STUDIES ON SELECTED MANUALLY OPERATED PUMPS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
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1990

DECLARATION

I hereby declare that this thesis entitled "Studies on selected manually operated pumps" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society

Tavanur,
7-4-'90

GEETA SUSAN PHILIP

CERTIFICATE

Certified that this thesis, entitled "Studies on selected manually operated pumps" is a record of research work done independendly by **Smt. Geeta Susan Philip** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her

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We, the undersigned, members of the Advisory Committee of **Smt. Geeta Susan Philip,** a candidate for the degree of Master of Science in Agricultural Engineering with major field in Farm Power Machinery and Energy, agree that the thesis entitled "Studies on selected manually operated pumps" may be submitted by Smt Geeta Susan Philip in partial fulfilment of the requirements for the degree

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Geeta Susan Philip

DEDICATED TO MY PARENTS

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SYMBOLS AND ABBREVIATIONS USED

beats/min	-	beats per minute
cm	-	centimetre
cm/kg	-	centimetre per kilogram
cu cm	-	cubic centimetre
cu m	-	cubic metre
ECG	-	Electro cardiogram
etc	-	et cetera
Fig	-	Figure
GI	-	Galvanized iron
ha cm/day	-	hectare, centimetre per day
HP	-	Horse power
JNKVV	-	Jawaharlal Nehru Kendra Vishwa Vidyalaya
KAU	-	Kerala Agricultural University
kcal	-	kilocalory
kcal/day	-	kilocalory per day
kcal/day/kg	-	kilocalory per day per kilogram
kcal/hr	-	kilocalory per hour
kcal/min	-	kilocalory per minute
kg	-	kilogram
kgf	-	kilogram force
kg m	-	kilogram metre
kg/sq cm	-	kilogram per square centimetre
l	-	litre

lb	-	pound
l/min	-	litres per minute
l/s	-	litres per second
m	-	metre
mm	-	millimetre
min	-	minute
ml/min	-	millilitre per minute
PVC	-	Poly Vinyl Chloride
Rs	-	Rupees
s	-	second
sq cm	-	square centimetre
sq m	-	square metre
TNAU	-	Tamil Nadu Agricultural University
UNICEF	-	United Nations International Children's Emergency Fund
W	-	Watts
WHP	-	Water horse power
/	-	per
%	-	percent
°	-	degree
"	-	inches

Introduction

INTRODUCTION

1.1 Role of human energy in water pumping

In India, the major share of farm power requirement is still met by human and animal power. Census reports reveal that hundred and thirty million labourers, and a draft cattle population of seventy million are engaged in agricultural operations. Share of human energy alone accounts for 13 percent of the total power consumed. The energy needs for raising a crop depends on variety of factors and one of the important factor is the level of mechanization. The availability of farm power and machinery with different classes of farmers is an indicator of mechanization and their skill to manage the energy resources effectively. Populari-zation of highly sophisticated and costly agricultural implements are constrained by the small holdings, and poor economic and educational background of the farmers. These facts implies that, in a country like India, mechanization can come mainly through improved manual and animal operated implements.

Development of irrigation facility is one of the first step for increasing agricultural production. Devices for water lifting, ranges from age old indegenous water lifts to highly efficient pumps. Most of the traditional water lifting devices are less efficient, and costly due to the bulk of materials required for their construction Pumps operated by electric motors and engines have come into prominence in all large scale lift irrigation schemes. This is because high output and efficiency levels can be more easily attained and controlled in them.

Still these highly efficient pumps are costly and the poor economy of rural India prevents the farmers from going for these pumps. In many cases due to the very small holdings of farmers, introduction of a pump for irrigation water supply will inevitably result in under-utilization and surplus capacity unless individuals can group together and share the system Often characteristics of these high discharge pumps does not match with the low yielding characteristic of the wells. Moreover we still have not achieved the goal of complete electrification of rural areas. Here comes the significance of manually operated pumps.

In many parts of Kerala farmers are drawing water from shallow wells using bucket and rope, for domestic use and for cultivating small areas upto about 0 1 hectares. In these areas, manually operated pumps are getting very popular. In costal areas of Kerala, Tamil Nadu, West Bengal Andhara Pradesh, and Bihar manually operated pumps are extensively used for lifting water for irrigation where the water table is high

Hand pumps play a major role in rural water supply also Their particular advantage like other renewable energy pumping system is that they are independent of fuel supplies. Compared with traditional devices, they also have potential for supplying safer water since the well or bore hole can be sealed from possible sources of contamination. Moreover they have the advantage that manufacture and maintenance of these pumps can be done at the village level itself. In recent years, ground water department of India has employed a number of hand operated pumps in shallow tube wells for rural water supply throughout Kerala.

These facts justify the significance of research work on manually operated pumps.

1.2 Ergonomic considerations

One of the major constraint in the popularisation of manually operated pumps is the labour and drudgery involved in operating them. The designers till date put emphasis on hydraulic performance of the pump but the ergonomic views are often overlooked. Ergonomics has a very important role to play in the design and use of manually operated implements, for better performance as well as for more human comfort. But too often a piece of equipment is first designed and the operator is added as a kind of after thought, leaving him to cope with the unsatisfactory working environment. An equipment designed or modified on ergonomic consideration will add enormous comfort to the operator. So while analysing the performance of a manually operated pump, a scientific approach based on anatomical, physiological, psychological considerations of human capacities and limitations should be adopted. In this context evaluation of ergonomic performance of the pumps are included in the present study.

1.3 Scope and objectives of the present study

In recent years, a wide variety of manually operated pumps are developed and introduced to Indian markets. However a critical study regarding their performance and energy requirement has not been conducted to bring out which of these pumps are efficient and what are their limiting factors of operation. Therefore a study to find out suitable efficient pumps for various operating conditions and to recommend them for popularization is undertaken.

Five manually operated pumps viz. Kirloskar high head pump, Pedal operated E.P. pumps (lift and force), Kumar Bharath pump and Bicycle operated diaphragm pump are selected for the study with the following objectives.

1. Critical study with respect to the design and constructional features of the selected pumps.

2. To evaluate hydraulic characteristics and human energy requirement of the pumps.

3. To recommend efficient and suitable pump for Kerala condition.

Review of Literature

REVIEW OF LITERATURE

A brief review of work done on design and development of manually operated pumps and their hydraulic and ergonomic testing are discussed in this chapter under the following heads

1. Share of human energy in irrigation pumping
2. Classification of manually operated pumps
3. Research work done on manually operated pumps
4. Ergonomic considerations

2.1 Share of human energy in irrigation pumping

Michael (1977) estimated the annual energy requirement for irrigation water pumping in India. The total requirements of various forms of power during the period of 1968-69 to 1998-99 was estimated. It was found that the share of human and animal power in irrigation pumping has gradually decreased from 2746.6 to 893.2 million kilowatt per hour during the last thirty years (Fig.1). He identified the need of introducing pumps with a higher efficiency to suit the condition of high discharge and low to medium pumping heads. He concluded that emphasis is necessary on the development of more efficient water lifts operated by human and animal power

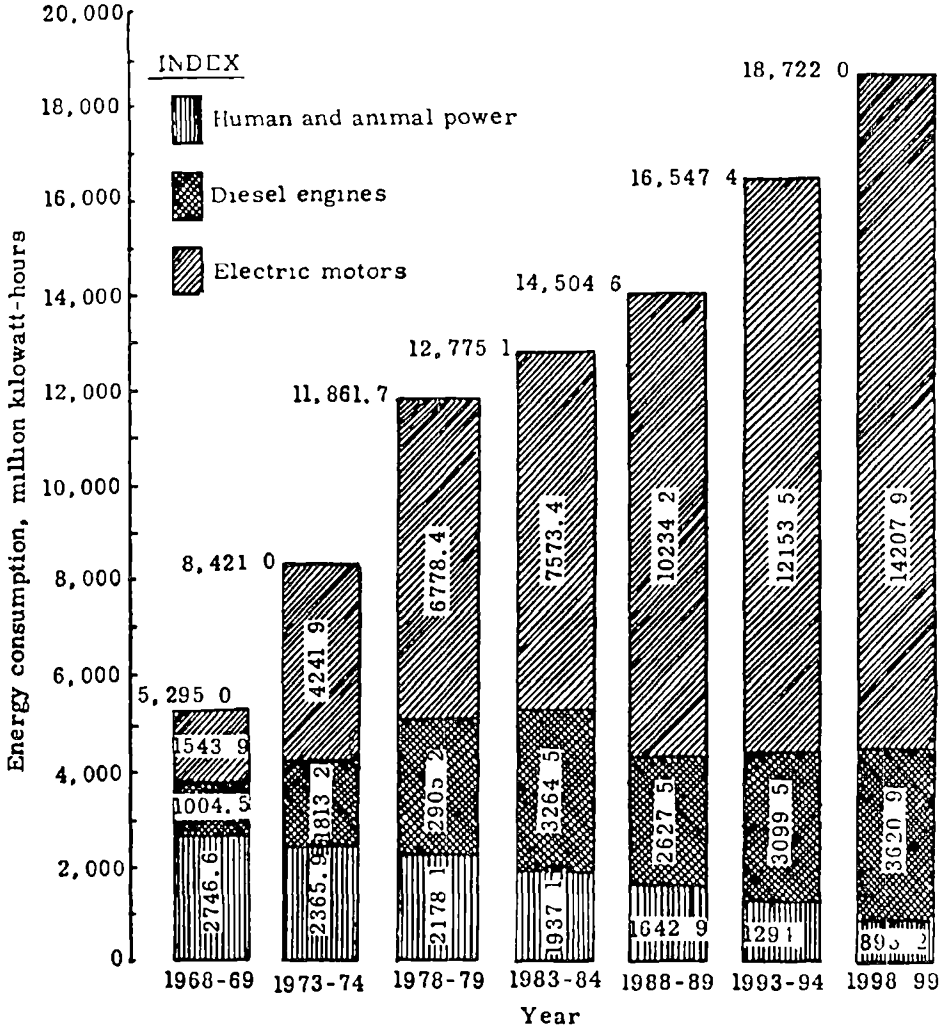


Fig. 1 Estimated annual requirement of energy in irrigation pumping in India

Patel and Madala (1979) studied the needs of energisation of pump sets. Statistical data showed that there would be a gradual release of man and animal power from irrigation pumping during the coming years. Studies on time consumed for irrigation of one hectare land in Aligarh district, Uttarpradesh revealed that electric pumps took 11 hours as against 54 hours from persian wheel and 84 hours from leather bucket for irrigating one hectare of planted fields with 7.5 cm depth of water. The total cost of water worked out at Rs.22 per 1000 cubic metres from electrically operated tube wells as against about Rs.132 and Rs.220 from persian wheel and leather bucket run wells. Cropping intensity under electrically operated tube wells was 594 percent as against 298 percent and 113 percent in case of persian wheel and leather bucket equipped wells. Inspite of all these facts, they have identified that at the current rate of well electrification in the country, it may perhaps take another 50 years to replace the manual and animal operated water lifting devices by electricity.

2.2 Classification of manually operated pumps

Kennedy and Rogers (1985) classified the manually operated pumps on the basis of their principle of operation. They are

1. Piston cylinder pump
2. Inertia (Joggle) pump
3. Diaphragm pump
4. Chain washer pump

2.2.1 Piston cylinder pump

Piston cy¢linder arrangement is the most common design found for hand pumps in most of the developing countries (Fig.2). The principle of operation is that with the pump primed, an upward movement in the piston creates a decrease in the water pressure under the piston and thus allows water to flow in through the foot valve. On the down stroke with the foot valve closed, the piston forces water out through the piston valve.

2.2.2 Inertia (Joggle) pump

The inertia pump undoubtedly a very simple device for in its basic form. It consists of a riser pipe with a flap valve and a discharge spout (Fig.3). It works on the induced flow principle. Inertially the pump is primed by maintaining the lower end of the pipe below the water surface and by rhythmic up and down movement of the tube. During pumping, the water in the tube acts as an operating mass whilst the air trapped below the flap valve acts as a spring. Joggle pumps are not easy to be primed when the lift exceeds 5 metre and it has been suggested that a foot valve could solve this problem.

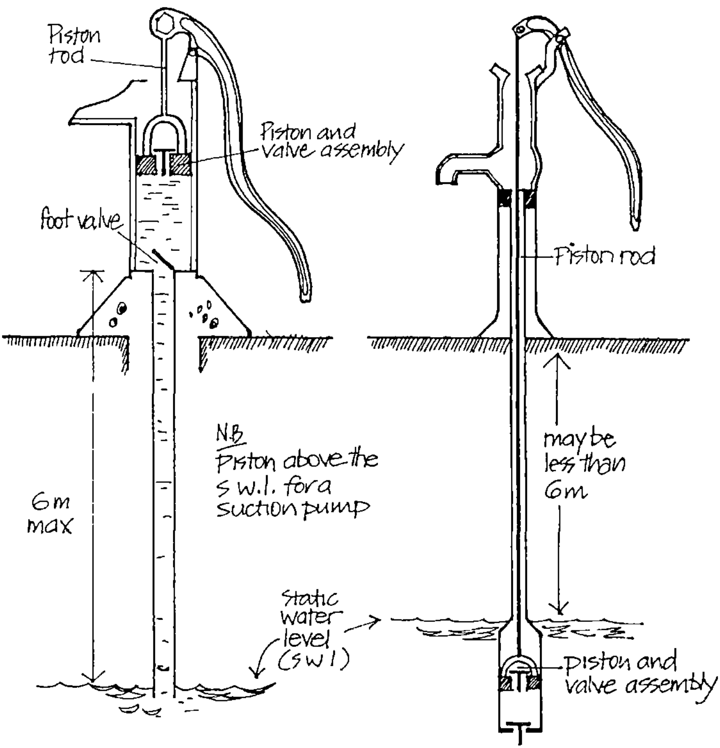


Fig. 2 Piston cylinder pump

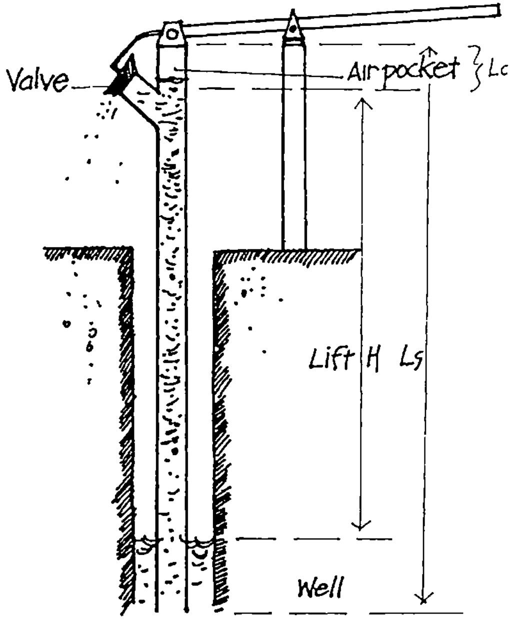


Fig. 3 Inertia (Joggle) pump

2.2.3 Diaphragm pump

The basic principle of this type of positive displacement pump is that a suction effect is obtained when the pumping element a flexible diaphragm - is lifted and so water is drawn in through the inlet valve. When diaphragm is depressed, liquid is forced out through the delivery valve (Fig.4).

2.2.4 Chain washer pump

This pump has been used for many countries in China and Europe. It is still commercially manufactured in China and low cost village technology designs are available. In this a continuous chain and washer disc loop is pulled up a riser pipe with a close fit between the washers and the pipe. The loop passes over a geared chain wheel and down again to the bottom of the pipe. The bottom of the riser pipe is bell mouthed to facilitate the entry of the washers (Fig.5). There is a trough for water collection at the top of the riser pipe.

2.3 Works done on manually operated pumps

2.3.1 Piston cylinder pumps

Daudi (1978) developed a hand operated pump best suited for small and marginal farmers. The pump could be operated by two

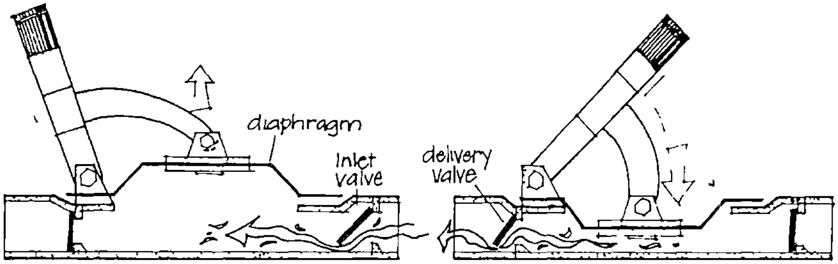
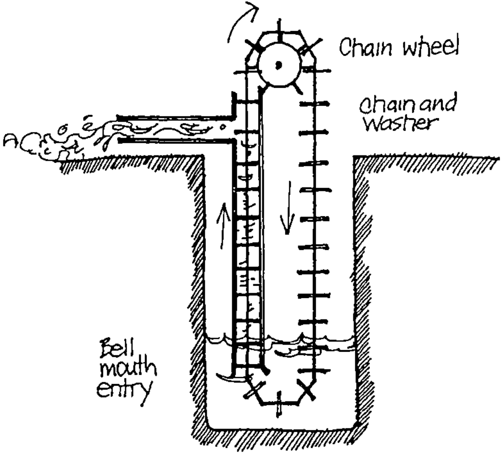


Fig. 4 Diaphragm pump

Fig. 5 Chain washer pump


Chain wheel
Chain and Washer
Bell mouth entry

men. It was a combination of reciprocating pumps with a common outlet and common inlet connected to the water source through a hose pipe. It could draw water from a depth of 8 m and give an output of 13650 litres per hour. The pump was workable on upto 10 cm diameter bore (to pump underground water) and can also be operated over wells, ponds or rivers using 10 cm diameter hose pipe The unit could easily be transported from one place to another as it was fitted on a four wheel trolley. All the parts used in the construction was indigenously available. The cost of production came upto Rs.2000/-. This pump had the advantage that by simple attachments it could be operated by a bullock also.

Chandrasekhar (1978) designed a pedal operated pump to take advantage of the gravitational force and body weight of the operator to the maximum extend (Fig.6). The proposed design consisted of a main cylinder attached to two smaller cylinders in which two pistons will operate separately to give a continuous flow. The two piston rods were connected through knuckle joint to levers which are directly connected to pedals by knuckle joints. The pedals are fixed to a supporting plate, which was centrally mounted on a fulcrum so that when one pedal is pressed downward the other rises upward operating the pistons in the smaller cylinders thus giving a continuous and abundant flow of water. A handle is provided for the operator to balance his body weight while in operation.

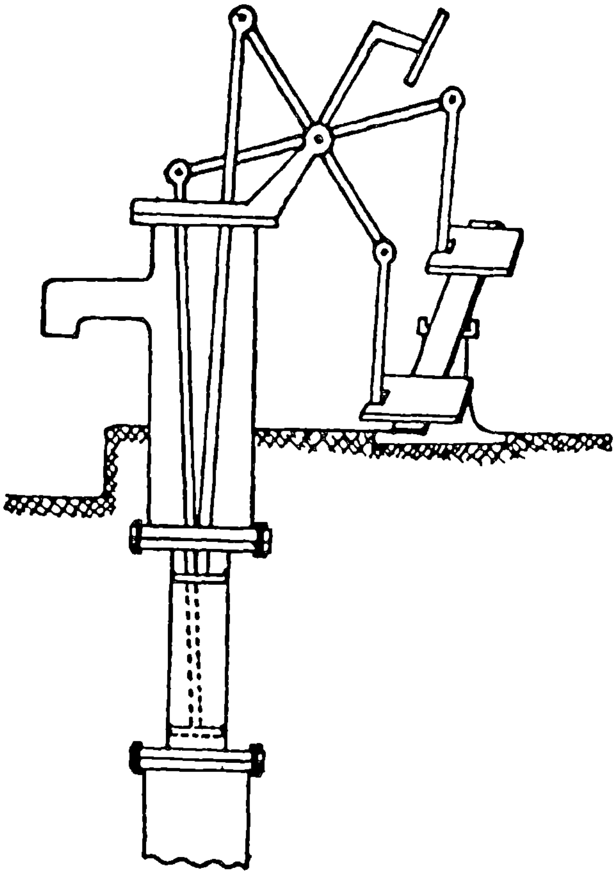


Fig. 6 Pedal operated bore pump

Kaliappan of Tamil Nadu Agricultural University (1980) developed a low cost hand pump for lifting water from low levels. The pump was having 2" (5 cm) diameter cylinder and gave an output of 2000 litres per hour. With a view of increasing the capacity the diameter of the cylinder was increased by 3" (7 5 cm) The unit gave an output of 4000 litres per hour at 3 m head He noted the following difficulties while in operation.

1. The worker had to bend his body and at the same time push and pull the handle continuously to lift the water There was no mechanical advantage of these types of pumps. Hence effort required was more.

2. The unit had necessarily be fitted above the ground level and nearer to the edge of the well. If water level goes 30 feet (9 m) below the ground level the unit cannot be used.

Zonal Research Centre, College of Agricultural Engineering, TNAU (1981) modified a low cost hand pump. It consisted of a 90 mm outer diameter PVC pipe of one metre length as cylinder Two 75 mm diameter GI couplings were bored to accommodate the ends of PVC pipes and fixed water tight by using adhesive. The coupling were jointed by two L angles to strengthen the PVC pipe. One end of the PVC pipe was connected to 2.5 m length GI pipe having outlet at 1.5 m height. The bottom of the PVC pipe is connected to 7.5 cm diameter alkathene pipe of required length, to the bottom of which a flap type foot valve is connected.

The piston was made of aluminium bottom rings, leather washer (Bucket washer) top perforated disc and a top chrome leather in series from bottom to top all secured by bolts and nuts. The top of the piston rod was hinged to a lever. The lever had a fulcrum at a distance 600 mm from the piston. The lever was extended beyond the hinge of the piston to a length of 1200 mm to serve as handle. The only wearable part of the pump was the leather washer which was easily replaceable. The pump could be fitted both in the open well and tube well, with the help of wooden planks. The pump could be lowered or raised according to the convenience of the operator.

This pump gave a discharge of 4750 to 5000 l/hr and 4250 to 4900 l/hr at 12 m and 2.4 m heads respectively. Although one man could operate this pump a rest period of 10 to 20 min after 60-90 min continuous operation was recommended. This pump was tested in borewells by lowering the piston and cylinder to a depth of 20 m and connecting it to a 50 mm diameter GI pipe as outlet pipe. The piston is connected to the top handle by means of 12 mm

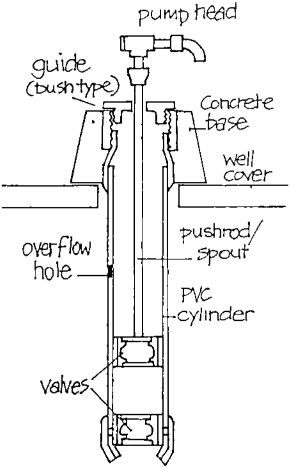


Fig. 7 Blair pump

diameter mild steel rods. Since a column of water was standing on the piston the pump was made to work on first principle of levers and mechanics. At 20 m depth the pump gave an output of 2200 to 2500 l/hr. However at 20 m depth it required 2 men to operate the pump. The cost of this pump was Rs.440/- when installed at ground level and Rs.525/- for deep borewells.

