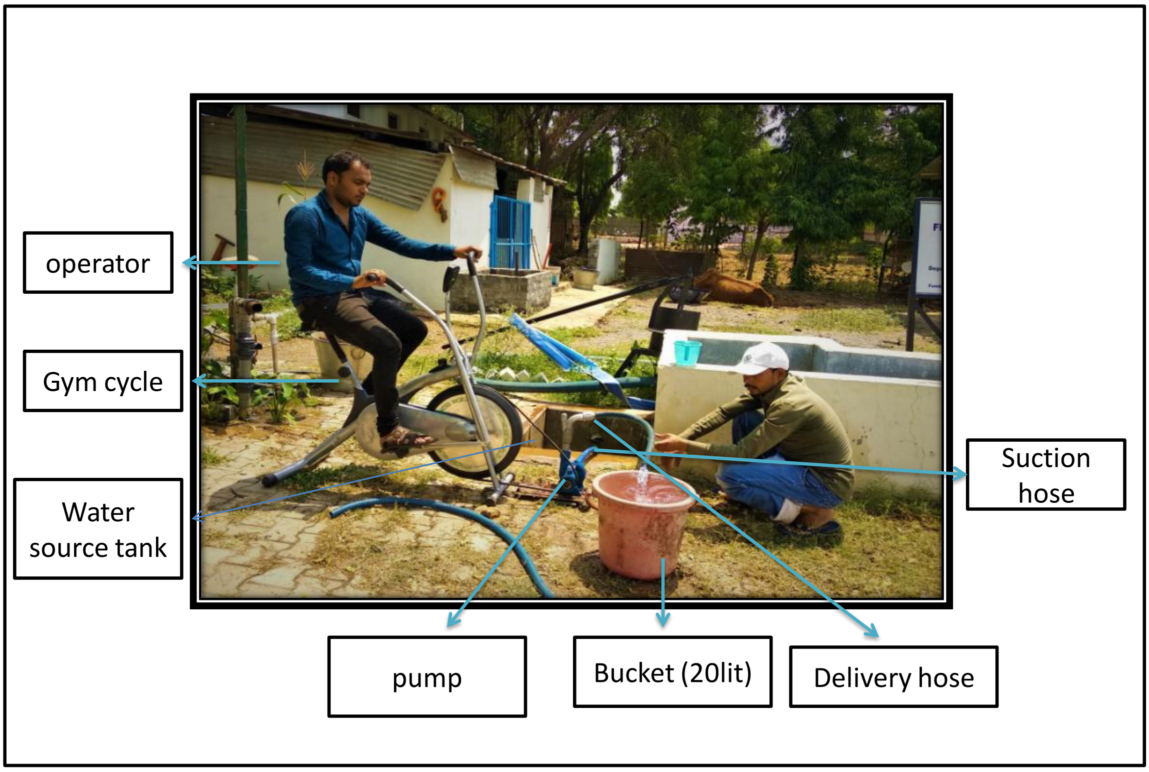

Plate 3.11: **Testing of improvised water pumping system**

3.9.2 Materials Required

The following equipment was needed to conduct the testing:

- Improvised water pumping device
- Suction pipe with foot valve
- Delivery pipe
- Measuring bucket (20 litres)
- Measuring tape
- Stopwatch
- Tachometer
- Pipe clamp

3.9.3 Procedure

All peddling should be done with the same power input as far as possible in order to ensure reliability of results.

1. Careful set up a cycle pump in pumping mode near the water source.
2. Place the foot valve and submerge at the bottom of the water source.

3. Remove air from the pipe to make sure flow isn't restricted.
4. Place measuring bucket on the bottom next for measuring the discharge water.
5. At the beginning of peddling the discharge rate was not constant wait until the flow becomes in steady-state condition then measure the flow rate of water in measuring bucket with the help of stopwatch.
6. Measure and record the water depth in the measuring bucket to calculate the flow rate and then empty it.
7. Repeat the step 6-7 twice for effective reading.
8. Repeat the step 6-8 with different suction head and horizontal distance.

3.10 Ergonomic analysis of improvised water pumping device

Experiments were carried out at experimental field of Department of Soil and Water Engineering and Krishi Vigyan Kendra, IGKV Raipur farm to ergonomic evaluation of improvised water pumping system from randomly selected different age group between 20- 50 years of persons (adult male and female). Each subject was asked to operate the gym cycle.

3.10.1 Instrumentation required for ergonomic analysis.

The following instruments and equipment were used during the ergonomic analysis.

3.10.1.1 Body composition analyzer

Following featuring a full body sensing technology that generates an accurate analysis of the visceral fat level, body fat, body weight, body fat percentage, skeletal muscle percentage and subcutaneous fat percentage, this battery operated fat analyzer comes with a step on analyzer function. It is an ideal device for effective weight management since it displays body mass index to indicate the optimum levels of fat according to the dimensions of the body and this can help validate services like personal training, patient care, and corporate wellness. This figure is shown as Plate 3.12

3.10.1.2 Blood pressure monitor

Blood pressure monitor was used to measure the blood pressure and pulse rate simply and quickly. It is a compact and fully automatic blood pressure monitor which works on the oscillatory principle to measure blood pressure and pulse rate. This figure is shown as Plate 3.13

3.10.1.3 Stop Watch

It was used for measuring the accurate time taken to do some work and comes with buttons i.e. start and stop.

3.10.1.4 Metric tape

It was used for measuring the height of operator in cm or inch.

Plate.3.12: Body composition analyzer

Plate.3.13: Blood pressure monitor

3.11 Selection of subjects

For conducting experiments for evaluating ergonomics analysis of improvised water pumping device, the selection of subjects plays a vital role. The 10 operators (adult male and female) were randomly selected from the age group of 20-50 yrs. All selected operator should be physically and mentally fit for conducting the experiments. Before starting the experiment, different physiological characteristics were measured i.e. age, weight, height, fat, vascular fat, energy and body mass index. The physiological characteristics of selected subjects are given in Table 3.1

Table 3.1 Physiological characteristics of participants

S.No	Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	Age (year)	25	22	23	22	29	24	26	23	29	23
2	Weight (kg)	45.6	65.8	48	55	55.6	49	52.2	49	54.6	60.2
3	Height (cm)	155	185	155	165	165	156	157	150	157	159
4	BMI	19	19.2	20	20.2	20.4	20.7	21.2	21.8	22.2	23.8
5	Fat (%)	32	10.5	49.4	23.2	22.6	20.2	22.4	30.1	25	18.2
6	Vascular fat (%)	2.0	2.5	4.5	4.0	2.5	1.9	3.0	3.5	3.5	7.0
7	Body Age (year)	24	20	28	22	27	24	26	27	29	29

3.12 Physiological response

3.12.1 Heart rate

The digital Sphygmomanometer was used to measure the average heart rate during rest and working condition (beats/min). Before taking the reading, monitor function was set according to the given manual instructions.

$$\Delta HR = \text{average working heart HR} - \text{average resting HR}$$

The American Heart Association generally recommends a target heart rate of:

- Moderate exercise intensity: 50% to about 70% of maximum heart rate
- Vigorous exercise intensity: 70% to about 85 % of maximum heart rate

  The maximum heart rate was calculated by subtracting operators/subjects from 220.

  (https//www.mayoclinic.org/healthy-lifestyle/fitness/in-depth/exercise-intensity/art-20046887)

3.12.2 Oxygen consumption rate

During the experiments, the mean values of heart rate were determined and corresponding to these values the oxygen consumption rate (VO_2) of subjects was determined and is given by the following equation (Singh *et al*., 2008).

$$\text{Oxygen consumption rate (l/min)} = 0.0114 \times \text{HR} - 0.68$$

$$\text{Oxygen consumption rate (kJ)} = \text{OCR} \times 0.93 \ (1\ VO_2 = 20.93\ \text{kJ})$$

The physiological response of operators was studied during the testing of the pedal operated water lifting device under load and without load condition. In this experiment, the change in pulse rate, diastolic and systolic blood pressure was measured and which effect by operating the device. The energy cost of the subject thus obtained was graded as per the tentative classification of strains in different types of jobs given in ICMR report as shown in the table 3.2

3.12.3 Energy expenditure rate

Energy expenditure is the amount of energy (or calories) that a person needs to carry out a physical function such as breathing, circulating blood, digesting food, or physical movement. The physiological response of the operator was studied throughout the testing of the pedal operated water pump. During this experiment, the result of the device on pulse rate and systolic and diastolic blood pressure was measured. The energy expenditure (kJ/min) was estimated using the following formula proposed by Varghese et al. (1994)

$$\text{Energy expenditure} = 0.159 \times \text{HR (beats/min)} - 8.72$$

The energy cost of the subject thus obtained was graded as per the tentative classification of strains in different types of jobs given in ICMR report as shown in Table 3.2.

