STUDIES ON THE EFFECTS OF VARIOUS PARAMETERS ON THE PERFORMANCE OF 'PETTI AND PARA'

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Technology in Agricultural Engineering

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DECLARATION

I hereby declare that this thesis entitled "Studies on the Effects of Various Parameters on the Performance of Petti and Para" 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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CERTIFICATE

Certified that this thesis entitled "Studies on the Effects of Various Parameters on the Performance of Petti and Para" is a record of research work done independently by Miss Saji M. Kuriakose 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 Miss Saji M. Kuriakose, a candidate for the degree of Master of Technology in Agricultural Engineering with major in Soil and Water Conservation Engineering, agree that the thesis entitled "Studies on the Effects of Various Parameters on the Performance of Petti and Para" may be submitted by Miss Saji M. Kuriakose, in partial fulfilment of the requirement for the degree.

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SYMBOLS AND ABBREVIATIONS AND SYMBOLS

Ag. Engg.	-	Agricultural Engineering
CAPART	-	Council for Advancement of People's Action and Rural Technology
cm	-	centimetre(s)
E	-	Efficiency of 'petti' and 'para'
Engg.	-	Engineering
Engrs.	-	Engineers
et al.	-	and others
Fig.	-	Figure
H	-	Head
ha	-	hectare(s)
hr	-	hour(s)
HP	-	Input power
hp	-	horse power
IRRI	-	International Rice Research Institute
KAU	-	Kerala Agricultural University
km	-	kilometre(s)
lit	-	litre(s)
lps (l/s)	-	litre(s) per second
m	-	metre(s)
MSL	-	Mean sea level
mm	-	millimetre(s)

Proc	-	Proceedings
Pub.	-	Publication
Q	-	Discharge
rpm	-	revolutions per minute
WHP	-	Water horse power
%	-	Per cent

DEFINITION OF VERNACULAR WORDS USED IN THE THESIS

Chakram	-	a manually operated low head water lift consists of wooden blades mounted radially on a horizontal shaft, used in Kuttanad. It is also known as paddle wheel.
Padasekharam	-	a group or block of rice fields enclosed with in the bunds to protect it from inundation.
Para	-	a cylindrical wooden drum used as suction casing of the 'petti' and 'para' pump.
Petti	-	a rectangular wooden box used as the delivery of the 'petti' and 'para' pump.
Petti and para	-	a crude form of axial flow propeller pump used widely in Kuttanad.
Punja	-	the traditional rice crop in Kuttanad cultivated normally from November to March.

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Introduction

INTRODUCTION

Rice production in the coastal regions of India and other countries in South and South-East Asia is profoundly influenced by appropriate water management practices, especially the drainage requirement. Coastal deltaic regions have been identified as rice bowls and account for a major part of rice production in the region. Kuttanad region of Kerala, which is considered as the rice bowl of the state, has very specific requirements in relation to drainage and other water management practices,to obtain a high level of sustained agricultural production. Kuttanad is a low-lying area which originally was a part of the shallow coastal area of the Arabian sea.

The total area of Kuttanad tract is 1100 km^2 (1,10,000 ha) and is spread over Alappuzha, Kottayam and Pathanamthitta districts of Kerala. It comprises of three distinct topographic units: the garden lands (dry lands), wet lands and water spread areas which include submerged lands, canals and lakes. The garden lands vary in elevation from 0.50 to 2.50 m above MSL and are about 31,000 ha in area. The wet lands include low lying areas slightly above MSL (11,000 ha) and also areas with elevations ranging from 0.60 to 2.10 m below MSL (55,000 ha) reclaimed from the lagoon. Lakes, rivers and channels make up the remaining 13,000 ha as water spread areas.

Due to extensive flooding of the region commencing from the onset of the South-West monsoon upto to the withdrawal of North-East monsoon, the area is practically unsuitable for cultivation during this period. However, the fertile soils of the lake beds are highly productive and are suitable for rice cultivation during the intervening period, namely between the withdrawal of the North-East monsoon and the onset of South-West monsoon.