Morgan of Blair Research Laboratory (1981) has developed Blair pump suited for shallow wells (Fig.7). The pump claimed to have minimum maintenance and suitable for wells less than 6 m deep. The distinguishing feature of the blair pump is its compact, above ground components. The pump required only one person to dismantle. Below ground the pump consisted basically of a stationary cylinder and a moving piston fixed to a hollow push rod which is attached to a galvanized iron handle. On the up stroke, water is drawn into the cylinder through the lower fixed foot valve, this closes, the water is forced through the piston valve and up the hollow push rod to the surface. The pump was tested with heads of 6 to 11.5 m using water to which soil has been added (1 kg per 200 litre). Minimum wear was observed after 5 5 million strokes.

Zonal Research Centre TNAU (1981) tested the India Mark II pump at different depths. The pump gave 1700 to

1900 l/hr discharge at 12 m head, while tested at 2.4 m head the discharge was 1500 to 1700 l/hr This pump was modified and tested over bore wells by lowering the piston and cylinder to a depth of 20 m. The discharge was found reduced to 900 to 1000 l/hr. At this depth the pump required two men for easy and continuous operation. Cost of this pump was estimated to Rs.1300/-

KAU (1982) evaluated manually operated water lifting devices viz. Kurali pump, Bardoli pump and E P. pumps (Fig 8, 9) with the objective of studying details of construction and the performance at different operating conditions. The three pumps were installed at different heads ranging from 215 cm to 340 cm Time taken and number of output strokes for delivering 200 litres of water were determined. The maximum load that was required to operate the pumps at different heads were also measured using a spring balance From the analysis it was concluded that the time needed to pump 200 litres was higher and load needed was lesser for Bardoli pump compared to Kurali pump The Bardoli pump has less discharge per stroke compared to Kurali pump. The average values of time and load of E.P. pump at 200 cm head were 510 s and 35 kgf, respectively. The number of useful strokes were 550 And at a head of 350 cm these values were 630 and 42 kgf respectively. Number of useful strokes were 580

Spare (1982) summarised the development of Rower pump from 1978-1982 (Fig.10). Rower pump is a reciprocating action

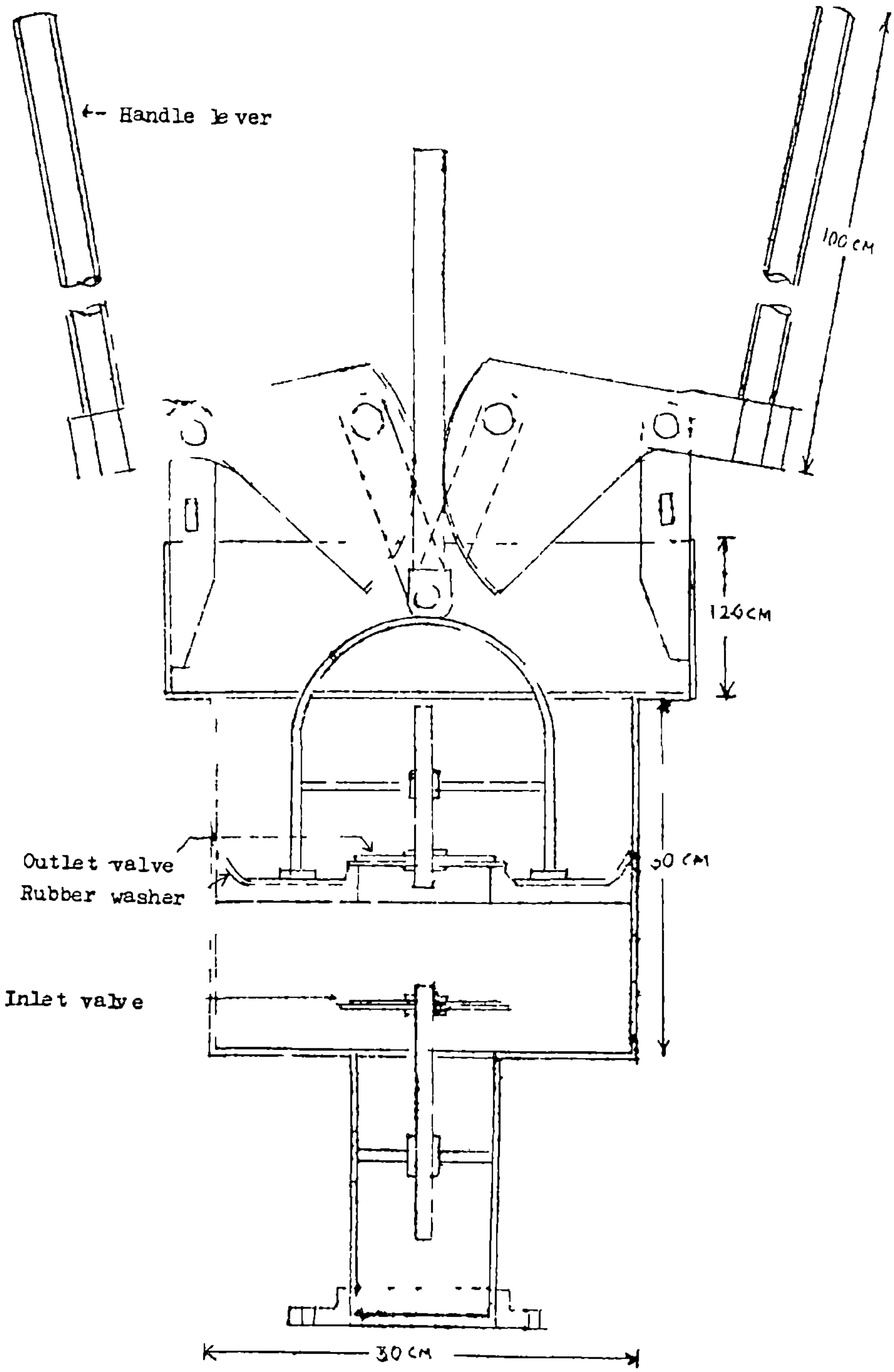


Fig. 8 Kurali pump

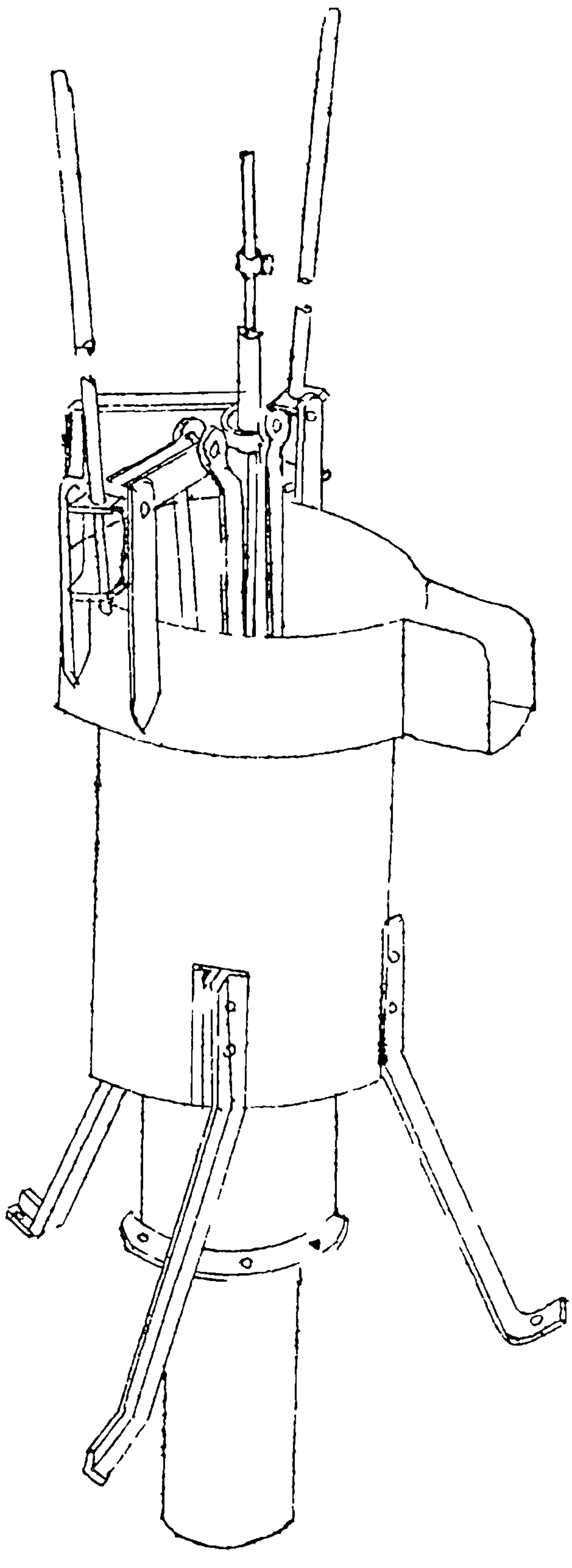


Fig. 9 Bardoli pump

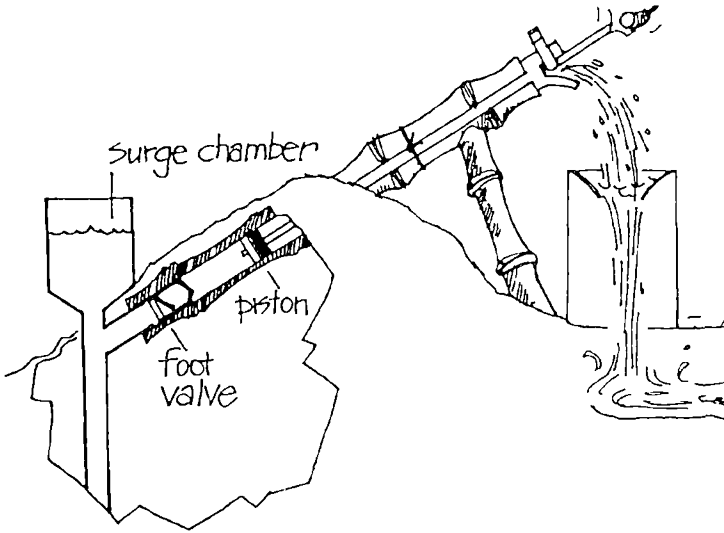
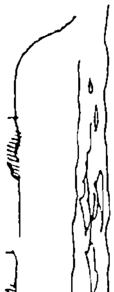


Fig. 10 Rower pump



piston pump whose PVC cylinder is inclined at an angle 30° to the horizontal. The unique feature of this pump is that it is fitted with a surge chamber at the pump suction. This provides a steadier upward flow of water. It had been found that a man can pump 50% more water in a given time using a pump fitted with surge chamber.

Kennedy and Rogers (1985) reported the work of UNICEF India and a group of voluntary agencies in Maharashtra state. They evaluated India MK II pump (Fig.11). The pump used welded steel fabrication, sealed lubrication roller bearing and had a single pivot linkage connecting the handle to the pump rod through a chain and quadrant arrangement. This facilitates pump rod alignment during pumping. The pump cylinder and piston are both cast iron. The cylinder is brass lined and the piston has a first grade leather bucket seal. It is reported to be highly efficient as far as ergonomic and hydraulic characteristics are considered.

Kennedy and Rogers (1985) reported the development of Malavi pump (MALDEV pump) (Fig.12). The pump had a steel well casing - a pipe with two steel brackets welded on. The bracket contained two steel bearings. A bolt passing through the bearing centres attaches the pump handle to the body and provides a pivot for the handle. A 'T' piece at the end of the handle facilitates

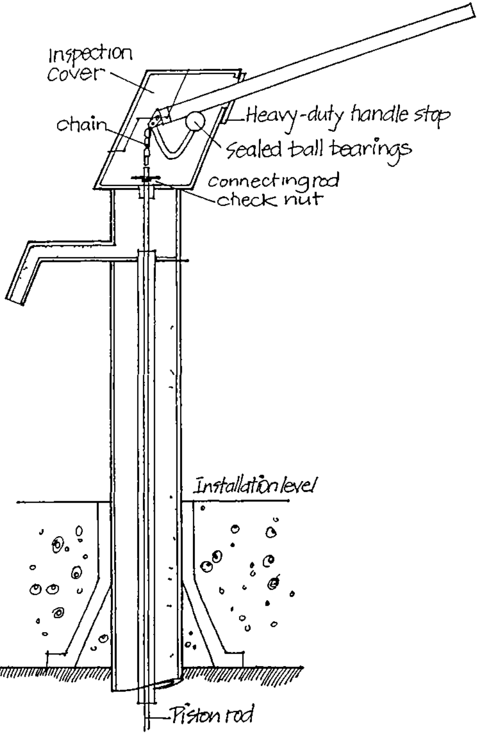


Fig. 11 India MK II pump

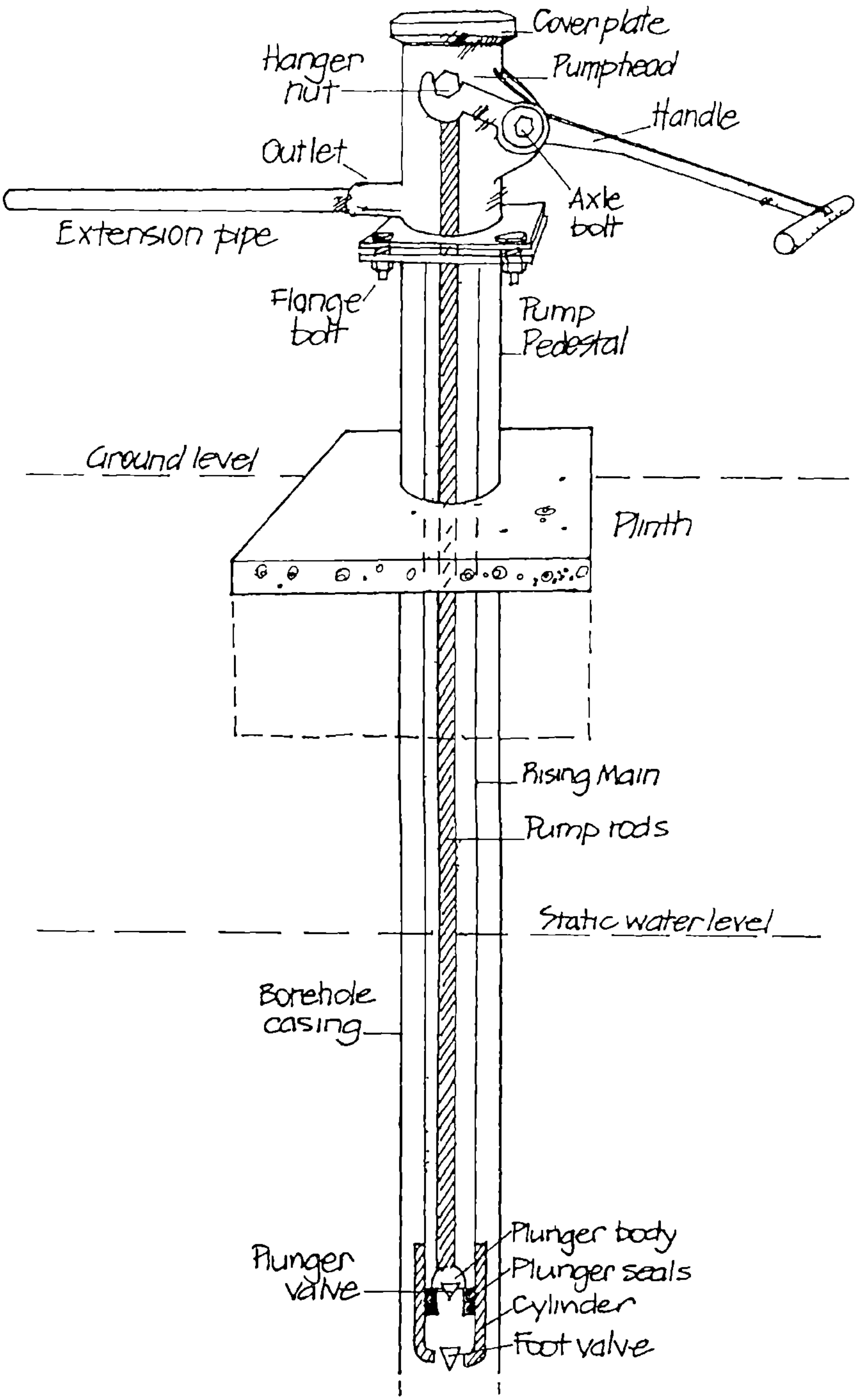


Fig. 12 MALDEV pump

pumping. The most important feature of this pump is the facility for connecting rod, piston, foot valve and rising main to be removed by hand through the pump head A village pump care taker, using perhaps only one spanner could do the maintenance work of the pump. Various makes of this pump were reported from Mark I to Mark VI. Since the pump normally operated at less than 6 m pumping head, it did not require a piston seal. A common cause of failure of this pump is the breakage of pump rods, most commonly at the PVC rod - steel handle connection. It was reported that UNICEF had conducted studies on the performance of these pumps in 1981 and recommended further developments including experimental plastic down hole components.

Kennedy and Rogers (1985) reported the development of a low cost quickly installable pump in Bangladesh, named as 'Tara pump' (Fig. 13). Almost all the components of the pump were made of locally fabricated GI iron. Piston and foot valve were the same as in the Rower pump. The 'consumers association' evaluated the performance of this pump and reported that it had very good ergonomic aspects and efficiency performance. They had also made remarks on ease of manufacturing and maintenance of this pump. It was reported to have poor safety aspects due to sharp edges.

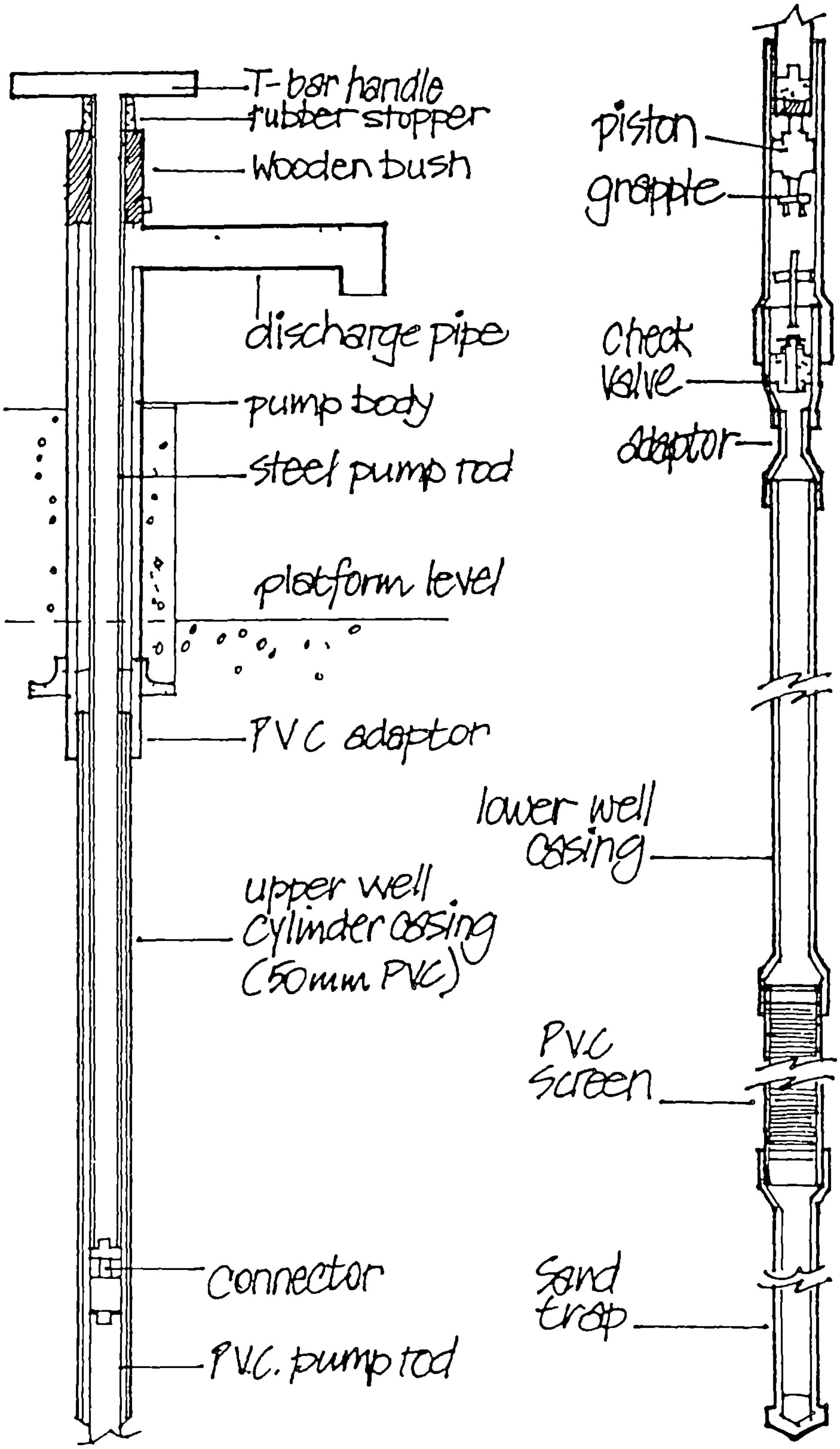


Fig. 13 Tara pump

2.3.3 Diaphragm pump

Rao *et al.* of Central Mechanical Engineering Research Institute (1980) developed a pedal operated pump having an average discharge rate of 6000 l/hr at a head of 2 m to 3 m. It could easily handle muddy water and was especially suitable for places where water is available almost at surface level. The pedal pump was operated by a single man standing on the foot pedal and shifting his weight from one foot to the other like a seesaw. This movement causes the diaphragm of the pump to be pulled alternatively creating suction in one of the two chambers of the pump for lifting water. Since the discharge will take place twice in each cycle of operation a continuous flow of water is ensured The rate of discharge depends upon the body weight and effect exerted by the operator.

Muhammad (1980) developed a diaphragm pump which can be operated by a bicycle. Power is transmitted from the bicycle to the flywheel provided which in turn drives the pump through cranks and connecting rods. The pump was claimed to be low cost due to its locally available components. It is suited for shallow water lifting purposes and found to discharge 0.5 l/s at head of 3 m.