Table 3.2 Tentative classification of strains in different types of jobs given in ICMR report

Grading	Physiological response		
	Heart rate (beats/min)	Oxygen uptake, (l/min)	Energy expenditure, (kcal/min)
Very light	<75	<0.35	<1.75
Light	75-100	0.35-0.70	1.75-3.5
Moderately heavy	100-125	0.70-1.05	3.5-5.25
Heavy	125-150	1.05-1.40	5.25-7.00
Very heavy	150-175	1.40-1.75	7.00-8.75
Extremely heavy	>175	>1.75	>8.75

3.12.4 Pulse rate

Pulse rate is a good index of physical as well as physiological load on the operator. The pulse rate was measured with the help of B. P. Monitor. The subjected were allowed to relax for 10 min before commencement of operation. The pulse rate reading was taken by the B. P. Monitor of the operator before and after commencement of operation and in this way the pulse rate per minute was computed. The pulse rate is affected due to force required, working time and operator posture. Increased pulse rate also signifies muscular fatigue of subjects.

3.12.5 Blood pressure

Blood pressure is the pressure exerted by the blood on the walls of the blood vessels. The pressure of the blood in other vessels is lower than the arterial pressure. The peak pressure in the arteries during the cardiac cycle is the systolic pressure and the lower pressure (at the resting phase of the cardiac cycle) is the diastolic pressure. The average blood pressure range are 120/80 – 140/90.

3.12.6 BMI (Body Mass Index)

BMI is a common method used to assess the health of an individual by comparing the amount of weight they carry to the height of individual. In most basic way be useful for identifying those who are at an increased heath risk as a result of excess fat accumulation.

3.12.7 Fat

Fat is an important foodstuff for many forms of life, and fats serve both structural and metabolic functions. They are a necessary part of the diet of most heterotrophy (including humans) and are the most energy dense, thus the most efficient form of energy storage. Fat was measured with the help of Body composition analyzer.

3.12.8 Visceral fat

Visceral fat is stored in a person's abdominal cavity and is also known as 'active fat' as it influences how hormones function in the body. An excess of visceral fat can, therefore, have potentially dangerous consequences. It is nearly found the several vital organs including liver, stomach and intestines. Healthy levels of visceral fat stay under 13%. If you're rating more than 13% immediate change the lifestyle and diet plan .Visceral Fat was measured with the help of Body composition analyzer.

3.13 Experimental procedure

1. Some trained subjected will be selected for the experiment.
2. Subjects are asked to report at the work site at 8 am and have a rest for 15min before starting the trial.
3. All the subjects trained in operation.
4. The resting heart rate, oxygen consumption rate, fat, vascular fat, blood pressure and BMI is measured at rest and 15 min prior to any experiment.
5. The HR and OCR measured between 6th to 20th min of work of each subject.
6. Oxygen consumption of subject on measured heart rate is estimated by equation as given by Singh et al (2008).

$$OCR = 0.0114\ HR\ (beats/min) - 0.68$$

7. The energy expenditure (KJ/min) was estimated using the following formula proposed by Varghese et al. (1994)

$$Energy\ expenditure = 0.159 \times HR\ (beats/min) - 8.72$$

8. After taking of HR the Oxygen Consumption (OC) was evaluated with the help of formula.

9. Increase in heart rate (ΔHR) and increase in oxygen consumption rate (ΔOCR) was computed from the difference between mean steady state of heart rate and oxygen consumption rate and their resting values respectively.

10. Steps 5 to step 6 were repeated for next 9 subjects.

Plate.3.14: Body composition analysis

Plate.3.15: Blood pressure measurement

3.14 Fatigue time

The fatigue can be defined as the lack of energy and motivation in both physical and mental. In bicycle fatigue refers to the muscle fatigue which decreases in muscle strength during cycling, often repeating movements, muscles may begin to feel tired. The fatigue time would be measured by performance consistent activity on a bicycle until it gets muscle fatigue. Before taken reading, it was ensured that the operators/subjects were in good health condition, had sound sleep in the previous night, and had a normal breakfast.

CHAPTER –IV

RESULTS AND DISCUSSION

This chapter contains the results and discussion of the experiment conducted in order to fulfill the objectives of the study. The experiment was conducted in the field laboratory of Soil and Water Engineering Department, SVCAET & RS, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). These experiments were carried out for study on improvisation of a common gym bicycle as water pumping device and its performance evaluation. The chapter deals with the performance and ergonomics evaluation of water pumping device in terms of suction head, horizontal distance, pump speed, pump discharge and heart rate, oxygen consumption rate, energy expenditure rate respectively. The result of this experiment was discussed under following sub heads:

4.1 Improvisation of a common gym bicycle as a water pumping device

The Improvised water pumping device (IWPD) has been developed as per the methodology and procedure discussed under article 3.2 to article 3.9. To improvised a common gym bicycle as water lifting system some modification has been done in gym bicycle. For power transmission a v-belt was fixed in gym cycle wheel. In this way the power from the cycle wheel was transferred to the pump pulley through the belt. The complete set-up of the device shown in Plate 4.1.

Plate 4.1 Set-up of improvised water pumping device

4.2 Performance Evaluation of IWPD

Performance evaluation was done under the following steps:

4.2.1 Determination of RPM

The experimental calculation for RPM generated on the pump pulley by an average adult operator measure with the help of tachometer. The RPM generated at the pump pulley by an average adult shown in Table 4.1

Table 4.1: RPM generated at the pump pulley by an average adult

S. No.	**Average adult operate per minute**	**RPM**	
1	**Gym cycle pedal**	**= 50 x 1**	**50**
2	**Gym cycle wheel** **(1 revolution of Gym cycle pedal = revolution of gym cycle wheel)**	**= 50 x 6**	**300**
3	**Pump pulley** **(1 revolution of Gym cycle wheel = 5.5 revolution of pump pulley)**	**= 300 x 5.5**	**1650**

4.2.2 Performance evaluation in terms of head - discharge

The improvised water pumping system has been tested independently in different sites with varying suction head and delivery head conditions, the system has been tested in the field laboratory of Department of Soil and Water Engineering, Swami Vivekananda College of Agricultural Engineering & Technology and Research Station, IGKV, Raipur (C.G.).

4.2.1 Testing of improvised water pumping system

The improvised water pumping system was developed to make ease in water lifting when operated by a human being. In this pumping system the power is transmitted through pedal crank wheel to the front wheel then to the pump pulley. This improvised water pumping system was tested on different heads for calculating its performance. The following Table 4.2 gives its performance at different heads. When the suction head (1m) and the delivery head (0.27 m) is constant and horizontal pipe length is varying from 1m to 30m it was seen that the discharge varying from 0.64 to 0.5 lps is decreasing as the discharge head increasing. So, it was found that the variation in horizontal pipe length affecting the discharge very much. This is shown in Table 4.2 and Fig. 4.1

Table 4.2: Testing of pump discharge at suction head 1 m, delivery head 0.27 m and at varying horizontal carrying distance

S. No.	Suction head (m)	Horizontal pipe length (m)	Discharge		
			lps	lpm	lph
1	1	1	0.641	38.50	2310
2	1	10	0.583	35	2100
3	1	15	0.562	33.72	2023
4	1	20	0.54	32.40	1944
5	1	25	0.526	31.56	1894
6	1	30	0.5	30	1800

When the suction head (2 m) and the delivery head (0.27 m) is constant and horizontal pipe length is varying from 1 m to 30 m it was seen that the discharge varying from 0.60 to 0.46 lps is decreasing as the discharge head increasing. So, it was found that the variation in horizontal pipe length affecting the discharge very much. This is shown in Table 4.3 and Fig. 4.2

Table 4.3: Testing of pump discharge at suction head 2 m and delivery head 0.27 m at different horizontal pipe distances.

S. No.	Suction head (m)	Horizontal pipe length (m)	Discharge		
			lps	lpm	lph
1	2	1	0.60	36	2160
2	2	10	0.56	33.60	2016
3	2	15	0.53	31.80	1908
4	2	20	0.50	30.40	1824
5	2	25	0.48	28.8	1728
6	2	30	0.46	28	1680

When the suction head (2.7 m) and the delivery head (0.27 m) is constant and horizontal pipe length is varying from 1m to 30m it was seen that the discharge varying from 0.51 to 0.33 lps is decreasing as the discharge head increasing. So, it was found that the variation in horizontal pipe length affecting the discharge very much this is shown in Table 4.4 and Fig. 4.3.

