DEVELOPMENT AND PERFORMANCE EVALUATION OF A LOW COST WATER-WHEEL FOR LIFTING WATER AT LOW HEADS

By

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THESIS

Submitted in partial fulfilment of the requirements for the degree

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DECLARATION

I hereby declare that this thesis entitled "Development and Performance Evaluation of a low cost water wheel for Lifting Water at Low Heads" 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.

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Dedicated to
my loving parents

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ABBREVIATIONS AND SYMBOLS

A	:	Cross - sectional area of waterflow
Agrl.	:	Agricultural
C	:	Constant factor
C - S	:	Cross Section
cm	:	centimetre (s)
Cumecs	:	Cubic metre per second
d	:	shaft diameter
E	:	Total energy per second
Engg.	:	Engineering
etc.	:	et cetera
et al.	:	and other people
e.g.	:	for example
F	:	Force on the plate by the jet
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
g	:	acceleration due to gravity
h	:	height of water lifted
hp	:	horse power
HYV	:	High Yield Variety
i.e.	:	that is
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology

Kg.	:	Kilogram (s)
Ltd.	:	Limited
lab	:	laboratory
lpm	:	litre (s) per minute
MS	:	Mild Steel
M_t	:	Twisting moment or Torque
m	:	meter (s)
m/sec	:	metre (s) per second
mm	:	millimetre (s)
m^2	:	Square metre
m^3/hr	:	Cubic metre per hour
m^3/sec	:	Cubic metre per second
N	:	Rotational speed of the wheel
No.	:	Number
PVC	:	Poly Vinyl Chloride
P_{in}	:	Input power
P_{out}	:	Output power
pp	:	pages
q	:	Discharge rate
Q	:	Total discharge
rpm	:	revolution (s) per minute
Rs.	:	Rupees
sq.m	:	Square metre
Sec	:	Second (s)

Sl.	:	Serial
t	:	Time
t_{mean}	:	Mean time
UN	:	United Nations
T	:	Total Torque
TMC	:	Trillion Meter Cube
V	:	Flow velocity of water
V_s	:	Versus
V_m	:	Mean flow velocity of water
V_f	:	Surface flow velocity
Viz	:	Namely
w	:	Unit weight of water
Y	:	The distance from centre line of plate to the axis of water wheel
Z	:	Datum head
/	:	Per...
$\therefore$	:	Therefore
%	:	Percentage
η	:	Efficiency
τ	:	Shear stress
α	:	Energy coefficient
β	:	Momentum coefficient
θ	:	Slope of channel section
ω	:	Angular velocity
ρ	:	Density of water

Introduction

INTRODUCTION

Irrigation is an artificial application of water to the land for enhancing the plant growth in order to produce more food and fibre. Irrigation has been practiced by mankind for the last several thousand years, yet only in the present century, extensive studies have been conducted in the general area of soil-water-plant relationships. These relationships, commonly known as irrigation management, involve irrigation practices on the farm, or on individual fields.

The objectives of irrigation are to serve as an insurance against crop failure due to unforeseen droughts, to make up production possible where it depends mainly on irrigation and to supplement natural precipitation when necessary.

Improper irrigation not only wastes water or reduces crop yields but frequently results in plant nutrients being leached from the soil. Excessive application of water causes high water tables or seepage spots which may be controlled only by the construction of expensive drainage systems. In addition, salts accumulate and an alkali soil may develop. Water losses due to deep percolation, which is the movement of water down to a depth below the roots of the plants, is difficult to observe. These losses are as the result of over-irrigation or of water being left in the field for longer period than required.

India has net sown area of over 140 million hectares under irrigation. However, only 65% of this area has been assured irrigation while the remaining area served by protective irrigation through canals, wells, tanks and other sources. The country has an ultimate irrigation potential of 113.5 million hectares, comprising 58.5 million hectares under major and medium projects and 55 million hectares under minor irrigation projects. Out of the area under minor projects 40 million hectares are through ground water and 15 million hectares are under surface water.

Kerala is a land, rich in water resources due to availability of heavy rainfall and large number of rivers. It is estimated that about 1500 TMC of water is only being used for irrigation and power. The average annual rainfall of the State is 3085 mm. Because of the uneven distribution of the rainfall and prolonged dry weather period the flows in the rivers get considerably reduced during the summer months. In such occasions, it become necessary to depend upon the ground water resources.

In order to protect the crops from the vagaries of nature with a view to stabilize cultivation, and also to enable an additional crop being raised during summer months, an assured supply of water is essential. A portion of the cultivable area is presently irrigated by the existing major irrigation projects, lift irrigation schemes and minor irrigation works consisting of small storage tanks, diversion weirs, ponds etc. In spite of all these, receipts by way of revenue from the irrigation projects are not satisfactory. The reasons for the low response to irrigatiion are transmission losses in canals, water losses in cultivated fields, water stagnation and lack of drainage and land levelling problems.

There are many different types of human and animal powered water lifts, some of which are better than others. The correct selection of water conveyance and field distribution system have a greater influence on the effectiveness, technically and economically of any irrigation system. In fact, the use of a well optimised and efficient water distribution system is vital when considering certain renewable energy system where the cost is closely related to the power rating and therefore a minimum power system needs to be selected. Before looking for radical new water lifting techniques, there is also much scope for improving traditional and conventional pumping and water distribution methods.

The purpose of a canal system is to provide adequate quantity of water and to serve all part of the farm and farm stead within the area. As the agricultural lands are not always levelled for surface irrigation, alternate arrangements are to be made to use such land profitably. Land levelling is one of the solutions for this. However, land levelling development programmes require careful planning and execution, which are exorbitantly costly.Such projects may not be feasible to small scale farmers with low capital resources.

These circumstances necessitate to develop a low cost water lifting device, which can be fabricated locally and run without additional expenditure of energy. The conventional water wheel (Chakram) requires either manual or animal power for its operation. The present study, makes use of the kinetic energy of flowing water in a canal to lift water to a certain height to irrigate the nearby cultivable lands.

The specific objectives of this study are :

1. To develop a low cost water wheel which can be operated by using flow velocity of canal or stream water.
2. To test and evaluate the performance of the wheel for different operating conditions.
3. To conduct an economic analysis of the system.

Review of Literature

REVIEW OF LITERATURE

A brief review of different aspects of irrigation, irrigation methods, water lifting devices, hydro power for irrigation and its application on water wheels are presented in this Chapter.

2.1 Irrigation and the Energy Crisis

The importance of irrigation as an essential input for agricultural development hardly needs any emphasis. Scientific practices such as the use of high yielding variety (HYV) seeds, fertilizers, insecticides etc., which have raised hopes for an ultimate solution of our chronic agricultural shortage, are all primarily dependent on the availability of irrigation. The timing, frequency and adequacy of irrigation supplies varies widely from place to place and these factors are roughly dependent on the source of irrigation. The three major sources for irrigation in the country are wells and tube wells, major and medium surface reservoirs and minor surface sources. It is estimated that out of the total quantity diverted from the source, only one third is effectively utilized for crop production, with roughly one third each lost before and after irrigation outlets (Gopinath, 1976).

Despite present short-term fluctuation in oil prices, conventional oil based engine-driven power sources and mains electricity are expected to continue to increase in the longer term. There are also major problems associated with maintenance of this kind of machinery. Hence a considerable incentive to discourage the use of oil is essential. As a result, there is an increasing need to find methods for energizing irrigation devices that are independent of oil and electricity (Fraenkel, 1986).

2. 1.1 Irrigation Water Requirement

Water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place. Water need or requirement includes losses due to evaporation or consumptive use plus the losses during the irrigation water and the quantity of water required for special operations such as land preparation, transplanting, leaching etc (Michael and Ojha, 1978).

2. 1.2 Irrigation Scheduling

It has to be decided if the irrigation water is to be supplied to the field continuously or in rotation. To determine the size of flow to be used with continuous irrigation, irrigation water need is multiplied by the area to be irrigated which gives the volume of irrigation water need per unit of time. This is the net flow of irrigation water which has to be supplied to the field continuously. This quantity of course varies over the growing season as the irrigation water need varies. If water is supplied to the same field on a rotational basis, the net flow of irrigation has to be increased (Brouwer and Prins, 1989).

2.2 Methods of Irrigation

The various factors such as slope of land, the crop to be irrigated, the water supply, the permeability of soil, water holding capacity etc. should be considered while selecting a suitable irrigation method. The method of irrigation selected should conserve the soil as well as water. The five general ways of applying irrigation water to the field are by flooding, furrows, sprinkler, sub irrigation and localised irrigation. Flooding can be accomplished by the use of borders, basin and well spaced contour field ditches. Furrow irrigation is the application in small, well defined parallel channels. Sprinklers simulate rainfall by spraying water from pipes under pressure. Localised irrigation applies water at or near the plant at a rate which is far less than the soil infiltration rate. In sub-irrigation, one applies water beneath the ground surface rather than on top of it. For successful use of any of these methods, complete control of water is essential at all times (Doneen and Westcot, 1984).

2.3 Water Lifting Devices

Lift irrigation requires that water be raised from its source to the field surface. There are many different types of human and animal powered water lift, some of which are better than others for different purposes. Devices for irrigation water lifting ranges from age old indigenous water lifts to highly efficient pumps. Selection of a particular water lifting device for a particular situation depends on the characteristics of the source of water, the lifting device, the amount of water to be lifted, the depth to the pumping water level, type and amount of power available and the economic status of the farmer. Basically there are four principles involved in pumping water. These are atmospheric pressure, positive displacement, centrifugal force and movements of columns of water caused by difference in specific gravity (Michael, 1978).

According to Michael and Khepar (1989), two more principles such as direct lift and water hammer effect are included in water lifting.

Several types of indigenous water lifts are in common use for small scale irrigation operated by human or animal power. Appendix I presents the performance characteristics and adaptability of some common types of indigenous water lifts. The scoop, swing basket, oscillating trough (don), Archemedian screw, water ladder and water wheel are the commonly used water lifts when the depth to the water source does not exceed 1.2 m. These devices are classified as manually operated low head water lifts. When the height of lift is within the range of 1.2 to 5 m, are classified as medium head water lifts. These are suitable for small scale irrigation includes counterpoise bucket lift and the manually operated chain pump or bucket pump (Persian wheel). Deep well water lifts or high head water lifts is limited to domestic water supply. The rope and bucket lift still remains the only manually operated device suitable for deep wells. Animal operated low head water lifts includes circular-mot , water wheels and saikia are suitable to lift water upto 1.5 m. The Persian wheel, chain pump, and rope and pulley operated self emptying buckets are suitable for 4 to 10 m lifts, generally classified under animal operated medium head water lifts. From the point of suitability for irrigation, the only animal operated high head water lift is the rope and bucket lift (Michael and Khepar, 1989).

2.4 Hydro Power for Irrigation

Given a suitable site in proximity to a suitable water need, hydro power has a number of important and fundamental applications. The energy of flowing water is used for raising water as in the water wheel and in the hydraulic ram. Water wheels are commonly used where there is a fairly constant flow in a river or canal. Hydraulic ram is a self acting pump in which a stream of water falling through a small height raises a portion of the water to a greater height. The rate of delivery will depend upon the supply available, the working head and the height to be lifted (Peterstern, 1982).

2.4.1 Water Wheels

The energy of flowing water is used in a water wheel for lifting water from a canal or stream. The water wheels are generally classified into two divisions as, over shot wheels and under shot wheels. In the over shot wheels (Fig.2.1), water is lead from the head race to the top of the wheel. The weight of the water forces the buckets downwards and thus makes the wheel to rotate. The buckets get emptied into the tail race as they approach the lowest

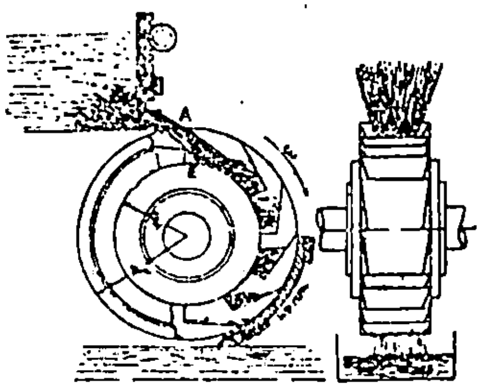


Fig.2.1 Overshot wheels

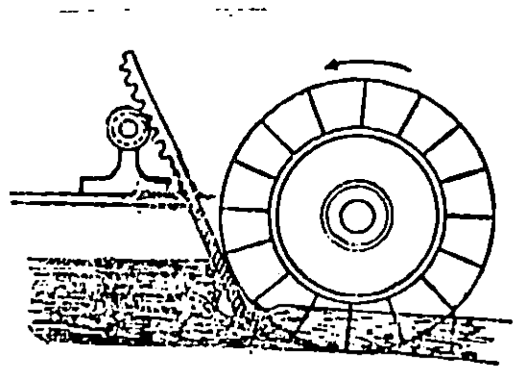


Fig.2.2 Undershot or Impulse wheel

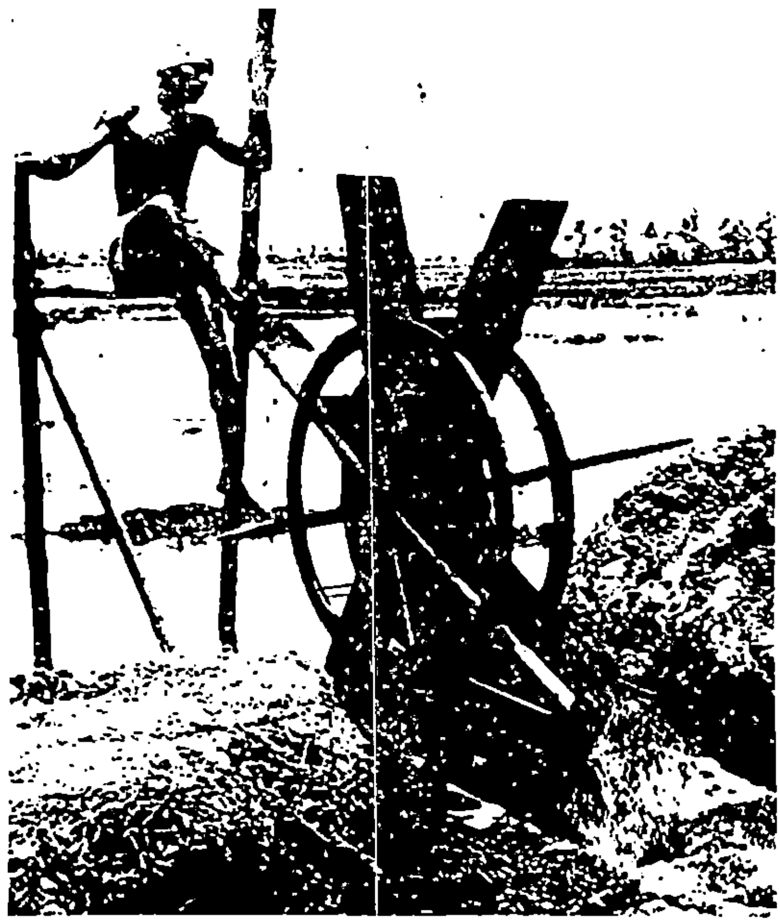


Fig.2.3 A paddle wheel -Chakram

position. In the under shot wheel or impulse wheel (Fig.2.2), the whole of the available head is converted into velocity head before the water strikes the wheel and the work is done by the change in the kinetic energy of the water (Shariff et al, 1988).

The under shot water wheel is probably the most obvious and the oldest method of extracting energy from rivers or canals. In many cases, the device simply dips into the water and is turned by the movement of water current.

Michael and Ojha (1978) reported that a paddle wheel (Fig.2.3) is commonly used in paddy growing areas of Kerala, known as Chakram. The wheel is operated by pedalling the treadles with the arm and the upper part of the body of the operator supported on wooden frame work. The number of blades in the wheel varies from 8 to 24 depending on its diameter, which in turn depends on the lift involved. They reported that the discharge varies from 10,000 to 14,000 lph, when the water level is within 0.6 m from the ground.

Michael (1978) reported that the Persian wheels (Fig2.4) operated either by animal or human power can lift water upto a head of 10 m. When the Persian wheel is operated, the brake drum revolves causing the buckets at the lower end of the chain get filled with water and carried to the top with their open mouth upward. The average discharge of these types of wheels varies from 14,000 to 18,000 lph.