College of Agricultural Engineering, Jawaharlal Nehru Krishi Viswa Vidyalaya (1985) developed and tested a pedal operated diaphragm irrigation pump (Fig.14) It had a cylindrical chamber of 19 cm height and 30 cm diameter. It consisted of two paddles The pump was operated by a single person standing on the paddles and shifting his weight from one foot to the other. The pump was tested with different lengths of connecting links i.e., 26.5 cm and 20 cm. The pump was found to discharge 1.2 and 1.24 l/s against a head of 1 m when the connecting links were 20 cm and 26.5 cm respectively. When the paddle location was changed from side to back of the chamber the discharge was decreased to 1.14 l/s. When the head was increased to 2 m the corresponding discharge were 0.426 l/s, 0.5 l/s and 0.476 l/s respectively It was concluded that the highest discharge in all cases was obtained when the connecting link length was 26.5 cm. It was found that the efficiency was increased from 80.1 to a maximum value of 88 percent when the head was increased to 1.25 m from 1 m. For higher heads than 1.25 m, the efficiency showed a decreasing trend and at 2 m head it was only 45.58 percent. Fatigue test was performed at each head of operation and with 26.5 cm length of connecting rod. Upto 1.5 m head, the pump could be operated continuously for 30 minutes and it get reduced to 25 and 22 5 min for 1 75 and 2 m head respectively. With ten minutes rest period, the operator could continue the work

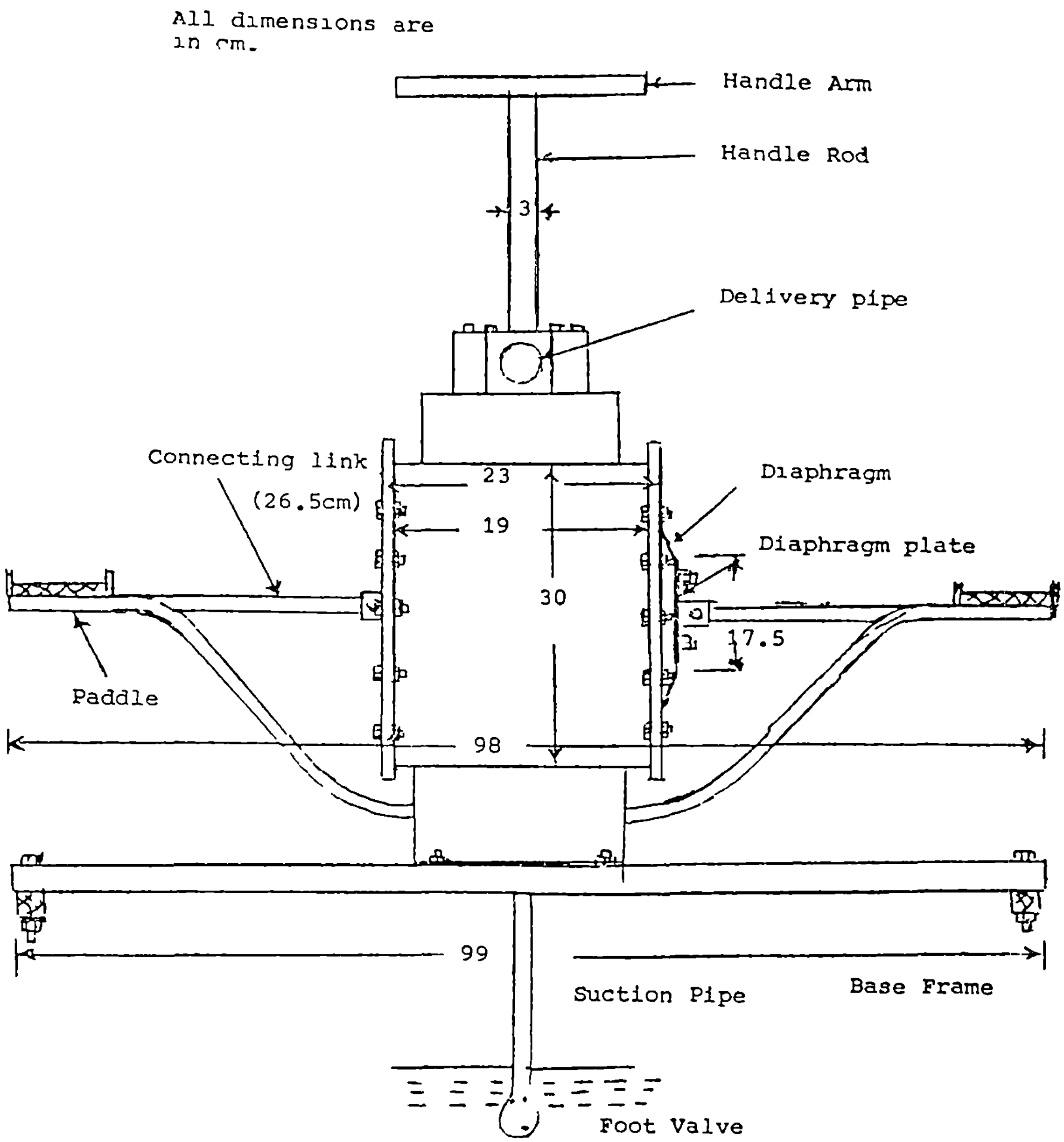


Fig. 14 Pedal operated diaphragm pump

2.3.4 Chain washer pump

Sahu et al. (1981) studied the performance characteristics of washers in manually operated chain washer pumps. Chain washer pumps were tested for different materials within the reach of rural people. They came up with the result that performance of the washer made of truck tyre tube was encouraging for chain washer pumps.

College of Agricultural Engineering, Jawaharlal Nehru Krishi Viswa Vidyalaya, Jabalpur (1985) developed a manually operated chain pump of the pipe size 51 mm. The washer diameter was equal to the diameter of the pipe and a constant spacing of 86 cm was maintained through out the length of the chain. While using the pump at different heads it was observed that as the head was increased from 2 m to 3 m, the reduction on discharge was only 2.76 percent which is very negligible. The volumetric efficiency decreased with increase in head. The maximum efficiency of 99 78 percent was obtained at a head of 2 m. The power required to operate the pump varied from 0.0619 to 0.0913 whp as head varied from 2 to 3 m It was found capable to irrigate an area of 0.547 ha cm/day This pump could easily be operated for 50 min with a rest period of 10 min. It was found capable of working upto a head of 3.29 m to deliver 2 28 litres per second.

Sharma *et al.* (1987) conducted performance study of manually operated chain washer pumps. They tested the washer made of truck tyre tubes with three types of pipes i.e., 100 mm GI sheet pipe, 104 mm and 86 mm PVC pipes. The experiment was conducted at various heads ranging from 1 m to 4.5 m and the diameter of the washer was kept 2 mm more than the inner diameter of the pipe. Comparing between the performance of two PVC pipes of different sizes it was observed that 104 mm pipe gave higher discharge than the 86 mm pipe at low operating head conditions. However the result was just reverse under high operating head conditions. For operating heads above 2.5 m the discharge was higher in 86 mm pipe than that of 104 mm pipe.

The discharge of 100 mm GI sheet pipe was found to be between that of 104 mm and 86 mm PVC pipes at lower operating head conditions. Above the head of 2 m the discharge from 100 mm GI sheet pipe was found to be lesser than the other two PVC pipes They came up with the conclusion that if it is discharge criterion only, then the following specifications may taken into account At operating heads less than or equal to 2 m discharge is directly proportional to the pipe size. On the other hand, for operating heads above 2.5 m the selection may be made with the consideration to the diameter of the pipe as well as the material of pipe

The variation of torque of the chain washer pump was tested for different pipe sizes and pipe materials under varying conditions of operating head. It was found that operating torque increased with increase in head in all three pipes. The torque was highest for 100 mm GI pipe followed by 104 mm PVC and 86 mm PVC pipes for the entire range of operating head considered.

As far as mechanical efficiency is concerned mechanical efficiency increases with the increase in operating head to attain its peak and then drops down at still higher heads. Among the three pipes considered the 104 mm PVC pipe had the maximum mechanical efficiency 74.72 percent at an operating head of 2 m. Second highest mechanical efficiency of 67.8 percent was attained at a head of 3.5 m in the case of 86 mm PVC pipe followed by the 100 mm GI sheet pipe where the peak value of mechanical efficiency was 64.43 percent at a head of 2.5 m.

2.4 Ergonomic considerations

2.4.1 Scaling of work load

Lehmann (1958) considered that 5 kcal/min (including basal metabolic rate about 1 kcal/min) was the maximum consistent level that a worker should be expected to expend. Much rest pauses should be included if the average level exceeds this value. He had suggested that for severe physical work frequent pauses are better for physiological recovery than infrequent but large rest pauses.

Babsky *et al.* (1970) divided various occupations into a number of groups according to daily energy expenditure Agricultural wokers engaged in partially mechanised works were reported to expend 4000 kcal/day.

Christensen (1970) proposed the scaling of physical work as follows

Work classification	Heart rate beats/min	Energy kcal/min
Light	75	2.5
Moderately heavy	100	5 0
Heavy	125	7 5
Very heavy	150	10 0
Unduly heavy	170	12.5

Malhotra (1971) correlated metabolic heat production per unit time in relation to grade of activity for average Indian male He scaled light work in the range of 70 to 260 kcal/hr, moderate work 261 to 390 kcal/hr and heavy work 391 kcal/hr and above

The Food and Agricultural Organisation (1973) estimated 2600 kcal of energy per day for average Indian man. They suggested the classification of work on the basis of energy requirement per unit of body weight Energy expenditure rates from light to exceptionally active work ranged from 42 to 62 and 36 to 55 kcal/day/kg body weight for men and women respectively

Kennedy et al. (1985) reported that power output of an adult male is 30 W when the work sustained upto 7 hours, 50 W when it is upto 15 minutes, and 70 W for few minutes when muscle group involved is mainly arms and shoulders. For pedalling the corresponding values are 75 W, 180 W and 300 W.

2.4 2 Working posture

The posture of an operator in controlling a machine is largely influenced by the layout of the controls Awkward and bend postures of the operator are likely to cause a feeling of discomfort and fatigue.

Karpovich (1955) found in most observations that heart rate was affected by the body position The heart rate was lowest in lying higher in sitting and highest in standing. He observed that more energy is required to maintain the body in sitting or standing posture than in the retiring position.

Astrand and Rodhl (1970) reported that the fatigue in a well balanced standing individual is usually not due to mascular fatigue but is more likely to cause by an inappropriate distribution of blood. The positions where the centre of gravity links and/or trunks are shifted from a balanced position, activity in counter-acting muscle groups must compensate and increase the load on the muscles.

Mathews and Knight (1971) reported that there is substantial basis for arranging work surface heights at a level that permits the work to be done some what below elbow height (50-100 mm) at least for light manipulative tasks. Where fuller arm movement is required lower levels were recommended (914 mm from the floor) (Fig.15).

Sek Daniela (1973) investigated influence of inclination angle (0-80°) of human body on its functions Integrated electro myography of the muscle was recorded and measurements of energy consumption and of blood circulation were taken during 2 min standing in inclined posture He showed the effect of fatigue caused by inclined working posture.

Vos (1973) studied the work load in different body postures. Energy expenditure and heart rate were measured during five minutes test period Results showed that kneeling and bending

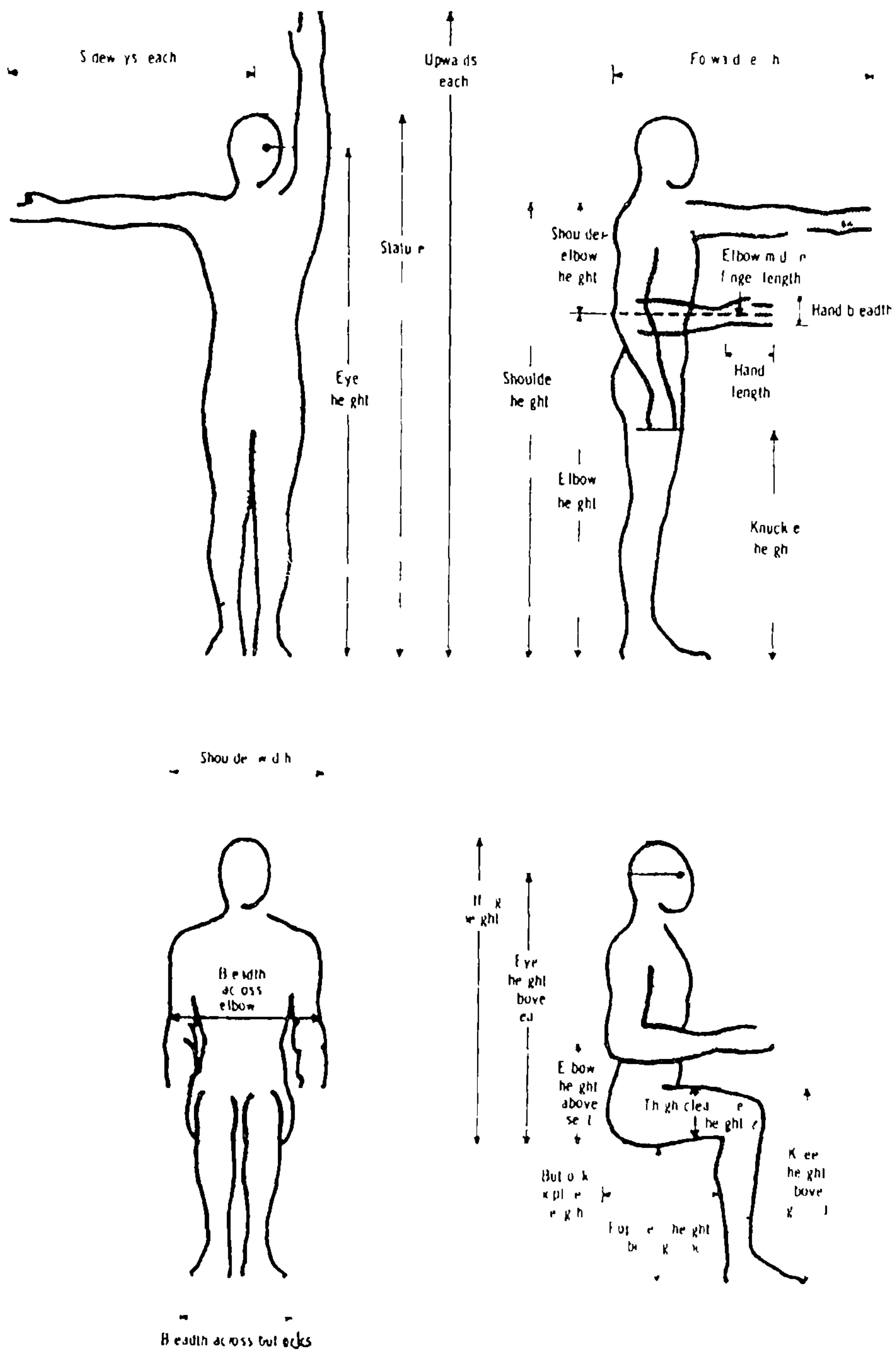


Fig. 15 Main human dimensions to be ascertained for design of work spaces

required less energy and less stress when one hand is used as a support to balance the trunk. At high forward frequency, the bending posture without arm support was less strenuous than squatting and sitting on one legged stool. When working level was lower than the level of the feet a remarkable increase in the work load was obsrved in the bending position.

Ayoub et al. (1974) studied the effect of operator s stance in pushing and pulling task. He found effect of height was relatively constant while horizontal pushing force increased with the weight of subject. They have also suggested that manual material handling equipments should preferably be designed where the point of application of forces are approximately of 70-80 percent of shoulder height above the floor.

2.4.3 Design characteristics of controls

Murrel (1965) studied the work load characteristics of a horizontal lever pulled up and pushed down continuously He found that for a male adult the maximum pull that can be exerted on a horizontal lever is at an average hand height, that is about 28 to 30 inches (70-75 cm) above the floor when standing or about 3 inches (7.5 cm) below the seat height of a seated operator At 30 inches (75 cm) an individual will be able to pull with a force of 105 lb (231 kg) with one hand. If the lever is lowered to 20 inches (50 cm) the pull will drop to 95 lb (209 kg) but if it is raised to 40 inches (100 cm) the pull will drop to 45 lb. These forces are maximum and if a force of more than 30 lb (66kg) is to be exerted regularly mechanical assistance should be given.

If body weight is not used the maximum push at hand height of 30 inches (75 cm) is about 88 lb (193.6 kg) The travel of lever to be pushed should be not more than 6 to 7 inches (15-17.5 cm) and the handle of lever is placed so that the arm is straight at the end travel. The greatest force is produced at the straightening of the arm. Force in excess of 40 lb (88 kg) should not be demanded of either a sitting or standing operator if the lever is to be used frequently.

He also conducted studies on pedal operated by the legs when the operator is in standing posture In this situation the force that can be applied by a standing operator will be determined entirely by the operator's weight If he is standing on both feet the maximum force that can be developed will be rather less than half of his body weight. The pedal should have minimum movement not more than 6-8 inches (15-20 cm) above the floor level at the top of its travel Ideally a satisfactory pedal can be obtained only if it is pivoted behind the operator with the arm of the pedal parallel to the thigh The position of pedal for the optimum application of force is when at the end of it's travel, it is at the floor level and when the two feet are placed side by side

Yadav (1985) made comparison of hand muscles and leg muscles for water pumping he reviewed the work of Wilkie (1960) who modified a reciprocating type double men operated pump to a bicycle operated rotary pump. The labour requirement of the pump was reduced to one. At the same time, the discharge before the operator gets tired, was doubled. It shows that man is more comfortable in rotary mode than reciprocating mode.

2.4.4 Methods of measurement

Human body is considered as an energy converter In principle, methods used to measure energy are directed either measuring of input or output of the system Input of the system is usually taken as chemical energy utilized and oxygen intake Output is usually measured in terms of mechanical energy, carbon-dioxide exhaled and heat dissipated. These methods are catogorised as direct calorimetry and indirect calorimetry

2 4 4.1 Direct calorimetry

Consolazio (1963) reported that energy expenditure could be measured directly in terms of heat produced by human body during physical activity The activity is carried out in a specially built chamber. Heat produced is absorbed by circulating water through a series of water pipes inside the chamber and is measured by recording the increase in water temperature. Although this method gave accurate measurements, in most of the practical cases it cannot be employed due to the high expense in its construction.

2.4.4.2 Indirect calorimetry

Christensen (1953) reported that heart rate can be related to the oxygen consumption and energy expenditure. For a normal average man, a heart rate of 75 beats/min seems to be equivalent to an oxygen consumption of about 0.5 l/min or energy expenditure of 2.5 kcal/min. Each increase above this of 25 beats is equivalent to an increase of 0.5 l/min of oxygen or 2 5 kcal/min. The resting pulse rate is usually taken as 62 beats/min. When the oxygen consumption is 250 ml/min and the calory expenditure is 1.25 kcal/min.

Murrel (1965) reported that according to Metz (1961) electro-cardiograph can be used for pulse measurement

Murrel (1965) suggested heart rate measurement as the most practically adopted technique for energy measurement and other postural studies. This view was supported by Astrand (1970) Tomlinson (1970) and Grand Gean (1975) In its simplest form the methods for pulse count requires no special apparatus

2.4.5 Safe work load and duration of rest period

Astrand (1952) and Christensen (1953) gave the relationship between oxygen consumption, energy expenditure and pulse rate as shown in the table below.

Oxygen (l/min)	Kcal/min	Pulse rate	
		Male	Female
2 5	12.5	175	195
2.0	10 0	150	165
1.5	7.5	125	140
1.0	5 0	100	110
0 5	2 5	75	85
0.2	1 0	60	68

Here 65 beats/min considered as the resting pulse rate and taken as the datum.

Muller (1953) reported that the energy reserve of an average man is 25 kcal. A work load higher than 5 kcal can be allowed until this energy reserve is completely utilised At the end of this time, the supply of oxygen will drop and lactic acid will start building up in the muscles causing the feeling of muscular fatigue. At this point rest should be given to the subject to recover the energy reserve. It was found that the energy reserve will be build up at a rate of 3.5 kcal/min.

Astrand and Rhyming (1954) put forward an expression to find out total rest required. According to them this calculation will give the total time during the working day which should be taken as rest.

$$a = \frac{W\ (b-s)}{b-1.5}$$

Where

a - recovery time in minutes

W - total working day in minutes

b - average calory expenditure per minute

s - level of energy expenditure adopted as standard

Generally work should cease at the point in time at which lactic acid starts accumulate in the body.

Lehman (1958) proposed 5 kcal/min as the safe limit of work load in an average male worker This value had met with acceptance by many researchers. It represents a reasonable maximum which on physiological grounds should be regarded as a figure which would not be exceeded when averaged over a long period of time. It had been suggested that the rate of the energy expenditure which corresponds to the level at which some of works ceases to be aerobic is about 5 kcal/min.

2.4.6 Ergonomic aspects of pumps

Consumer association (1980) analysed the ergonomic aspects of some manually operated pumps. The ease of operation was judged while operating shallow pumps at 7 m head and deepwell pumps at 20 m head. The conclusion was "It is important for optimum performance that the user should make use of an all body movement utilizing as many muscle groups as possible". The pumps which allowed arm - shoulder movement only, were more tiring and exhausting. Although this test reveals the importance of ergonomics in pump design, it did not analyse the link between the ergonomic aspects of the pumps and their performance in detail.

Materials and Methods

MATERIALS AND METHODS

Materials used and methodology adopted in hydraulic and ergonomic testing of selected manually operated pumps are discussed in this chapter under the following headings.

1. General description of the pump
2. Test set-up
3. Test procedure

The manually operated pumps selected for this study are

1. Kirloskar high head hand pump
2. Pedal operated E.P. pump (Lift)
3. Pedal operated E.P. pump (Force)
4. Kumar Bharath pump
5. Bicycle operated diaphragm pump

3.1 General description of the pumps

The general description of the pump should include the following details as per the Regional net work for agricultural machinery test code (1983).

1 Type of machine (Rotary or reciprocating, piston, diaphragm) etc.

2. (i) Make
   (ii) Model
   (iii) Manufacturer's address
   (iv) Serial No.
   (v) Market price

3. Overall dimension

   (i) Length
   (ii) Width
   (iii) Height

4. Weight in kg

5. Principle of operation of the pump

6. Recommended angle of installation (vertical or horizontal)

7. Number of workers required for operating the pump

8. Details of delivery (variable delivery or fixed delivery)

9. Physical part of the worker for operating the machine (foot or hand)

10. Materials of the pump

11. Details of suction side and delivery side

The above details are collected for the five pumps which are tested under the present study

3.2 Test set-up

To conduct a systematic study of hydraulic and ergonomic characteristics of the pumps the following parameters are to be considered.

1. Discharge
2. Head
3. Speed of operation
4. Time of operation
5. Energy expenditure for pumping

Test set-up used to measure these parameters are described in brief (Fig.16).