Table 4.4: Testing of pump discharge at suction head 2.7 m and delivery head 0.27 m at different horizontal pipe distances.

S. No.	Suction head (m)	Horizontal pipe length (m)	Discharge		
			lps	lpm	lph
1	2.7	1	0.51	31	1860
2	2.7	10	0.44	26.30	1578
3	2.7	15	0.41	24.60	1476
4	2.7	20	0.38	23	1380
5	2.7	25	0.35	21	1260
6	2.7	30	0.33	20	1200

When the suction head (3.3m) and the delivery head (0.27 m) is constant and horizontal pipe length is varying from 1m to 30m it was seen that the discharge varying from 0.46 to 0.23 lps is decreasing as the discharge head increasing. So, it was found that the variation in horizontal pipe length affecting the discharge very much. This is shown in Table 4.5 and Fig. 4.4

Table 4.5: Testing of pump discharge at suction head 3.3 m and delivery head 0.27 m at different horizontal pipe distance

S. No.	Suction head (m)	Horizontal pipe length (m)	Discharge		
			lps	lpm	lph
1	3.3	1	0.466	28	1680
2	3.3	10	0.383	23	1380
3	3.3	15	0.364	22	1310
4	3.3	20	0.325	19.5	1170
5	3.3	25	0.284	17	1022
6	3.3	30	0.233	14	840

When the delivery head (0.27 m) and horizontal pipe length is constant and suction head is varying from 1m to 3.58 m it was seen that the discharge varying from 0.58 to 0.30 lps is decreasing as the suction head increasing. So, it was found that the variation in suction head not affecting the discharge very much. This is shown in Table 4.6 and Fig. 4.5

Table 4.6: Testing of pump discharge at constant horizontal pipe length 10 m and delivery head 0.27 m at different suction head.

S. No.	Suction head (m)	Discharge		
		lps	lpm	lph
1	1	0.583	35	2100
2	2	0.56	33.60	2016
3	2.7	0.44	26.30	1578
4	3.3	0.383	23	1380
5	3.58	0.30	18	1080

When the suction head is constant (1m) and delivery head is varying from 0.27 m to 3 m it was seen that the discharge varying from 0.60 to 0.25 lps is decreasing as the delivery head increasing. So, it was found that the variation in delivery head is affecting the discharge. This is shown in table 4.7 and fig. 4.6

Table 4.7: Testing of pump discharge at constant suction head (1m) at different delivery head

S. No.	Delivery head (m)	Discharge		
		lps	lpm	lph
1	0.27	0.60	36	2160
2	1	0.40	24	1440
3	2	0.31	18.75	1125
4	3	0.25	15	900

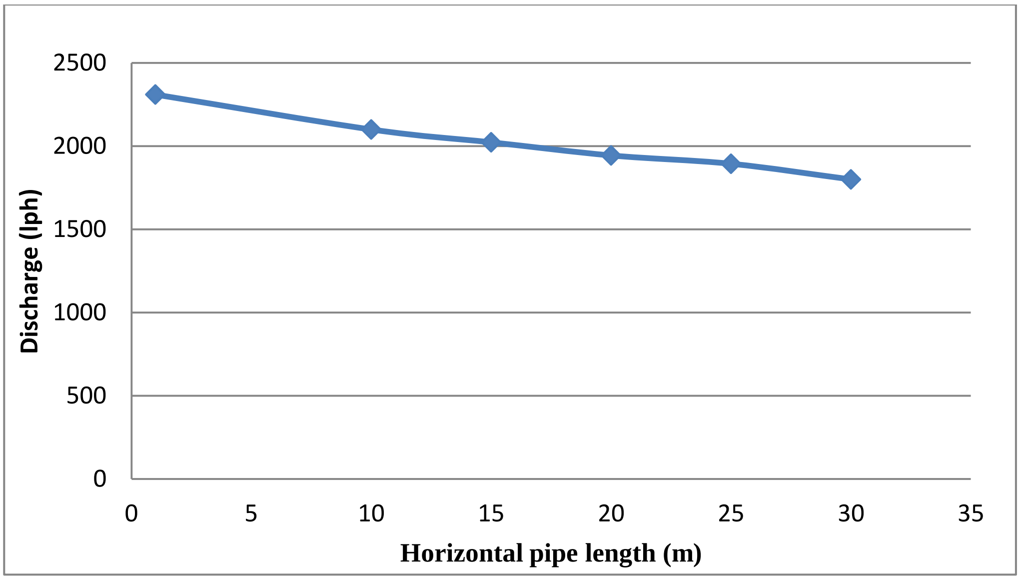

Figure 4.1: Discharge vs horizontal pipe length at constant suction head (1 m) and delivery head (0.27 m)

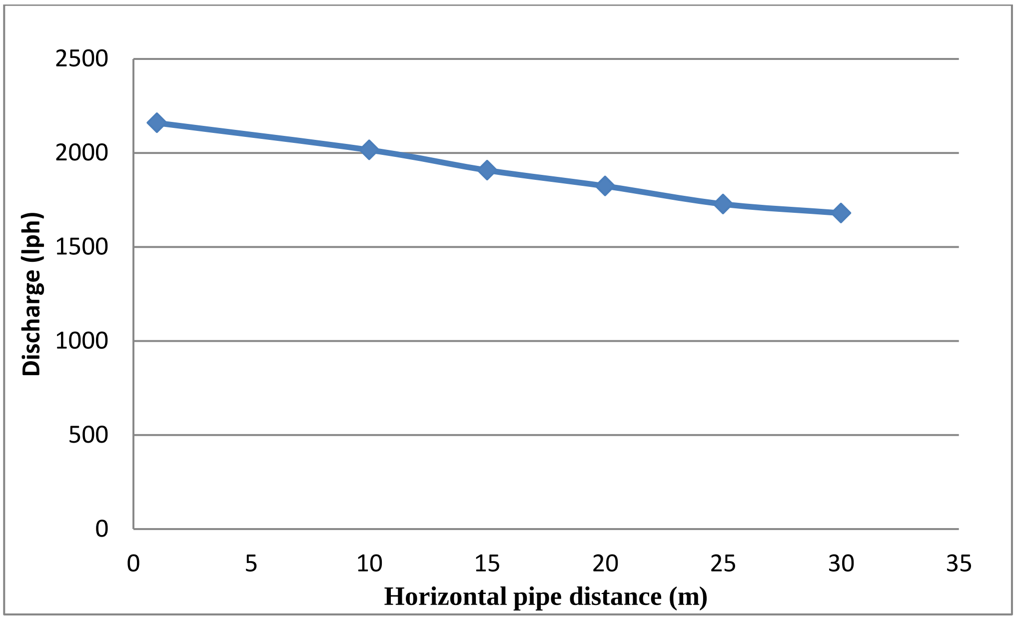

Figure 4.2: Discharge vs horizontal pipe length at constant suction head (2 m) and delivery head (0.27 m)

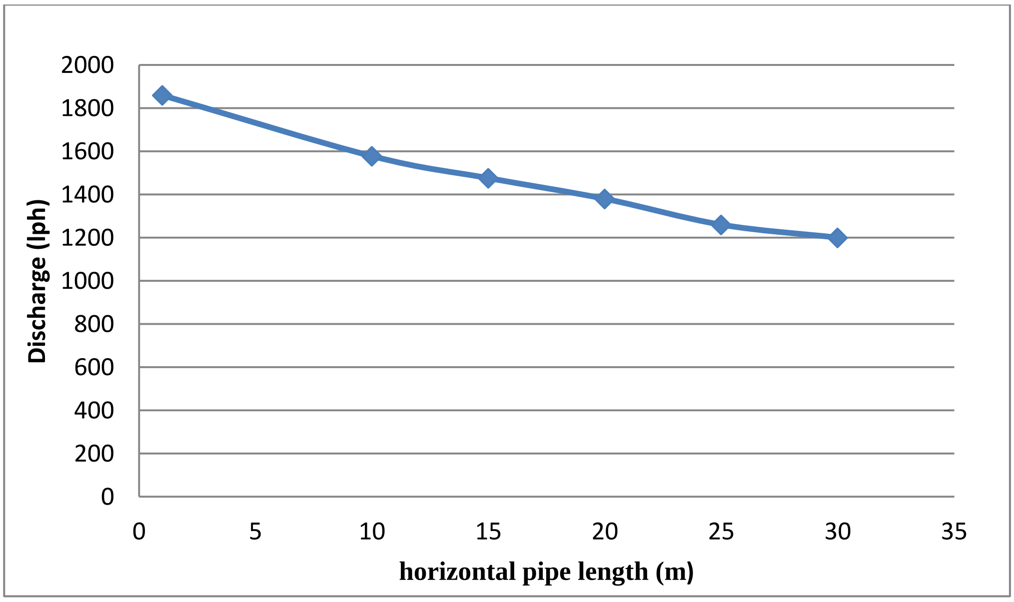

Figure 4.3: Discharge vs horizontal pipe length at constant suction head (2.7m) and delivery head (0.27 m)