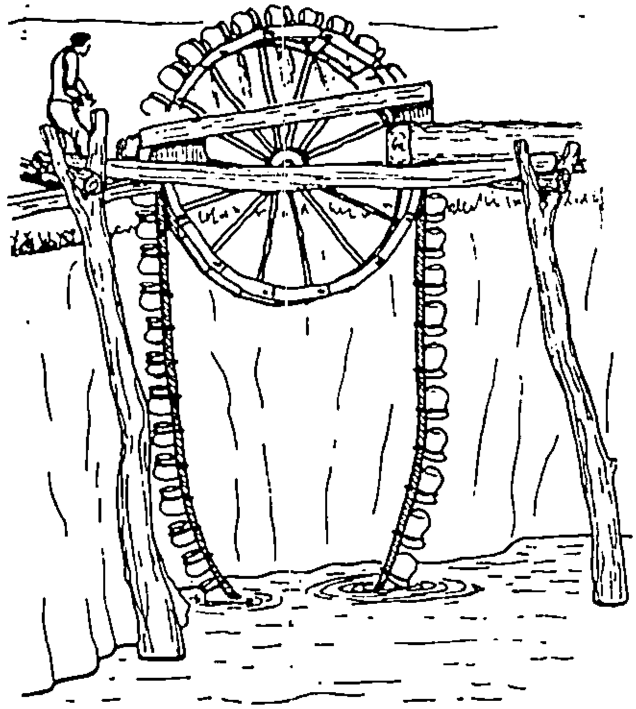
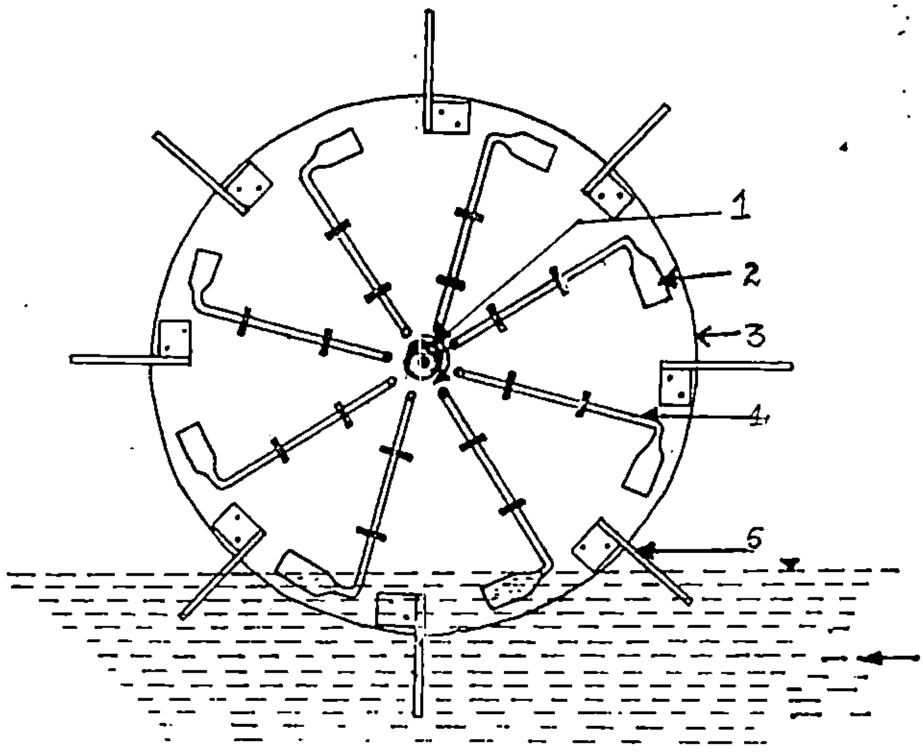


Fig.2.4 A manually operated perisan wheel



1. Centre shaft *2. Cup (Water can)* *3. Circular plate*
4. PVC - pipe *5. Wing (Vane)*

Fig.2.5 Water wheel developed at KAU

Jobi V. Paul (1980) has developed a lab model of a water wheel shown in (Fig.2.5). In this model he had used a wheel of diameter of 4 feet in order to raise the water to a height of 2 feet. The. discharge rate varies from 1,500 lph to 25,00 lph depending on the velocity of flowing water in the stream.

Kennedy and Rogers (1985) has analysed an improved type of the paddle wheel and modified by placing the lower parts of the blades in a close fitting box. This reduces the slippage of water from the edges of paddle, so that an increased capacity is obtained to lift water to a greater height.

Fraenkel (1986) illustrated a bamboo water wheel (Fig.2.6) commonly used for lifting water by extracting energy from rivers. The entire structure is made of bamboo tubes and these tubes with one end closed are mounted arouned the rim of the wheel. The bamboo tubes dip into the river water and re-emerge with water filled tubes. This water pours out into a trough when it reaches near the top. It is reported that bamboo water wheel of 10 m diameter is able to irrigate about 8 ha. These types of wheel are otherwise known as 'norias', of which a modern version of Asian noria is the floating coil pump shown in (Fig.2.7). The 10 m diameter Vietnamese noria turns at the rate of about one revolution in 10 seconds and delivers water at the rate of 7 lps. The claimed performance of the prototype floating coil pump (Asian noria) has a discharge of 6.6 lps against a delivery head of 5 m with a river current velocity of 1.2 m/s.

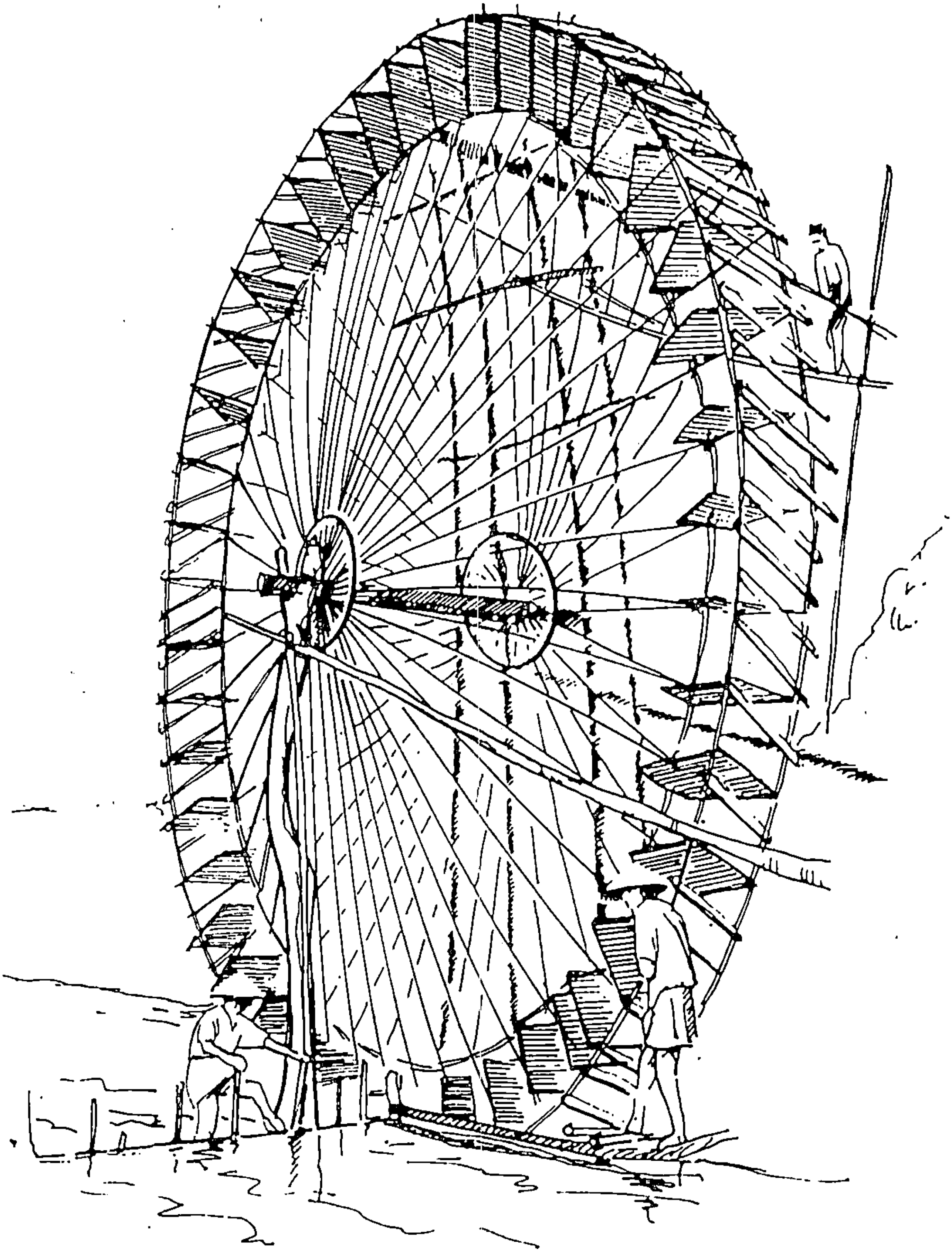


Fig.2.6 Bamboo water wheel - Vietnám model.

He reported a modified version of Persian wheel known as Zawaffa or Jhallar (Fig.2.8) has an advantage of reducing splashing or spillage losses during operation. The discharge capacity of this wheel is 42.5 lps lifted through 0.75 m. He has also reported on Saikia or Tympanum. These devices has some factors in common with 'noria', with a difference of having a divided outer compartments by an internal baffle plates. This prevents water running back into the compartments. The modified type of Saikia, known as 'taflia' has another advantage of which water discharge a few centimeters above the centre shaft and therefore increases the useful head in relation to the diameter. The diameter of Saikias ranges from 2 to 5 m can lift water from 0.3 to 1.8 m respectively. It is claimed that a 3 m taflia will lift water 1.5 m compared with 0.9 m for a centre discharge Saikia.

Egharevba (1988) has developed and evaluated a water driven wheel for low lift irrigation from a distributory canal. His device (Fig.2.9) was operated by the stream current with no additional power source. At load condition and threshold stream velocity of 0.55 m/s it moves at a speed of 2.15 rpm. With increase in stream velocity up to 0.8 m/s, the speed of rotation was 3 rpm and the corresponding average discharge was 9 lpm at 1.5 m head.

Michael and Khepar (1989) reported that an animal driven water wheel known as 'Jalar' is commonly used to lift water from canal water courses, which run below the level of irrigated fields. The lift is usually limited to about 1.2 m. The wheel (Fig.2.10)

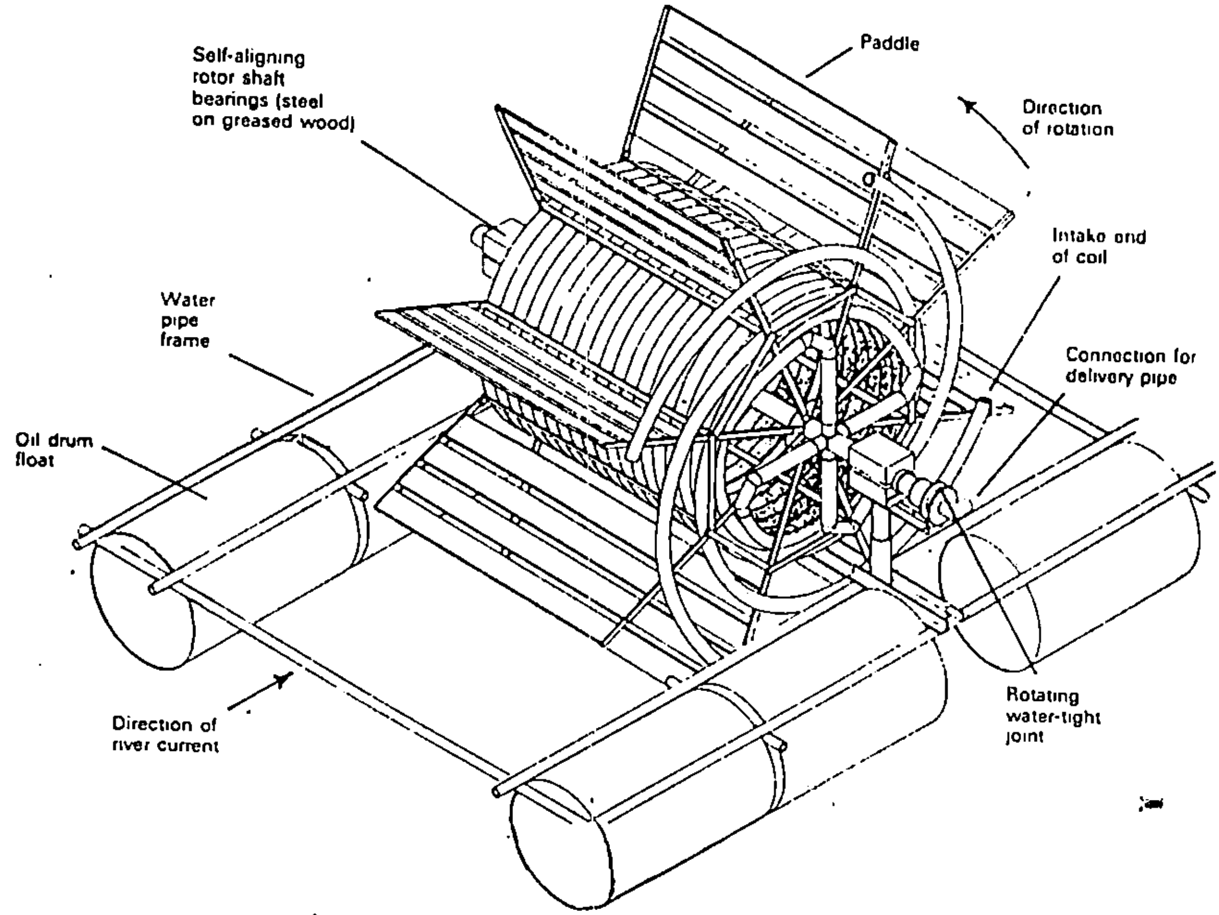


Fig.2.7 Water wheel driven coil pump.

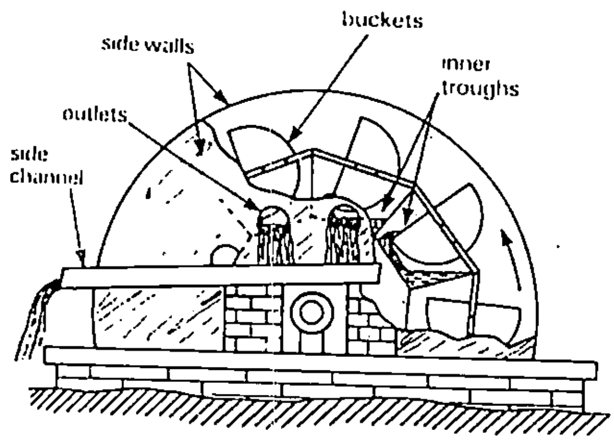
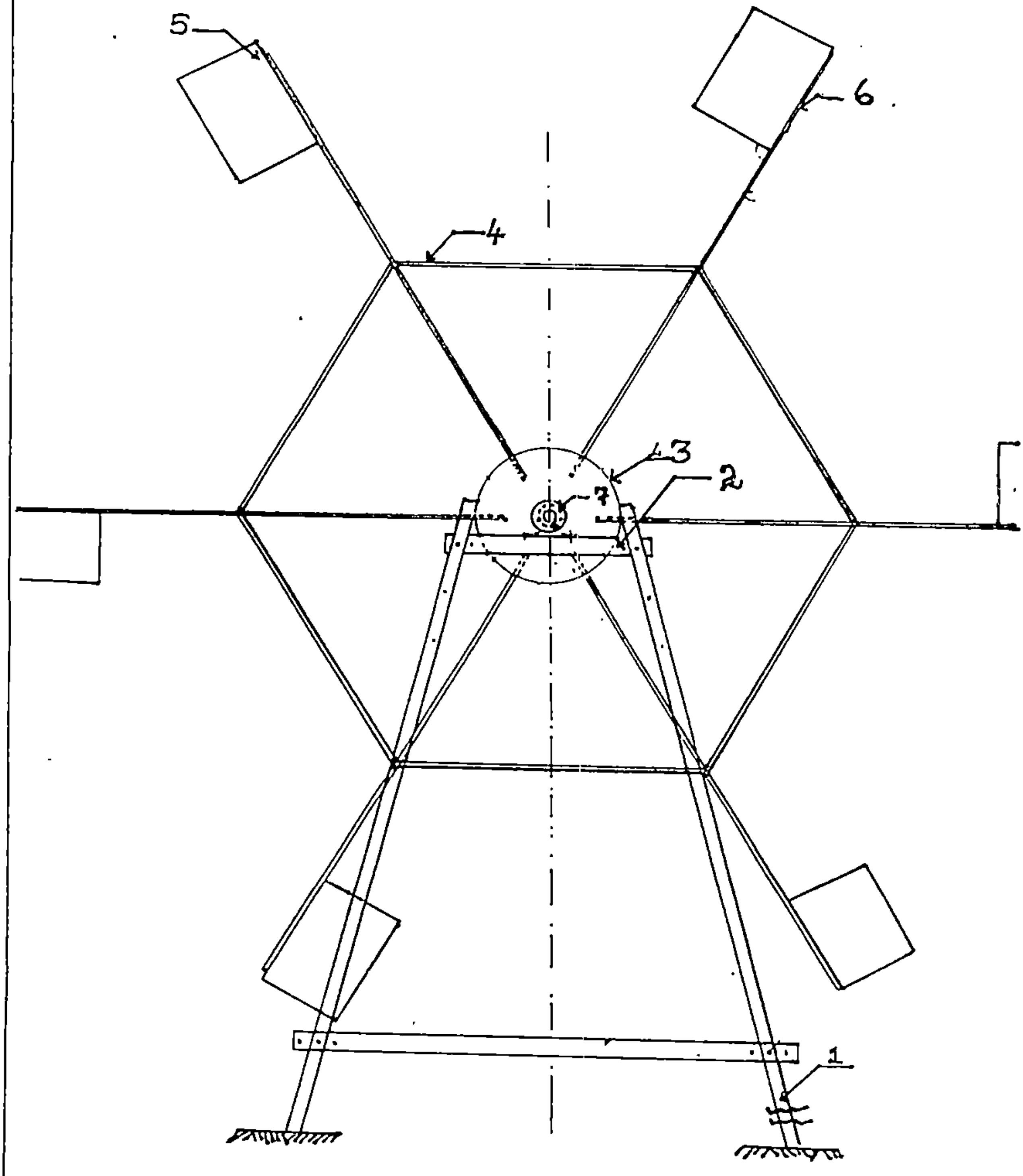


Fig.2.8 Zawaffa type Persian wheel.



1. Stand
2. Support
3. Circular plate
4. Spacer rod
5. Cup (Water can)
6. Blade (plate)
7. Centre shaft

Fig.2.9 Water wheel developed at Nigeria.

works in a close fitting concave masonry trough constructed at the end of the water course. It is reported that the discharge rate varies from 40,000 to 60,000 lph with an optimum lift ranges from 1 to 1.2 m.

They have reported a water current driven wheel consisting of individual, closed compartments (Fig.2.11), known as 'Tympanum'. Each compartment has an inlet on the perifery of the wheel and an outlet adjascent to the wheel hub. Hence, it is not necessary to lift the water above the required elevation. Tympanum diameter must be slightly more than twice the head to which the water is lifted. Due to this size requirement, tympanums are usually limited to lifts of less than 3 m.

2.4.2 Pelton Wheel and Hydraulic Ram

Out of the different types of water turbines, pelton turbine is highly resembled to the water wheel in construction and working. It is a axial flow impulse turbine, mounted on a horizontal axis. A number of buckets or cups are mounted round the perifery of the wheel. The momentum for the runner of the pelton wheel to rotate is obtaned by the jet of water impinges is identical with the force of water flow in a canal (Shareef et al., 1988).