3.2.1 Source of water

The test tank at the hydraulic laboratory of Kelappaji College of Agricultural Engineering and Technology was used for the test. The overall dimension of the tank was 5 4 x 1.25 x 1.35 m

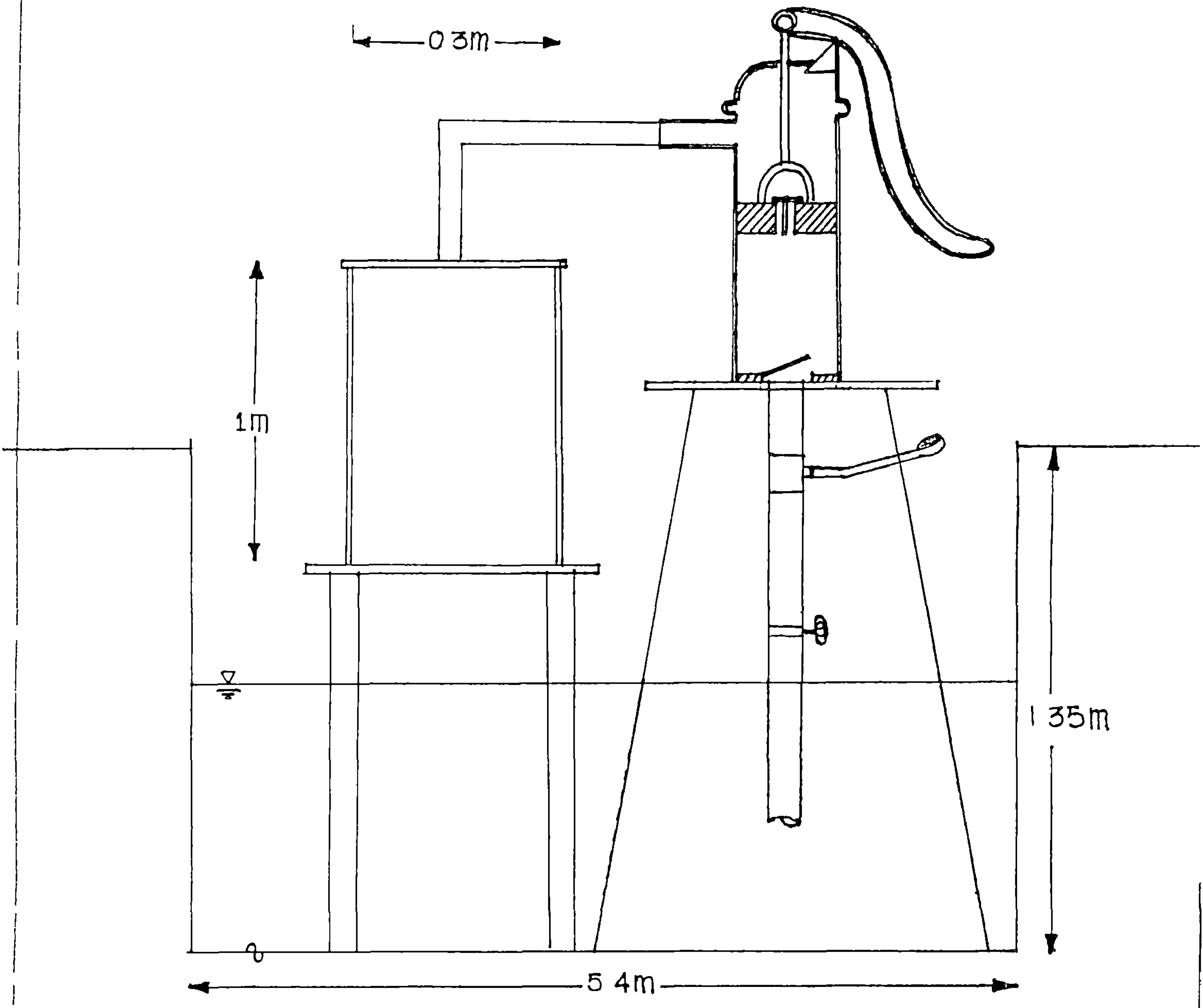


FIG 16 EXPERIMENTAL SET-UP

Due to the high capacity, the volume of water pumped out from the tank does not make considerable effect on the suction head.

3.2 2 Design of the stand

A stand was designed and fabricated for the hand pumps since it requires external support The maximum pull that can be exerted on the horizontal lever is at an average hand height that is 75 cm from the floor level while standing (Murrel K H F 1965). The height of the stand was kept at 2 1 m so that when it is placed in the tank this optimum height is obtained Top of the stand was 40 x 40 cm square An inclination of 20° was given to the legs for the stability of the stand It was made up of 6 25 x 6.25 x 0.32 cm angle iron and wooden plate of 45 x 45 cm was fixed on the top. Pump was fixed on the top plate with nuts and bolts The suction line of the pumps passed through a 5 cm diameter hole drilled at the centre of wooden plate

For the pedal operated pumps, a rectangular frame of 2.5 x 1 m dimension was fabricated 3 75 x 3 75 x 0.32 cm angle iron was used for the frame work and a wooden plate having a 5 cm diameter hole at the centre was bolted to the frame. This frame was kept over the tank while in operation

3.2.3 Measuring tank

Discharge of the pumps were measured by a measuring tank of 30 x 30 x 100 cm dimension. A scale was provided at the side of the container from which height of water column in the tank can be read. Time of operation of the pump was noted using a stop watch. Thus discharge is given by

$$Q = \frac{A \times h}{1000\ t}$$ Where Q is the discharge in l/s.

A - base area of the container sq cm

h - height of water column cm

t - time of operating the pump

A tap was provided at the bottom of the tank to drain out the water after each operation.

3.2.4 Measurement of head

In order to vary the suction head against which the pump was working a gate valve was fixed at the suction line. By adjusting the gate valve the resistance offered to the flow was varied which in turn regulated the head against which the pump had to work. Gate valve was adjusted in ten different positions and the corresponding head was noted A vacuum gauge was used to measure the head at the suction line The vacuum gauge was connected to the suction line through a 'T

3 2 5 Speed of operation

Speed of operation of the pumps were expressed as number of strokes per second. Movement of the piston from bottom dead centre to top dead centre and again to bottom dead centre constitute one stroke. Total number of strokes were counted and divided by the time duration to get the number of strokes per second.

$$N = \frac{N^1}{t}$$

Where,

N = Number of strokes per second

N^1 - Total number of strokes during operation

t = Time of operation in second

3 2 6 Heart rate measurement

Review of literature revealed that heart rate could be taken as a direct measure of energy expenditure (Murrel 1965)

Since a sophisticated instrument like ECG, was not available, a stethescope was used to measure the heart rate The subject was allowed to operate the pump 15 minutes at each head. Heart rate was taken after an interval of 5 minutes for a duration of 2 min Heart rate per minute is calculated for each case. The average of these three values gave the heart rate of the subject while operating the pump at that particular head

3.3 Test procedure

3.3.1 Selection of subject

In this present study a single subject was selected to avoid individual differences as its scope was restricted to the evaluation of design and operational features of the pumps. A farm labourer from the college farm was randomly selected and his anthropometric measurements were taken to define the subject characteristics (Appendix I).

Dubois (1964) put forward an expression to find out the body surface area of the subject and is given by

$$A = W^{0.425} \times H\ C^{0.725}$$

Where A is the body surface area of the subject (sq cm)

W body weight of the subject (kg)

H = height (cm)

C = 74.66 cm/kg for Indian male adult

C = 78 28 cm/kg for Indian female adult

In the present study weight of the subject was 47 kg and height was 161 cm.

Thus body surface area was calculated as

$$(47)^{0\ 425} \times (161)^{0\ 725} \times 74\ 66$$

$$= 15263.768 \text{ sq cm}$$

3 3 2 Calibration of the subject for the basic task

Heart rate was taken as the measure of the energy expenditure of the subject The subject has to be calibrated first, to find out the energy expenditure corresponding to a particular heart rate For this a device as in (Plate 1) was fabricated It consisted of the casing of a India Mark II pump to which a platform for adding weight was attached through a suspended rod A known weight was added on the platform and the subject was

ate I Calibration of Hand operated pumps

allowed to operate the handle, lifting and dropping the weight through a known distance Work done by the subject in moving the weight was calculated and corresponding heart rate was noted

Work done/stroke was calculated by

$$W = w \times s$$

Where,

W - work done per stroke kg - m

s - distance through which the weight was lifted - m

w - weight added to the platform - kg

Experiment was repeated for 10 different set of weights and corresponding heart rate of the subject was noted In each trial lever was operated for 15 minutes and heart rate was measured at an interval of 5 minutes for a period of 2 minutes The average heart rate per minute was calculated and calibration curve was drawn between work done and corresponding heart rate of the subject

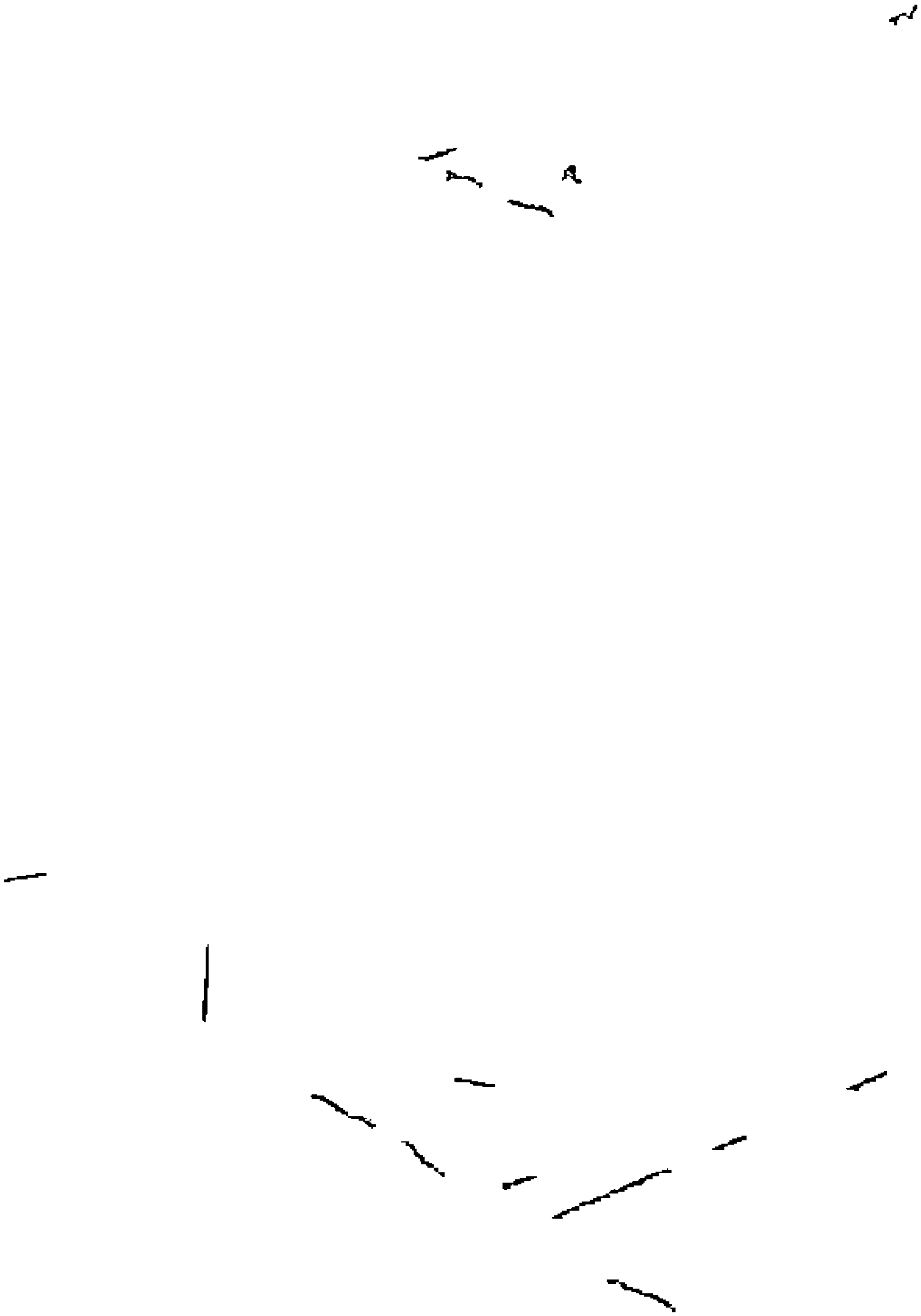
Subject was separately calibrated for hand operated and foot operated pumps. For the pedal operated pumps, calibration device was modified to be operated by simple attachments

late III Testing of Kumar Bharath pump

While calibration, care was taken to see that the environmental conditions and the body movement of the subject match with the actual field condition. Characteristics of the subject will be given by the intercept and slope of this calibration curve.

3.3.3. Hydraulic characteristics of the pump

The pumps under study was completely dismantled and overhauled before starting the experiment. Components of the pumps are checked against leakage and wear and worn out valve were replaced. Pumps were installed over the tank on the stand and operated at different heads by adjusting the gate valve. Corresponding heads were noted from the vacuum guage and discharge was collected in the measuring tank. Pumping was continued for a duration of 15 minutes. Heart rate of the subject was taken at an interval of 3 minutes for 2 minutes. The average of the three reading thus obtained would give the average heart rate of the subject during the pumping operation. Heart rate per minute was calculated. Total number of strokes were counted and strokes per minute computed Thus, discharge in l/min, head in 'm', heart rate in beats/min and number of strokes per minutes were obtained.



3.3.3.1 Horse power requirement

Force required for suction and delivery stroke of a positive displacement pump is given by

$$F_s = w\ a\ h_s \quad \text{and}$$

$$F_d = w\ (a-a_1)h_d$$

Where,

F_s - force requirement for suction kg

F_d - force requirement for delivery stroke kg

w - specific weight of water kg/cum

a - area of the piston sq m

a_1 - area of the piston rod sq m

h_s - suction head m

h_d - delivery head m

Horse power requirement of the pump is given by

$$HP - \frac{(F_s + F_d)\ 2l\ N}{4560}$$

Where,

l - length of stroke m

N - number of stroke per minute

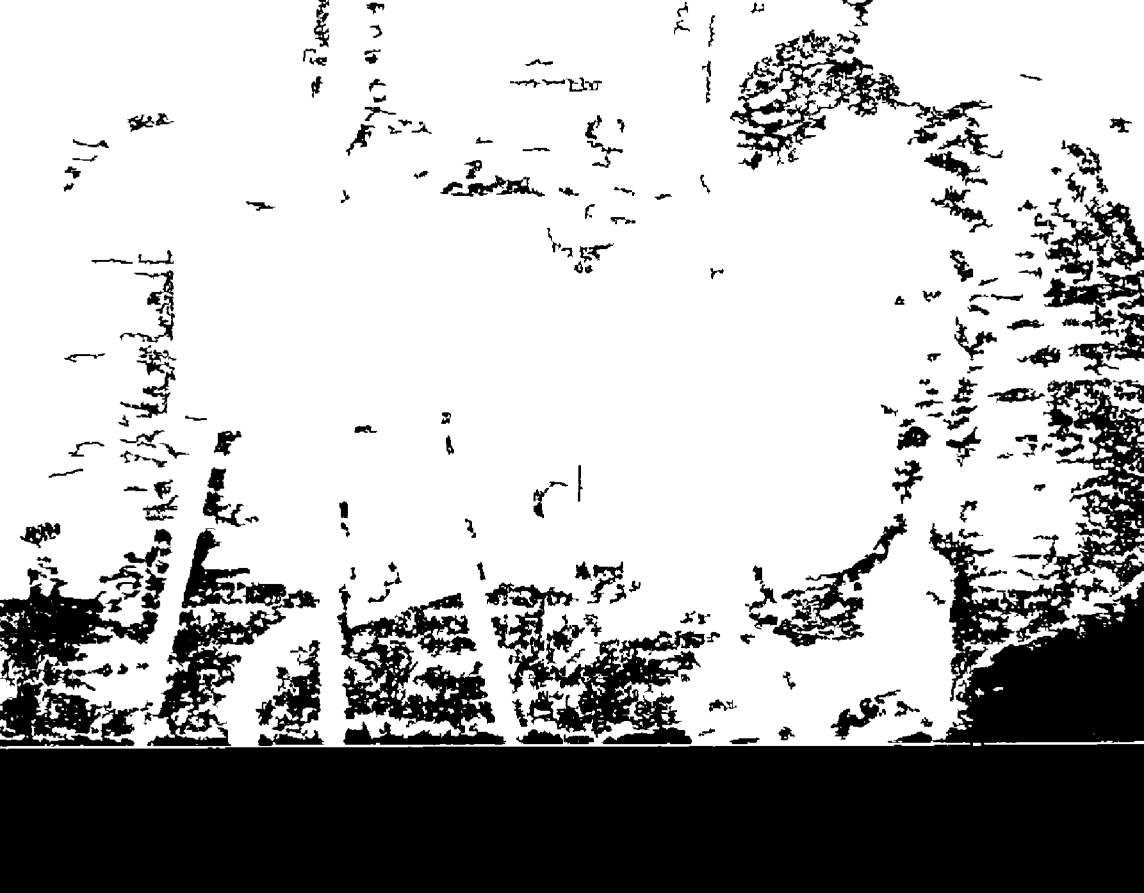


Plate V Testing of Kirloskar pump

Water horse power developed by the pump is given by

$$WHP = \frac{Q \times H}{75}$$

Where Q is the discharge l/s

H = total head m

3.3.3.2 Volumetric efficiency

Volumetric efficiency of a pump is defined as the ratio of actual discharge of the pump to the theoretical discharge. Theoretical discharge of the pump is given by

$$Q_{th} - a \times l \times N$$

Where,

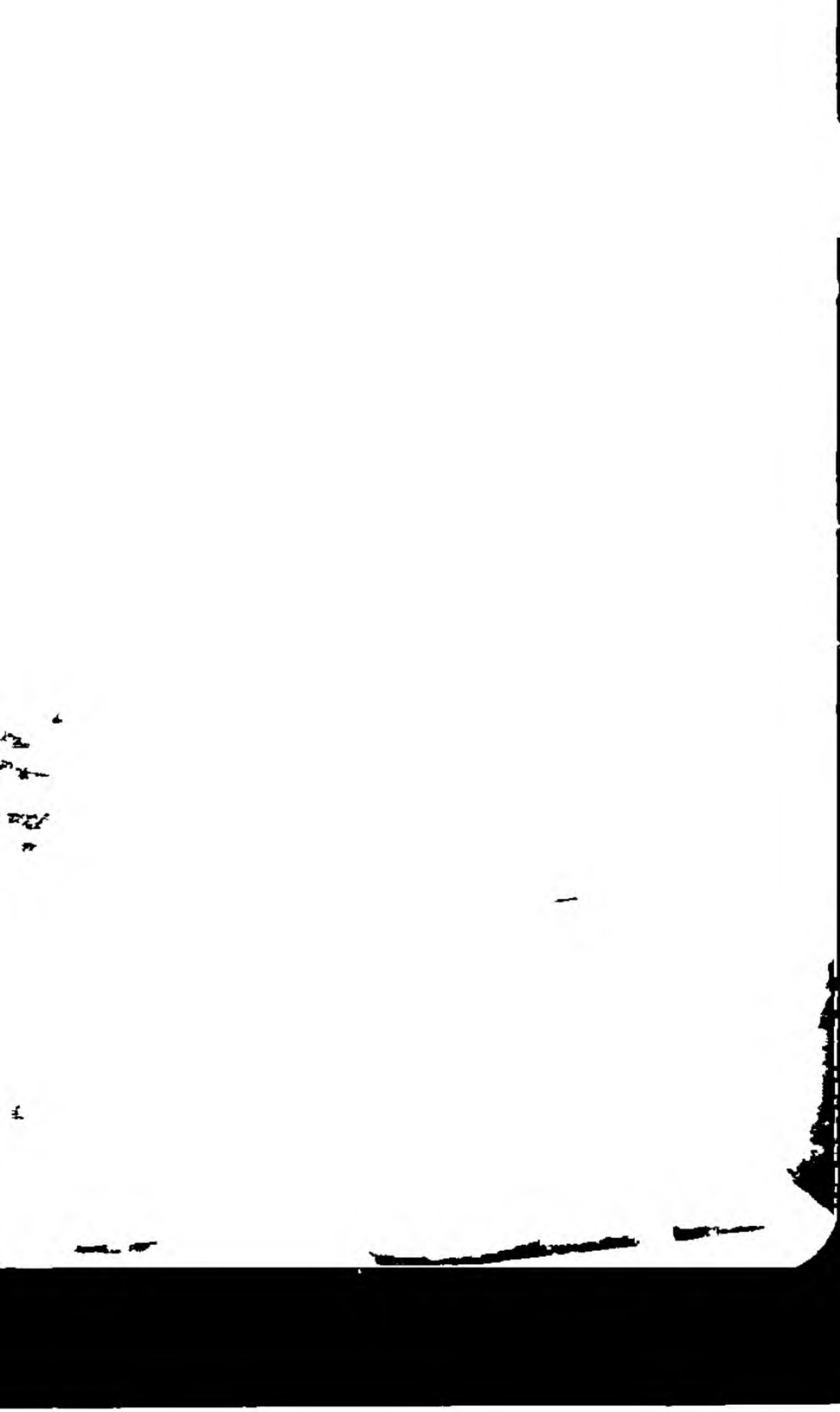
a - area of the piston sq m

l - length of stroke m

N - number of useful strokes of the pump

3 3.3.3 Variation of discharge with head

The pumps were operated at various heads and corresponding discharge was noted as described earlier. A plot was made between head and discharge of the pump.



VI Testing of E.P. Lift pump

3.3.3.4 Variation of time taken to deliver 100 l and number of strokes to deliver 100 l with the variation in head

Time taken by the pump to deliver 100 l (T) and number of strokes to deliver 100 l (N) at different heads were calculated from the head, discharge and number of strokes etc. A graph was plotted showing the relation of head with T and N.

3.3.3.5 Variation of volumetric efficiency with head

Volumetric efficiency of the pump at varying neads were computed as described in section 3.3.3.2. A graph was plotted showing the variation of volumetric efficiency with the change in head. Head at which the volumetric efficiency is maximum was noted. This can be recommended as the optimum head of the pump as far as hydraulic characteristics are concerned.

3.3.4 Ergonomic characteristics

3.3.4.1 Variation of heart rate with head

Heart rate of the subject while operating at different heads were noted as discussed in section 3.3.3. A graph was plotted to study the variation of heart rate with change in head.

Plate VII Testing of Diaphragm pump

Review of literature reveals that the safe limit of power output of an average Indian male in continuous pumping is 50 W for hand operated and 180 W for pedal operated pumps The corresponding heart beat of the subject was noted from the calibration graph From the head versus heart rate graph, head of operation corresponding to this heart rate was marked This could be recommended as the safe head against which the pump can be operated as far as ergonomic side was concerned Discharge of the pump at this head was noted from head versus discharge curve This gave the expected discharge of the pump at that ergonomically safe head

Results and Discussion

RESULTS AND DISCUSSION

Result of the experiments conducted are presented and discussed in this chapter under the following heads

1 General description of the pumps
2 Subject calibrations
3 Hydraulic characteristics
4 Ergonomic characteristics

4.1 General description of the pumps

As per section 3.1, general description of the pumps under study are tabulated in table.