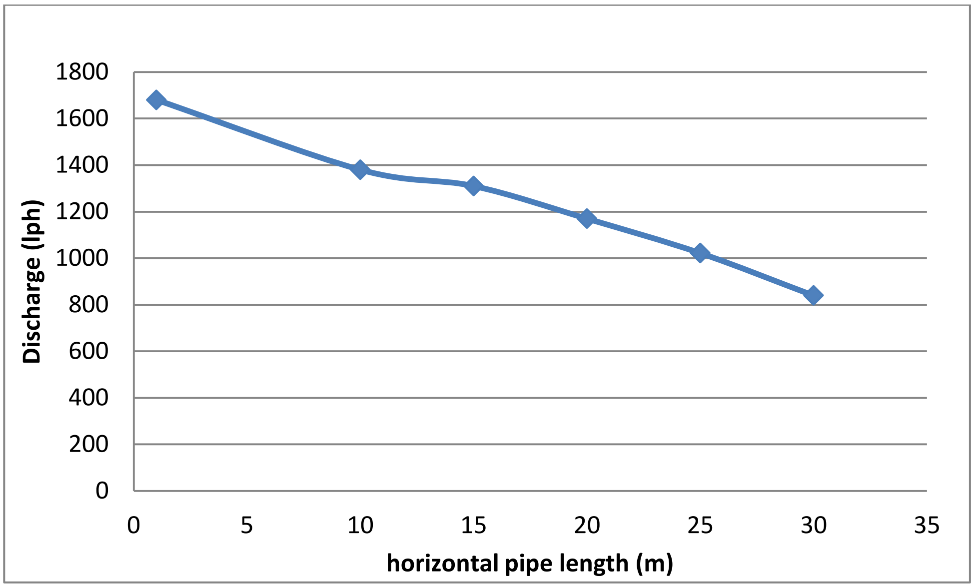

Figure 4.4: Discharge vs horizontal pipe length at constant suction head (3.3 m) and delivery head (0.27 m)

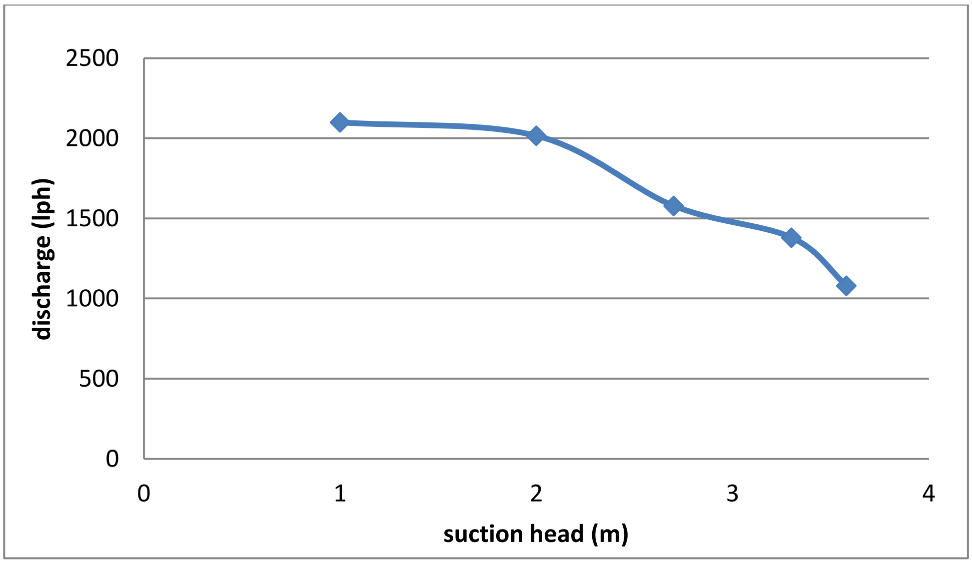

Figure 4.5: Discharge Vs suction head relationship at constant horizontal pipe length (10m) and delivery head (0.27m)

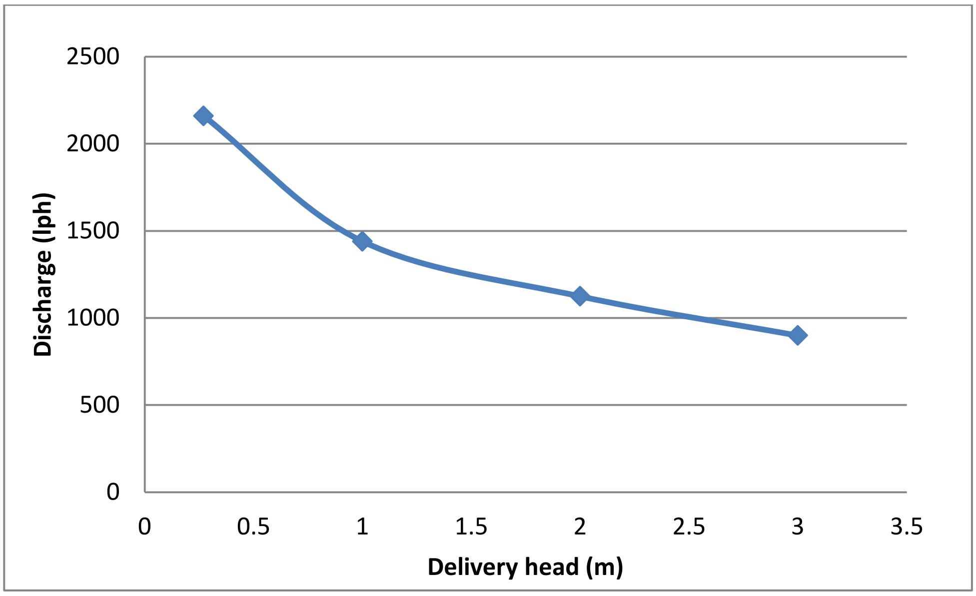

Figure 4.6: Discharge vs delivery head relationship at constant suction head (1 m)

4.3 Ergonomic analysis of improvised water pumping device

All the physiological characteristics data of operators/subjects were collected using measuring instrument as shown in Table 4.8.

Table 4.8 Physiological characteristics of participants

S.No	Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	Age (year)	25	22	23	22	29	24	26	23	29	23
2	Weight (kg)	45.6	65.8	48	55	55.6	49	52.2	49	54.6	60.2
3	Height (cm)	155	185	155	165	165	156	157	150	157	159
4	BMI	19	19.2	20	20.2	20.4	20.7	21.2	21.8	22.2	23.8
5	Fat (%)	32	10.5	49.4	23.2	22.6	20.2	22.4	30.1	25	18.2
6	Vascular fat (%)	2.0	2.5	4.5	4.0	2.5	1.9	3.0	3.5	3.5	7.0
7	Body Age (year)	24	20	28	22	27	24	26	27	29	29

The basic Physical characteristics of 10 subjects (S1, S2, S3, S4, S5, S6, S7, S8, S9 and S10) at different age group (25, 22, 23, 22, 29, 24, 26, 23, 29 and 23) participated in the experiment for ergonomics analysis of IWPD under, with-out load (W1) and with load (W2) condition of male operators were recorded.

4.3.1 Heart rate response of the subjects during operating water pumping device

The mean dry bulb temperature, wet bulb temperature, relative humidity and wind velocity varied between 25.3 to 30.4 °C, 70 to 90 %, 2.2 km/h respectively in during the experiments. Table 4.9 shows that the mean working HR (beats/min) and mean work pulse (ΔHR) of the subjects during all four manual weeding operations. The mean HR of the subjects during operating water pumping device was 113.1beats/min and 117 beats/min for without pump load conditions and with pump load conditions respectively. Mean working HR and change in heart rate (ΔHR) for all operations are presented in Fig 4.7 the lowest mean working HR was observed as 99 beats/min for without load conditions and highest was 129 beats/min for load conditions.