Hydraulic ram or Hydram is a simple automatic device which utilizes the Kinetic energy of water falling a moderate height to raise a part of it to a much greater height. The device can be used wherever a stream of water flows with a minimum of 1 m fall in

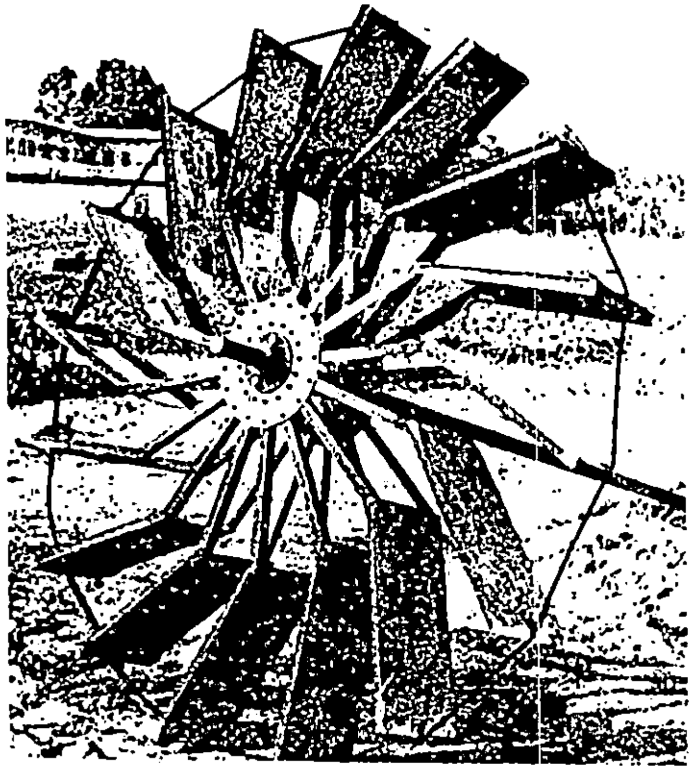


Fig.2.10 Animal operated paddle wheel(Jalar).

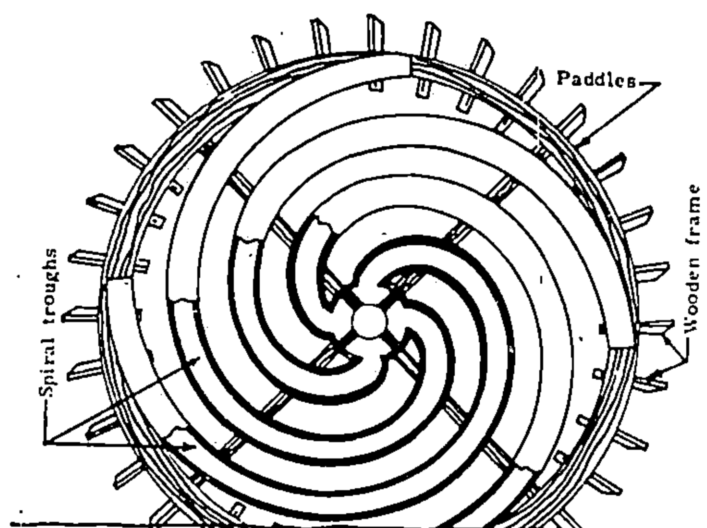


Fig.2.11 Tympanum operated by water current.

altitude. Hydram works on the water hammer principle defind as a phenomenon resulting in an instant rise in pressure of the water flowing in a pipe, due to sudden stoppage of its motion. Generally it lifts about 1/20 th to 1/10th of the water supplied through the drive pipe (Michael and Khepar, 1989).

The Cherepnov water lifter is a novel device to lift or pump water, using potential energy of water. This device is similar to the hydraulic ram with the major difference that the Cherepnov lifter uses the potential energy rather than the kinetic energy to lift the water. Liu et al. (1985) reported that the lifter has an average delivery rate of 7.1 lps with an efficiency of 59%.

Fraenkal (1986) reported a plata pump has been designed to operate at the heads of 0.25 - 1 m. The typical performance with a working flow of 85 lps in 1.3 lps at 6 m, 0.25 lps at 24 m, 0.11 lps at 38 m were obtained during experimental study.

2.5 Canal Irrigation-an Open Channel Flow

An open channel is a passage, through which the water flows under the force of gravity i.e. under atmospheric pressure. The flow in an open channel occurs due to the slope of the bed of the channel. This during the construction of a channel, a uniform slope in its bed is provided to maintain the flow of water (Khurmi, 1985).

The distance of a farmer's field from the outlet of the supply channel, size of the farm, number of intervening farmers, social characteristics and possession of wells for supplementing the canal water

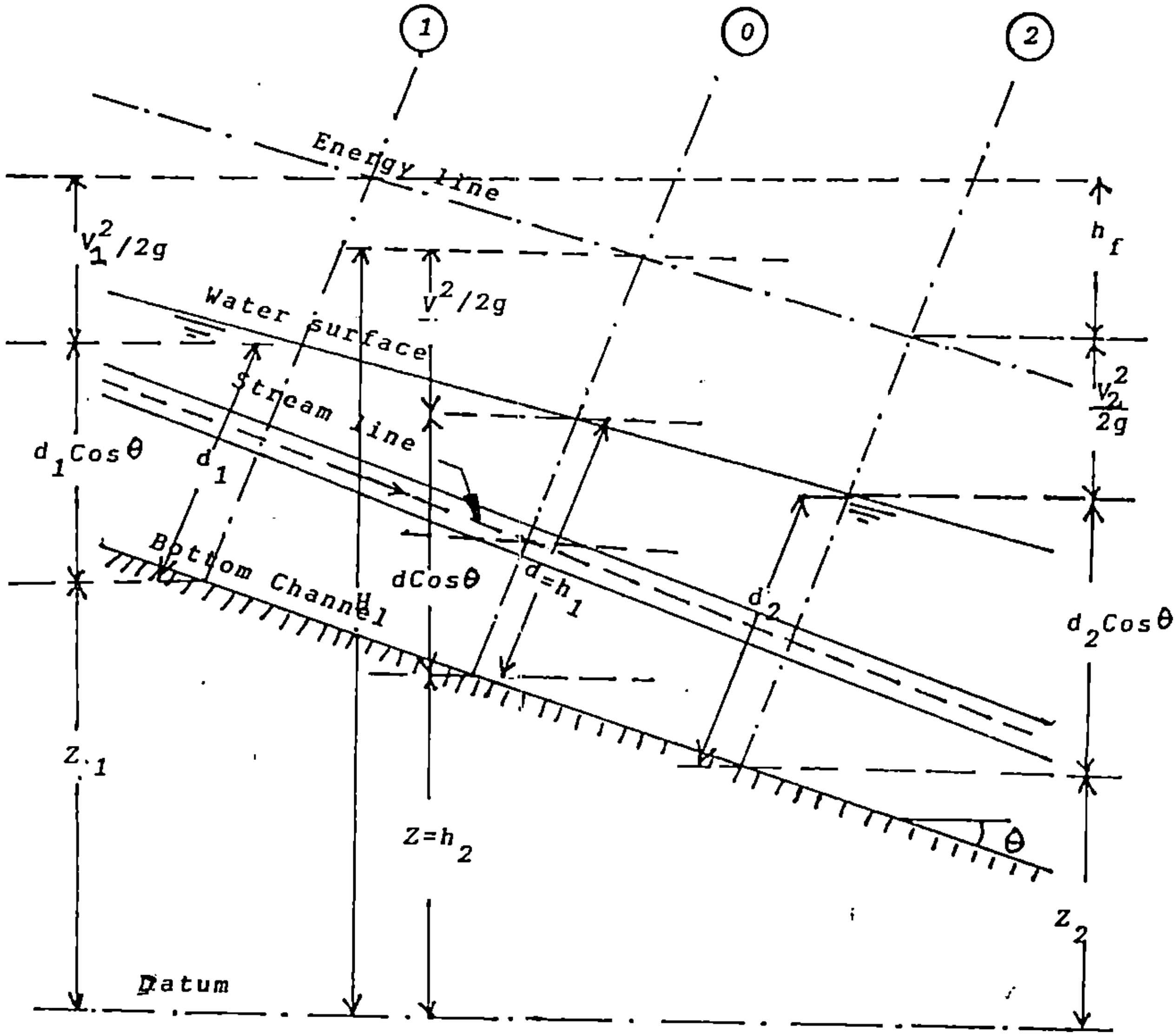


Fig.2.12 Energy in gradually varied open channel flow

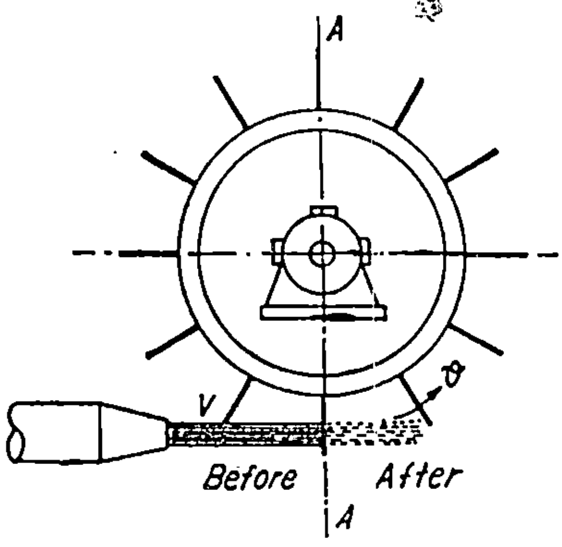


Fig.2.13 Hydraulic machine - (series of moving vanes).

are the key variables determining the canal water supply at the farm level. The pattern of water allocation at farm level in the irrigated dry season is based on rotation of water supplies among the farmers based on the concept of water allowance. The water allowance in a distributory is determined by dividing the length of irrigation week (i.e. 7 days) by the culturable command area of that distributory. The water allowance per hectare multiplied by the number of hectares of farmers land will give the total length of time the farmer is entitled to irrigate (Palanisami and Subramanian, 1984).

2.5.1 Energy and Head Relation of Channel Flows

Consider, stream lines of an open channel are parallel and that velocities at all points in a cross section equal to the mean velocity V. Assuming the flow as a gradually varied flow, the velocity heads for all points in the channel section are equal and the energy coefficient (α) may be used to correct overall effect of non uniform velocity distribution. Refering to the Fig.2.12, the total energy at the channel section is given by : $H = d + Z \cos\theta + \alpha V^2/2g$. For small slopes, $\theta = 0$; $H = d + Z + \alpha V^2/2g$, where H is the total energy head, d is the piezometric head or pressure head, Z is the datum head and $V^2/2g$ is the velocity head. According to the principle of conservation of energy, the total energy head at the upstream section (1) should be equal to the total energy head at the down stream section (2) plus the loss of energy head h_f between the two sections. Hence, $Z_1 + d_1 \cos\theta + \alpha_1(V_1^2/2g) = Z_2 + d_2 \cos\theta + \alpha_2(V_2^2/2g) + h_f$. When $\alpha_1 = \alpha_2 = 1$ and $h_f = 0$; $Z_1 + d_1 + (V_1^2/2g) = Z_2 + d_2 + V_2^2/2g =$ Constant. This gives the Bernoulli's equation (Chow, 1959).

2.5.2 Exploitation of Channel-flow Energy

According to the Newton's second law of motion, change of momentum per unit time in the body of water in a flowing channel is equal to resultant of all the external forces that are acting on the body. Momentum of water flowing in a channel section per unit time is expressed by, $(\beta WQV)/g$ where β is the momentum coefficient, W is the unit weight of water, Q is the discharge, V is the mean velocity and g is the acceleration due to gravity (Chow, 1959).

When the plate is moving in the same direction as the jet, the velocity with which water strikes the plate will be the relative velocity between the water and the plate. When a number of blades are attached to the circumference of a wheel and placed in the direction as that of the jet (Fig.2.13) the weight of water striking the wheel/second at section AA equals waV. The energy supplied by the jet is given by $WV^2/2g$ and work done/second is $W(V-v)/g$, where, W is the weight of water striking the plate/second, V is the velocity of jet, v is the velocity of the plate and g is the acceleration due to gravity. Shareef <u>et al.</u> (1988) reported that the maximum efficiency of such a machine is 50%.

2.6 Design Criteria of the Water Wheel

The diameter of the centre shaft of the water wheel can be designed by correlating the momentum equation of the channel flow and the torque equation of shafts given by the Data book (PSG-TECH, 1978). The other accessories of the wheel were arbitarily taken to suit the various operating conditions.

2.7 Determination of Flow-Velocity in Channel-Flow

Ghosh and Swami (1990) has described a float method to find the flow velocity in an open channel flow. The experimental accessories include a flowing channel, wooden float, tape, scale, stop watch etc. A wooden or other float is thrown into the flowing water and the time taken to reach a pre-determined point, say 5 m apart, was noted. The velocity (V) is calculated by dividing the distance travelled with time. If V_f is the surface water velocity, the mean velocity (V_m) of the retaining bulk of water is calculated from the relation, $V_m = C\ V_f$, where C is a constant varies from 0.8 to 0.9.

2.8 Determination of Discharge of the Wheel

The discharge of the water wheel was measured by using a container calibrated in litres. Hence the discharge rate in lit/min was obtained directly by collecting water in 1 minute.

2.9 Efficiency of Water Lifting Devices

The general principle that hydraulic power is the product of head and flow rate and the energy is the product of head and total weight of water lifted. The actual power and energy needs are always greater than the hydraulic energy need because of the inevitable losses occur during operation of the devices due to friction.

The hydraulic power P_{hyd} required to lift or pump water is given by the relation, $P_{hyd} = \rho\ g\ H_a Q$ where ρ is the density of water, g is the acceleration due to gravity, H_a is the vertical height and Q is the flow rate. The hydraulic energy (E_{hyd}) is defined by the equation $E_{hyd} = (QH)/367$, where Q is the flow rate in m^3/day, H is the static head in metres and E_{hyd} is the hydraulic energy in KWh/day. The system hydraulic efficiency is defined as the ratio of the hydraulic energy to raise the water delivered to the field through the static head to the hydraulic energy actually needed for the amount of water drawn by the pump (Fraenkel, 1986).

Materials and Methods

MATERIALS AND METHODS

The design criteria, fabrication details of individual components of the water wheel and the test procedures are presented in this chapter.

3.1 Theoretical Analysis of Channel-Flow

The design criteria is based on the level of exploitable energy in channel flow. The exploitable energy level in a channel flow was analysed in two parts viz. total energy possessed by the channel flow and the expression for the level of energy exploitation.

3.1.1 Energy in an Open-Channel Flow

Consider that the stream-lines of flow in an open channel flow are parallel and velocities at all points in a cross section are equal to the mean velocity V. The total energy possessed by the stream water can be classified as: Potential (static) energy and kinetic (motive) energy. Refering to the Fig.2.12 if W is the weight of a mass of water m, the mass possesses Wh_1 Joules of energy due to the pressure exerted by the water above it and Wh_2 Joules of energy with respect to the datum. Thus the potential energy of the mass m is $W(h_1 + h_2)$. This value is same for each particle of mass in the cross section. Assuming uniform velocity, the kinetic energy of the mass m is $WV^2/2g$. Thus the total energy of each particle is

$$E_m = W(h_1 + h_2 + V^2/2g) \tag{3.1}$$

Applying the above relation to the whole discharge Q of the cross section in terms of unit weight of water W,

$$E = QW(d + Z + V^2/2g) \tag{3.2}$$

Where E is the total energy per second at the cross section, $d = h_1$ is the pressure head and $z = h_2$ is the datum head.

3.1.2 Exploitation of Channel-Flow Energy

The momentum of water moving in the form of a jet = $\frac{WQV}{g}$, where W is the unit weight of water (1000 Kg/m^3), Q is the discharge (m^3/sec), V is the velocity of jet (m/sec) and g is the acceleration due to gravity (9.81 m/sec^2). If this jet is made to impinge on a moving plate, moving with velocity V_1 m/sec, the relative velocity of the jet with respect to the plate is given by $(V-V_1)$m/sec. Then the force exerted by the jet on the plate is given by the expression,

$$F = \frac{QW}{g}(V - V_1) \tag{3.3}$$

3.2 Design Equation

When water strikes the flat plate (blade) of the water-wheel, the initial velocity of the plate can be taken as zero (i.e. $V_1 = 0$). The force or pressure of the stream of water, F will exert a horizontal force on the plate. If the distance from the centre line of the plate to the axis of the wheel is Y metres, total torque (T) on the shaft is given by;

$$T = F.Y$$

$$= \frac{QW(V - 0)}{g} Y$$

$$= \frac{QWV.Y.}{g} \qquad (3.4)$$

With $Q = AV$; where A is the C-S area of water flow equivalent to the water thrust area of the cup (vane) and V is the mean flow velocity.

$$\therefore \quad T = \frac{W\ A\ V^2.\ Y.}{g} \qquad (3.5)$$

As per the Design Data 7.23 (PSG-TECH, 1978), the diameter of the shaft subjected to torsion, twisting moment or torque (M_t) is given by,

$$M_t = \frac{\pi d^3}{16} \tau \qquad (3.6)$$

Where d is the diameter of the shaft and τ is the shear stress.

Equating (3.5) and (3.6) the diameter of the centre shaft of the water wheel was calculated. A shaft of diameter 25 mm was selected as per the calculations shown in Appendix II. The dimensions of the other components of the water wheel were arbitrarily selected to meet the various local operating conditions. The specification of the water wheel is given in Appendix III.

When the wheel rotates, the shaft power,

P = Torque x Angular velocity (ω). From the equation (3.5) and $\omega = \frac{2\pi N}{60}$, where N is the rotating speed in rpm,

$$P_{in} = \frac{WAV^2Y}{g} \frac{\pi N}{30} \qquad (3.7)$$

Here the unit weight of water, W = 1000 Kg/m^3, the distance from the centre line of the plate (cup) to the axis of the wheel, Y = 0.5 m and acceleration due to gravity, g = 9.81 m/sec^2. Hence the power input (P_{in}) is,

$$P_{in} = \frac{1000 \times 0.5 \times \pi}{9.81 \times 30} A.V^2.N \frac{Kg.\ m}{Sec.}$$

$$= 5.33 \; A.V^2.N \; \frac{kg.m}{sec.}$$

$$= 5.33 \times 9.81 \; A.V^2.N \; \frac{N.m}{Sec.}$$

$$= 52.28 \; A.V^2.N \quad \text{watts} \tag{3.8}$$

Where A is the water thrust area of cup (Vane) in m^2, V is the mean flow velocity in m/sec and N is the rotational speed in rpm.