Non-monsoon period rice crop in Kuttanad locally called the 'punja' crop, has distinct water management requirement. The water-logged lands have to be drained in the shortest possible time to initiate seed bed preparation. The short time available for seed bed preparation need adoption of high discharge low head pumps.

The first attempt for large scale drainage pumping in Kuttanad has been the introduction of an adaptation of an axial flow propeller pump called "petti and para" in the year 1918 AD by George Brendan, a British Engineer. Brendan introduced the device utilizing locally available fabrication facility which confined to the blacksmithy and carpentry prevailing in the region. The device grew in popularity and spread over the entire region during 1920's. It is still the only type of pump widely used for dewatering which is capable of giving a high discharge at low head operating conditions.

"Petti and para" device, though meeting the requirement of pumping is highly inefficient in terms of energy consumption. No serious attempt seem to have been made for an effective evaluation of the pumping unit and the development of design or selection criteria for improving the performance of the device. The present work has been an attempt to study the working of the pump under widely varying situations and to evaluate its performance.

The specific objectives of the study are:

1. Optimising the speed of operation of the pump for maximum efficiency.

2. Evaluate the efficiency of the pump for various designs of the impeller

3. Performance evaluation of the pump at different submergence levels

The hydraulic performance of 'petti and para' is carried out at the specially designed and constructed test bed at the Kerala Agricultural University Headquarters, Vellanikkara.

Limitations of the study

Since the present study was conducted as a part of the post-graduate research programme, the study had the inherent limitations in terms of time and coverage. Being a post-graduate research work, the study had to be completed within the period of two years along with course work.

Since the procedure involved for attainment of third objective would take up more time than that available within two years, would require the involvement of lot of manpower and the necessary physical conditions were not feasible, it was decided to drop the third objective.

Review of Literature

REVIEW OF LITERATURE

2.1 Works done on axial flow pumps

Kaplan (1935) observed that for a given wetted area of the vane, the number of vanes should be minimum. With heavy vanes and low chord angle, the maximum number of vanes is almost fixed since adding vanes will restrict the free area of flow.

Schlimbach (1935) studied the performance of a four-vane impeller, with different vane settings. The vane curvature B_2-B_1 or vane camber, remained the same, the discharge angle B_2 and the inlet angle B_1 being changed by the same amount. The same head produced for all vane settings and thus is a function of vane curvature alone. Thus although the tangential component at the impeller discharge was higher at higher values of B_2, the tangential component at inlet increased by approximately the same amount. The peripheral velocity being the same at inlet and outlet no change in head resulted. Efficiency was good over a wide range of capacities.

Eckert (1944) tested two axial flow impellers, one with airfoil vanes well streamed and polished, the other of the same solidity and camber line but made of stamped steel sheet welded to the hub. The performance of the two impellers proved identitical. Later he observed that another impeller of the same airfoil pattern, but made of cast iron with the trailing edge about one-third thick, was lower in efficiency. The efficiency reduction was caused by the greater relative roughness of the cast iron vanes as compared to the polished alloy vane.

Stepanoff (1957) designed a 61 cm adjustable vane axial flow pump in which the adjusting mechanism was arranged external to the pump. Except for the impeller the rest of the pump parts were the same as those of pumps, which have one piece impellers. The pump tests showed that, a 25 per cent reduction in capacity resulted in over 50 per cent saving in power. The pump could be started with the discharge valve closed and when the impeller vanes were flat, the pump required about 25 per cent of the maximum rated brake horse power.

The comparison of the performance of 35 cm elbow type axial flow pump with no diffuser vanes and that of an axial flow pump with vaned diffuser was also made. When the pump was tested with vaned diffuser the maximum efficiency was 85 per cent where as in the case of pump without diffuser the maximum efficiency was 76 per cent. A reduction of head and brake horsepower was noted for both the pumps at partial capacities caused by the fact that in an elbow type axial flow pump liquid rotation is not prevented by the pump. In this respect the shape of the inlet pipe has a marked effect on the pump performance at partial capacity.