Table 4.9 Heart rate response during operating water pumping system

S.No	**Method**	**Without load condition**			**With load condition**		
	Subjects	Resting HR (beats/min)	Working HR (beats/min)	ΔHR (beats/min)	Resting HR (beats/min)	Working HR (beats/min)	ΔHR (beats/min)
1	S1	67	99	32	67	106	39
2	S2	69	106	37	69	108	39
3	S3	70	107	37	70	110	40
4	S4	75	112	37	75	118	43
5	S5	79	119	40	79	116	37
6	S6	77	116	39	77	112	35
7	S7	70	114	44	70	122	52
8	S8	75	111	36	75	121	46
9	S9	72	124	52	72	128	56
10	S10	80	123	43	80	129	49
	mean	73.4	113.1	39.7	73.4	117	43.6

Mean ΔHR value during operating water pumping device without pump load conditions and with load conditions was 39.7 beats/min and 42.3 beats/min respectively. Maximum increase in heart rate was observed as 56 beats/min shows by subject (9) and minimum as 32 beats/min by subject (1), in without load conditions. Under load conditions, subject (9) showed that the highest increase in heart rate as 56 beats/min and minimum increase was 35 beats/min by subjects (6). The results show that, average heart rate increment was higher under with pump load conditions as compared to without pump load conditions; this may be due to application of more continuous push and pull force as compared to other methods.

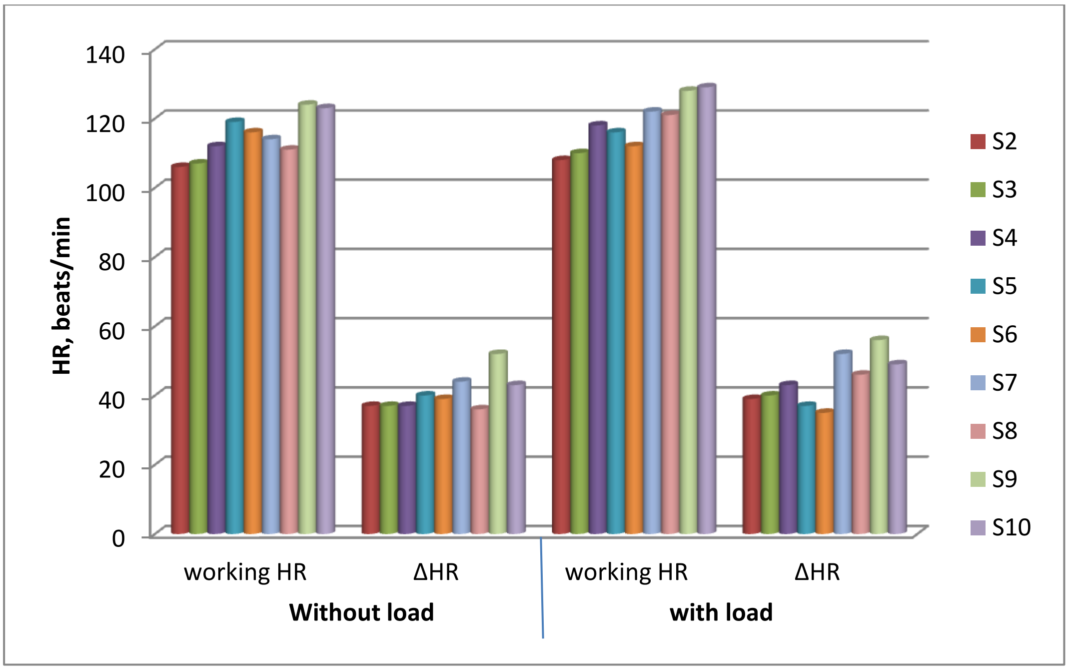

Fig.4.7: Mean working HR during operating water pumping system

4.3.2 Oxygen consumption rate during operating water pumping device

The working OCR of the subjects during operating water pumping device ranged from 0.45 l/min to 0.73 l/min and 0.53 l/min to 0.79 l/min for without pump load and with pump load conditions respectively. The ΔOCR during without pump load condition ranged from 0.36 l/min to 0.59 l/min, and 0.53 l/min to 0.59 l/min, for without pump load and with pump load conditions, respectively.

Fig 4.8 shows mean working OCR and ΔOCR during operation was found to be 0.61 l/min and 0.45 l/min for without pump load and with pump load condition was found to be 0.65 l/min and 0.49 l/min respectively. Mean working OCR was highest for with pump load condition because it required more physical effort than without pump load conditions.

Table 4.10 Oxygen consumption rate of the subjects during operating water pumping system

S.No	**Method**	**Without load condition**			**With load condition**		
	Subjects	Resting OCR (l/min)	Working OCR (l/min)	Δ OCR (l/min)	Resting OCR (l/min)	Working OCR (l/min)	Δ OCR (l/min)
1	S1	0.08	0.45	0.36	0.08	0.53	0.45
2	S2	0.11	0.53	0.42	0.11	0.55	0.44
3	S3	0.12	0.54	0.42	0.12	0.57	0.45
4	S4	0.18	0.60	0.42	0.18	0.67	0.49
5	S5	0.22	0.68	0.46	0.22	0.64	0.42
6	S6	0.20	0.64	0.44	0.20	0.60	0.40
7	S7	0.12	0.62	0.50	0.12	0.71	0.59
8	S8	0.17	0.58	0.41	0.17	0.70	0.53
9	S9	0.14	0.73	0.59	0.14	0.77	0.63
10	S10	0.23	0.72	0.49	0.23	0.79	0.56
	mean	**0.16**	**0.61**	**0.45**	**0.16**	**0.65**	**0.49**

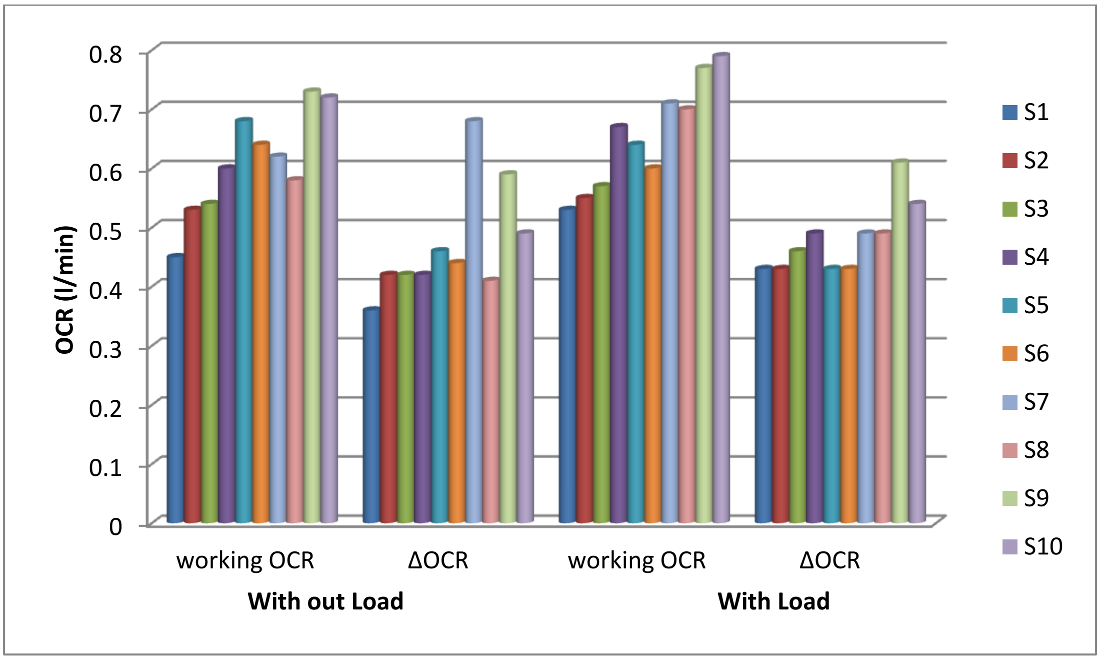

Fig.4.8: Mean working OCR during operating water pumping system

4.3.3 Energy expenditure rate (EER) of the subjects during operating water pumping system

Since oxygen consumption rate (OCR) is a better parameter than heart rate, the energy expenditure rate was estimated by formula taken from vargish et al.