The power output (P_{out}) is the product of the quantity of water discharged and the lift obtained.

$$\text{i.e.} \quad P_{out} = w.q.h \tag{3.9}$$

Here unit weight of water, W = 1000 kg/m^3, and the lift obtained, h = 0.6 m. Hence the power output (P_{out}) is,

$$P_{out} = 1000 \times 0.6 \; q \; \frac{kg.m}{sec.}$$

$$= 600 \; q \; \frac{kg.m}{sec.}$$

$$= 600 \times 9.81 \; q \; \frac{N.m}{sec.}$$

$$= 5886 \; q \quad \text{watts} \tag{3.10}$$

Where q is the discharge in cumecs. By dividing the equation (3.10) by (3.8), the efficiency (η) is calculated.

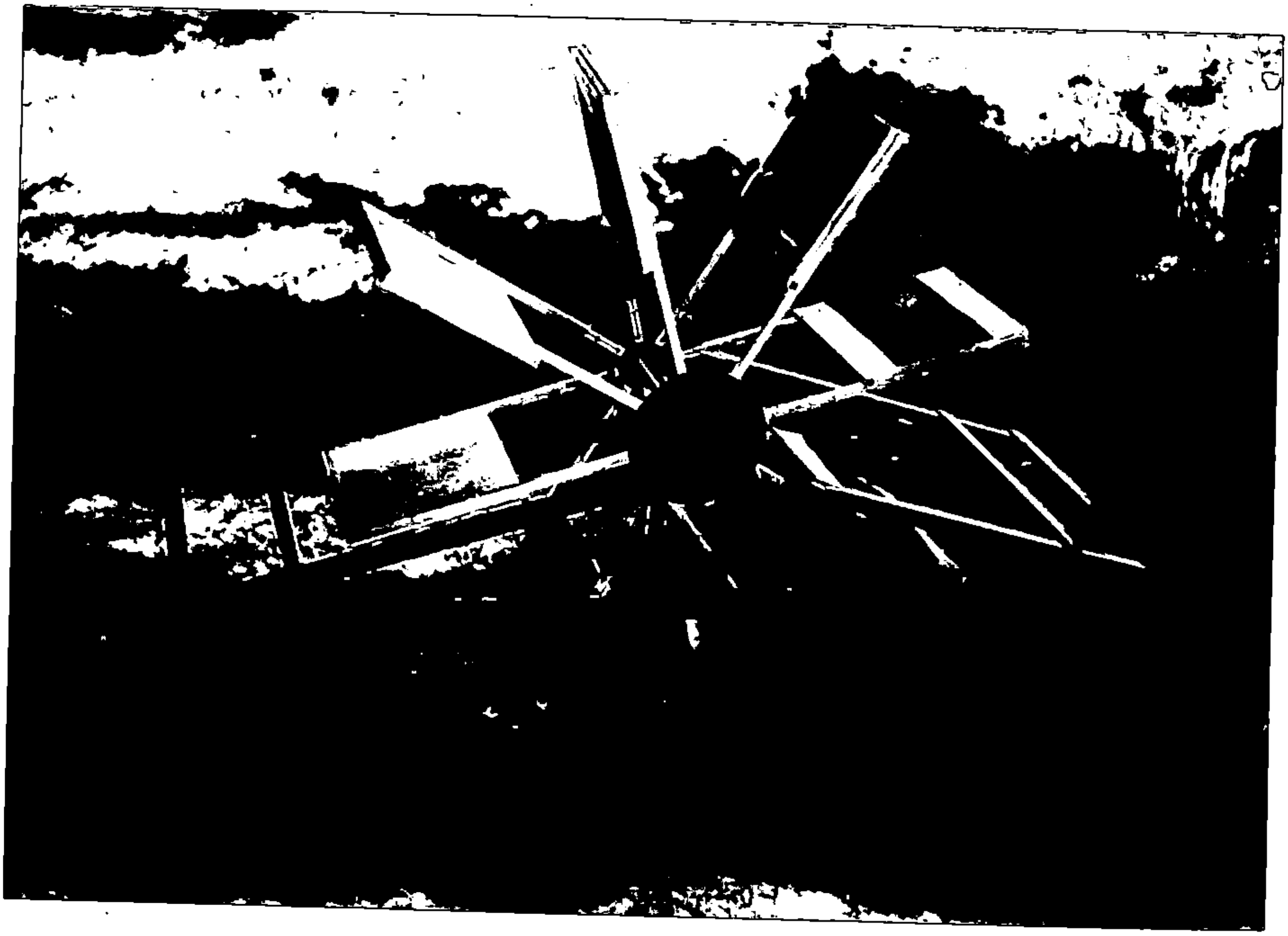
Plate I Developed low cost Water Wheel

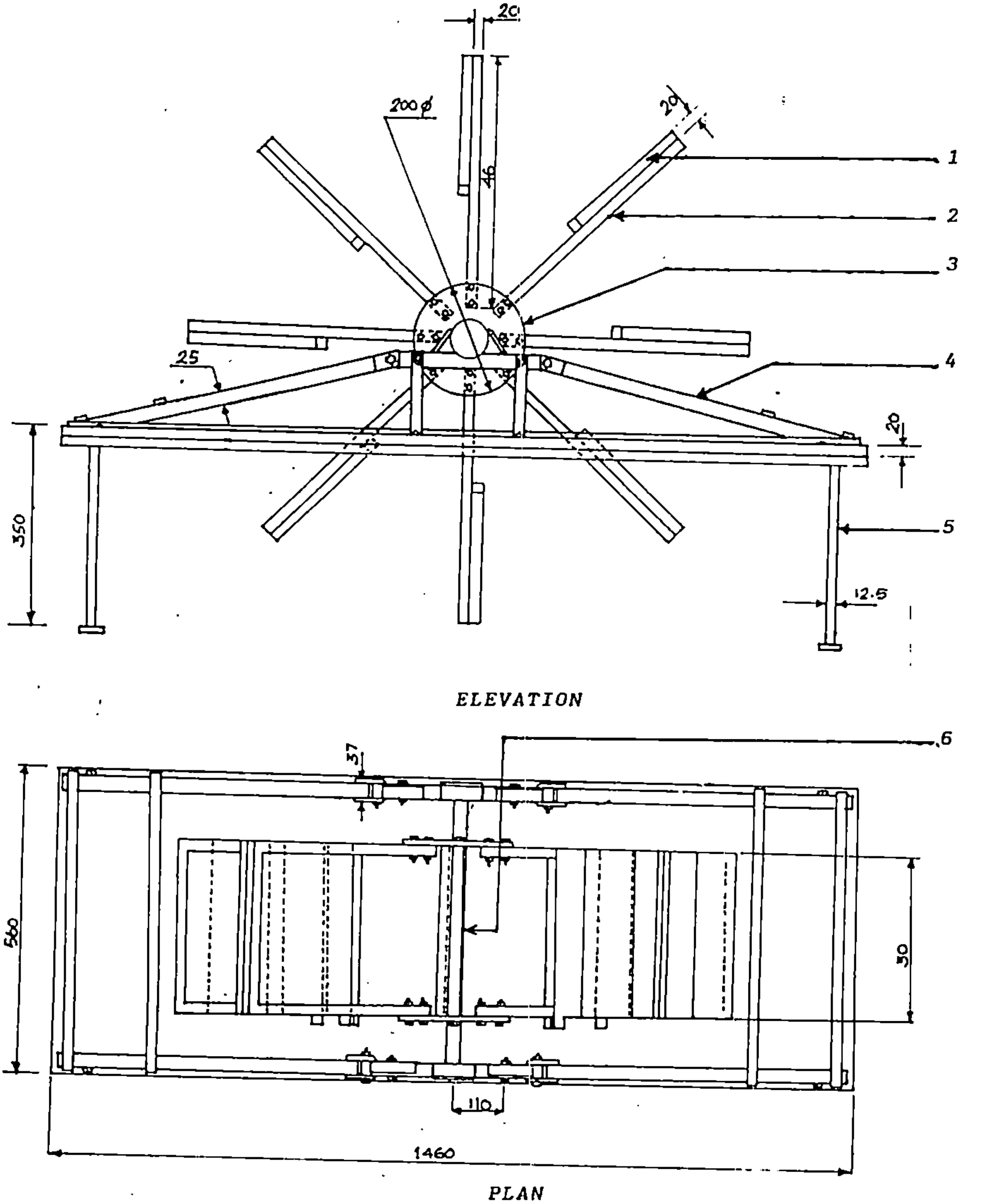
3.3 Fabrication Details of the Water Wheel

A water-wheel has been designed with minimum hydraulic loss to get highest efficiency. Fabrication of the water-wheel includes the selection and assembly of the mainshaft with bearing block, circular disc with provision for six and eight cup (wing) holding frames, cups or wings, supporting frame, etc. Fig.3.1 shows the overall dimensions of the water-wheel.

A shaft of diameter 25 mm was selected as per the design criteria explained in 3.2. A mild steel rod of 25 mm diameter and 530 mm length, machined all over was attached with two ball bearings on either end. A bearing block of suitable dimensions was fabricated in order to suit the above machine element (plate II). This bearing block assembly was bolted to the main supporting frame as shown in Plate III. Two circular mild steel plates of diameter 200 mm were welded to the main shaft at 305 mm distance apart (Fig.3.2). These circular plates were provided with 2 sets of holes of 6 mm diameter at 45° and 60° in order to test the wheel with 8 and 6 cups (Plate I and Plate VI). The overall diameter of the wheel was fixed at 1 m, so as to lift water to a height of about 0.6 m.

Cups (Wings) are the main working part of the system. These were made of tin sheet of less weight and are separately made for the





1. CUP(WING)
2. CUP HOLDING FRAME
3. CIRCULAR PLATE
4. SUPPORTING FRAME
5. STAND
6. CENTRE SHAFT

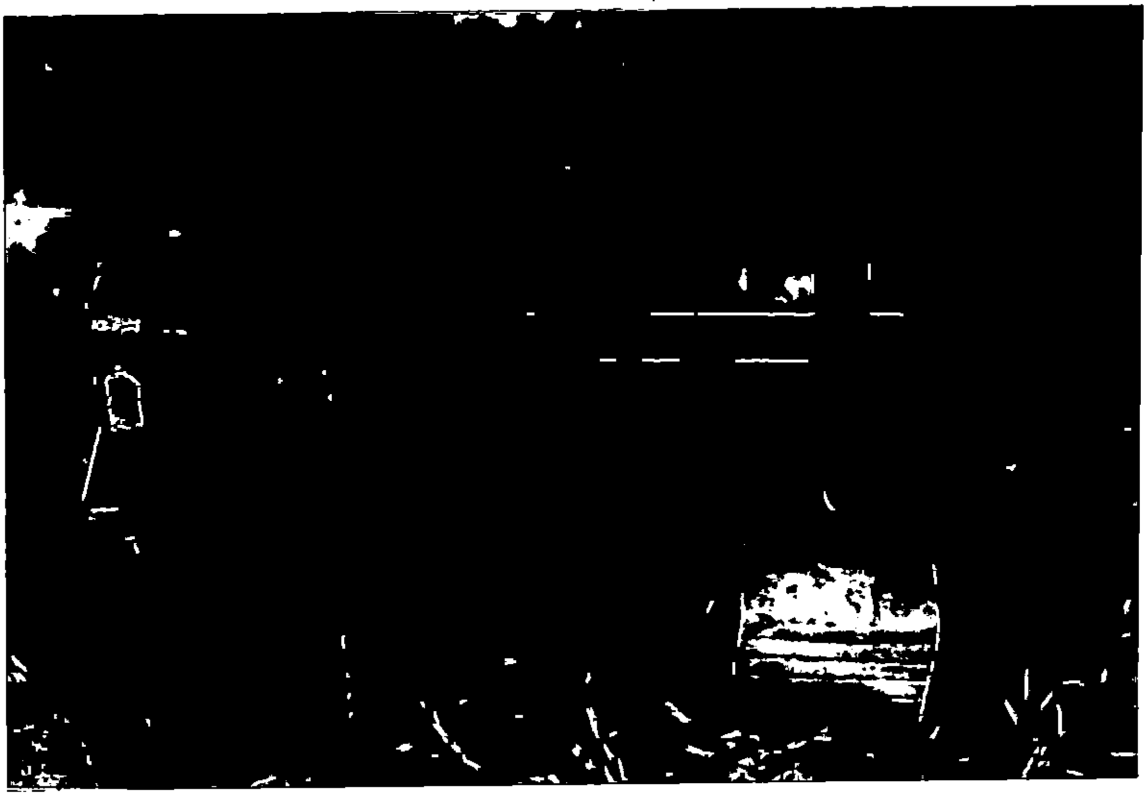
SCALE 1:10

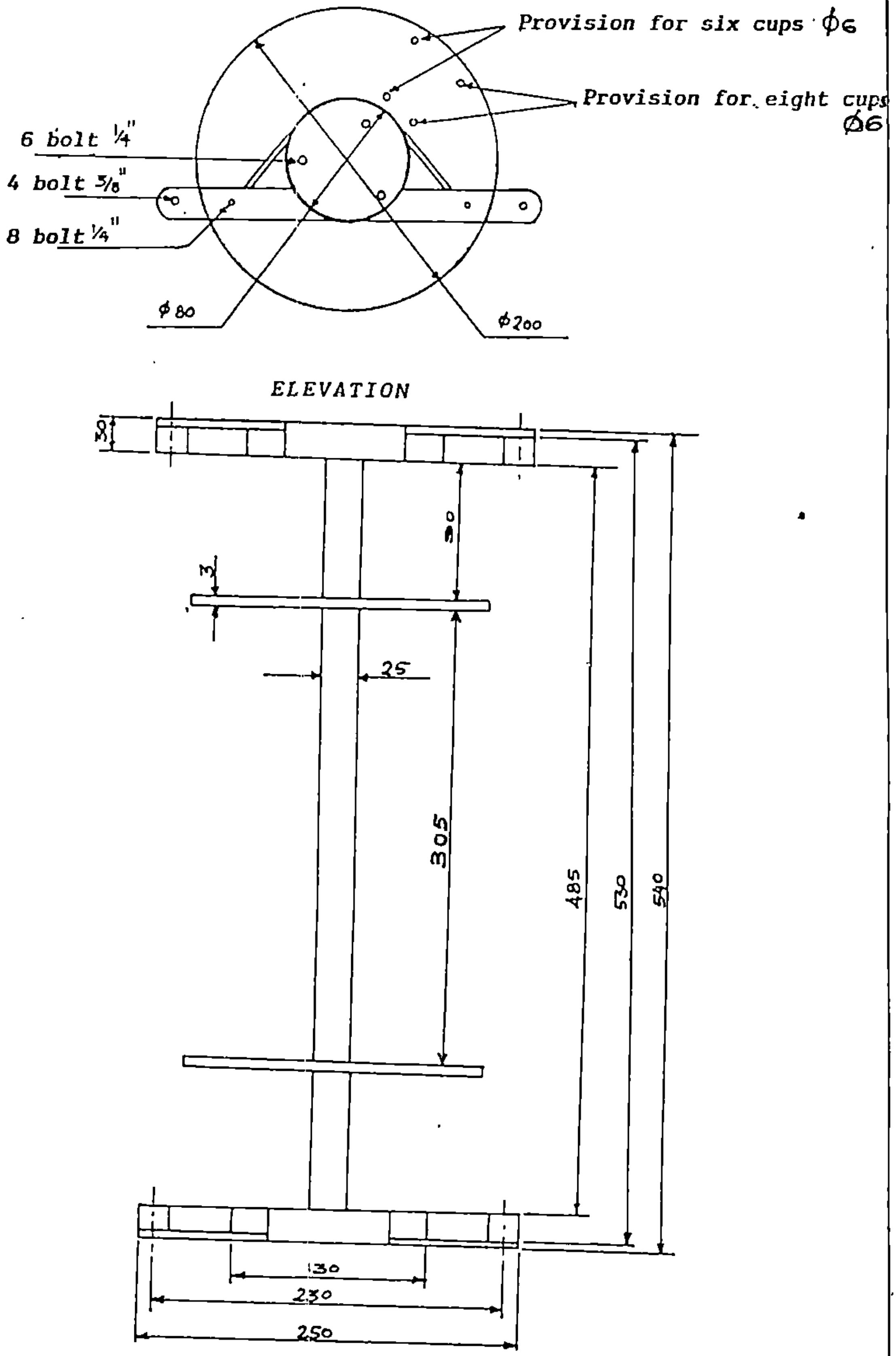
ALL DIMENSIONS ARE IN MM

Fig.3.1 WATER WHEEL WITH CUPS (WINGS) ATTACHMENTS

Plate II Main shaft with bearing block assembly

Plate III Bearing block assembly with supporting frame





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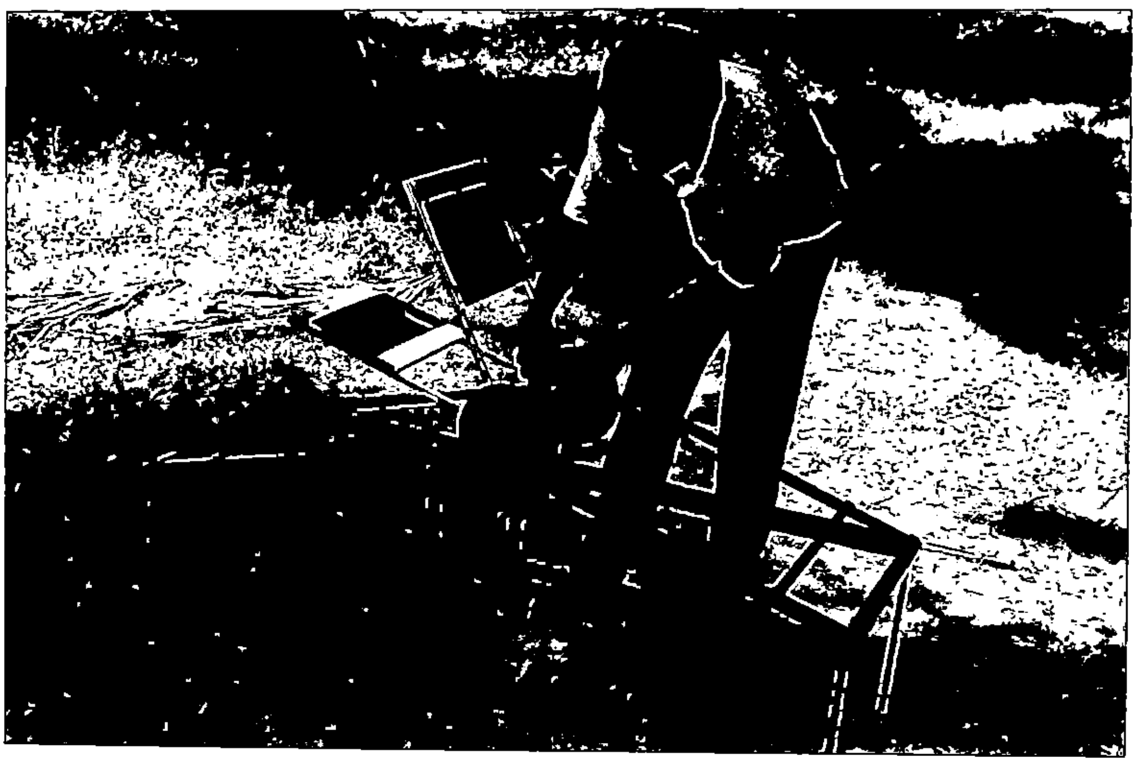
ALL DIMENSIONS ARE IN MM