Addison (1976) conducted a series of tests on axial flow pumps at speed constants between 2 and 2.7. When the speed constant was 2, efficiency was 56 per cent with a discharge rate 86.0 lps against a head of 2.6 m. When the speed constant was 2.7, efficiency improved to 57.2 per cent at a discharge of 84 lps against a head of 2.6 m.

The International Rice Research Institute, Los Banos, Philiphines (1979) designed and developed a portable axial flow pump which may be coupled to a 5 hp engine or on a power tiller. The discharge rate of the pump varied from 25 to 50 lps at heads ranging from 4 m to 1 m when driven by a 5 hp engine. The pump inlet was flared at 30° for low entrance losses. For improved efficiency the pump was provided with a vaned diffuser and the pumping tests gave a maximum efficiency of 69.1 per cent at a discharge rate 44.8 lps against a head of 2.5 m at 2890 rpm.

Calilung <u>et al</u>. (1982) measured the capacities of an axial flow pump 15 cm diameter and a centrifugal pump 10 cm diameter, for conditions of low lift (1m-3m) to compare their relative performance. Each pump was driven by the same 5 HP gasoline engine at approximately the same load. The test results showed that the capacity of the axial flow pump was between 2 to 3 times greater than that of the centrifugal pump for lifts between 2.80 and 1.07 metres. However based on an extrapolation of their capacity performance curves, it was estimated that the two pumps have approximately the same capacity at 4 m lift. Economic considerations of the results illustrated that substantial fuel saving could be gained by using an axial flow pump in place of a centrifugal pump for low lift applications. Moreover it was shown that the fixed cost of the two pumping units are approximately equal, because the longer life of the centrifugal pump is counter balanced by its shorter engine life.

Department of Agricultural Engineering, College of Technology, Pantnagar (1982) developed a propeller pump for a discharge rate of 30 to 65 lit/sec at heads varying from 3 to 1 m. The pump with 22 cm diameter impeller was provided with a diffuser tapering from 22 cm to 30 cm diameter. The efficiency of the pump varied from 50 to 65 per cent at a discharge rate of 65 to 45 lps against head of 1 m to 2 m at 1440 rpm. The power source was a 5 hp electric motor. Later a three vaned propeller was designed with a view to increase the pump discharge. The diameter of the propeller was 30 cm.

It was provided with a four vaned diffuser tapering from 30 cm to 37.5 cm in dia and 45 cm long. The pump was tested at 1440 rpm using 15 hp electric motor. The pumping tests gave discharge rates of 87 to 122 lit/sec against heads of 3 to 2 m and the efficiency varied from 29 to 32 per cent.

Chetty (1983) designed a low lift high volume pump taking into account prerotation and vortex free or forced condition by considering the Euler's head. The four impellers developed were the impeller with or without pre-rotation under forced vortex condition, or with or without prerotation in the free vortex conditions of aerodynamic nature. The design features included hub ratio of 0.4, speed constant of 1.98 capacity constant of 0.432, head coefficient of 0.128, capacity coefficient of 0.218 and specific speed of 188, to discharge water at the rate of 24.7 lps for a design head of 3.65 metres. The flow indices of speed constant, capacity constant, head coefficient and capacity coefficients were compared for different speeds for, one-fourth, half and full

delivery openings and the pump with the optional provision of diffuser, with a view to investigate their performance characteristics, in order to choose an appropriate design. The impact of delivery opening was distinctly noticed and the full open position alone was found to suit the design conditions. Based on the investigations the free vortex impeller with prerotation and with the diffuser was identified as the unique one which could meet the design speed constant, capacity constant, head coefficient and capacity coefficients. The discharge that could be attained with this pump under a total head of 4.3 metres was 193 lps under full open condition resulting a specific speed of 155.

Sasi (1984) designed and developed a propeller pump with three bladed impeller and specific speed of 250 rpm. The pump was tested at two water levels above the impeller, one 20 cm above the impeller and the other 10 cm above the impeller. For the above two cases at the designed head of 1.5 m the efficiencies obtained were 33 per cent and 29.5 per cent corresponding to discharge rates 121 lps and 114 lps. The maximum efficiency obtained at these two water levels were 33.07 per cent and 29.61 per cent against the total heads of 1.41 m and 1.54 m respectively at the discharge rates of 124.88 lps and 114.1 lps. The maximum working capacity was 165.19 lps against a head of 1 m with an efficiency of 31.95 per cent.