The energy expenditure rate of the selected subjects in during operation is presented in Table 4.11.The mean working EER was 9.24 kJ/min and 9.87 kJ/min for without pump load conditions and with pump load conditions respectively. Mean lowest energy expenditure rate in during operation was 7 kJ/min and highest was 10.9 kJ/min for without pump load condition and lowest 8.1 kJ/min and highest 11.7 kJ/min for with pump load conditions respectively. The mean ΔEER was 6.31 kJ/min and 6.93 kJ/min for without pump load and with pump load conditions respectively. This is shown in Fig. 4.9

Table 4.11 Energy expenditure rate of the subjects during operating water pumping system

S.No	**Method**	**Without load condition**			**With load condition**		
	Subjects	Resting EER (kJ/min)	Working EER (kJ/min)	Δ EER (kJ/min)	Resting EER (kJ/min)	Working EER (kJ/min)	Δ EER (kJ/min)
1	S1	1.9	7.0	5.1	1.9	8.1	6.2
2	S2	2.3	8.1	5.9	2.3	8.5	6.2
3	S3	2.4	8.3	5.9	2.4	8.8	6.4
4	S4	3.2	9.1	5.9	3.2	10.0	6.8
5	S5	3.8	10.2	6.4	3.8	9.7	5.9
6	S6	3.5	9.7	6.2	3.5	9.1	5.6
7	S7	2.4	9.4	7.0	2.4	10.7	8.3
8	S8	3.2	8.9	5.7	3.2	10.5	7.3
9	S9	2.7	10.9	8.2	2.7	11.6	8.9
10	S10	4.0	10.8	6.8	4.0	11.7	7.7
	Mean	**2.94**	**9.24**	**6.31**	**2.94**	**9.87**	**6.93**

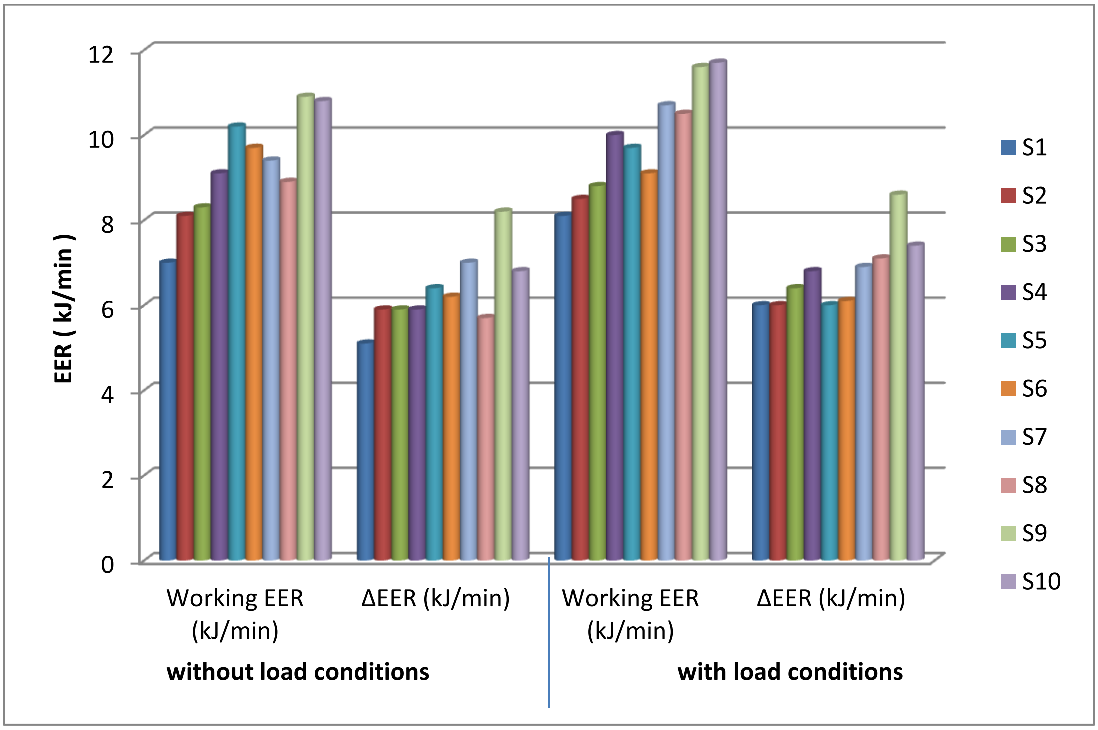

Fig.4.9: Mean working EER during operating water pumping system

4.3.4: Fatigue time of the subjects during operating IWPD

The fatigue time (min) of the selected subjects under without load and with pump load conditions were observed. Mean fatigue time value operation under without load and with pump load conditions were 22.3 min and 13.1 min respectively. The maximum fatigue time was observed as 27 min shown by 22.2 BMI operator and less fatigue time was observed as 18 min shown by 19 BMI operator under the with-out load condition. While in under load condition, the maximum fatigue time was observed as 16 min shown by 22.2 BMI operator and minimum fatigue time was observed as 10 min shown by 19 BMI operator. The details has been presented in Table 4.11 and Fig 4.10. The results showed that under the load condition the operators got fatigue in short time as compare to the with-out load condition. As seen from Table 4.11 and from the point of view of buring some calories and utilizing that energy for some useful work, the same can be achieved load condition (13.1 min) in nearly half of the from as compared to no load condition (22.3 min).

Table.4.12: Mean fatigue time during operating water pumping system

S.No.	Subject	BMI	Fatigue time (min)	
			With-out load	**With load**
1	S_1	19	18	10
2	S_2	19.2	22.42	14.30
3	S_3	20	20.04	14
4	S_4	20.2	23	15.20
5	S_5	20.4	23	13
6	S_6	20.7	19.50	12
7	S_7	21.2	26	15.40
8	S_8	21..8	20	13
9	S_9	22.2	27	16
10	S_{10}	23.8	24	14
		Mean	22.3	13.06

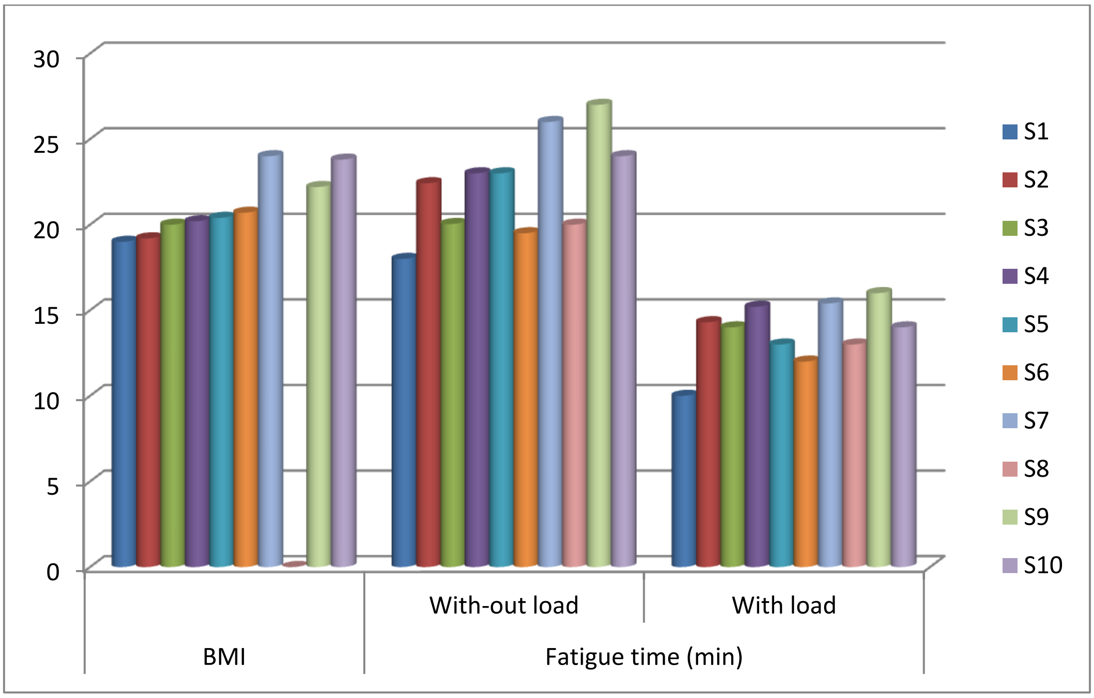

Fig.4.10: Mean fatigue time during operating water pumping system

CHAPTER –V

SUMMARY AND CONCLUSIONS

5.1 Summary

The present study entitled "Improvisation of a common gym bicycle as water pumping device and its performance evaluation" was carried out in the experimental field of Soil and Water Engineering Department, SVCEAT Raipur (C.G).