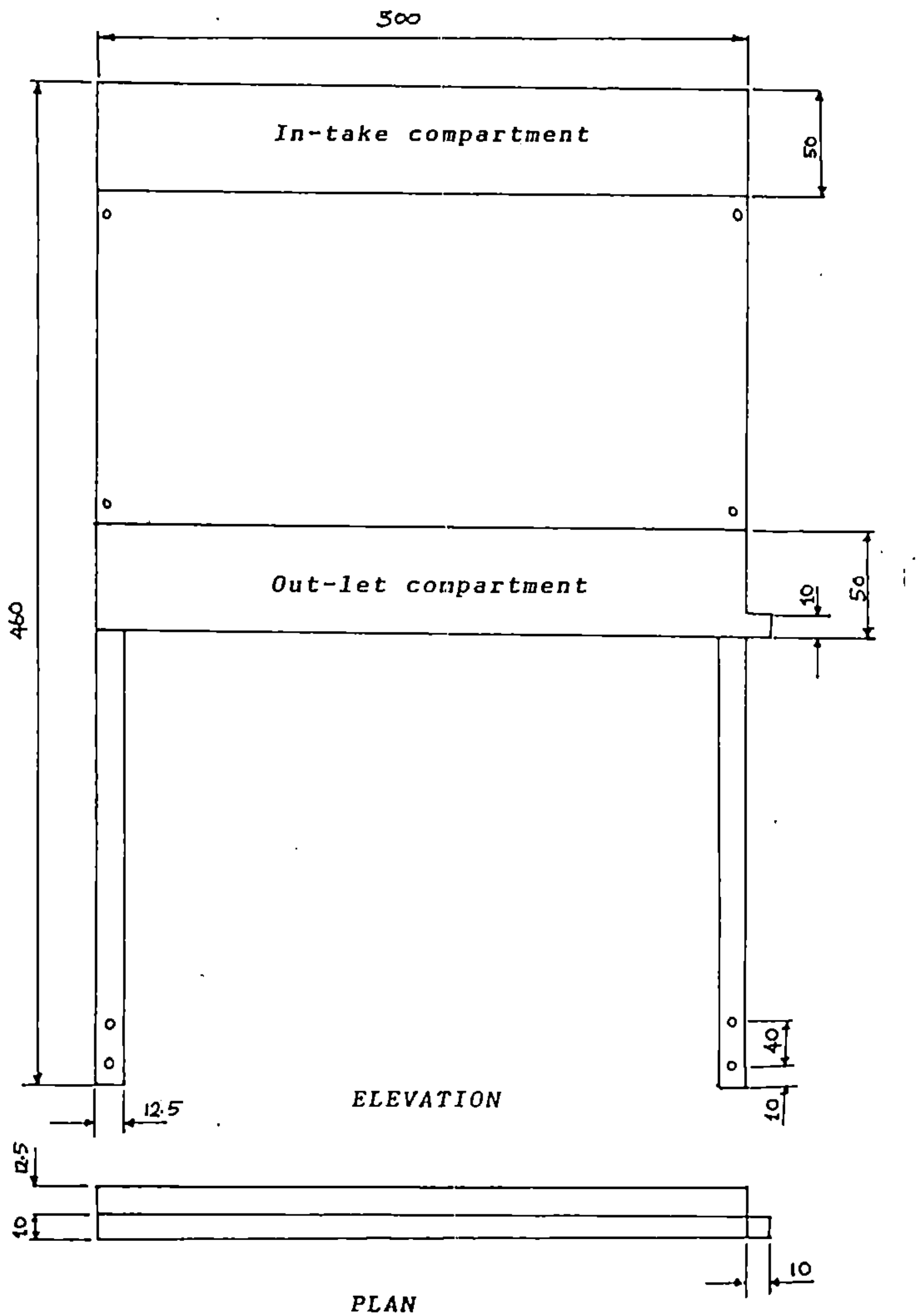
Fig.3.2 MAIN SHAFT WITH BEARING BLOCK ASSEMBLY easy replacement of cups. The number of cups (wings) on the wheel was varied according to the flow velocity available in the canal and the quantity of water required. The cups were fabricated in such a way that its reverse side was made flat to take the water force or impact. Each cup was provided with two compartments (in-take and outlet) and one outlet hole. The intake compartment was for taking water from the canal and the outlet compartment for delivering the water through the outlet hole during upward motion. The discharge outlet of suitable dimension was provided on the extreme corner of the outlet compartment, so as to discharge water completely in short time. The cup was bolted to the attaching frame, made of half inch square aluminium pipe as shown in plate IV. The various dimensions of a cup with frame is shown in Fig.3.3.

3 sets of cups with different intake compartments (Fig.3.4) were used to test the wheel for different submergence depths. A main stand made of MS Z-angle frame was fabricated to place the wheel when it is not in use. Water collecting through was also made to collect and discharge the water to the field or wherever necessary.

Plate IV Cup with frame

Plate V Fitting the cups (wings) to the wheel





SCALE 1:3

ALL DIMENSIONS ARE IN MM

Fig.3.3 CUP WITH FRAME

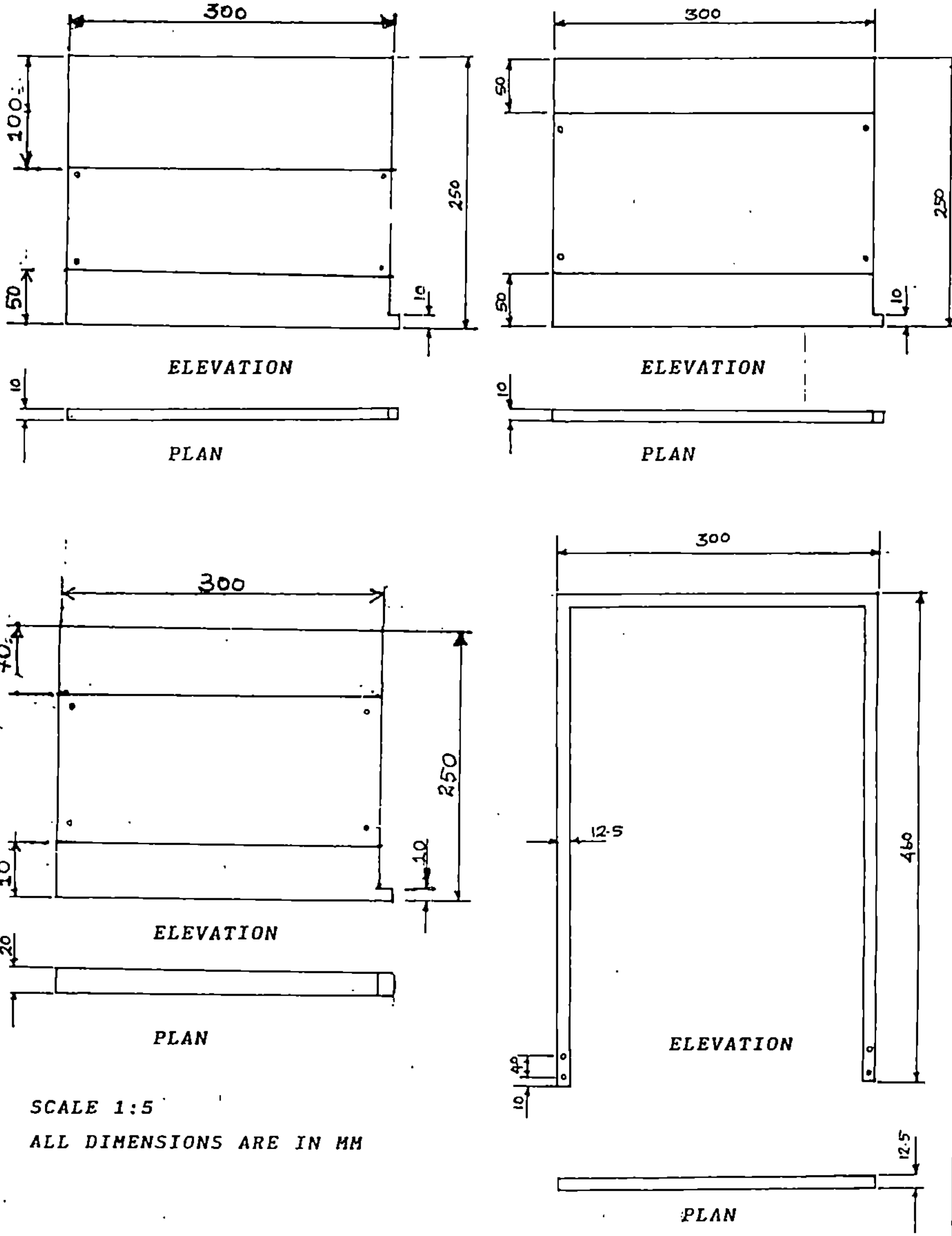
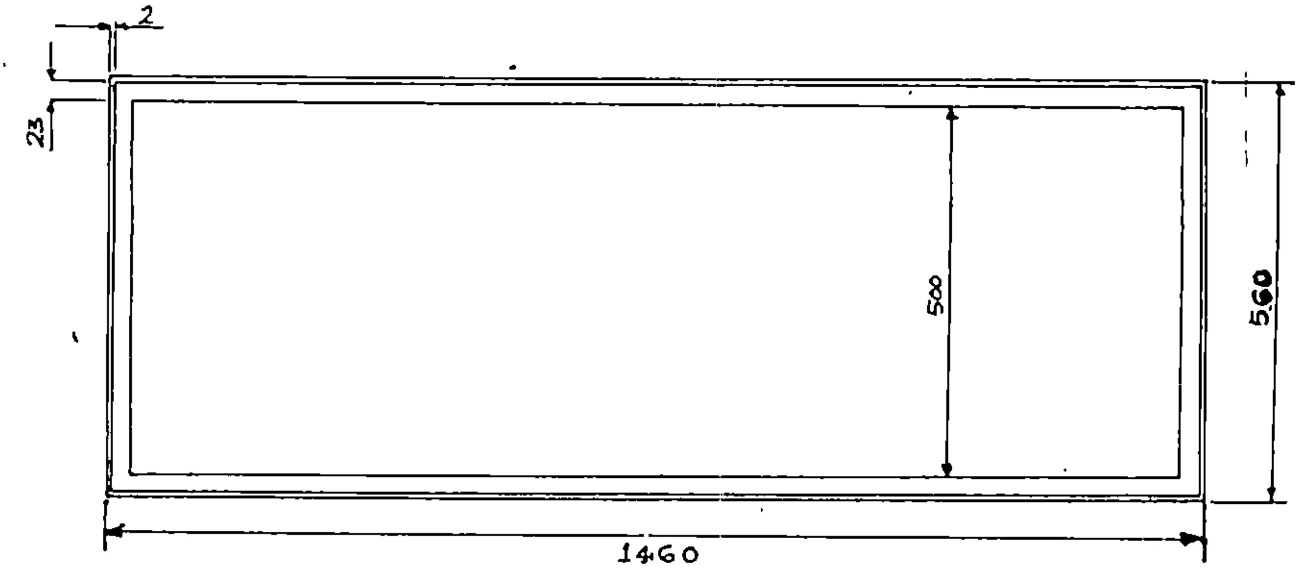
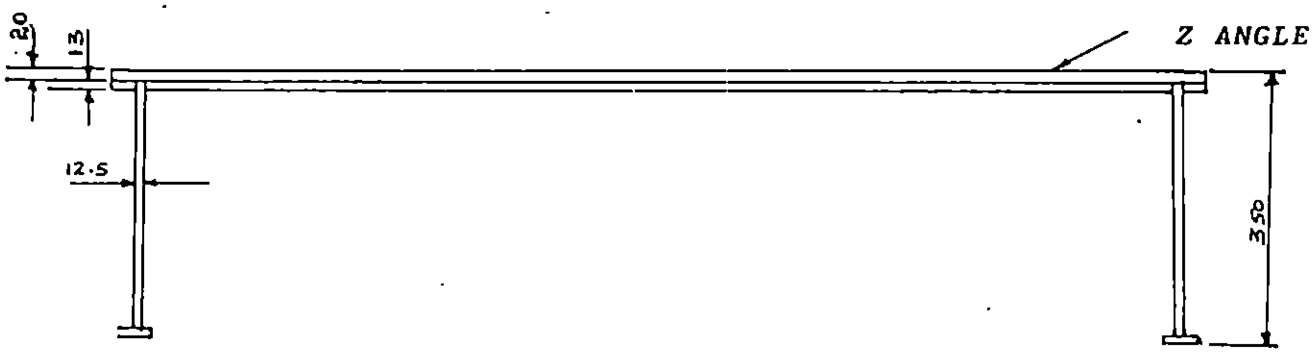


Fig.3.4 DIFFERENT SIZES OF CUPS AND CUP HOLDING FRAME



ELEVATION



PLAN

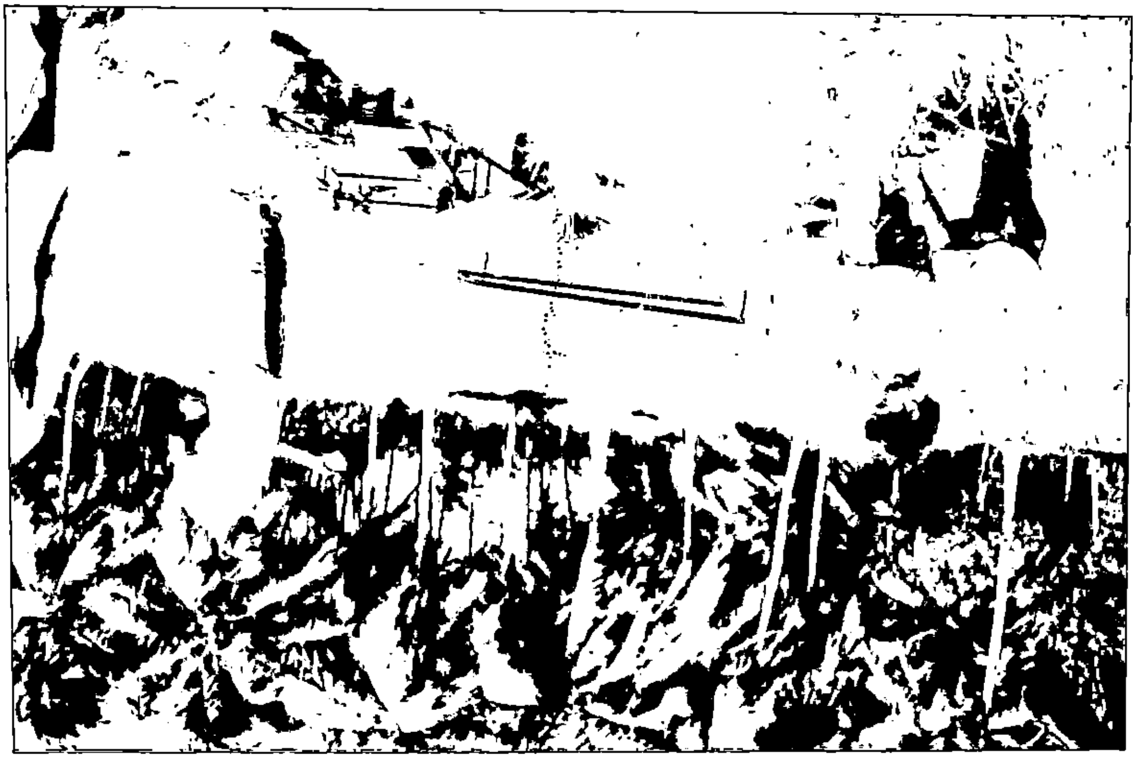
SCALE 1:10

ALL DIMENSIONS ARE IN MM .