1	Name of the pump	Kumar Bharath pump	E.P. Force pump	E P L ft pump	Kirloskar pump	Bicycle operated Diaphragm pump
2.	Type of machine	Recipro- cating	Recipro- cating	Recipro- cating	Recipro- cating	Diaphragm
3.	Manufactures' Address	M/s Kumar Bharath Industries Ottapalam Palghat, Kerala	E P. Agro Machinery Ottapalam, Palghat, Kerala	E P Agro Machinery Ottapalam Palghat Kerala	Kirloskar Brothers Limited, Udyog Bhavan, Tilak Road Pune - 411 002	Dept. of Farm Power Machine and Energy, K C A E T , Tavanur

4.2.2 Calibration of the subject

The heart rate response of the subject at different rates of mechanical work is used to calibrate the subject for basic task Data obtained while calibrating the subject for hand and pedal operated pumps are tabulated in table 1 and table 2 respectively Calibration curves are given in Fig 17 and Fig 18 From the figures it can be seen that the heart rate increases linearly as the mechanical work increases The slope and intercept of the curve defines the subject characteristics The moderate slope indicates that the subject is healthy to perform continuous operation Calibration curve for pedal operated pumps are flatter than that of hand operated pumps. This shows that for a particular mechanical load, hand operated pumps extracts more human energy than the pedal operated pumps Kennedy and Roger (1985) stated that for design purposes the average value of adult power output while the muscle group involved is mainly hand is 50 W for 10 to 15 min operation For pedalling it is 180 W From calibration curve, it can be seen that this corresponds to the heart rate of 110 beats/min So this heart rate can be taken as the limit while operating the pumps, beyond which the operation is not ergonomically safe

4.	Overall dimensions	Dia 7 5cm Stroke 16.25 cm	Dia 8 75cm Stroke 8.75 cm	Dia 7 5cm Stroke 7 5 cm	Dia. 7 5cm Stroke 16 25 cm	A = 8 sq cm Stroke-8 cm
5	Recommended angle of installation	Vertical	Vertical	Vertical	Vertical	Horizontal
6.	Number of workers required to operate the pump	One	One	One	One	One
7	Physical part of the worker used for operating the pump	Hand	Fcot	Foot	Hand	Foot
8	Material of construction	Cast iron cylinder	Cast iron cylinder	Cast iron cylinder	Cast iron cylinder	Cast iron and Rubber diaphragm

4.2 Subject calibration

4 2.1 Anthropometric data

Anthropometric data of the subject selected for the study are collected and displayed in Appendix I The body surface area of the subject is calculated as discussed in section 3 3 1 and is found to be 15263.768 sq cm. Heart rate of the subject in rest position was measured and was found to be 69 beats per min

Table 1 Mechanical work and corresponding heart rate of the subject (hand operated pumps)

No	Rate of mechanical work (kg m/min)	Heart rate (beats/min)
1	48.19	74
2	87.65	79.5
3	120.83	84.5
4	158.59	89 5
5	184.29	93
6	211.30	97
7	238.46	101
8	266.99	105 1
9	295 87	109
10	324 76	113

Table 2 Mechanical work and corresponding heart rate of the subject (pedal operated pumps)

No	Rate of mechanical work (kg m/min)	Heart rate (Beats/min)
1	263 68	79 5
2	342 72	82 5
3	414 44	85 1
4	486 7	88 0
5	560 88	90 5
6	629 76	93
7	700 12	96
8	771 12	98 5
9	1100	109

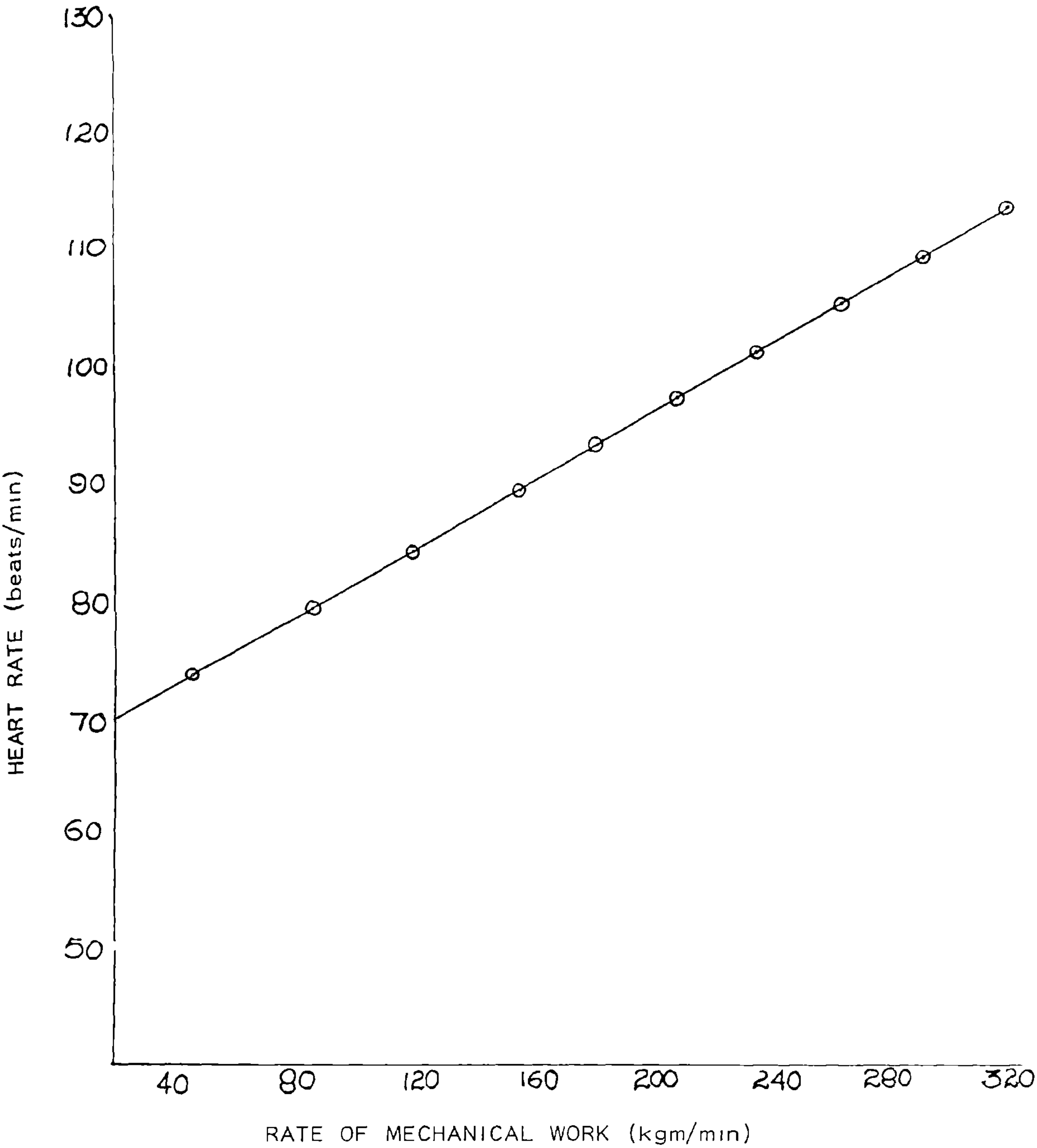


Fig. 17 Calibration curve (hand operated pumps)

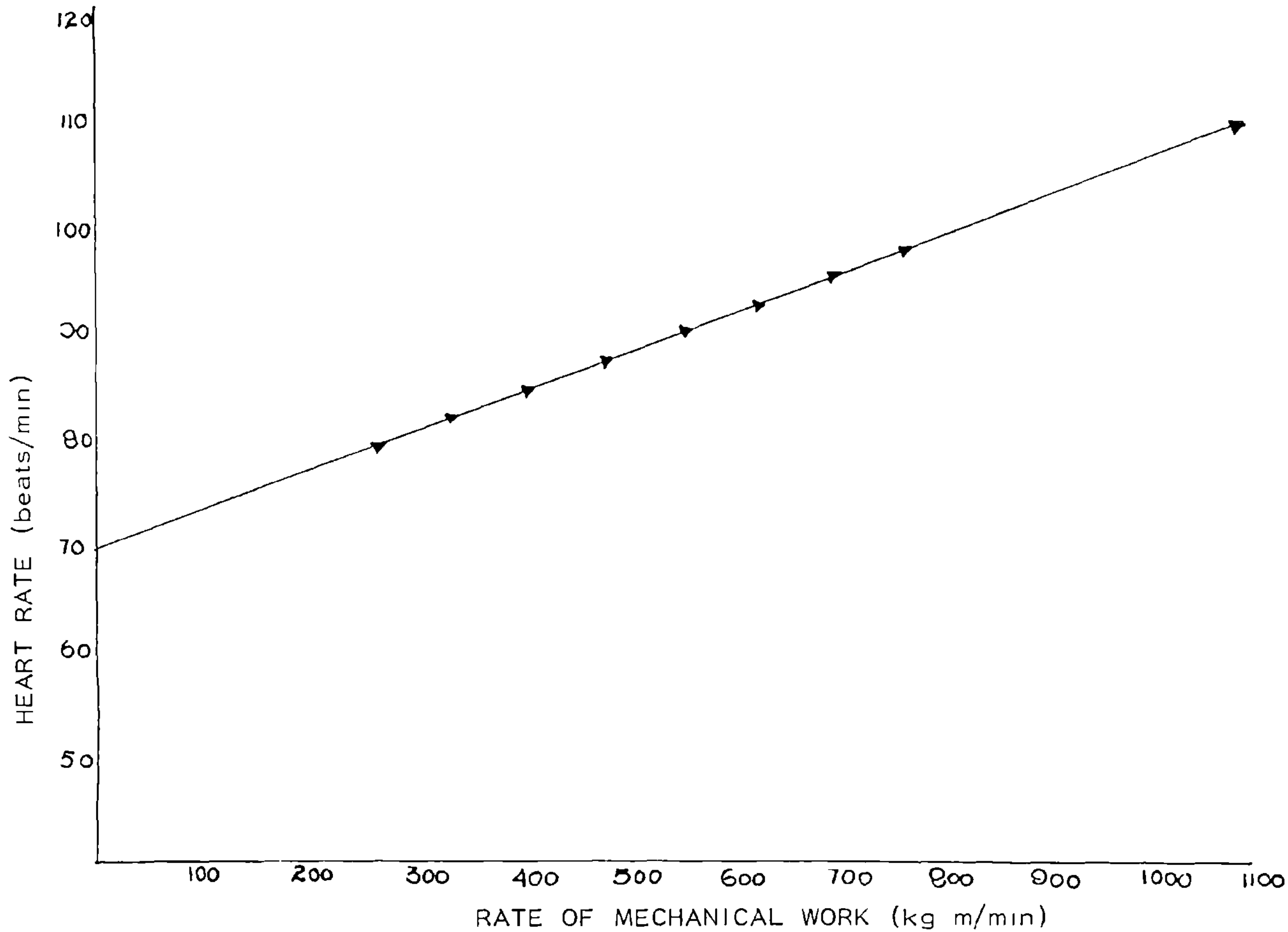


Fig. 18 Calibration curve (pedal operated pumps)

4.3 Hydraulic characteristics

4.3.1 Variation of discharge with head

Discharges of the five pumps under different heads are tabulated in table 3. Graphs are plotted showing head discharge relation (Fig.19 to 23).

All the pumps showed a reduction in discharge with increase in head. In Kumar Bharath pump, discharge showed a gradual decrease upto 6 m head and above that it showed a steep decline in discharge. Similarly for the other pumps, Kirloskar pump delivered a reasonable discharge upto 5 m head, E P lift upto 5.5 m and E P Force upto 4 8 m. The diaphragm pump showed a steep reduction in discharge when the head is increased, even at lower heads

For positive displacement pumps, the discharge is expected to be constant irrespective of the variation in head upto a certain head. But since these pumps are manually operated, as the head is increased, the effort required is increased which will decrease the ease of operation This will reduce the speed of operation of the pumps (number of strokes per minute) and thus the discharge is reduced. In case of the diaphragm pump it was observed that air was sucked in while operating at higher heads,

Table 3 Variation of discharge with head

Kumar Bharath		E P Force		Kirloskar		E.P. Lift		Bicycle operated Diaphragm	
Head (m)	Discharge (l/min)	Head (m)	Discharge (l/min)	Head (m)	Discharge (l/min)	Head (m)	Discharge (l/min)	Head (m)	Discharge (l/min)
1.6	24.6	1 8	29.481	1 4	2 4	1.6	20 1	0 6	32.4
2 0	24.0	2 4	29.28	2.2	23.7	2.2	19.98	1.4	25.2
2.6	23.52	3.0	29.1	3.0	23.52	2.8	19.86	2 0	19.8
3 2	22 44	3 8	29.4	4.0	23.28	3.4	19.74	2 8	15 6
4 0	21.6	4 8	28 8	4.6	22.8	4.0	19.5	3.6	11.4
4 4	21 1	5 6	27.6	5.0	22.32	4.6	19.2	5.0	7.2
5 0	20.94	6 0	26.4	5 4	21.6	5.4	18.6	5.8	5.4
5 6	19.5	6 8	22.2	6.2	18.0	6.0	16.8		
6 0	13 0	7 4	15 0	6.6	15.521	6.6	13.2		
6.4	15.66	8 0	2.4	7.0	12.0	7.0	8.1		
6.8	12.9			7.4	7.2	7.2	1.8		
7.8	3.9			8.0	1.2				
8 0	1.8								

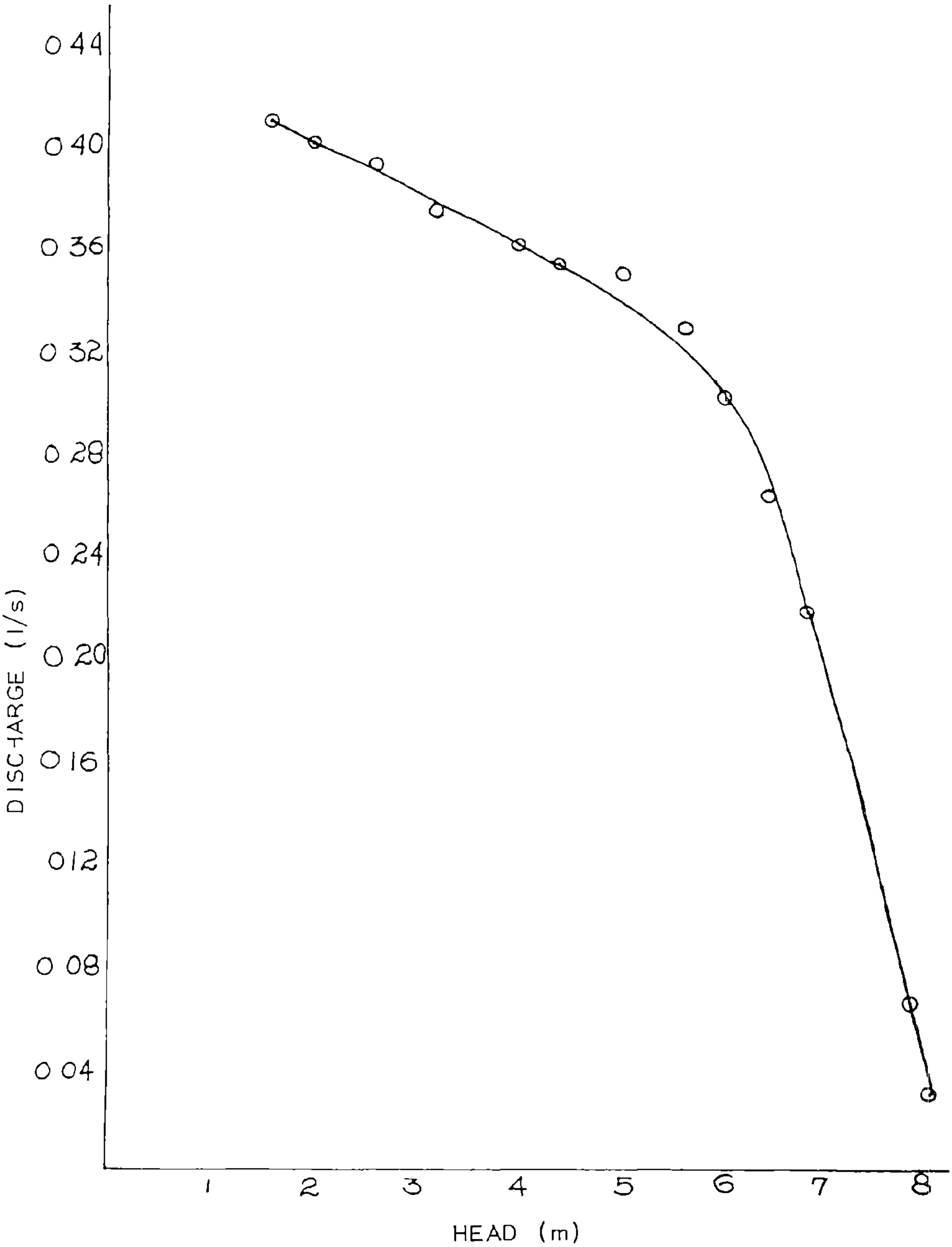


Fig. 19 Variation of discharge with head (Kumar Bharath pump)

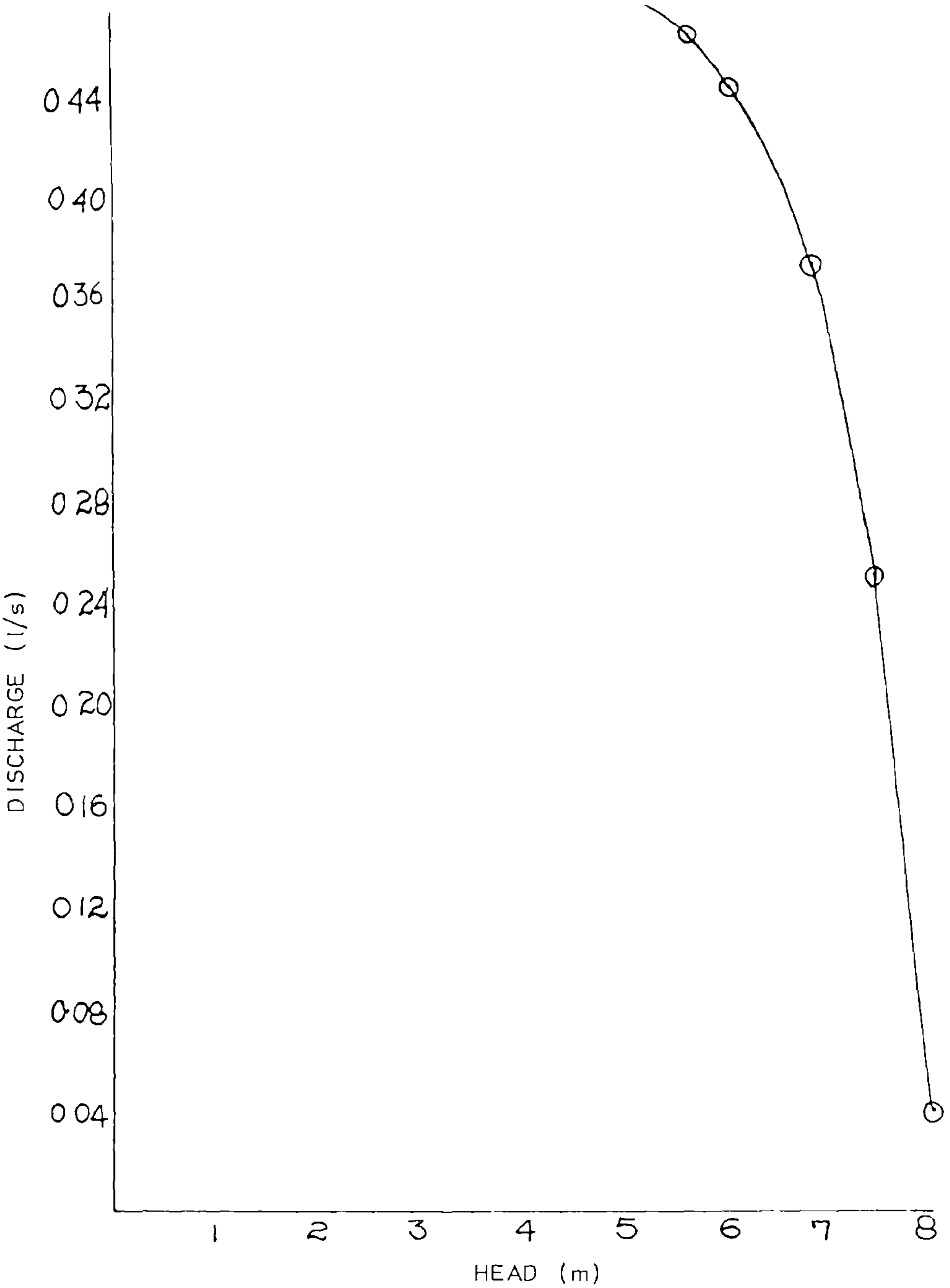


Fig. 20 Variation of discharge with head (E.P. Force pump)

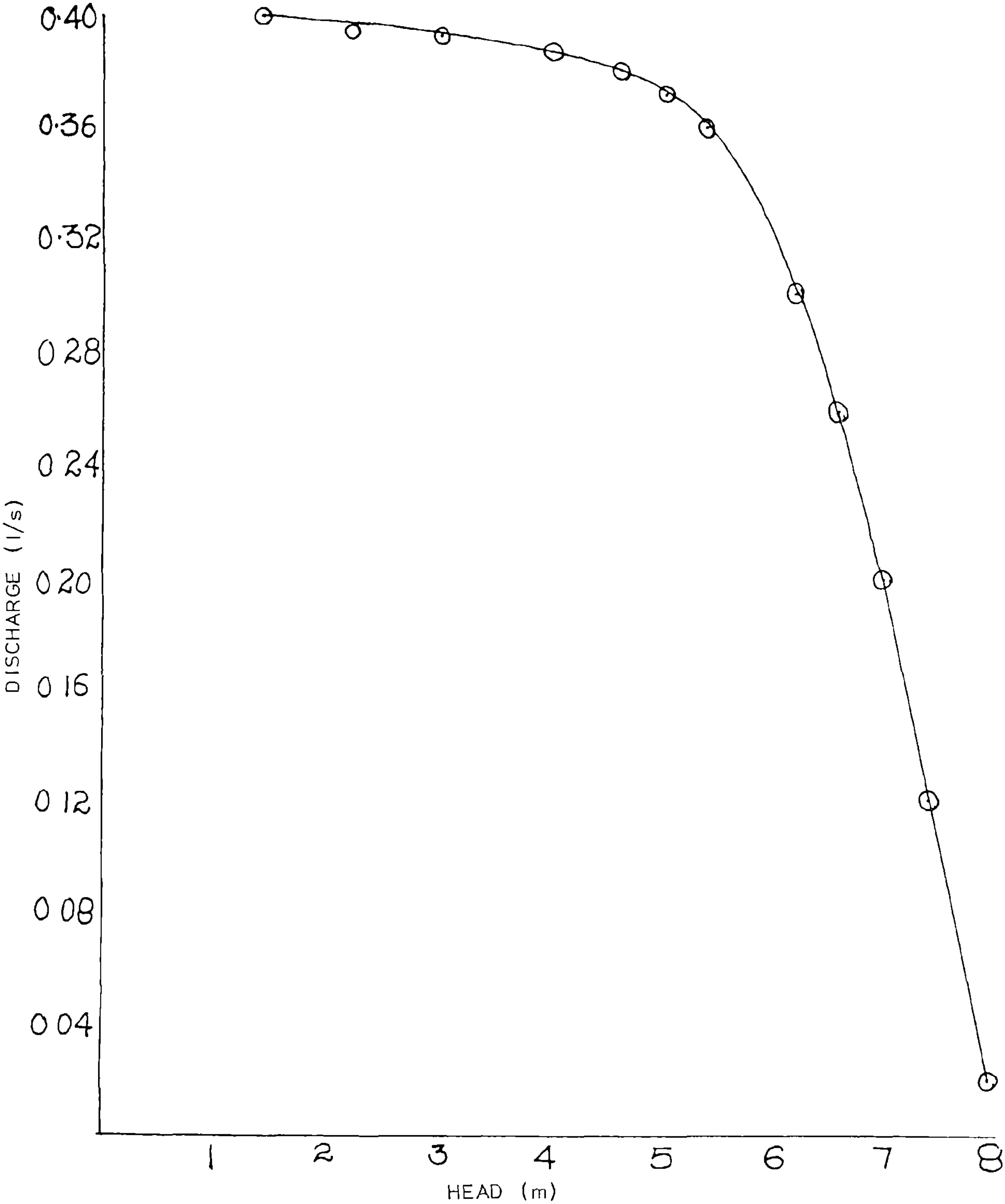


Fig. 21 Variation of discharge with head (Kirloskar pump)