The whole study over the subject concludes over the actual fact that the IWPD is advantageous particularly for urban areas. The problem on portability of available water pumping device operated by human pedal power due to their heavy frame which can be solved by this improvised common gym cycle as a water pumping device. With respect to the objectives of the project, an idea and prototype for an improvised common gym cycle as water pumping device was designed, built and ergonomics analysis of operator. The pumping system was specifically improvised to be used in an urban area especially for urban applications however; the technology might simply be used in any developing country or place where the electricity is not available or costly. The device was tested under the following condition varying delivery head from 0.27 to 3 m and for different suction heads varying from 1 to 3.58 m and different horizontal pipe distance from 1 m to 30 m. When the suction head (1m) and delivery head is (0.27 m) is constant therefore the horizontal pipe distance is varying from 1 m to 30 m. It can be seen that the discharge varying from 0.64 to 0.5 lps was decreasing because that as the horizontal distance increasing. When the delivery head (0.27 m) and horizontal pipe distance (10 m) is constant and the suction head is varying from 1 m to 3.58 m it was seen that the discharge varying from 0.58 to 0.30 lps is decreasing as the suction head increasing. So, we found that the variation in suction head up to 3.58m is not affecting the discharge very much. When the suction head (1m) constant and therefore the delivery head was variable from 0.27 to 3 m it absolutely was seen that the discharge variable from 0.60 to 0.25 lps was decreasing because that as the delivery head increasing. So, it absolutely was found that the variation in the delivery head affecting the discharge significantly.

Its main advantages over the available technology were its mobility that means the device can be easily transported from one place to another place and also suitable for a variety of application in an urban area such as irrigation, water supply in domestic and livestock purpose, hostels, open gymnasium, schools with Poshan-Vatika.

In order to achieve the specific objective i.e., ergonomic analysis of improvised water pumping device was conducted. Selected the 10 male subjects of different BMI between 18.9 to 29.4. These were used in field trials.

Table based on the results of various experiments conducted under the study the following results were drawn. The operations methods include were without load condition and with load condition. The mean fatigue time under without load and with-load condition were compared. The different physiological characteristics of subjects were collected and measure the different ergonomically parameter was measured which include heart rate, oxygen consumption rate, energy expenditure rate and fatigue time.

The average working heart rate (HR) of the operator was 113.1 beats/min in without-load condition and 117 beats/min in with-load condition and the corresponding value of oxygen consumption rate (OCR) were 0.61 l/min for without-load and 0.65 1/min for the with-load condition. The corresponding value of energy expenditure (EER) was 9.24 kJ/min in without-load condition and 9.47 kJ/min in with-load condition. Based on the EER operation was graded as “light” work. The mean fatigue times were measure under the with-out load and with -load condition was 22′30″ and 13′06″ respectively.

5.2 Conclusions

The following conclusion was taken on the basis of the work performed:

1. A common gym cycle can be improvised to work as human pedal powered water lifting device.
2. The effect of delivery head on discharge is more prominent as compared to suction head.
3. The value of all physiological parameters increases with the duration of operation. These values were higher in the under pump load conditions of work as compared to without pump load conditions.

4. Looking to the life style shortage of time in burning calories operation of gym cycle under the pumping load conditions is more beneficial as compare to no load conditions as nearly same amount of calories can be burnt in half of the time and utilizing that energy for some useful work.

Suggestions for future study:

On the basis of the investigation the following suggestions are made for further study

1. A reciprocating pump can be tried in a place of centrifugal pump for constant discharge.
2. RPM of pump pulley can be increased with some suitable mechanical engineering interventions.
3. The system can be further improved provided an efficient pump operating at 1600 RPM be made available.
4. A gym cycle with larger diameter wheel can be used to further speed up the RPM of pump pulley.

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APPENDIX-A

S.No	Suction head (m)	Horizontal distance (m)	Discharge (lps)	lpm	Lph
1	1	0	0.641	38.50	2310
2	1	10	0.583	35	2100
3	1	20	0.54	32.40	1944
4	1	30	0.5	30	1800

Appendix-A1: Testing of pump at constant suction head (1 m) and constant delivery head (0.27 m) at different horizontal distance.

S.No	Suction head (m)	Horizontal distance (m)	Discharge (lps)	lpm	Lph
1	2	0	0.60	36	2160
2	2	10	0.56	33.60	2016
3	2	20	0.50	30.40	1824
4	2	30	0.46	28	1680

Appendix-A2: Testing of pump at constant suction head (2 m) and constant delivery head (0.27 m) at different horizontal distance.

S. No	Suction heat (m)	Horizontal distance (m)	Discharge (lps)	lpm	Lph
1	2.7	0	0.51	31	1860
2	2.7	10	0.44	26.30	1578
3	2.7	20	0.38	23	1380
4	2.7	30	0.33	20	1200

Appendix-A3: Testing of pump at constant suction head (2.7 m) and constant delivery head (0.27 m) at different horizontal distance.

S. No	Suction heat (m)	Horizontal distance (m)	Discharge (lps)	lpm	Lph
1	3.3	0	0.466	28	1680
2	3.3	10	0.383	23	1380
3	3.3	20	0.325	19.5	1170
4	3.3	30	0.233	14	840

Appendix-A4: Testing of pump at constant suction head (3.3 m) and constant delivery head (0.27 m) at different horizontal distance.

S.No	Suction head (m)	Delivery head (m)	Discharge (lps)	Lpm	Lph
1	1	0.27	0.583	35	2100
2	2	0.27	0.56	33.60	2016
3	2.7	0.27	0.44	26.30	1578
4	3.3	0.27	0.383	23	1380
5	3.58	0.27	0.30	18	1080

Appendix-A5: Testing of pump at variable suction head and at constant delivery head (0.27 m) and horizontal pipe distance

S.No	Delivery head (m)	Discharge (lps)	lpm	lph
1	0.27	0.60	36	2160
2	1	0.40	24	1440
3	2	0.31	18.75	1125
4	3	0.25	15	900

Appendix-A6: Testing of pump at variable delivery head and at constant suction head (1 m)

APPENDIX-B

S.No	Subject	Replication	Without load condition (W1)			With load condition (W2)		
			Resting HR, beats/min	**Working HR beats/min**	**ΔHR, beats/min**	**Resting HR, beats/min**	**Working HR, beats/min**	**ΔHR, beats/min**
1	S_1	R_1	68	99	31	68	105	37
		R_2	67	99	32	67	107	40
		R_3	67	98	31	67	105	38
		Average	**67**	**99**	**32**	**67**	**106**	**39**
2	S_2	R_1	70	104	34	70	109	39
		R_2	68	107	39	68	105	37
		R_3	70	108	38	70	109	39
		Average	**69**	**106**	**37**	**69**	**108**	**39**
3	S_3	R_1	72	110	38	72	112	40
		R_2	71	106	35	71	112	39
		R_3	69	108	39	69	108	39
		Average	**70**	**107**	**37**	**70**	**110**	**40**
4	S_4	R_1	79	115	36	79	120	41
		R_2	80	117	37	80	122	42
		R_3	81	119	38	81	124	43
		Average	**75**	**112**	**37**	**75**	**118**	**43**
5	S_5	R_1	78	118	40	78	116	38
		R_2	81	122	41	81	118	37
		R_3	78	120	42	78	118	40
		Average	**79**	**119**	**40**	**79**	**116**	**37**
6	S_6	R_1	78	117	39	78	124	46
		R_2	78	118	40	78	125	47
		R_3	75	113	38	75	120	45
		Average	**77**	**116**	**39**	**77**	**112**	**35**
7	S_7	R_1	73	118	45	73	125	52
		R_2	68	106	38	68	121	53
		R_3	67	110	43	67	122	55
		Average	**70**	**114**	**44**	**70**	**122**	**52**
8	S_8	R_1	76	110	34	76	119	43
		R_2	77	110	33	77	122	35
		R_3	74	112	38	74	120	46

		Average	**75**	**111**	**36**	**75**	**121**	**46**
9	S_9	R_1	75	130	55	75	127	52
		R_2	74	126	52	74	126	52
		R_3	70	122	52	70	129	59
		Average	**72**	**124**	**52**	**72**	**128**	**56**
10	S_{10}	R_1	83	124	41	83	133	50
		R_2	79	125	46	79	129	50
		R_3	84	126	42	84	131	47
		Average	**80**	**123**	**43**	**80**	**129**	**49**

Appendix-B1: Change in heart rate (beats/min) obtained from 10 subjects/operators during IWPD operation.