Fig.3.5 MAIN STAND OF THE WATER WHEEL

Plate VI Water wheel with six cups

Plate VII Measurement of flow velocity and discharge



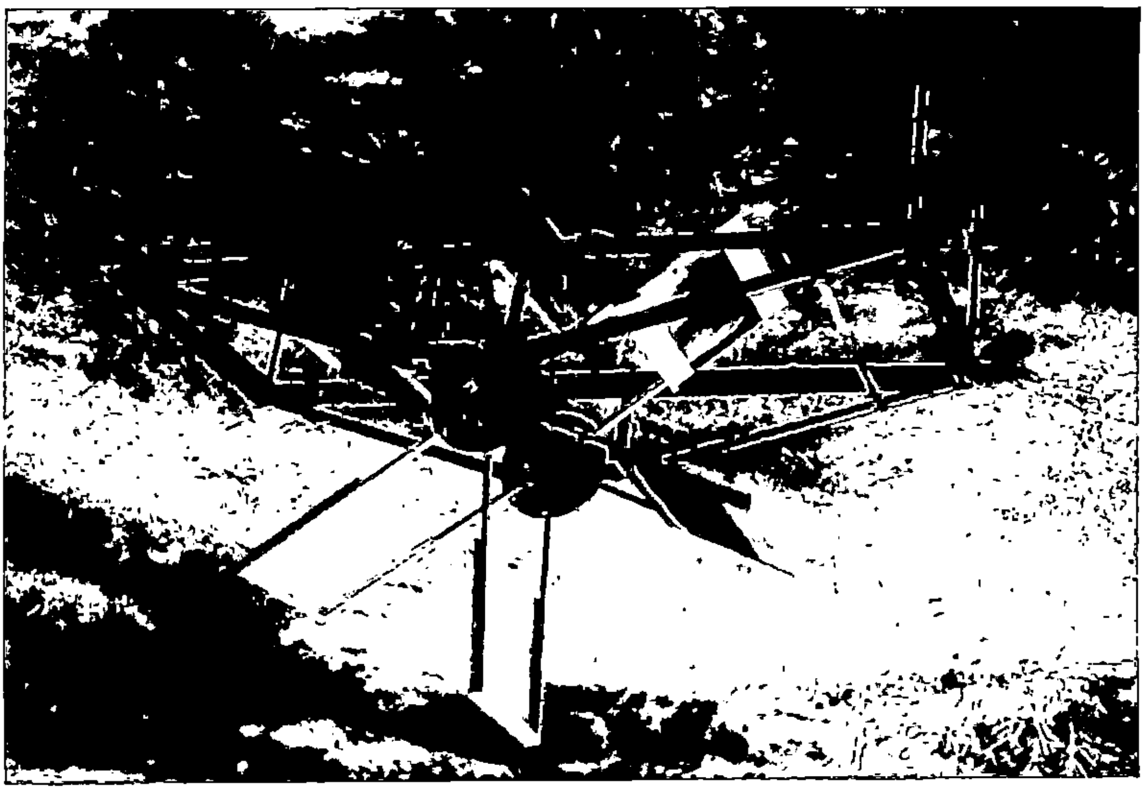
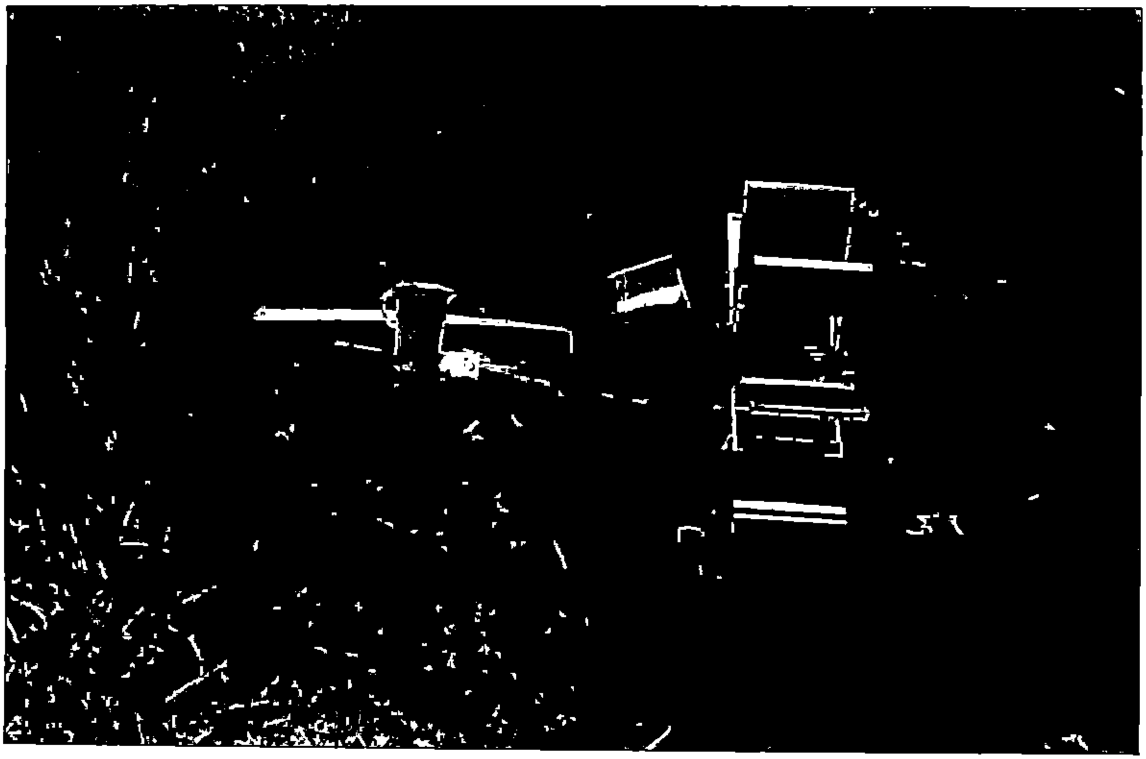


Plate VIII Water Wheel in working condition



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3.4 Test Procedure and Methodology

The test procedure includes testing the wheel for different flow velocity, rotational speed of the wheel, wing (vane) submergence, discharge capacity and number of cups. The sequential steps are as follows:

3.4.1 Site Selection

A reach of distributory canal of uniform depth, free of weed and near a drop structure was selected. The drop structure with an adjustable metal gate was used to vary the flow regime in the canal. In addition, the canal pavement up stream at the drop structure provided a firm ground for an easy installation in the canal bed.

3.4.2 Wing (Vane) submergence

The depth of cup (blade) which receive water thrust i.e., the wing (vane) submergence at each setting of wheel rotation was measured with a scale. This submerged depth is referred to as blade or vane submergence. The blade submergence depth is gradually increased from 0.12 to 0.15, 0.18, 0.22, 0.24 and 0.25 m by adjusting the height of the main shaft of the device. The maximum depth of flow at the selected irrigation canal this normally forms to be about 26 cms. Hence the depth of submergence was restricted to 25 cms.

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Since the blade width is 0.3 m, the corresponding water thrust areas of cup are 0.036, 0.045, 0.054, 0.066, 0.072, 0.075 m^2 respectively.

3.4.3 Stream Velocity

The surface velocity of water flow in the stream was measured by using a float, as explained in 2.7. The time taken by the float to travel a distance of 5 m was noted using a stop watch. Such three timings were recorded in different submergence depths and the mean time (t_{mean}) was calculated. The surface velocity (V_f) in m/sec was calculated and the mean flow velocity (V_m) of water was obtained from the relationship, $V_m = C \times V_f$. Where C is a constant factor, assumed as 0.85.

3.4.4 RPM of water-wheel

The cups (blades) were first given initial force manually and the rotation started. In order to set the rotational speed of the water wheel in rpm for different submergence depths of cup, the number of revolutions, completed by the water wheel for a time of one minute was observed and recorded.

3.4.5 Discharge Capacity

Discharge from the cups was collected in a container calibrated in litres. Hence the discharge rate was obtained in lpm directly by collecting water in 1 minute.

3.4.6 Size and Number of cups (wings)

Since the selected canal is having a width of 31 cm and a maximum depth of water flow of 26 cm, the size of cup is fixed as 30 cm x 25 cm, giving allowance on both sides. Two series of tests were conducted both in the laboratory and field tests. The first series of tests are with eight cups of 30 cm x 10 cm x 1 cm, 30 cm x 5 cm x 1 cm and 30 cm x 7 cm x 2 cm intake compartments. The second series of tests are with six cups of same intake compartment. The outlet compartment of all cups are of same size i.e. 30 cm x 5 cm x 1 cm with an outlet hole of 1 cm x 1 cm, having a projection of 1 cm.

3.4.7 Methodology

By recording the above mentioned parameters, the system efficiency was calculated for different submergence depths.

$$\text{Efficiency (\%)} = \frac{\text{Power Output}}{\text{Power Input}} \; \frac{(P_{out})}{(P_{in})} \times 100$$

where power output (watts) = 5886 q

and power input (watts) = $58.28\ A.V^2.N$, as explained in 3.2.

Results and Discussion

RESULTS AND DISCUSSION

The results of the laboratory and field studies conducted and economics of the low cost water wheel are presented in this chapter.

4.1 Laboratory Tests

The tests were conducted at the Hydraulics Laboratory, KCAET, Tavanur, as explained in 3.4. The discharge capacity and efficiency of the water wheel were tested for different submergence depths by noting the corresponding flow velocities, the rotational speed (rpm) and the discharge rates. Tests were repeated in two series by using eight and six cups with in-take compartments sizes of 30 cm x 10 cm x 1 cm, 30 cm x 5 cm x 1 cm and 30 cm x 7 cm x 2 cm.

4.1.1 Flow Velocity for Different Submergence Depths

The flowing water in the canal was used as the motive force of the wheel. The mean flow velocity in the canal for each settings was calculated as per 3.4.3 and is presented with the other readings. Initially a blade submergence of 0.12 m was given and it was gradually increased to 0.15, 0.18, 0.22, 0.24, 0.25 m respectively by adjusting the height of the main shaft of the device. The device can lift water as long as the mean flow velocity is greater than or equal to 0.35 m/sec. The height to which water can be lifted was 0.6 m in all settings of the wheel.

4.1.2 Testing the Wheel with Eight Cups (Wings)

Eight cups (wings) of 30 cm x 10 cm x 1 cm in-take compartment were attached to the wheel and temporarily installed in the lab canal. With a maximum mean flow velocity of 0.61 m/sec, the discharge obtained 14.4 lpm with a rotational speed of 6.0 rpm. The corresponding submergence depth was 0.12 m. When the submergence depth was gradually increased, accordingly the rotational speed found to be gradually decreased. At a submergence depth of 0.22 m, the rotational speed was 4.0 rpm with a discharge of 9.6 lpm. As the submergence area increased with depth, the mean flow velocity decreased. For this setting, the minimum mean flow velocity required for the wheel to rotate was 0.35 m/sec (Table 4.1).

By the same wheel with eight cups of 30 cm x 5 cm x 1 cm in-take compartment, the maximum discharge obtained was 7.2 lpm while the mean flow velocity at 0.63 m/sec and the corresponding rotational speed recorded 6.0 rpm. This was at a submergence depth of 0.12 m. Similar to the above case, as the submergence depth increased to maximum, *i.e.*, at 0.25 m, the mean flow velocity decreased to 0.39 m/sec with a corresponding discharge of 3.6 lpm and rotational speed of 3.0 rpm. When a cup of 30 cm x 7 cm x 2 cm in-take compartment was attached to the same wheel and tested for the same submergence depths, it was found that a higher discharge of 16.8 lpm was obtained with a rotational speed of 5.0 rpm in the initial submergence depth. At the maximum submergence depth of 0.25

m, a discharge of 8.4 lpm was obtained. Then the rotational speed and mean flow velocity were 2.5 rpm and 0.41 m/sec respectively. Test results are presented in Tables 4.2 and 4.3.

Performance characteristics of the water wheel with eight cups of different size in-take compartments are shown in Figure 4.1. The submergence depth is plotted on the abscissa and the efficiency and discharge rates are plotted as ordinates. The efficiency-submergence depth curves show that as the depth increases, the efficiency gradually increases and reaches a maximum value, and then decreasing. This is because of the fact that the velocity of the flow decreases with the decreasing impact force on the cup. Hence the energy input was also decreased, increasing the system efficiency. The discharge Vs submergence depth curves indicate that the discharge rate gradually decrease with the increase in depth. This is because of the decreasing rotational speeds with respect to the submergence depths. After certain submergence depths, the discharge decreased due to the decrease in rpm. Hence the output of the system decreased. At the same time, the energy input was low. But in both cases, the decrease was not in the same proportion. The best submergence depth at which the maximum efficiency of the system was found to be at 24 cm.

It is clear from the graph that the cups having in-take compartments of 30 cm x 10 cm x 1 cm and 30 cm x 7 cm x 2 cm have better efficiencies and higher discharge rates at various submergence depths. The wheel with 30 cm x 5 cm x 1 cm in-take compartment cups have lesser efficiencies and discharge rates than others, at the same submergence depths. This wheel has a maximum efficiency of 20.5% whereas the former wheels have 50% efficiency under the same operating conditions. Hence these wheels were considered for field testing.

Table 4.1 Test results of the Water Wheel with eight cups of 30 cm x 10 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	7.0	6.9	6.8	6.9	0.72	0.61	6.0	14.4	2.4×10^{-4}	4.20	1.41	33.57
2.	0.15	8.0	8.0	8.0	8.0	0.62	0.53	5.0	12.0	2.0×10^{-4}	3.30	1.17	35.45
3.	0.18	9.2	8.8	9.0	9.0	0.55	0.46	4.5	10.8	1.8×10^{-4}	2.69	1.06	39.43
4.	0.22	11.0	11.1	11.2	11.1	0.45	0.38	4.0	9.6	1.6×10^{-4}	1.99	0.94	47.23
5.	0.24	12.1	12.1	12.1	12.1	0.41	0.35	3.5	8.4	1.4×10^{-4}	1.61	0.82	50.93
6.	0.25	11.8	11.9	12.0	11.9	0.42	0.35	3.25	7.8	1.3×10^{-4}	1.56	0.77	49.35

Table 4.2 Test results of the Water Wheel with eight cups of 30 cm x 5 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	6.8	6.7	6.9	6.8	0.74	0.63	6.0	7.2	1.2×10^{-4}	4.48	0.71	15.84
2.	0.15	7.7	7.7	7.7	7.7	0.65	0.55	5.75	6.9	1.1×10^{-4}	4.09	0.68	16.62
3.	0.18	8.2	8.1	8.0	8.1	0.62	0.52	5.5	6.6	1.1×10^{-4}	4.19	0.65	15.51
4.	0.22	8.9	9.0	8.8	8.9	0.56	0.48	5.0	6.6	1.1×10^{-4}	3.97	0.65	16.37
5.	0.24	10.8	10.8	10.8	10.8	0.46	0.39	4.0	4.8	8.0×10^{-5}	2.29	0.47	20.52
6.	0.25	10.9	10.8	10.7	10.8	0.46	0.39	3.0	3.6	5.0×10^{-5}	1.79	0.29	16.20

Table 4.3 Test results of the Water Wheel with eight cups of 30 cm x 7 cm x 2 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	6.8	6.7	6.6	6.7	0.74	0.63	5.0	16.8	2.6×10^{-4}	3.73	1.53	41.01
2.	0.15	7.1	7.1	7.1	7.1	0.70	0.59	4.75	16.8	2.6×10^{-4}	3.88	1.53	39.43
3.	0.18	8.7	8.8	8.6	8.7	0.57	0.49	4.0	13.4	2.24×10^{-4}	2.71	1.32	48.70
4.	0.22	9.6	10.0	9.8	9.8	0.51	0.44	3.5	11.7	1.95×10^{-4}	2.33	1.15	49.35
5.	0.24	10.2	10.2	10.2	10.2	0.49	0.42	3.25	11.4	1.9×10^{-4}	2.15	1.12	52.09
6.	0.25	10.5	10.4	10.3	10.4	0.48	0.41	2.5	8.4	1.4×10^{-4}	1.65	0.82	50.90

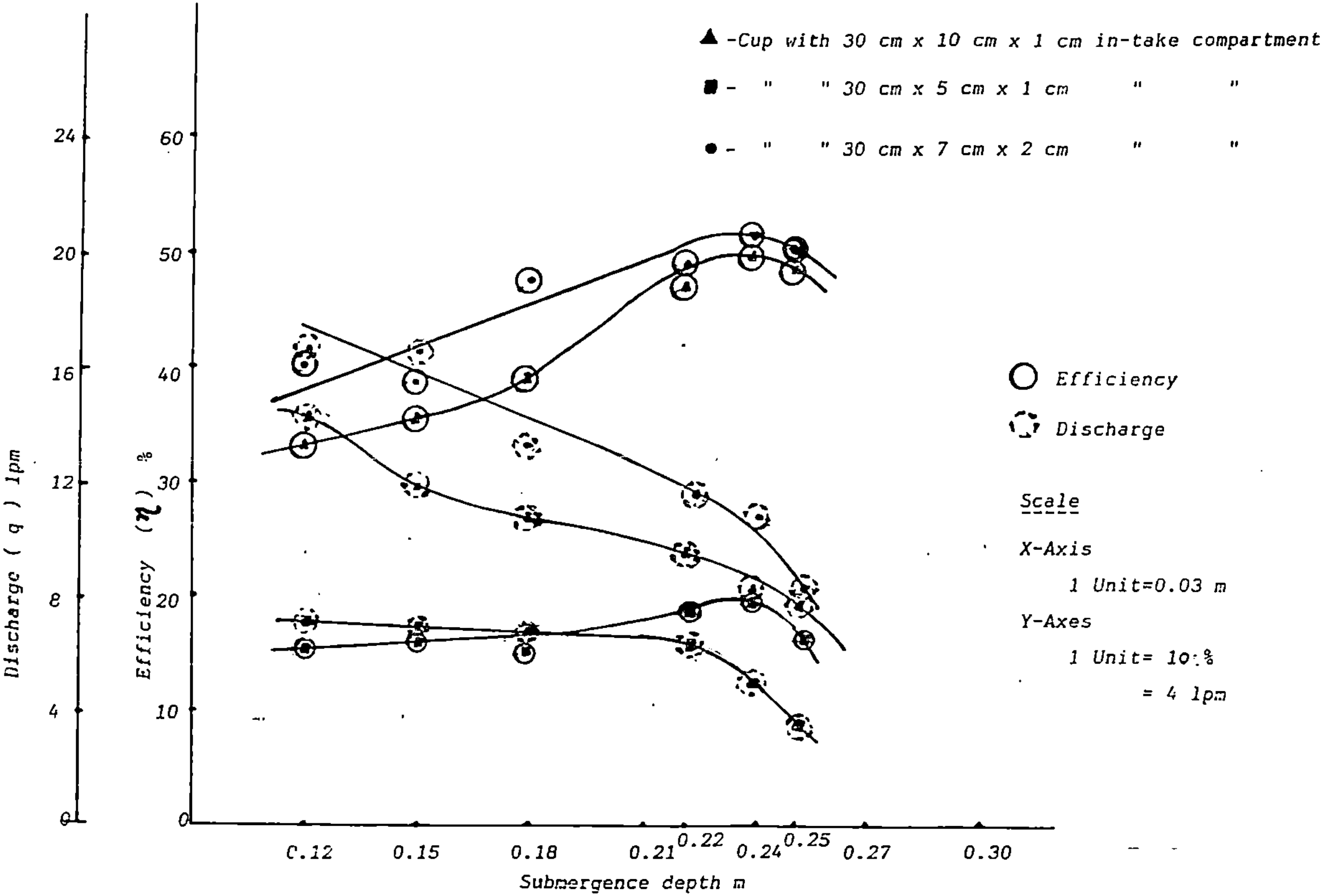

Fig.4.1 Performance charecteristics of the Water wheel with eight cups

4.1.3 Testing the Wheel with Six Cups (Wings)

Water wheel with six cups of 30 cm x 10 cm x 1 cm, 30 cm x 5 cm x 1 cm and 30 cm x 7 cm x 2 cm in-take compartments were tested at different submergence depths. The surface flow velocity, rotational speed and discharge rates of each sizes of cups were recorded and corresponding efficiencies were calculated (Tables 4.4, 4.5 and 4.6).