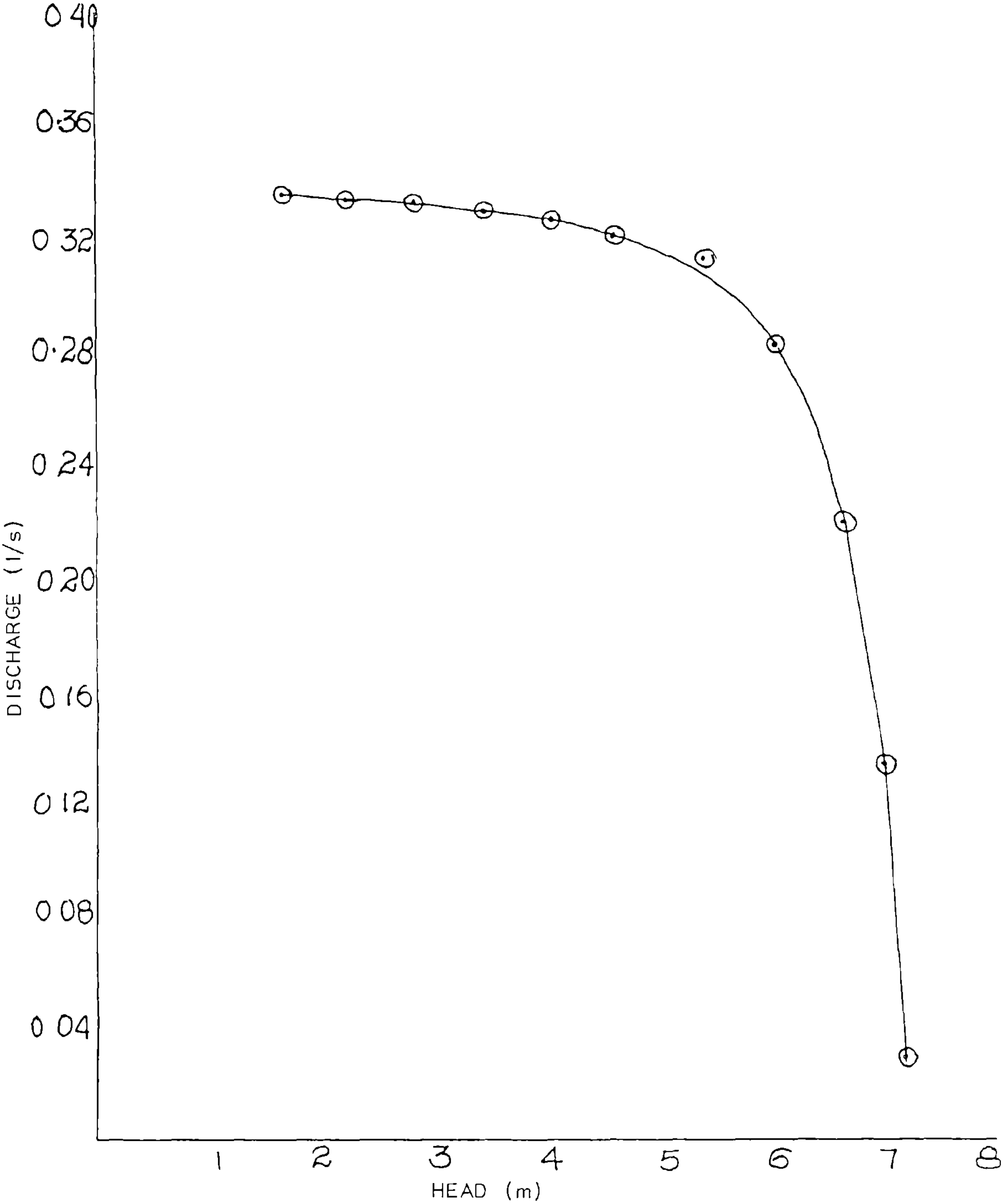


Fig. 22 Variation of discharge with head (E.P. Lift pump)

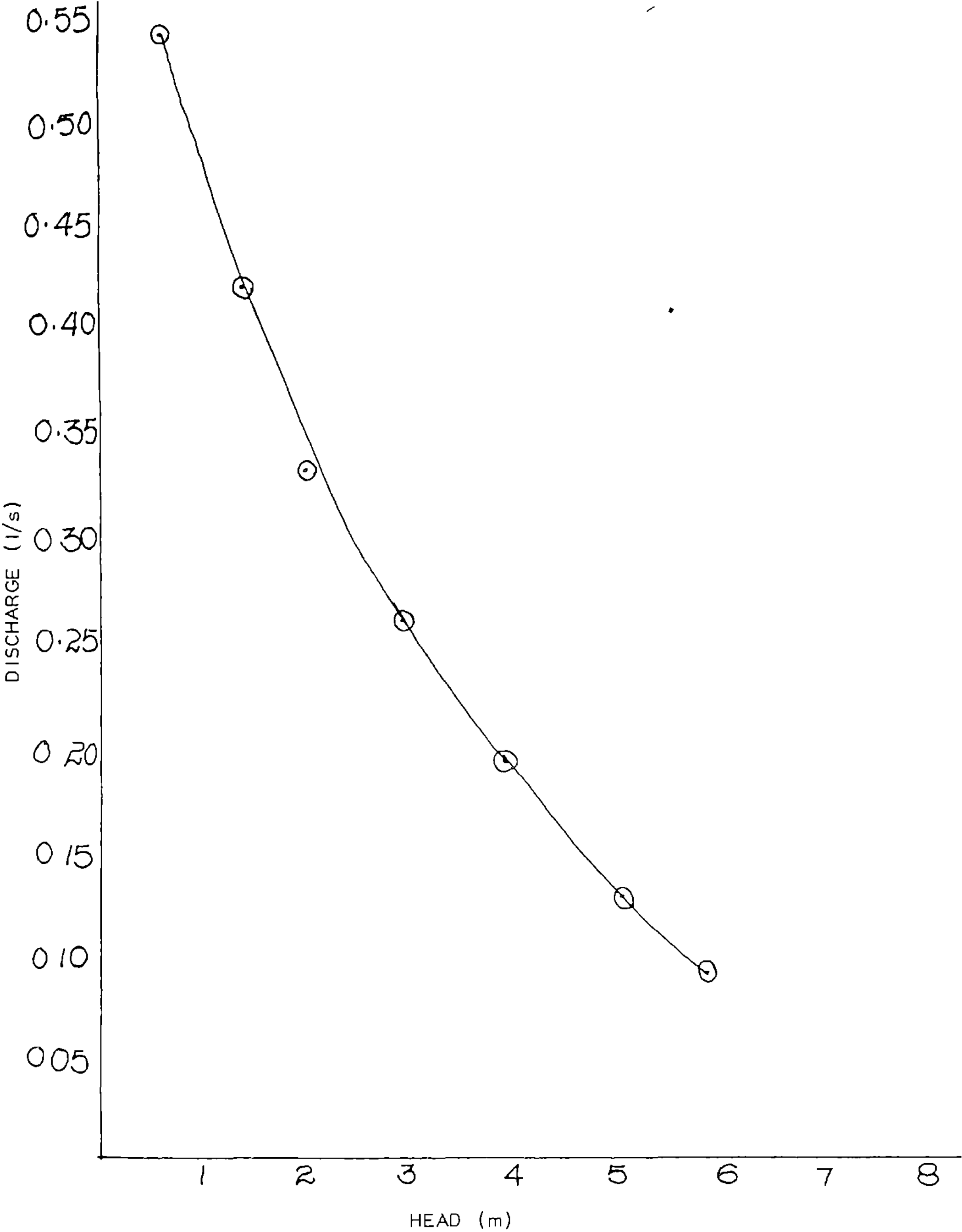


Fig. 23 Variation of discharge with head (Diaphragm pump)

through the connecting rod-diaphragm junction This also contributed the reduction in discharge

4 3 2 Variation of volumetric efficiency with head

Changes in the volumetric efficiency of the pumps with change in head is displayed in table 4. The relationship of volumetric efficiency with head is graphically represented in Fig 24 to Fig.28.

From the figure it can be seen that at higher heads, pumps showed lower volumetric efficiency. Reduction in volumetric efficiency is gradual upto a certain head and beyond this the reduction is steep Volumetric efficiency of Kumar Bharath pump was reduced below 75% beyond the head 6 9 m Corresponding heads for the other pumps are 6 7 for Kirloskar, 5 8 for E P Force pump, 5 7 for E P Lift pump and 1 1 for Diaphragm pump Diaphragm pump was found to be very inefficient at higher heads

Table 4 Variation of volumetric efficiency with head

Kumar Bharath		E P Force pump		Kirloskar		E.P. Lift pump		Bicycle operated Diaphragm pump	
Head (m)	Volumetric efficiency (%)	Head (m)	Volumetric efficiency (%)	Head (m)	Volumetric efficiency (%)	Head (m)	Volumetric efficiency (%)	Head (m)	Volumetric efficiency (%)
1 6	96 21	1 8	87 3	1 4	93 59	1.6	90.49	0.6	87.0
2 0	98.2	2 4	85 6	2 2	94 64	2.2	94.52		
2 6	97 5	3 0	81 3	3 0	94 55	2 8	92.22	1 4	64.8
3 2	97 5	3 8	80 76	4 0	92 95	3 4	90.54	2 0	50.15
4 0	96 06	4 8	79 13	4 6	92 42	4 0	89 65	2,8	41 53
4 4	94 88	5 6	80 76	5 0	91 05	4 6	86 46	3.6	30 39
5 0	93 75	6 0	73 68	5 4	88 38	5 4	89 39	5 0	19 5
5 6	90 98	6 8	66 06	6 2	82 154	6 0	83 57	5.8	15 4
6 0	87 68	7 4	45.3	6 6	78 06	6 6	64 55		
6 4	85 0	8 0	6 89	7 0	65 13	7.0	40 35		
6 8	76 92			7 4	40 03	7 2	9.22		
7 8	49 39			8 0	25 26				
8 0	42 7								

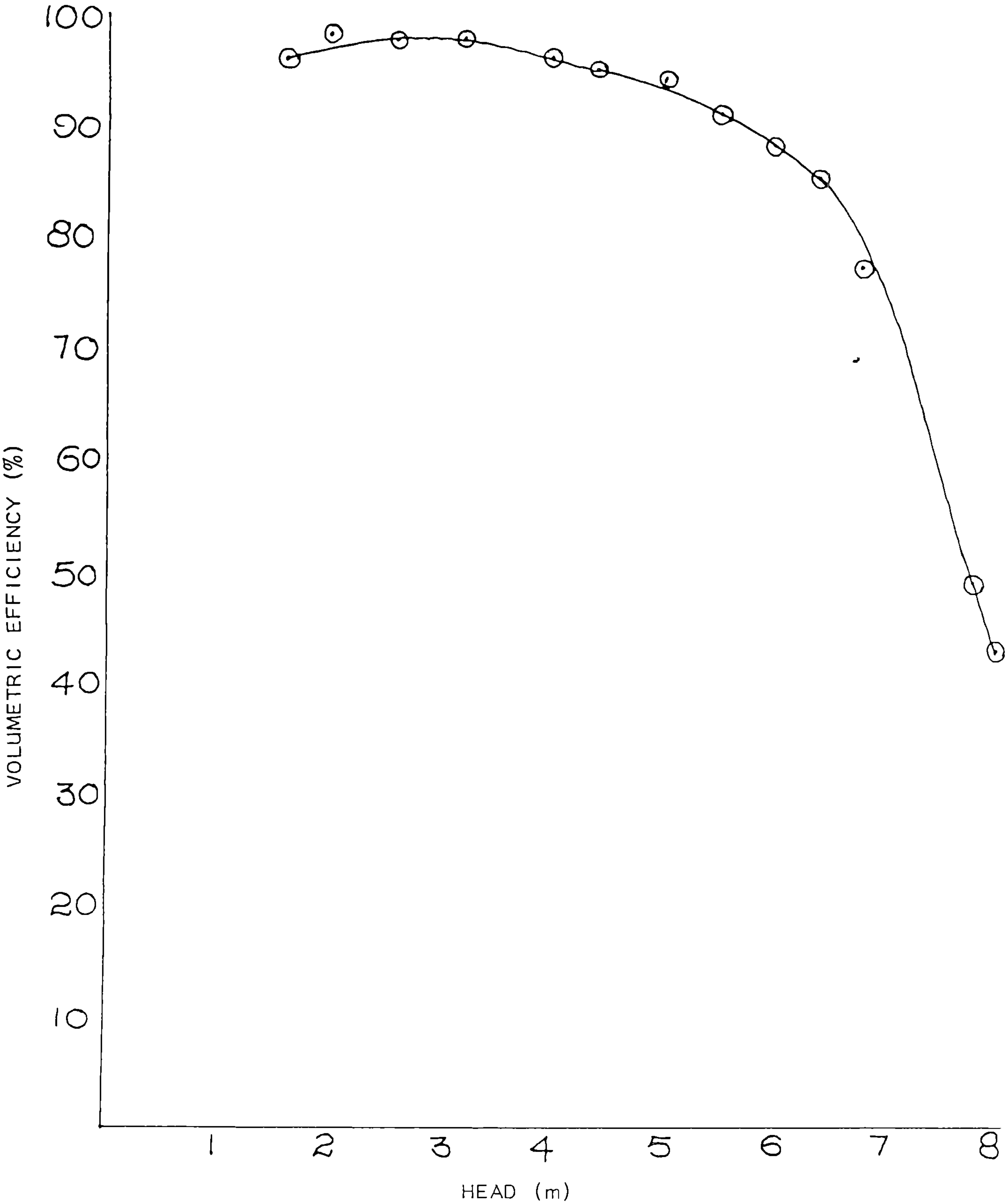


Fig. 24 Variation of volumetric efficiency with head (Kumar Bharath pump)

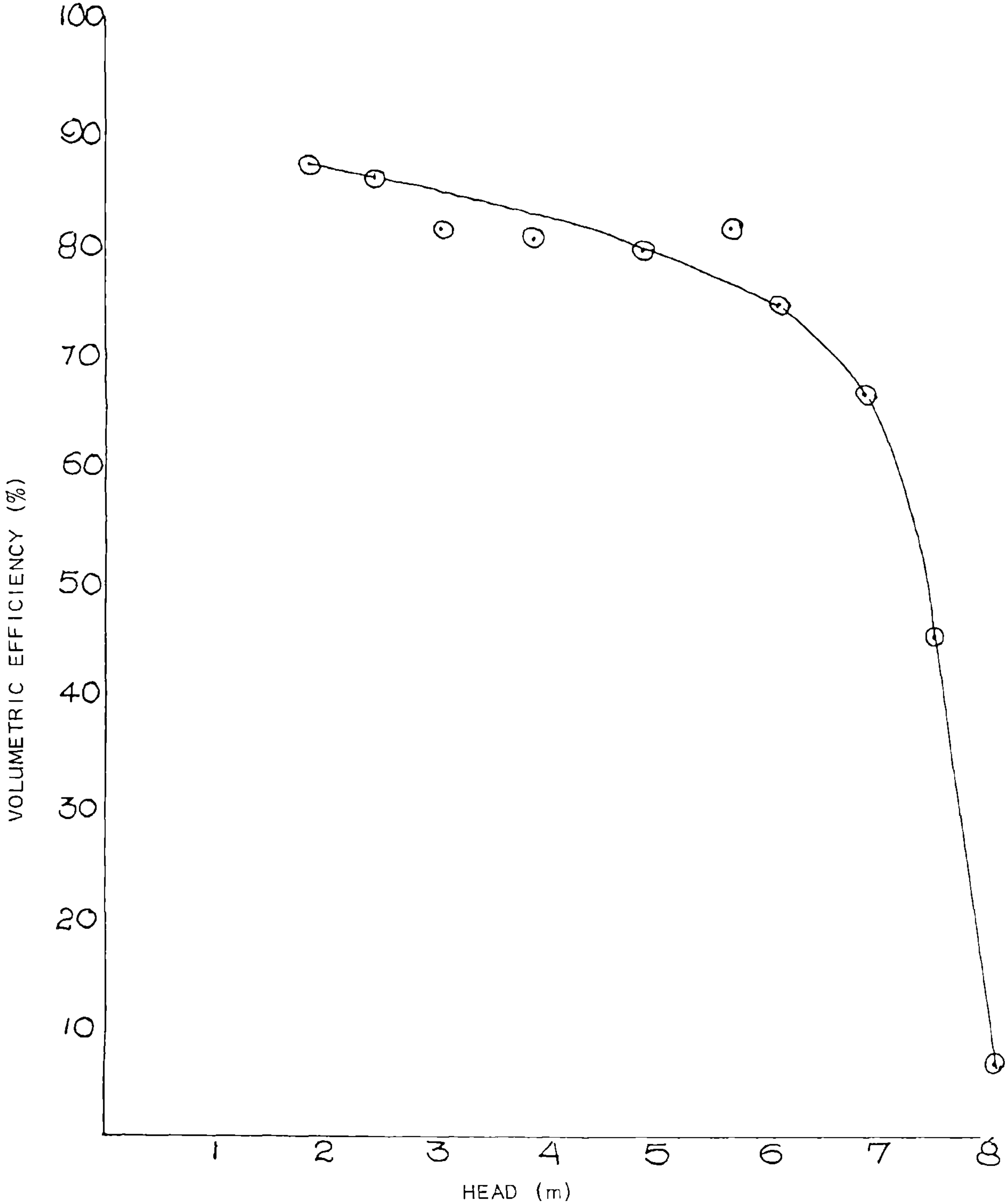


Fig. 25 Variation of volumetric efficiency with head (E.P. Force pump)

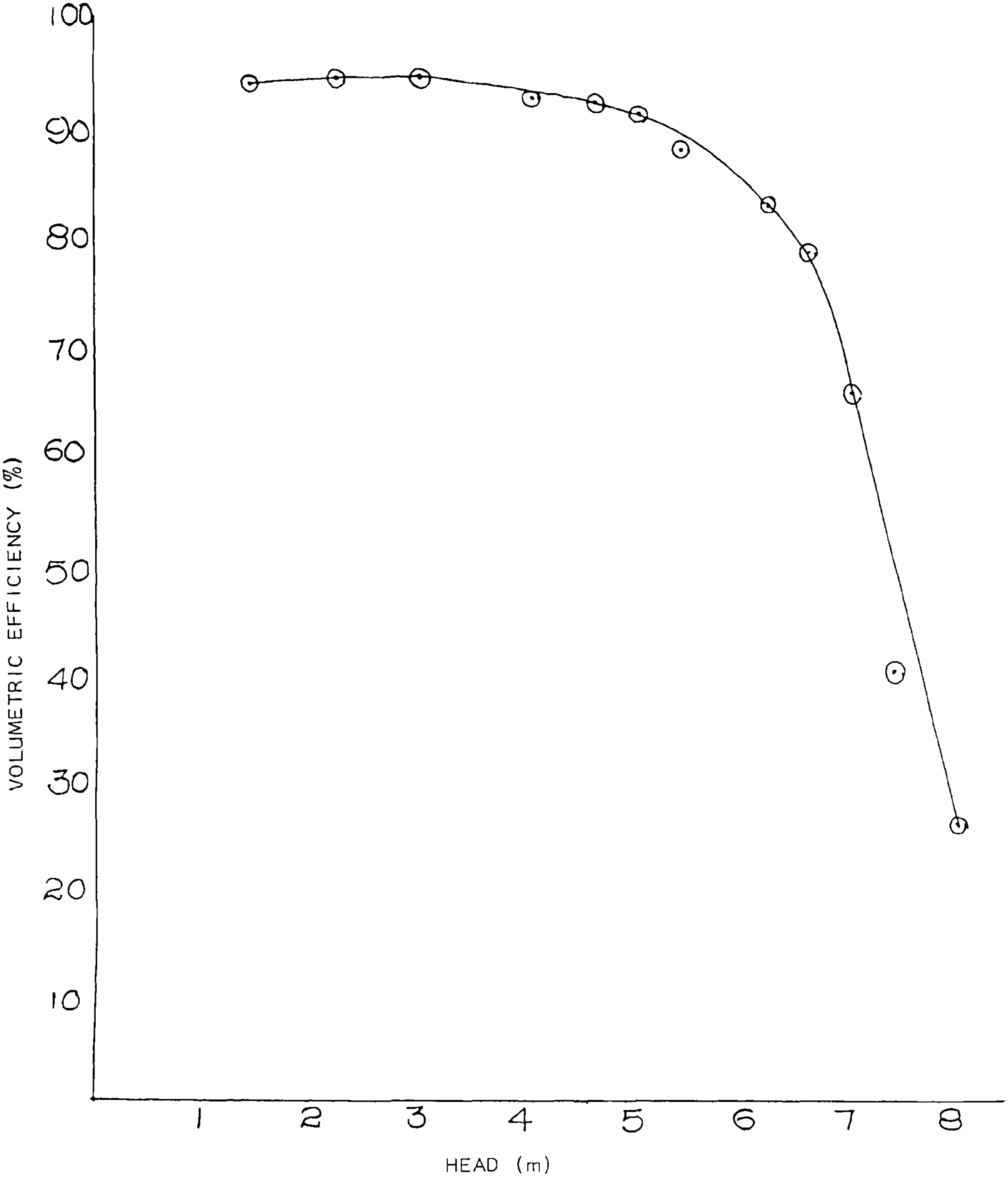


Fig. 26 Variation of volumetric efficiency with head (Kirloskar pump)

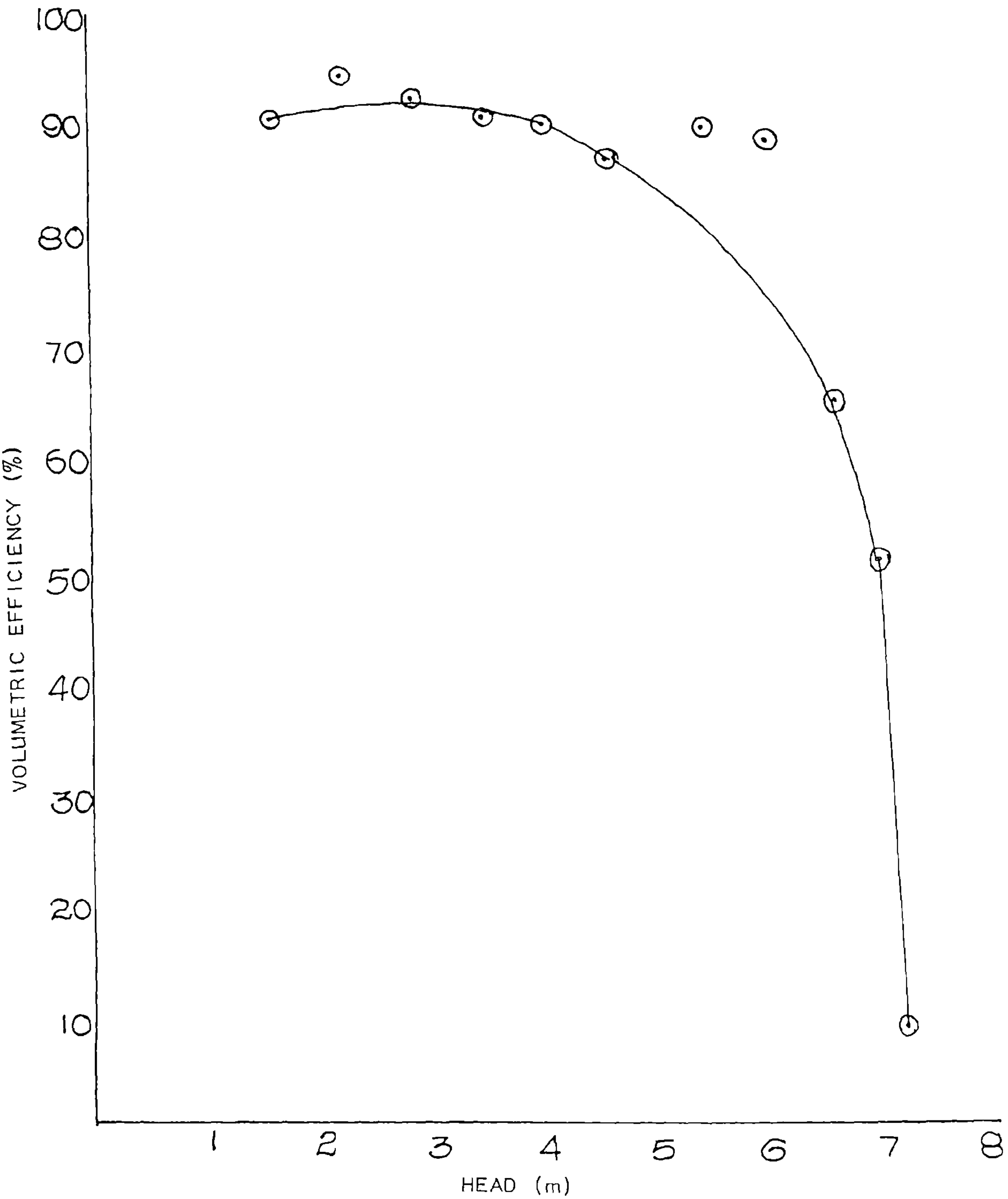


Fig. 27 Variation of volumetric efficiency with head (E.P. Lift pump)