S.No	Subject	Replication	Without load condition (W1)			With load condition (W2)		
			Resting OCR, 1/min	**Working OCR, 1/min**	**ΔOCR, 1/min**	**Resting OCR, 1/min**	**Working OCR, 1/min**	**ΔOCR, 1/min**
1	S_1	R_1	0.09	0.44	0.35	0.09	0.51	0.42
		R_2	0.08	0.44	0.36	0.08	0.53	0.45
		R_3	0.08	0.43	0.35	0.08	0.51	0.43
		Average	**0.08**	**0.45**	**0.36**	**0.08**	**0.53**	**0.45**
2	S_2	R_1	0.11	0.50	0.39	0.11	0.56	0.45
		R_2	0.09	0.53	0.44	0.09	0.51	0.42
		R_3	0.11	0.55	0.44	0.11	0.56	0.45
		Average	**0.11**	**0.53**	**0.42**	**0.11**	**0.55**	**0.44**
3	S_3	R_1	0.14	0.57	0.43	0.14	0.59	0.43
		R_2	0.12	0.52	0.40	0.12	0.59	0.47
		R_3	0.10	0.55	0.45	0.10	0.55	0.45
		Average	**0.12**	**0.54**	**0.42**	**0.12**	**0.57**	**0.45**
4	S_4	R_1	0.22	0.63	0.41	0.22	0.69	0.47
		R_2	0.23	0.65	0.42	0.23	0.71	0.48
		R_3	0.24	0.68	0.43	0.24	0.73	0.49
		Average	**0.18**	**0.60**	**0.42**	**0.18**	**0.67**	**0.49**
5	S_5	R_1	0.20	0.66	0.46	0.20	0.64	0.44
		R_2	0.24	0.65	0.47	0.24	0.64	0.40
		R_3	0.20	0.67	0.48	0.20	0.66	0.46
		Average	**0.22**	**0.68**	**0.46**	**0.22**	**0.64**	**0.42**
6	S_6	R_1	0.20	0.65	0.45	0.21	0.73	0.51
		R_2	0.20	0.66	0.46	0.21	0.74	0.53
		R_3	0.17	0.60	0.43	0.18	0.68	0.50
		Average	**0.20**	**0.64**	**0.44**	**0.20**	**0.60**	**0.40**
7	S_7	R_1	0.15	0.66	0.51	0.15	0.74	0.42
		R_2	0.09	0.52	0.43	0.09	0.69	0.44
		R_3	0.08	0.57	0.49	0.08	0.71	0.43
		Average	**0.12**	**0.62**	**0.50**	**0.12**	**0.71**	**0.59**
8	S_8	R_1	0.18	0.57	0.39	0.18	0.67	0.49
		R_2	0.19	0.57	0.38	0.19	0.71	0.52
		R_3	0.16	0.59	0.43	0.16	0.68	0.52
		Average	**0.17**	**0.58**	**0.41**	**0.17**	**0.70**	**0.53**
9	S_9	R_1	0.17	0.80	0.53	0.17	0.76	0.59
		R_2	0.16	0.75	0.59	0.16	0.75	0.59
		R_3	0.11	0.71	0.60	0.11	0.71	0.60
		Average	**0.14**	**0.73**	**0.59**	**0.14**	**0.77**	**0.63**

10	S_{10}	R_1	0.26	0.73	0.47	0.26	0.84	0.58
		R_2	0.22	0.74	0.52	0.22	0.79	0.57
		R_3	0.23	0.75	0.52	0.23	0.81	0.58
		Average	**0.23**	**0.72**	**0.49**	**0.23**	**0.79**	**0.56**

Appendix-B2: Change in OCR (1/min) obtained from 10 subjects/operators during IWPD operation.

S.No	Subject	Replication	Without load condition (W1)			With load condition (W2)		
			Resting EER, (kJ/min)	**Working EER, (kJ/min)**	**ΔEER, (kJ/min)**	**Resting EER, (kJ/min)**	**Working EER, (kJ/min)**	**ΔEER, (kJ/min)**
1	S_1	R_1	2.09	7.02	4.93	2.09	7.97	5.88
		R_2	1.93	7.02	5.09	1.93	8.29	6.36
		R_3	1.93	6.86	4.93	1.93	7.97	6.04
		Average	**1.9**	**7.0**	**5.1**	**1.9**	**8.1**	**6.2**
2	S_2	R_1	2.41	7.81	5.40	2.41	8.61	6.20
		R_2	2.09	8.29	6.20	2.09	7.97	5.88
		R_3	2.41	8.45	6.04	2.41	8.61	6.20
		Average	**2.3**	**8.1**	**5.9**	**2.3**	**8.5**	**6.2**
3	S_3	R_1	2.72	8.77	6.05	2.72	9.08	6.36
		R_2	2.56	8.13	5.57	2.56	9.08	6.52
		R_3	2.25	8.45	6.20	2.25	8.45	6.20
		Average	**2.4**	**8.3**	**5.9**	**2.4**	**8.8**	**6.4**
4	S_4	R_1	3.84	9.56	5.67	3.84	10. 36	6.52
		R_2	4.00	9.88	5.88	4.00	10.67	6.67
		R_3	4.16	10.20	6.01	4.16	11.00	6.49
		Average	**3.2**	**9.1**	**5.9**	**3.2**	**10.0**	**6.8**
5	S_5	R_1	3.68	10.04	6.36	3.68	9.72	6.04
		R_2	4.10	10.67	6.57	4.10	9.72	5.62
		R_3	3.68	10.36	6.68	3.68	10.04	6.36
		Average	**3.8**	**10.2**	**6.4**	**3.8**	**9.7**	**5.9**
6	S_6	R_1	3.68	9.88	6.20	3.68	11.00	7.31
		R_2	3.68	10.04	6.36	3.68	11.16	7.47
		R_3	3.20	9.24	6.04	3.20	10.36	7.16
		Average	**3.5**	**9.7**	**6.2**	**3.5**	**9.1**	**5.6**
7	S_7	R_1	2.88	10.04	7.16	2.88	11.15	8.27
		R_2	2.09	8.13	6.04	2.09	10.51	8.58
		R_3	1.93	8.77	6.84	1.93	10.67	8.74
		Average	**2.4**	**9.4**	**7.0**	**2.4**	**10.7**	**8.3**
8	S_8	R_1	3.36	8.77	5.41	3.36	10.20	6.84
		R_2	3.52	8.77	5.35	3.52	10.67	7.15
		R_3	3.04	9.08	5.88	3.04	10.36	6.84
		Average	**3.2**	**8.9**	**5.7**	**3.2**	**10.5**	**7.3**
9	S_9	R_1	3.20	11.95	8.75	3.20	11.47	11.47
		R_2	3.04	11.31	8.27	3.04	11.31	11.31

		R_3	2.41	10.67	8.26	2.41	13.79	11.79
		Average	**2.7**	**10.9**	**8.2**	**2.7**	**11.6**	**8.9**
10	S_{10}	R_1	4.47	11.00	5.63	4.47	12.42	7.95
		R_2	3.84	11.15	7.31	3.84	11.79	7.95
		R_3	4.63	11.31	6.68	4.63	12.11	7.47
		Average	**4.0**	**10.8**	**6.8**	**4.0**	**11.7**	**7.7**

Appendix-B3: Change in EER (kJ/min) obtained from 10 subjects/operators during IWPD operation.

S.No	Subject	BMI	Replication	Fatigue time (min)	
				Without load	**With load**
1	S_1	19	R_1	17.95	9.55
			R_2	19.90	12
			R_3	17.42	9
			Average	**18**	**10**
2	S_2	19.2	R_1	21.75	14.20
			R_2	22.15	14.35
			R_3	22.10	14.35
			Average	**22.04**	**14.30**
3	S_3	20	R_1	20.35	14.20
			R_2	21.40	13.30
			R_3	19	15.50
			Average	**20.04**	**14**
4	S_4	20.2	R_1	25.95	17
			R_2	21.40	13.15
			R_3	22.25	13.20
			Average	**23**	**15.20**
5	S_5	20.4	R_1	22.25	12.85
			R_2	22.90	14.90
			R_3	21.85	11.25
			Average	**23**	**13**
6	S_6	20.7	R_1	19.90	13.00
			R_2	19.15	13.05
			R_3	22.95	11.10
			Average	**19.50**	**12**
7	S_7	21.2	R_1	25	16.31
			R_2	26.20	14.20
			R_3	26	15
			Average	**26**	**15.40**
8	S_8	21.8	R_1	20.85	13.95
			R_2	18.20	11.20
			R_3	20.45	13.10

			Average	**20**	**13**
9	S_9	26.9	R_1	26.15	14.90
			R_2	26.00	15.80
			R_3	28.00	18.30
			Average	**27**	**16**
10	S_{10}	29.4	R_1	27.15	15.15
			R_2	19.10	16.25
			R_3	27.05	13.20
			Average	**24**	**14**

Appendix-B4: Fatigue time (min) of 10 subjects/operators under with-out and with load condition.

RESUME

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