When using 30 cm x 10 cm x 1 cm in-take compartment cups maximum discharge of 8.1 lpm was obtained with a rotational speed of 4.5 rpm for a mean flow velocity of 0.51 m/sec and submergence depth of 0.12 m. When the submergence depth was increased to 0.25 m, the corresponding discharge was 4.0 lpm with a rotational speed of 2.2 rpm. The mean flow velocity at this setting was 0.35 m/sec.

For a wheel with 30 cm x 5 cm x 1 cm in-take compartment cups, the maximum discharge obtained was 4.5 lpm at the mean flow velocity 0.49 m/sec. The rotational speed at this setting was 5.0 rpm. When the mean flow velocity was at minimum 0.35 m/sec and at maximum submergence depth of 0.25 m, the discharge obtained was 2.7 lpm with a rotational speed of 3.0 rpm. Wheel with 30 cm x 7 cm x 2 cm in-take compartment cups, a maximum discharge of 9.6 lpm was obtained with a rotational speed of 4.0 rpm. Then the submergence depth was 0.12 m and the mean flow velocity was 0.54

m/sec. At the maximum submergence depth of 0.25 m and mean flow velocity of 0.35 m/sec, a discharge of 4.5 lpm was obtained with a rotational speed of 2.1 rpm.

Figure 4.2 shows the performance characteristics of the water wheel with six cups of size 30 cm x 10 cm x 1 cm, 30 cm x 5 cm x 1 cm and 30 cm x 7 cm x 2 cm of in-take compartments. The shape of the curves remain same with that of the wheel with eight cups. The characteristic curves of the wheel with 30 cm x 10 cm x 1 cm and 30 cm x 7 cm x 2 cm in-take compartment cups indicate that these wheels have better efficiencies and higher discharge rates at various submergence depths. The wheel with 30 cm x 7 cm x 2 cm in-take compartment cups has a maximum efficiency of 47.16% at a submergence depth of 0.24 m and mean flow velocity of 0.35 m/sec. The wheel with 30 cm x 10 cm x 1 cm in-take compartment cups has a maximum efficiency of 39.55% at a submergence depth of 0.22 m and mean flow velocity of 0.35 m/sec. But for the wheel with 30 cm x 5 cm x 1 cm in-take compartment cups has maximum efficiency of only 19.74% at a submergence depth of 0.22 m and mean flow velocity of 0.36 m/sec. Hence the wheel with 30 cm x 10 cm x 1 cm and 30 cm x 7 cm x 2 cm in-take compartment cups was considered for field testing.

Table 4.4 Test results of the Water Wheel with six cups of 30 cm x 10 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	8.1	8.5	8.3	8.3	0.60	0.51	4.5	8.1	1.35×10^{-4}	2.20	0.79	35.90
2.	0.15	9.6	9.6	9.6	9.6	0.52	0.45	3.75	6.8	1.13×10^{-4}	1.78	0.67	37.64
3.	0.18	10.6	10.2	10.4	10.4	0.48	0.41	3.50	6.6	1.1×10^{-4}	1.66	0.65	39.15
4.	0.22	11.9	11.8	12.0	11.9	0.42	0.36	3.0	5.4	9×10^{-5}	1.34	0.53	39.55
5.	0.24	13.6	13.5	13.4	13.5	0.41	0.35	2.5	4.5	7.5×10^{-5}	1.15	0.44	38.26
6.	0.25	13.5	13.5	13.5	13.5	0.41	0.35	2.2	4.0	6.6×10^{5}	1.06	0.39	36.79

Table 4.5 Test results of the Water Wheel with six cups of 30 cm x 5 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity	Mean flow velocity	Rotational speed	Discharge		Power Input	Power Output	Efficiency
		t_1	t_2	t_3	t_{mean}	(V_f)	(V_m)	(N)	(q)		(P_{in})	(P_{out})	(η)
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	8.7	8.6	8.5	8.6	0.58	0.49	5.0	4.5	$7.5x10^{-5}$	2.26	0.44	19.47
2.	0.15	9.6	9.6	9.6	9.6	0.52	0.45	4.5	4.0	$6.75x10^{-5}$	2.14	0.40	18.69
3.	0.18	10.7	10.6	10.5	10.6	0.47	0.40	4.0	3.6	$6x10^{-5}$	1.81	0.35	19.33
4.	0.22	11.7	11.7	11.7	11.7	0.43	0.63	3.5	2.2	$5.25x10^{-5}$	1.57	0.31	19.74
5.	0.24	12.1	12.2	12.3	12.2	0.41	0.35	3.1	2.8	$4.7x10^{-5}$	1.43	0.28	19.58
6.	0.25	12.2	12.2	12.2	12.2	0.41	0.35	3.0	2.7	$4.5x10^{-5}$	1.44	0.26	18.05

Table 4.6 Test results of the Water Wheel with Six cups of 30 cm x 7 cm x 2 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	7.9	7.8	7.7	7.8	0.64	0.54	4.0	9.6	1.6×10^{-4}	2.19	0.94	42.92
2.	0.15	8.7	8.7	8.7	8.7	0.57	0.48	3.5	8.4	1.4×10^{-4}	1.89	0.82	43.38
3.	0.18	9.5	9.4	9.3	9.4	0.53	0.45	3.25	8.4	1.4×10^{-4}	1.86	0.82	44.08
4.	0.22	11.4	11.5	11.3	11.4	0.44	0.37	2.5	5.5	9.2×10^{-5}	1.18	0.54	45.76
5.	0.24	12.2	12.2	12.2	12.2	0.41	0.35	2.3	5.1	8.5×10^{-5}	1.06	0.50	47.16
6.	0.25	12.1	12.3	12.2	12.2	0.41	0.35	2.1	4.5	7.5×10^{-5}	1.01	0.44	43.56

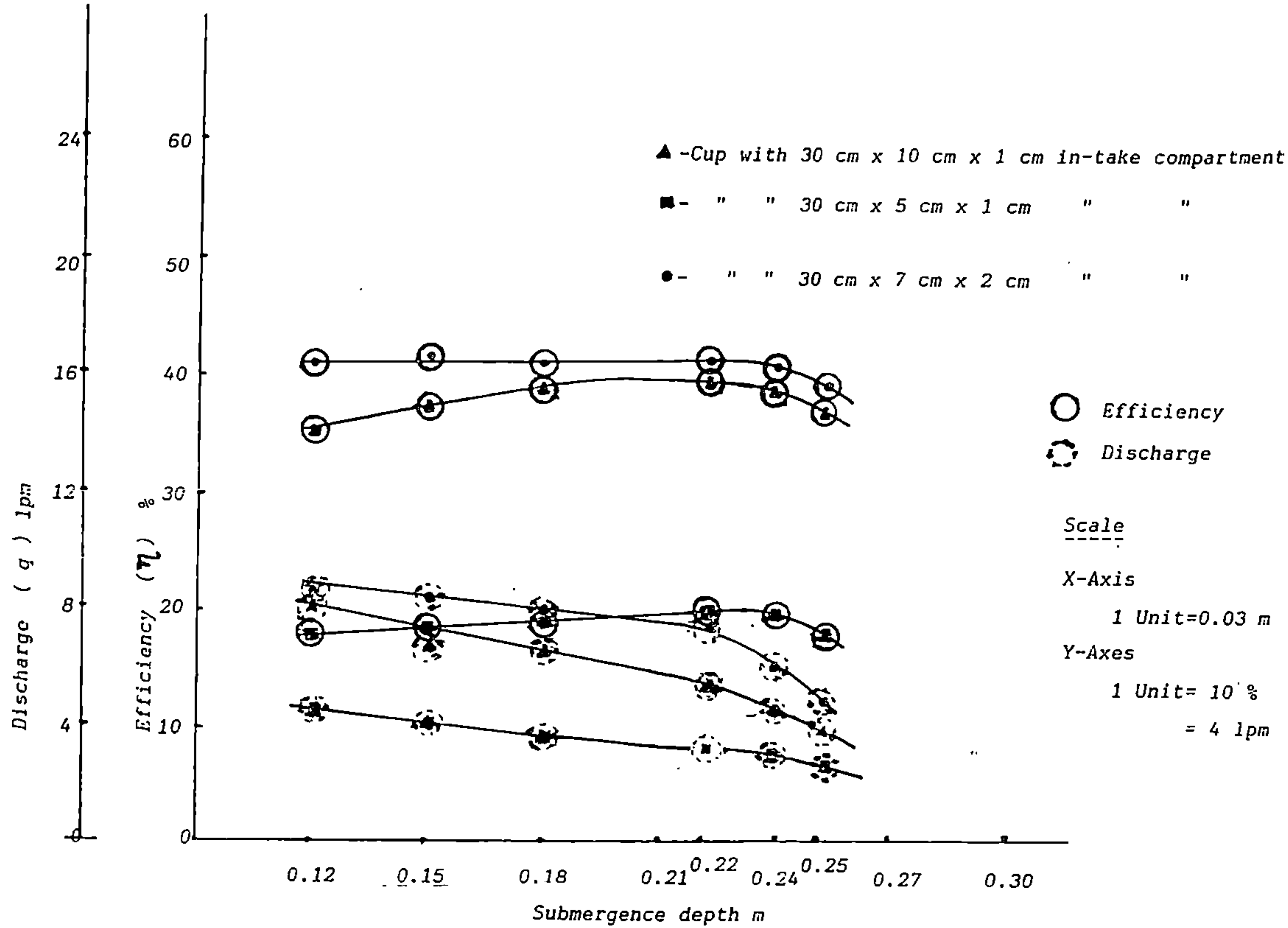

Fig.4.2 Performance charecteristics of the Water wheel with six cups

4.2 Field Tests

Field tests were conducted at the KCAET farm, Tavanur to study the performance of the water wheel at the actual field conditions. The water wheel was tested both with eight and six cups of 30 cm x 10 cm x 1 cm and 30 cm x 7 cm x 2 cm in-take compartments and the results are given in Tables 4.7, 4.8, 4.9 and 4.10.

From the results, it is obvious that the maximum water discharge is for wheel with eight cups of 30 cm x 7 cm x 2 cm in-take compartment. For these wheels, a maximum discharge of 15.0 lpm with a rotational speed of 4.5 rpm was obtained for a mean flow velocity of 0.63 m/sec and a submergence depth of 0.12 m. A minimum discharge of 5.8 lpm was obtained at a maximum submergence depth of 0.25 m. The rotational speed and mean flow velocity at this setting were 2.0 rpm and 0.40 m/sec respectively. The lowest efficiency obtained was 41.77% at a submergence depth of 0.15 m whereas the maximum efficiency of 47.50% obtained at 0.24 m submergence depth.

The performance curve of the water wheel with eight and six cups for different size of in-take compartments are shown in Fig.4.3 and Fig. 4.4. The maximum efficiency of 48% is obtained for the water wheel with eight cups of in-take 30 cm x 7 cm x 2 cm in-take compartments for a submergence depth of 0.23 m. The corresponding value of mean flow velocity of water is 0.44 m/sec. Hence 0.44 m/sec is taken as the optimum flow velocity of water at a optimum submergence depth of 23 cm.

Comparing the figures with those characteristic curves of laboratory tests, it is clear that the discharge rate as well as the efficiency is lesser in field tests; probably due to two main reasons. During the field testing the rotation of the water wheel was affected by the local wind velocity and some floating materials. These will either retard the rotational speed or arrest completely the motion of the rotating cups. In order to overcome the above, a high quality thrust or radial bearing was provided. A wire net was also provided in front of the wheel to eliminate the floating materials obstructing the wheel.

From the laboratory and field test results, it was observed that the wheel with eight numbers of cups having 30 cm x 7 cm x 2 cm in-take compartment is the most efficient under various operating conditions.

Table 4.7 Field test results of the Water Wheel with eight cups of 30 cm x 10 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	7.0	7.0	7.0	7.0	0.71	0.61	5.5	13.2	2.2×10^{-4}	3.85	1.29	33.51
2.	0.15	7.5	7.6	7.7	7.6	0.66	0.56	5.25	12.6	2.1×10^{-4}	3.87	1.24	32.04
3.	0.18	8.8	8.8	8.8	8.8	0.57	0.49	4.75	11.4	1.9×10^{-4}	3.22	1.12	34.28
4.	0.22	10.0	10.4	10.2	10.2	0.49	0.42	4.5	10.8	1.8×10^{-4}	2.74	1.06	38.68
5.	0.24	10.5	10.4	10.6	10.4	0.48	0.4	4.0	9.6	1.6×10^{-4}	2.53	0.94	37.15
6.	0.25	10.4	10.5	10.6	10.4	0.48	0.41	3.0	7.2	1.2×10^{-4}	1.97	0.71	36.04

Table 4.8 Field test results of the Water Wheel with eight cups of 30 cm x 7 cm x 2 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	6.7	6.8	6.9	6.8	0.74	0.63	4.5	15.0	$2.5x10^{-4}$	3.36	1.48	44.04
2.	0.15	7.8	7.8	7.8	7.8	0.68	0.58	4.5	13.4	$2.2x10^{-4}$	3.16	1.32	41.77
3.	0.18	8.3	8.5	8.7	8.5	0.59	0.50	3.75	12.6	$2.1x10^{-4}$	2.65	1.24	46.79
4.	0.22	9.5	9.4	9.6	9.4	0.53	0.45	3.5	11.8	$1.9x10^{-4}$	2.44	1.15	47.13
5.	0.24	10.2	10.1	10.0	10.2	0.49	0.42	2.5	8.0	$1.3x10^{-4}$	1.66	0.79	47.59
6.	0.25	10.8	10.4	10.6	10.6	0.47	0.40	2.0	5.8	$9.6x10^{-5}$	1.25	0.57	45.60

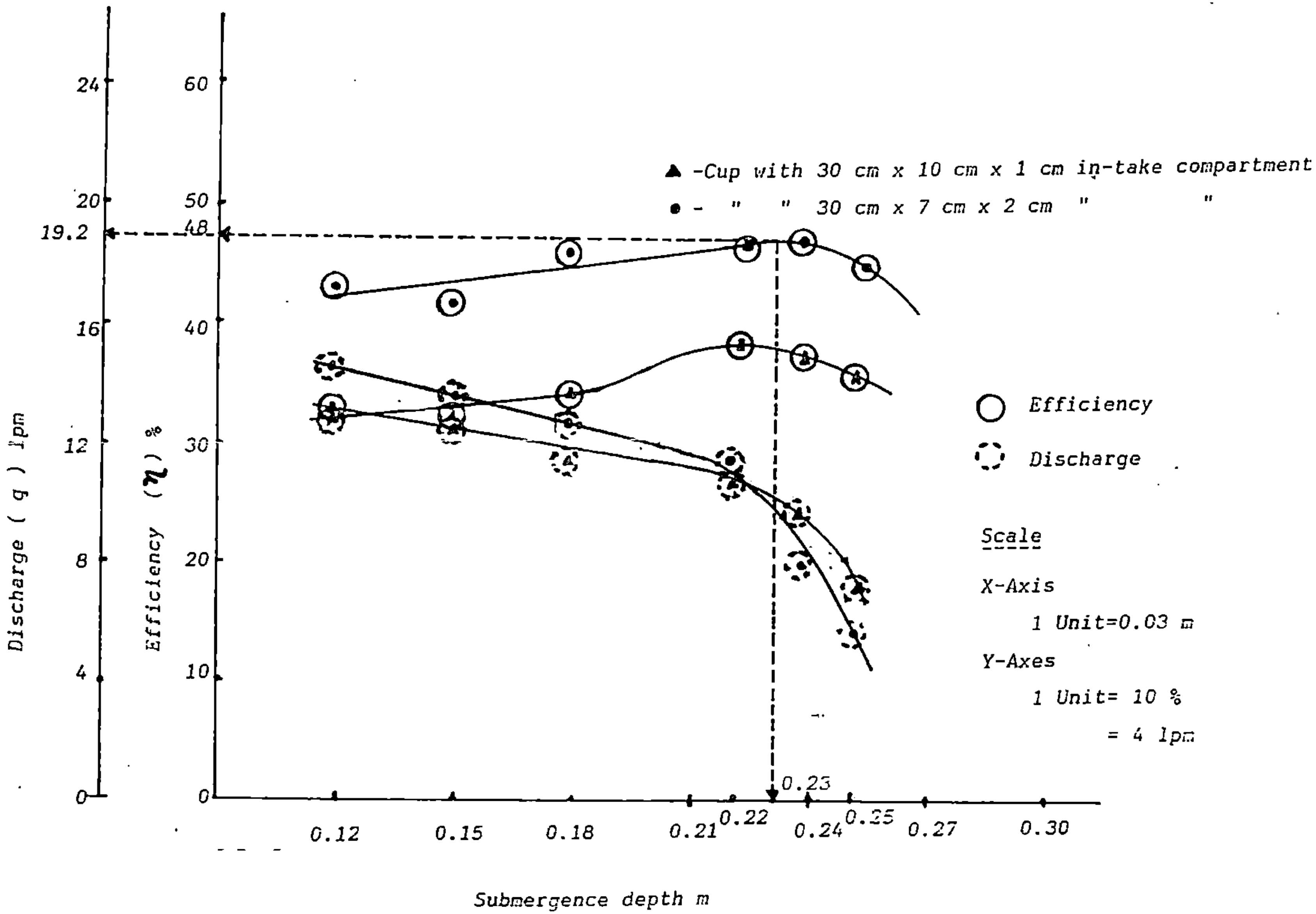

Fig.4.3 Performance characteristics of the Water wheel with eight cups - field test