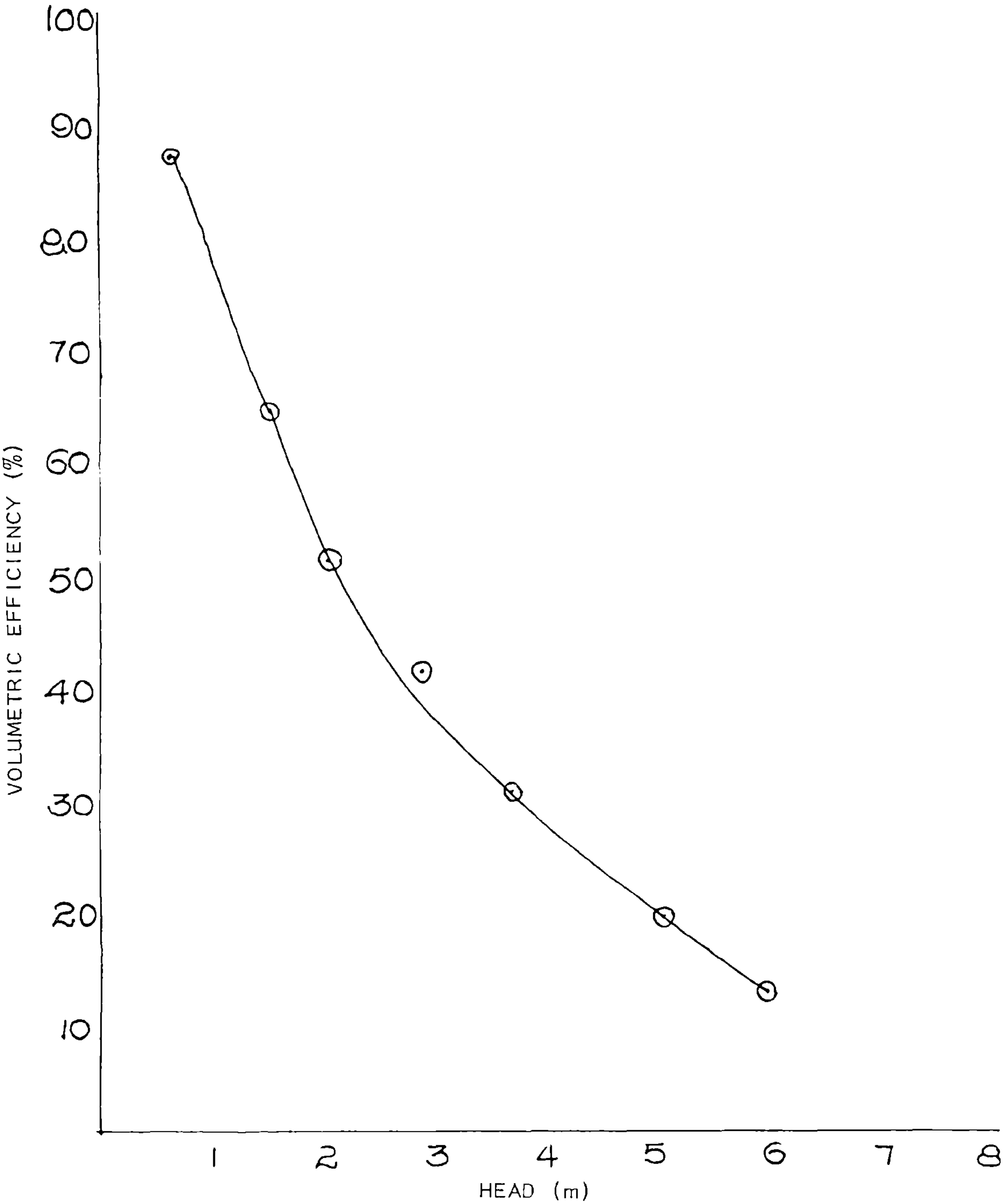


Fig. 28 Variation of volumetric efficiency with head (Diaphragm pump)

Table 5 Hydraulically efficient head limits recommended for the pumps

No.	Pump	Recommended head (m)
1	Kumar Bharath	6 9
2	Kirloskar	6 7
3	E.P. Force	5.8
4	E.P. Lift	5 7
5	Diaphragm	1 1

4.3 3 Variation of time for 100 litre discharge with head

Time taken to deliver 100 litre discharge at different heads are as shown in table 6. A graph is plotted between head and time taken for 100 litre discharge for different pumps (Fig 29) The combined effect of cylinder volume of the pumps and ease of pumping is reflected in these graphs

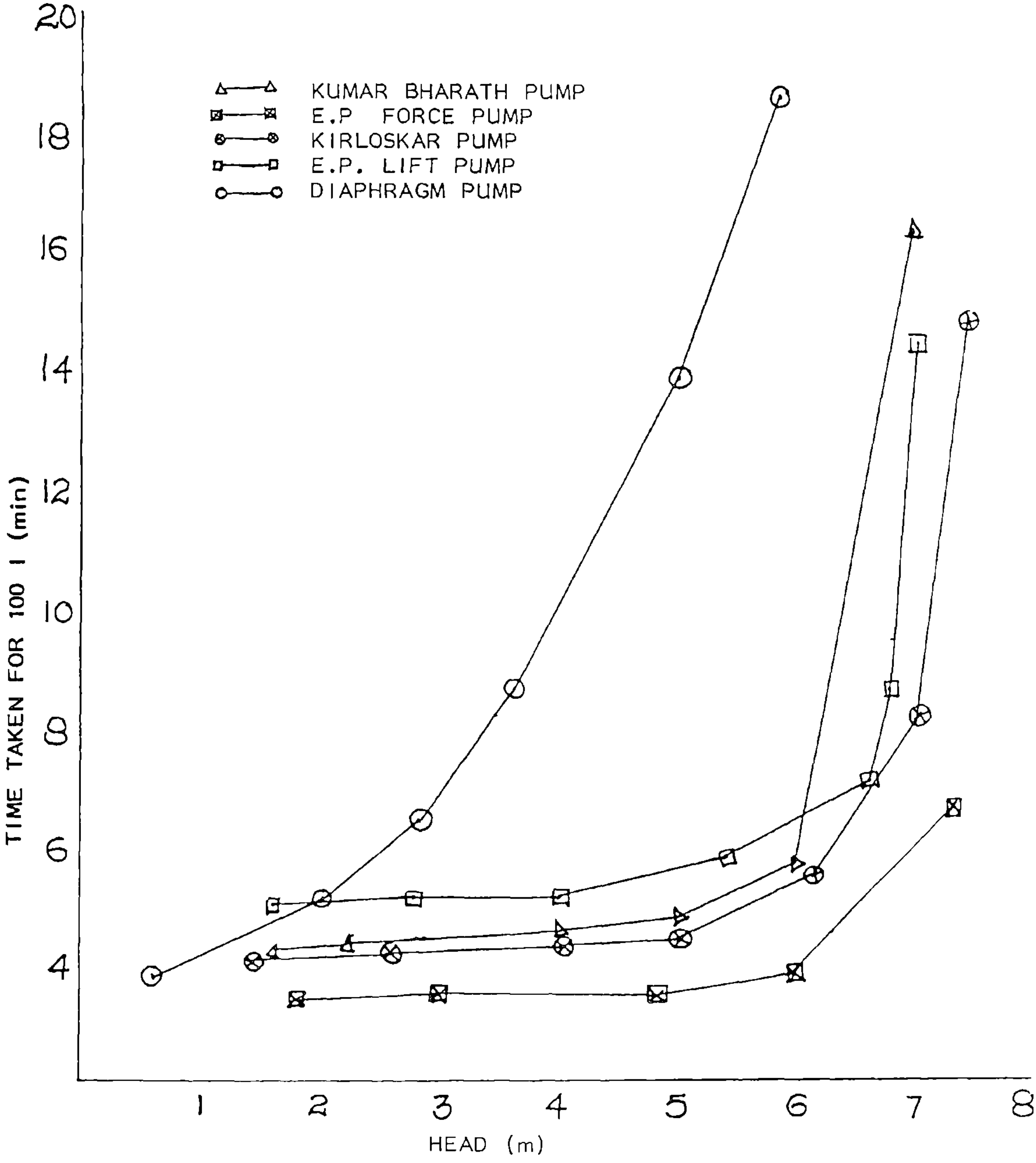


Fig. 29 Variation of time taken for 100 l discharge with head

Table 6 Variation in time taken for 100 l discharge and number of strokes for 100 l discharge with head

Kirloskar pump			E.P. Force pump			Kirloskar			E.P. Lift pump			Bicycle operated Diaphragm pump		
Head (m)	N	T (min)	Head (m)	N	T (min)	Head (m)	N	T (min)	Head (m)	N	T (min)	Head (m)	N	T (min)
1.6	138.21	4.065	1.8	207.4	3.40	1.4	142.08	4.167	1.6	318.4	4.975	0.6	190.96	3.00
2.6	136.48	4.252	3.0	223.34	3.436	2.2	140 50	4 219	2.8	312.17	5.035	2 0	308.03	5.05
4 0	138.46	4.630	4.8	229.13	3 472	4.0	143 04	4 296	4.0	323 06	5 128	2.8	371 78	6 41
5.0	141.84	4.776	6.0	246.22	3.788	5 0	146.06	4 48	5.4	322 56	5.376	3 6	499.89	8.77
6.0	151.78	5 556	7 4	400.02	6.667	6.2	161.11	5 556	6 6	447 22	7 580	5 0	791.16	13.88
6.8	172.87	7.752				7.0	204 17	8.33						
8.0	311.11	55.556				7.4	331.94	13 89						

* N - Number of strokes taken to deliver 100 l

**T - Time taken to deliver 100 l.

From the graph it can be seen that although the cylinder volume of bicycle operated diaphragm pump is comparatively higher than that of E P. Force pump and E P Lift pump (648 cu cm), time taken for delivering 100 litres is higher especially after 2 m head. This may be due fact that high effort is required and volumetric efficiency is low at higher heads Kumar Bharath pump and Kirloskar pump which have equal cylinder volume (752 534 cu cm) shows similar trend upto 6 m head After that Kirloskar pump takes, lesser time than Kumar Bharath pump Comparing E P Lift pump and E P. Force pump, latter performs better. As far as time is concerned, this can be accounted to its higher cylinder volume (551.537 cu cm for force pump and 347 3 cu cm for lift pump)

4.3.4 Variation in number of strokes for 100 litre discharge with head

Number of strokes for delivering 100 litre discharge at different heads are given in table 6. A graph is plotted showing the variation in number of strokes for 100 litre discharge at different heads (Fig.30). Number of strokes was highest in the case of bicycle operated diaphragm pump after 2 m head It went upto 500 strokes at 3 2 head. Number of strokes for E P Lift pump is also higher due to its lower cylinder volume. Kirloskar and Kumar Bharath pumps showed almost equal trends.

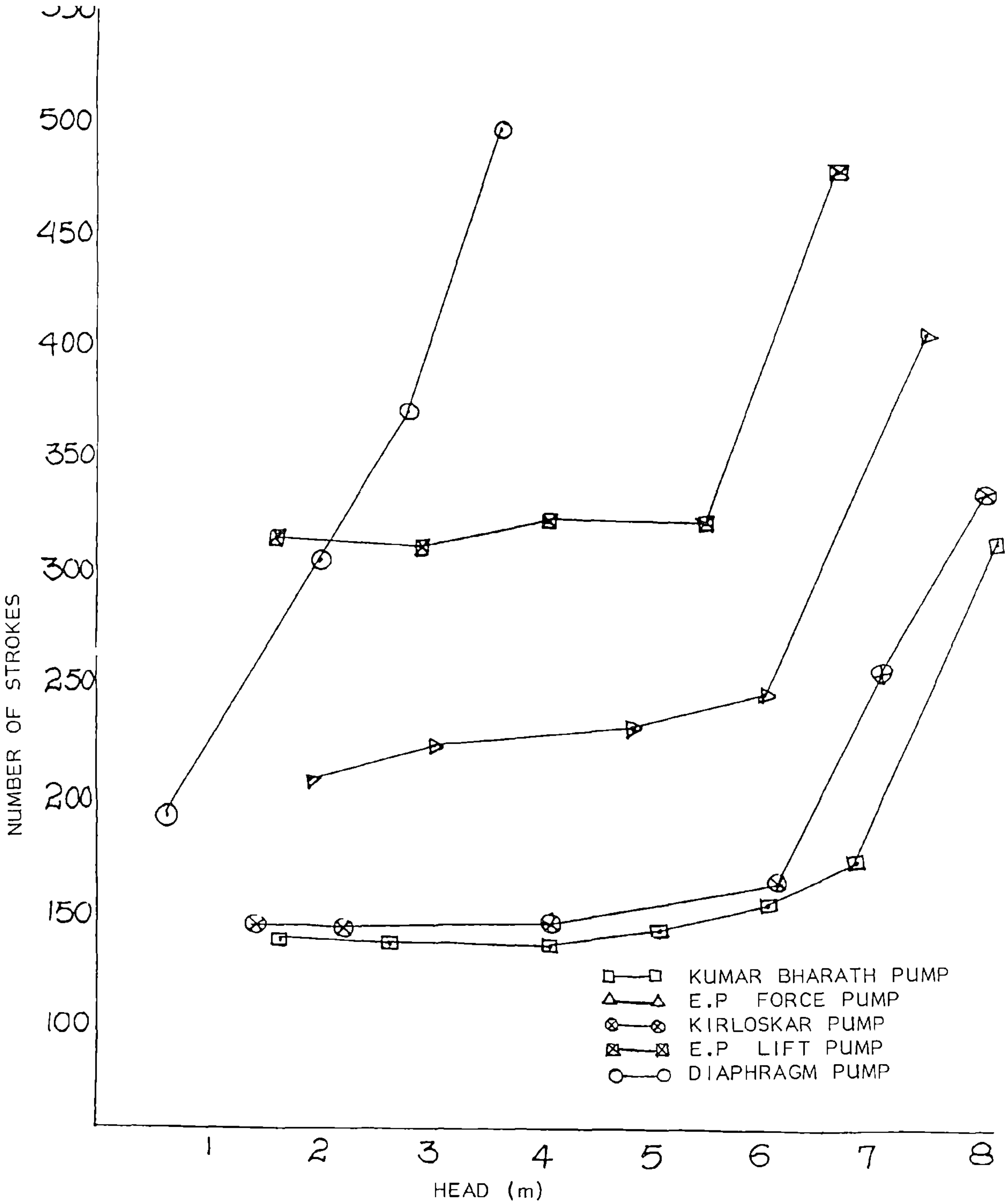


Fig. 30 Variation of number of strokes for 100 l discharge with head

Table 7 Heart rate response of the subject at different heads

Kumar Bharath		E.P. Force pump		Kirloskar		E.P. Lift pump		Bicycle operated Diaphragm pump	
Head (m)	Heart rate (beats/min)	Head (m)	Heart rate (beats/min)	Head (m)	Heart rate (beats/min)	Head (m)	Heart rate (beats/min)	Head (m)	Heart rate (beats/min)
1.6	79.5	1.8	82	1.4	79	1.6	80.0	0.6	76
2.6	85 5	3 0	90	2 2	84	2.8	87.5	2.0	86
4 0	94	4.8	102 5	4 0	96	4.0	95.0	2.8	93
5 0	100	6 0	110 0	5 0	102	5.4	104	3.6	102
6.0	106	7.4	119 0	6 2	110	6.6	112	5.0	112
6.8	110 5	8.0	122 5	7 0	115	7.2	115.5	5.8	126
8.0	118			7 4	117.5				

4.4 Ergonomic characteristics

Heart rate of the subject while operating at different heads are tabulated in table 7. Graphs are plotted showing the heart rate response of the subject at different heads (Fig 31 to 35)

As discussed in section 4.2.2 for operating the pump for 10 to 15 min duration, the safe heart rate of the subject is 110 beats/min. The head at which the heart rate is 110 beats/min can be taken as the safe limit of the head as far as ergonomics is considered.

Table 8 Ergonomically safe heads for different pumps

Sl.No	Pump	Safe head (m)
1	Kumar Bharath	6.6
2	Kirloskar	5 25
3	E.P. Force	6 0
4	E.P Lift	6 3
5	Bicycle operated diaphragm	3 4

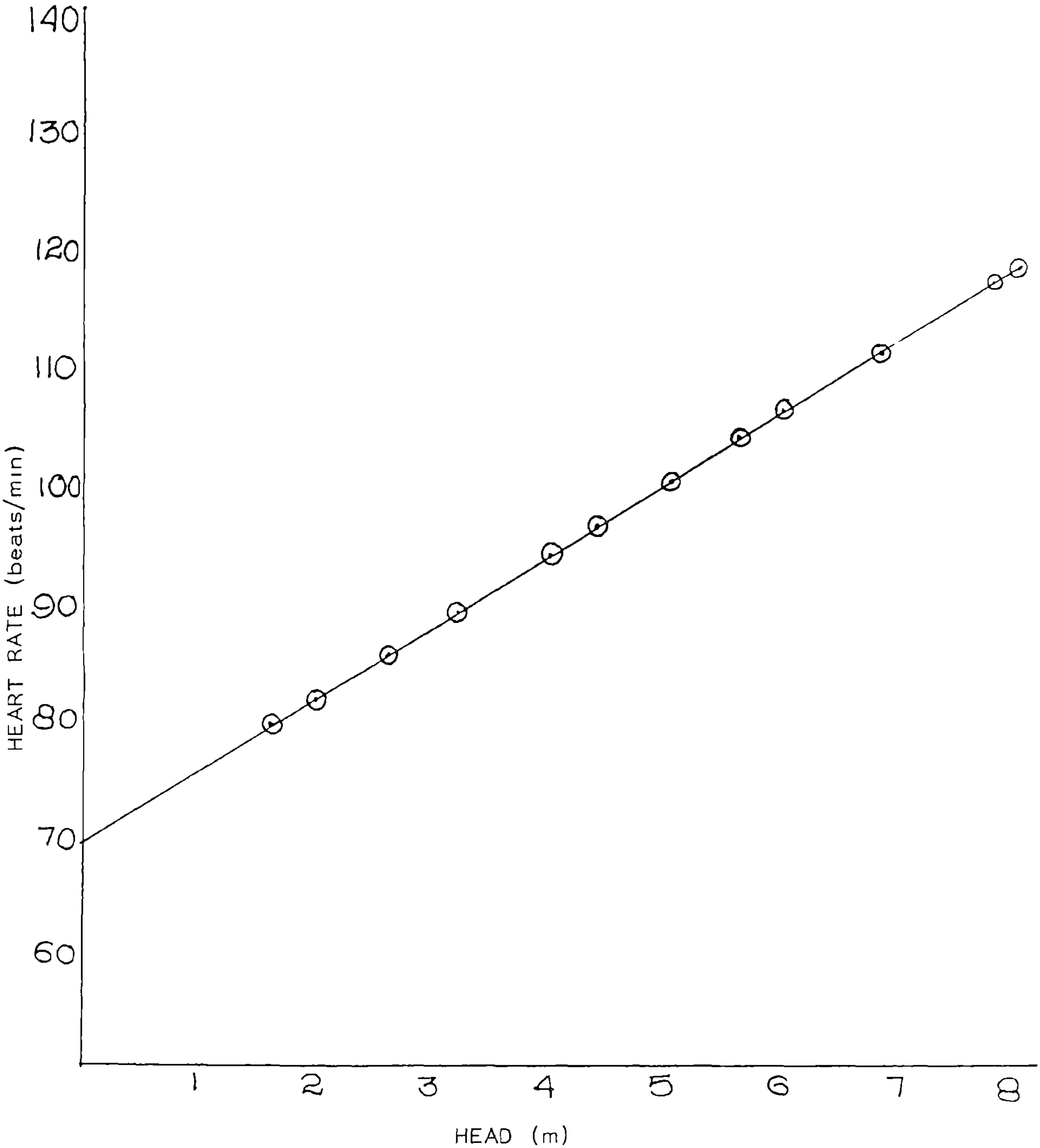


Fig. 31 Heart rate response of the subject at different heads
(Kumar Bharath pump)

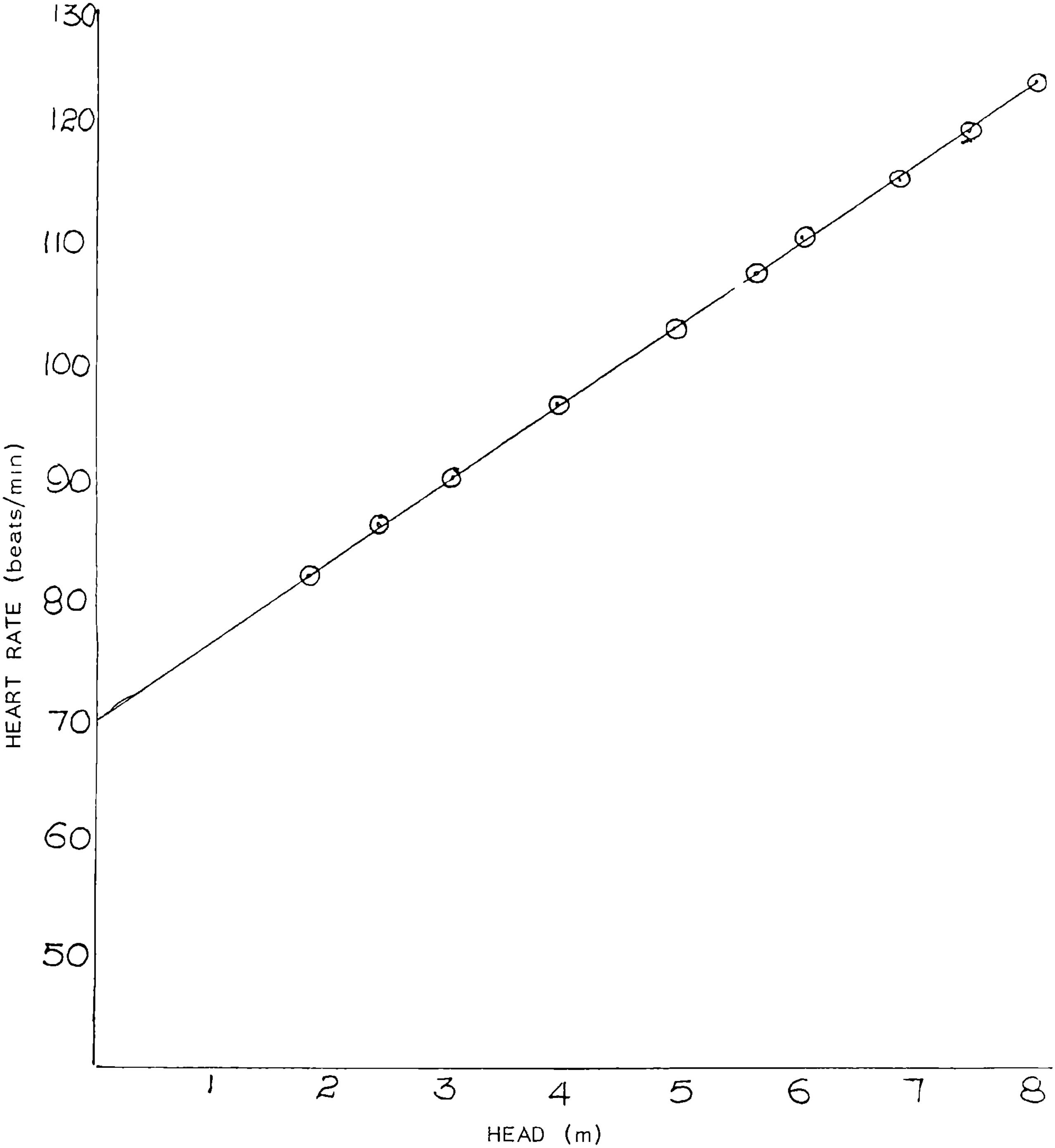


Fig. 32 Heart rate response of the subject at different heads
(E.P. Force pump)

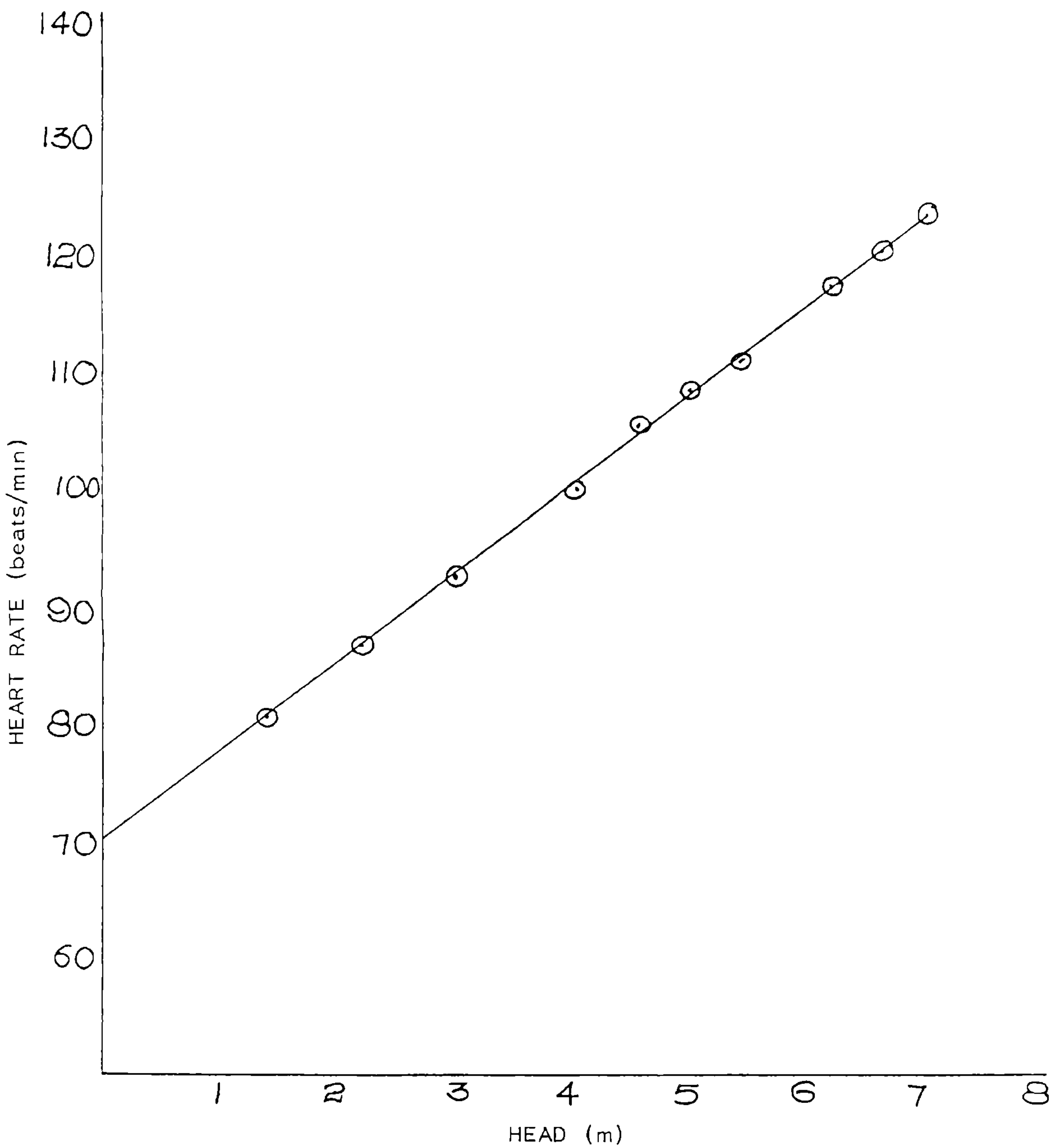


Fig. 33 Heart rate response of the subject at different heads (Kirloskar pump)

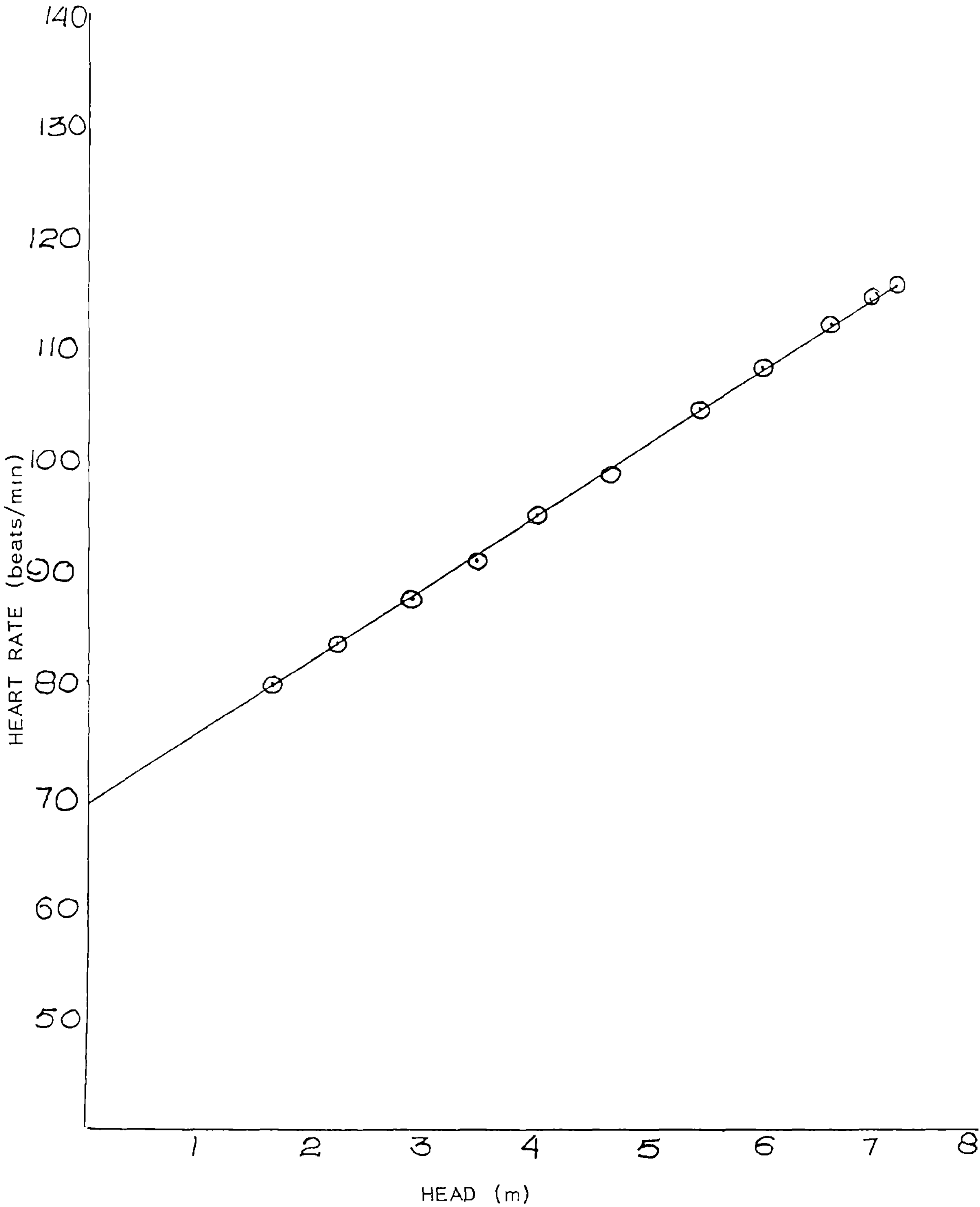


Fig. 34 Heart rate response of the subject at different heads (E.P. Lift pump)

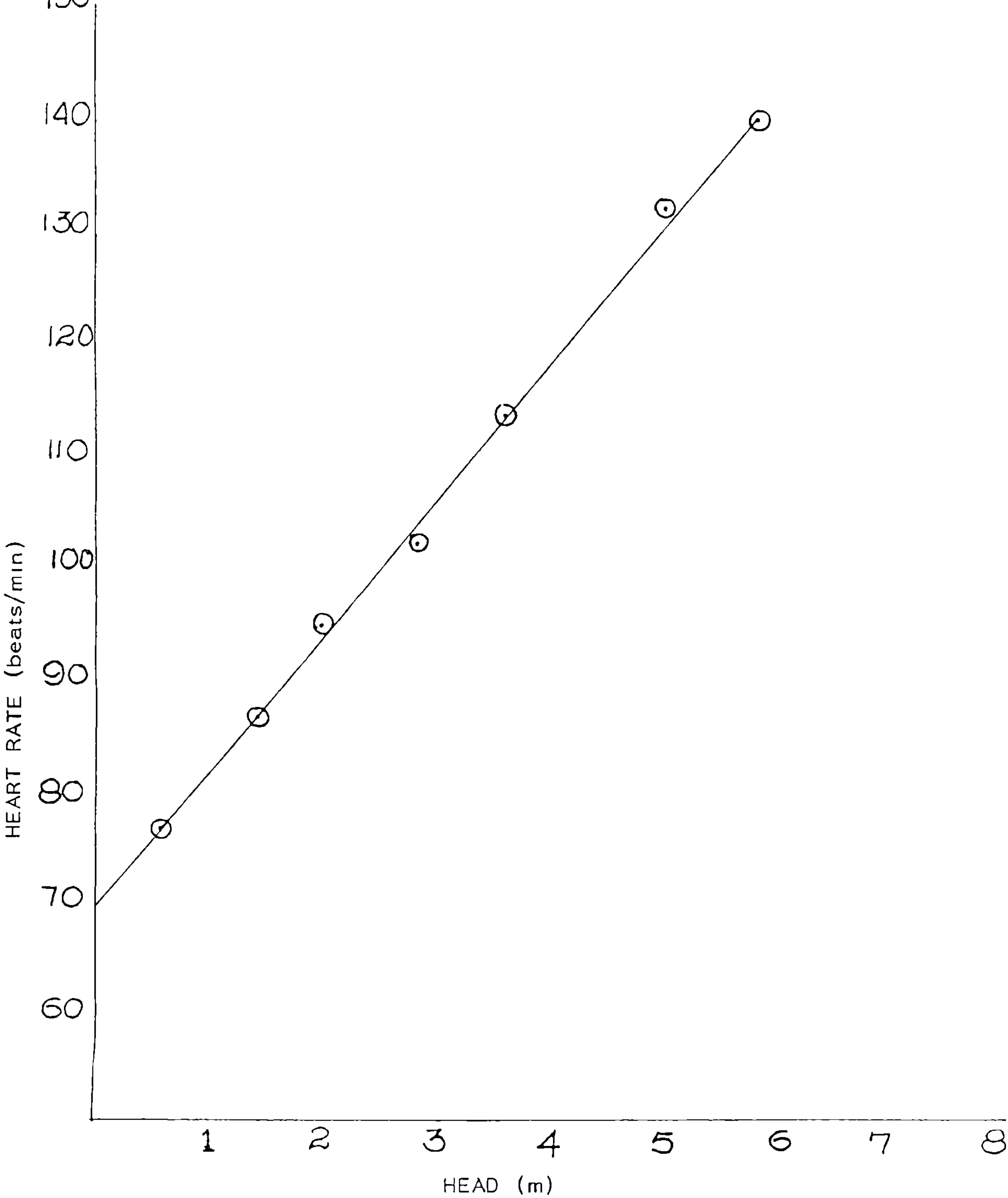


Fig. 35 Heart rate response of the subject at different heads (Diaphragm pump)

It can be seen that Kumar Bharath pump is having the highest suction head 6 6 m E P Force and E P Lift pumps shows higher safe heads since they are pedal operated Bicycle operated diaphragm pump s not efficient and has the lowest suction head (3 4 m) Kirloskar pump is safe upto 5 25 m head

Conclusion

Table 9 Recommended maximum heads considering hydraulic and ergonomic characteristics of the pumps and discharge at these heads

Sl No.	Pump	Recommended (m)	Discharge (l/s)
1	Kumar Bharath	6.6	0 23
2	Kirloskar	5.25	0 37
3	E.P. Lift	5.7	0 3
4	E P. Force	5.8	0 45
5	Bicycle operated diaphragm pump	1.1	0 45

Kumar Bharath pump is found to be the most efficient pump among the five pumps and bicycle operated diaphragm pump least efficient. Bicycle operated diaphragm pump is not suitable for heads higher than 1.1 m, which implies that the pumpshould be modified before popularization. Except the bicycle operated pump, all other pumps can be worked under moderate heads but their discharges are low. So they can be successfully employed for domestic water pumping. At lower heads, discharge is slightly higher. Hence they can be employed for small scale irrigation in areas where water table is high as in the case of coastal areas of Kerala.

Recommendation for future work

1. In the case of pedal operated pumps while operating, if a hand bar is provided to support the hands of the operator, his body weight can also be utilised for pumping.

2. In the case of bicycle operated diaphragm pump, junction point of the connecting rod and diaphragm should be properly sealed.

3 Number of moving parts of diaphragm pump should be minimised to increase the efficiency.

4 For more accurate measurement of heart rate stethescope may be replaced by ECG.

Summary

SUMMARY

Share of human and animal power for irrigation pumping is estimated to be 1294 kilowatt per hour for the next decade. Manually operated pumps are getting popularised in coastal areas where the water table is high. These pumps have the advantage that they are independent of fuel supply, and manufacturing and maintenance can be done at the village level.

In recent years a wide variety of manually operated pumps are introduced to Indian markets. However a critical study regarding their performance and energy requirement has not been conducted Design of manually operated pumps should be based upon ergonomic principles to reduce labour and dredgery involved in the operation. While evaluating a manually operated pump, the ergonomic characteristics should also be given due weightage with hydraulic characteristics. Therefore a study was conducted to evaluate the hydraulic and ergonomic performances of some selected manually operated pumps viz. Kirloskar pump, Kumar Bharath pump, E P pumps (Lift and Force), Bicycle operated diaphragm pump.

Methodology adopted for the study is briefly accounted below

1. General details of the pumps were collected as per the regional network for agricultural machinery test code.

2. A subject was selected for the study and his anthropometric datas were collected.

3. A stand of 210 cm height and having 45 x 45 cm top cover was fabricated. Pumps were installed over this stand while in operation. A 5.4 x 1.25 x 1.35 m water tank was selected as the source of water. Discharge of the pumps were collected in a measuring tank of 30 x 30 x 100 cm size.

4. Suction head of the pumps were varied by adjusting a gate valve connected in the suction line. Suction head was measured by a vacuum guage.

5. Heart rate was taken as the measure of work load on the subject. A device was fabricated to calibrate the subject for the basic task. While calibration heart rate of the subject was measured and a calibration graph was plotted between the mechanical work load and heart rate Subject was separately calibrated for pedal and hand pumps.

6 Pumps were installed over the tank and operated for 15 minutes. Discharge, speed of operation and time of operation were noted. Heart rate of the subject was noted at an interval of 3 minutes, for 2 minutes. Average heart rate was calculated. This procedure was repeated for different suction heads by setting the gate valve in different positions.

7 Hydraulic characteristics of the pumps were analysed by studying the variation of discharge, time to deliver 100 l, number of strokes to deliver 100 l and volumetric efficiency with variation in head. Ergonomic feature was analysed by studying the variation of heart rate with head.

8 Heart rate of the subject corresponding to a power out put of 50 W for hand operated pumps and 180 W for pedal operated pumps was noted from the calibration graph. Head of operation corresponding to this heart rate is noted from head versus heart rate graph. This could be recommended as the safe limit of head as far as ergonomic characteristics are concerned.

Results obtained are summarised below

1 Body surface area of the subject is calculated as 15263 sq cm. Heart rate of the subject at rest position is 69 beats per minute.

2 Slope of the calibration curve of the subject is moderate. Calibration curve for the pedal operated pumps are flatter than that of hand operated pumps indicating that hand operated pumps extracts more human energy than pedal operated pumps.

3 While studying the variation of discharge with head, Kumar Bharath pump gave a reasonable discharge upto 6 m head, Kirloskar upto 5 m, E.P. Lift upto 5.5 m and E.P. Force upto 4.8 m. The diaphragm pump showed a steep reduction in discharge when the head is increased.

4 Volumetric efficiency of Kumar Bharath pump is reduced below 75 percent beyond the head 6.9 m. Corresponding heads for the other pumps are 6.7 m for Kirloskar pump, 5 8 m for E.P. Force pump, 5.7 m for E.P. Lift pump and 1 1 m for diaphragm pump. Diaphragm pump was found to be least efficient at higher heads.

5 Time taken to deliver 100 l discharge is maximum in the case of diaphragm pump. Kumar Bharath pump and Kirloskar pump showed similar trends upto 6 m head, after that Kirloskar pump takes lesser time compared to E P. Lift pump, E.P. Force pump performed better.

6 In the case of diaphragm pump, number of strokes to deliver 100 l discharge went upto 500 strokes at 3.2 m head. It was higher in the case of E.P. Lift pump. Kumar Bharath pump and Kirloskar pump showed equal trends.

7 Ergonomically safe work load on the subject corresponds 110 heart beats/min. Corresponding head of the pumps are 6.6 m for Kumar Bharath, 5.25 m for Kirloskar, 6.0 m for E.P. Force, 6.8 m for E.P. Lift and 3.4 m for diaphragm pump

Taking hydraulic and ergonomic performance into consideration following heads can be recommended for the pumps. Kumar Bharath 6.6 m, Kirloskar 5.25 m, E.P. pump (Lift) 5.7 m, E P. pump (Force) 5.8 m, and diaphragm pump 1.1 m. Corresponding discharge of the pumps are 0.23 l/s, 0.39 l/s, 0 3 l/s, 0 45 l/s and 0.45 l/s respectively.

Further improvements on the pumps may be attempted by

1. providing a hand bar to support the hands of the operator and thus utilizing the body weight of the operator in the pedal operated pumps.

2. providing proper seal to the junction point of connecting rod and diaphragm in the diaphragm pump.

3. minimizing the number of moving parts of the diaphragm pump.

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*Originals not seen

Appendices

APPENDIX I

Anthropometric data of the subject

I General descriptive characteristics of the subject

a) Name - Kari

b) Age - 46 yrs.

c) Sex - Male

d) Attitude towards work - participative

e) Name of present duty - Farm labourer

II Physical characteristics of the subject

a) Weight 47 kg

b) Height 161 cm

c) Shoulder height - 137 cm

d) Elbow height - 102 cm

e) Finger tip height - 58 cm

f) Shoulder width - 40 cm

g) Sideways arm reach - 86 cm

h) Body surface area $= W^{0.425} \times H^{0.725} \times C$

$$= (47)^{0.425} \times (161)^{0.725} \times 74.66$$

$$= 15263.768 \text{ sq cm}$$

(Where C = 74.66 for Indian male)

APPENDIX II

Instrumentation

a) Specifications of the stop watch

Make - DOLMY, Switzerland

Least count - 1/10

b) Specifications of vacuum gauge

Make - Bourdon's patent, Germany

Range - 0 to -1 kg/sq cm

Least count - 0.02

c) Specifications of stethescope

Make - Bi-chem, India

STUDIES ON SELECTED MANUALLY OPERATED PUMPS

By

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ABSTRACT OF A THESIS

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ABSTRACT

The study was conducted with the objective of evaluating hydraulic and ergonomic performance of some selected manually operated pumps viz. Kirloskar pump, Kumar Bharath pump, E.P. pump (Lift), E P. pump (Force) and Bicycle operated diaphragm pump.

A subject was selected for the study and his body surface area was calculated. Heart rate was taken as the measure of mechanical work load on the subject and he was calibrated for the basic task. From the calibration curve it was found that heart beat of the subject should not exceed 110 beats/min for the ergonomic safety.

Pumps were tested against different suction heads by varying the position of the gate valve connected in the suction line. Discharge, speed of operation, time of operation and heart rate of the subject were noted.

Hydraulic characteristics of the pumps were analysed by studying the discharge, time to deliver 100 l, number of strokes to deliver 100 l, and volumetric efficiency with variation in head. Ergonomic features were analysed by studying the variation of heart rate with head.

Among the five pumps the volumetric efficiency of Kumar Bharath pump reduced below 75% beyond the head 6.9 m corresponding heads for the other pumps are 6.7 m for Kirloskar, 5.8 m for E.P. pump (Force) 5.7 m for E.P. pump (Lift) and 1.1 m for diaphragm pump.

Time to deliver 100 l and number of strokes to deliver 100 l were highest in the case of diaphragm pump and least in Kumar Bharath and Kirloskar pumps.

Taking hydraulic and ergonomic performance into consideration the following heads can be recommended for the pumps. Kumar Bharath 6.6 m, Kirloskar 5.25 m, E.P. pump (Lift) 5.7 m, E.P. pump (Force) 5.8 m and diaphragm pump 1.1 m corresponding discharge of the pumps are 0.23 l/s, 0.37 l/s, 0.3 l/s, 0.45 l/s, 0.45 l/s respectively.