Table 4.9 Field test results of the Water Wheel with six cups of 30 cm x 10 cm x 1 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	8.2	8.2	8.2	8.2	0.61	0.50	4.0	7.2	1.2×10^{-4}	1.88	0.71	37.76
2.	0.15	9.6	9.4	9.2	9.4	0.53	0.44	3.5	6.3	1.1×10^{-4}	1.59	0.69	38.36
3.	0.18	10.6	10.7	10.5	10.6	0.47	0.40	3.25	5.9	9.8×10^{-5}	1.47	0.57	38.77
4.	0.22	11.6	11.6	11.6	11.6	0.43	0.37	3.0	5.6	9.4×10^{-5}	1.41	0.55	39.00
5.	0.24	12.0	12.2	12.4	12.2	0.41	0.35	2.5	4.5	7.5×10^{-5}	1.15	0.44	38.26
6.	0.25	12.2	12.2	12.2	12.2	0.41	0.35	2.0	3.6	6.0×10^{-5}	0.96	0.35	36.45

Table 4.10 Field test results of the Water Wheel with six cups of 30 cm x 7 cm x 2 cm intake compartment

Sl. No.	Submergence depth	Time by the float to travel 5 m				Surface flow velocity (V_f)	Mean flow velocity (V_m)	Rotational speed (N)	Discharge (q)		Power Input (P_{in})	Power Output (P_{out})	Efficiency (η)
		t_1	t_2	t_3	t_{mean}								
	(m)	(Sec)	(Sec)	(Sec)	(Sec)	(m/sec)	(m/sec)	(rpm)	(lpm)	(m^3/s)	(Watts)	(Watts)	(%)
1.	0.12	7.8	7.8	7.8	7.8	0.64	0.55	3.5	8.4	1.4×10^{-4}	1.99	0.82	41.20
2.	0.15	8.7	8.6	8.5	8.6	0.58	0.50	3.25	8.4	1.4×10^{-4}	1.91	0.82	42.93
3.	0.18	9.3	8.9	9.1	9.1	0.55	0.47	3.0	7.8	1.3×10^{-4}	1.87	0.77	41.17
4.	0.22	9.9	9.8	9.7	9.8	0.51	0.44	2.75	7.8	1.3×10^{-4}	1.83	0.76	41.53
5.	0.24	10.8	10.9	11.0	10.9	0.46	0.39	2.5	6.0	1.0×10^{-4}	1.43	0.59	41.25
6.	0.25	10.9	10.9	10.9	10.9	0.46	0.39	2.0	4.8	8.0×10^{-5}	1.19	0.47	39.49

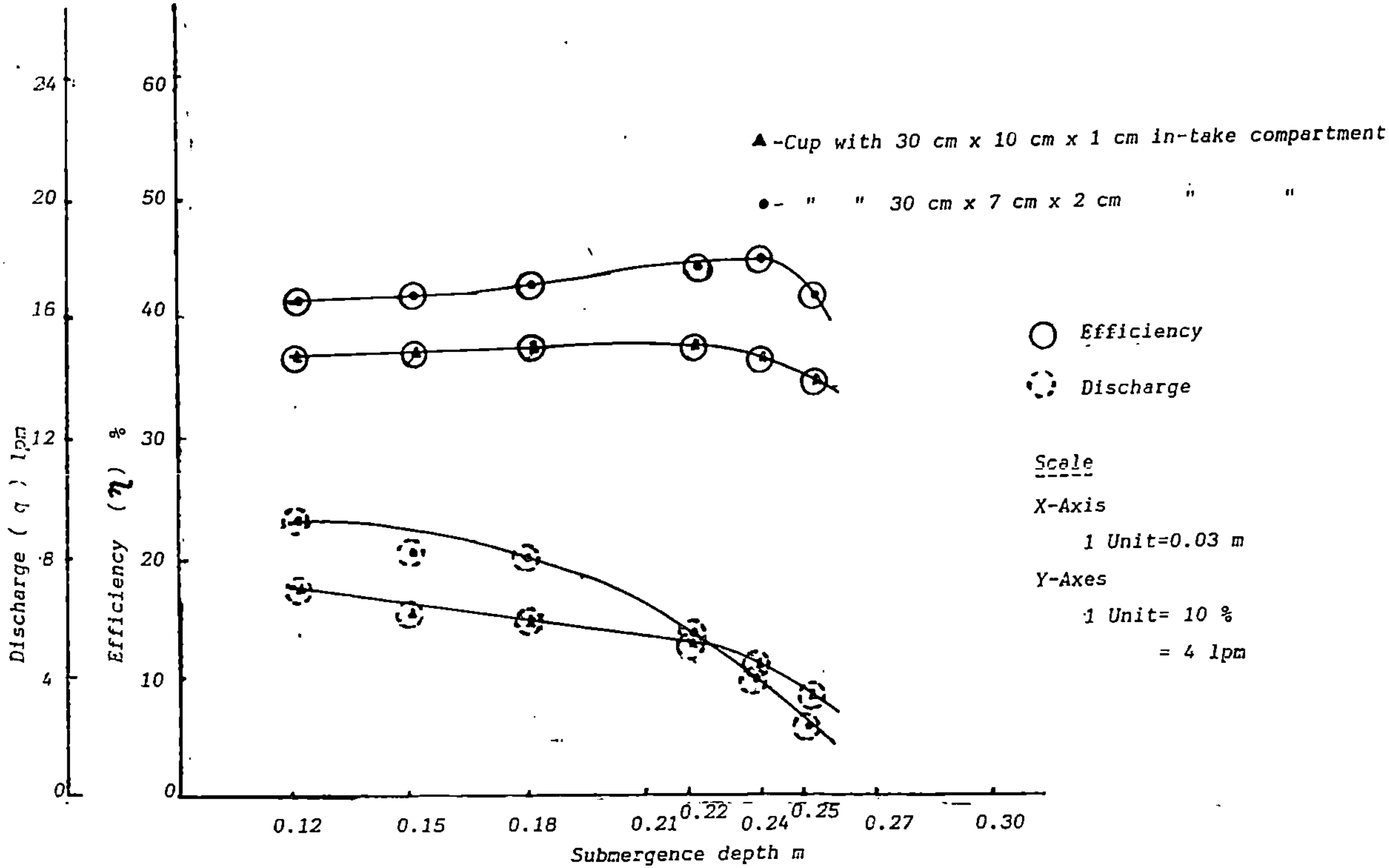

Fig.4.4 Performance characteristics of the Water wheel with six cups - field test

4.3 Cost of Operation of the Low Cost Water Wheel

One of the major requirements for the acceptance of any equipment by the farmers is its economic feasibility. Along with other desirable qualities, the equipment should offer to the farmer, increased economic benefits over the existing conventional equipment/ methods. Since the velocity of the flowing water in the canal was used as the motive force it does not require fuel or any other energy source for its operation. The device can be fabricated by local artisans from the easily and readily available low cost materials. Its fabrication cost is also low. The total investment cost of the water wheel comes to Rs.800/- and the annual operating cost amounts to Rs.204/-. The detailed cost analysis of the low cost water wheel is given in Appendix IV.

Summary

SUMMARY

A simple portable low cost water wheel having reasonable capacity with a good pumping efficiency and operated by flow velocity of canal has been developed and tested at the Kelappaji College of Agricultural Engineering and Technology, Tavanur.

The water wheel is fabricated by series of cups (Wings) arranged radially 45° or 60° apart on two circular mild steel plates of 3 mm thickness and 200 mm diameter. These plates are welded at 305 mm apart on a mild steel rod (main shaft) of 25 mm diameter and 530 mm length. This main shaft was attached with two ball bearings which is fixed on a bearing block of suitable dimensions. The bearing block assembly was attached to the main frame of the wheel.

Cups (wings) made of tin sheet are the main working part of the system. Each cup of size 30 cm x 25 cm is provided with two compartments - intake compartment is for taking water from the canal and the out-let compartment is for delivering water from the cup to the field.

Eight and six cups with 30 cm x 10 cm x 1 cm, 30 cm x 5 cm x 1 cm and 30 cm x 7 cm x 2 cm intake compartments were tested with respect to various submergence depths varying from 0.12 to 0.25 m.

Corresponding flow velocities were also noted. The overall dimensions of the wheel are – Length : 1455 mm Width : 555 mm Height : 1000 mm and Weight : 16 Kg.

The flowing water in the canal was used as the power source of the wheel. The flow velocity in the canal was adjusted by a drop structure to get a gradually varied flow. The blade (cup) submergence was controlled by adjusting the height of main shaft of the device in the stream. The rotational speed (rpm) and the discharge rates were noted for the submergence depths at 0.12, 0.15, 0.18, 0.22, 0.24 and 0.25 m. Corresponding efficiencies were calculated for each settings.

Based on the laboratory and field tests conducted on the water wheel the following conclusions are drawn:

(i) Water wheel with eight cups of 30 cm x 7 cm x 2 cm in take compartment was found to be the most efficient under the field conditions. A maximum efficiency of 48% was obtained at 0.23 m of submergence depth.

(ii) The device can lift water without additional operating cost as long as the mean stream velocity is greater than or equal to 0.44 m/sec for the optimum depth of submergence at 23 cm.

(iii) The optimum discharge of the system is 19.2 lpm at 0.6 m head.

(iv) Use of this water lifting device at the remote village level will reduce the use of human energy and ensure higher crop yield.

(v) The device can be locally fabricated using easily available materials and is very economical.

(vi) The annual operating and maintenance cost are low.

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Appendices

Appendix I
Performance and Adaptability of Commonly used Indigenous Water Lifts

Name of device	Kind of power	Lift m	Average discharge l/h	Remarks
Swing basket	Two men	0.5 - 1.2	7,000-10,000	Used in rice-growing belts in developing countries
Oscillating trough (Don)	Single man	0.5 - 1	9,000-14,000	Commonly used in the eastern region of India, Bangladesh
Archemediam screw	One or two men	0.5 - 1.2	14,000-19,000	Commonly used in the Godavari delta of Andra Pradesh (India) and in Lower Egypt.
Water wheel (animal operated)	One pair of bullocks (or single camel/ buffalo) and one man	0.8 - 1.2	40,000-60,000	Commonly used in the canal- irrigated areas of north India, to lift water from water courses which run below field level.
Persian wheel	One pair of bullocks or buffaloes, or single camel and one man.	5 - 10	14,000-18,000	Traditional water lift in northern India, Pakistan, Iran, Iraq and Egypt.

Name of devices	Kind of power	Lift m	Average discharge l/h	Remarks
Animal - operated chain pump	One pair of bullocks and one man	3-6	15,000 - 20,000	Used in some parts of Uttar Pradesh
Self -emptying type rope and bucket lift	One pair of bullocks and one man	4-6	10,000 - 15,000	Commonly used in Southern India, the Deccan region and parts of Rajastan
Circular two - bucket lift	Single bullock and one man	4-5	12,000 - 14,000	Used in some parts of Tamil Nadu
Counterpoise-bucket lift	Single man	1.2-4	8,000 - 11,000	Commonly used in Southern India, Bihar and the Deccan region. Extensively used in Egypt, Sudan and other developing countries.
Leather bucket lift (Mhote or charas)	Two Pairs of bullocks and three men	10-30	6,000 - 10,000	Commonly used in Rajastan Maharashtra and other areas with deep water table.

Source : Michael and Khepar, 1989.

Appendix II

Design of centre shaft of the water wheel

The momentum of water moving in the form of a jet - WQV/g, where W is the unit weight of water (1000kg/m^3), Q is the discharge (m^3/sec), V is the velocity of jet (m/sec) and g is the acceleration due to gravity (9.81m/sec^2). If this jet is made to impinge on moving plate, moving with velocity V_1 m/sec, the relative velocity of the jet with respect to the plate is equal to $(V - V_1)$ m/sec. Then the force (F) on the plate by the jet is given by the expression,

$$F = \frac{WQ\,(V - V_1)}{g}$$

When water strikes on the flat plate of the water wheel, the initial velocity of the plate is assumed as zero.

i.e. $V_1 = 0$

Let A = Maximum cross sectional area of the water flow impinging on cup (Vane), sq.m.

= 0.3 m x 0.25 m

V = Maximum velocity of water flowing in canal, m/sec

= 0.75 m/sec.

Q = Total discharge,

= A.V.

= 0.3 x 0.25 x 0.75 = 0.056 m^3/sec

Hence,

Force on the plate, $F = \frac{WQ}{g} (V - V_1)$

$$= \frac{1000 \times 0.056 \ (0.75-0)}{9.81}$$

$$= 4.28 \text{ kg.}$$

If the distance from the centre line of the plate to the axis of the wheel is Y metre and the total force on the plate by the jet is F kg., the total torque T on the shaft is;

$$T = F.Y$$

Here, F = 4.28 kg. and $Y = 0.5$m

$$T = 4.28 \times 0.5 = 2.14 \text{ kg.m}$$

The shaft size based on torque (M_t) alone is given by the relation (PSG - TECH, 1978),

$$M_t = \frac{\pi d^3}{16} \tau$$

Where d = Shaft diameter, m

τ = allowable shear stress, kg/m^2

M_t = twisting moment or torque, kg - m

The shaft is made of mild steel, for which a safe shear stress of 3×10^6 kg/m^2 is assumed (Michael and Khepar, 1989).Twisting moment or torque (M_t) is assumed as torque T, due to water force.

Hence,

$$M_t = T = 2.14 \text{ kg.m}$$

Substituting these values in the relation of M_t,

$$\text{Shaft diameter, } d = \sqrt[3]{\frac{16 \times M_t}{\pi \times \tau}}$$

$$= \sqrt[3]{\frac{16 \times 2.14}{\pi \times 3 \times 10^6}}$$

$$= \underline{\underline{0.015}} \text{ m.}$$

$$= \underline{\underline{1.5}} \text{ cm.}$$

This shaft diameter of 1.5cm satisfies the requirements of torque only. With a view to satisfy the requirements of the bending moment and availability in the local market, 2.5cm diameter shaft is selected.

Appendix III

Specifications of the low cost Water Wheel

1. Function : To lift water from streams or canals to the near by cultivable lands

2. Specifications

Overall length	: 1455 mm
Overall width	: 555 mm
Overall height	: 1000 mm
Weight	: 16 kg

Centre Shaft

Length	: 485 mm
Diameter	: 25 mm
Material	: Mild steel

Bearings

Number	: Two
Type	: Ball bearing
Size	: 63-0-5

Cups (Wings)

Number	: 8 and 6
Size	: 300 mm X 250 mm
Intake compartments	: 300 mm X 100 mm X 10 mm, 300 mm X 50 mm X 10 mm & 300 mm X 70 mm X 20 mm
Outlet compartment	: 300 mm X 50 mm X 10 mm
Outlet hole	: 10 mm X 10 mm with a projection of 10 mm
Material	: Tin sheet

Cup holding frame

Section	: 12 mm Square
Length	: 460 mm
Width	: 300 mm
Material	: Aluminium pipe

Circular disc

Number	: Two
Diameter	: 200 mm
Thickness	: 3 mm
Material	: MS Sheet

Provision for attaching 8 and 6 cups radially 45^{o} or 60^{o} apart is given by making two sets of holes of 6 mm diameter.

Supporting frame

Overall length	: 1460 mm
Overall width	: 560 mm
Height	: 350 mm
Type	: MS Z - angle

3. Other Details

1. Portable/stationary	: Portable
2. Power Source	: Flow velcity of canal water.
3. Labour requirement	: Nil
4. Capacity	: Optimum discharge of 19.2 lpm at 0.6 m head
5. Lift obtained	: 0.6 m

6. Maximum rotational speed : 6 rpm

7. Minimum flow velocity required : 0.44 m/sec.

8. Maximum efficiency : 48%

9. Investment cost : Rs.800.00

10. Operating cost : Rs.204.00

Appendix IV

Cost of Operation of the low cost water wheel

Total operating cost of water wheel = Fixed cost + Variable Cost.

Cost of major components	Rs. Ps.
M.S. Rod	- 125 - 00
Ball bearings (2 Nos)	- 170 - 00
Aluminium (square) pipe	- 35 - 00
Tin Sheet	- 52 - 00
Cost of miscellaneous items of frame work	- 150 - 00
Total material cost	- Rs.532.00
Overhead charges @ 10% of material cost say,	- 68.00
Fabrication cost	- 200.00
Total cost of water wheel (P)	- Rs.800.00

Assumptions :

a. Life of the water wheel (L) - 5 years

b. Salvage value (S), - 3% of the cost of the water wheel

i.e. - Rs. 24.00

c. Annual interest rate 10% of the cost of the water wheel

I. Fixed cost

1. Depreciation/year $= \frac{P - S}{L}$

$= \frac{800 - 24}{5}$

= Rs. 155.20

2. Annual interest cost $= \frac{P + S}{2} \times i$

$= \frac{800 + 24}{2} \times \frac{10}{100}$

= Rs. 41.20

3. Taxes and Insurance = Nil

4. Housing charges = Nil

∴ Total fixed cost/year = 155.20 + 41.20

= Rs.196.40

II. Variable cost

1. Labour charges = Nil

2. Energy cost = Nil

3. Repair and maintenance cost @ 5% of initial cost of the water wheel/year $= \frac{P}{L} \times \frac{5}{100}$

$= \frac{800}{5} \times \frac{5}{100}$

∴ Total variable cost = Rs. 8.00

Total operating cost		= Fixed Cost + Variable Cost
		= 196.40 + 8.00
		= Rs. 204.40
	Say	= Rs. 204.00

DEVELOPMENT AND PERFORMANCE EVALUATION OF A LOW COST WATER-WHEEL FOR LIFTING WATER AT LOW HEADS

By

JAYAN. P. R.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirements for the degree

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ABSTRACT

A low cost water wheel was designed, fabricated and tested in the distributory canal of KCAET farm, Tavanur. The device is operated by the stream current with no additional power source and was tested for different submergence depths varying from 0.12 to 0.25 m. Water wheel with eight cups of 30 cm x 7 cm x 8 cm intake compartment was found to be the most efficient under various operating conditions. A maximum efficiency of 40% was obtained at 0.23 m of submergence depth. The device can lift water without additional operating cost as long as the mean stream velocity is greater than or equal to 0.44m/sec for the optimum depth of submergence at 23 cm. The corresponding discharge of the system is 19.2 lpm at 0.6 m head. The investment cost of the device is Rs. 800/- and the annual operating cost is Rs.204/- with low maintenance cost. Though the power output and the discharge capacity were low, it has a two fold advantage of functional reliability and simplicity of design and fabrication at village level. It can successfully be utilised by the small farmers when the cultivating fields are adjuscent to the canal water courses.