Taneja and Kaushal (1986) designed and fabricated two types of propeller pumps - inclined propeller pump and vertical propeller pump. The inclined pump was able to lift water at the rate of 44 to 35 lps against total head ranging from 1.2 to 2.9 m and correspondingly the efficiency varied from 50 per cent to 80 per cent at 2600 rpm. When operated at 3000 rpm it delivered water at the rate of 56.3 to 43 lps. for heads of 1.67 to 3.68 m and the efficiency varied from 57 to 83 per cent. The pumping tests on vertical propeller pumps showed that at 2800 rpm, the discharge varied from 32 to 19 lit/sec at static heads ranging from 84 cm to 250 cm. The efficiency of the pump was found to vary from 65 per cent to 31 per cent.

Anilkumar *et al*. (1987) designed and fabricated an axial flow pump for a discharge of 250 lps and head 2 m. The wooden parts of the conventional model of 'petti and para' were replaced by cast iron and mild steel. The petti was made of angle iron and mild steel sheets. The para was made from cast iron sheet metal. The pump was tested at 960 rpm and 730 rpm. At 730 rpm the discharge of the pump varied from 168 lps to 210 lps against total heads of 98.5 to 160 cm and the efficiency obtained varied from 28.64 to 24.78 per cent. The maximum efficiency obtained was 28.72 per cent, at a discharge of 176.5 lps, and against a head of 152.5 cm. At 960 rpm the maximum efficiency was 23.89 per cent at a discharge of 258.5 lps, and the total head was 152.5 cm.

Abraham (1988) conducted a field survey and collected information on the general characteristics of 'petti' and 'para'. Field pumping tests were conducted on 15 hp and 20 hp 'petti' and 'para' using standard methods. The experiments on 15 hp petti and para showed that the unit was capable of discharging 217.75 to 143.63 lps against a head variation of 65.44 to 100.11 cm with efficiency varying from 21.19 to 18.16 per cent. The experiments on 20 hp petti and para showed that the unit could deliver water at a rate of 369.5 to 281.2 lps against a total head of 73.2 cm to 132 cm with efficiency ranging from 21 to 26 per cent. Later a propeller pump was designed and fabricated considering the specific requirements of Kuttanad. The pump was designed as a high specific speed pump operating at 1900 rpm. When tested at a constant static head of 120 cm it delivered 39.64 to 13.34 lps against a total head of 183.1 cm to 283.02 cm and corresponding efficiency ranged from 23.72 to 9.6 per cent. The power unit was a 10 hp induction motor.

2.2. Theoretical considerations

2.2.1 Basic theory

In an axial flow pump water enters axially and leaves the impeller axially or in a direction parallel to the shaft. In this case no centrifugal head is impressed on water by centrifugal force. But pressure is developed by the flow of liquid over the blades.

Typical velocity triangle is shown in Fig.2.1. The blade inlet angle is so designed that the water enters axially without any shock. The rotating impeller imparts a whirl component at the exit. There is a great variation in velocity of the blade at different radii and so the hydraulic conditions are not the same at all radii.

The usual range of specific speeds covered by axial flow pumps extends from 10,000 to 15,000. Axial flow pumps having specific speeds lower than 10,000 have been designed, but they cannot compete with mixed flow impeller design in efficiency. Also they lead to very high values of shut off brake horse power and undesirable cavitation characteristics. Specific speed above 15,000 are possible, but the peak efficiency will not be higher than that of pumps with a specific speed of 15,000 operating at capacities above the normal. Axial flow air blowers are designed for specific speeds as low as 5000, but they are built as multistage units to obtain a maximum possible pressure to compete with centrifugal compressors in price size and efficiency. Multistage axial flow pumps, however, would not be commercially valuable.

2.2.2 Theoretical head

The fundamental Euler's energy transfer equation for the pump is obtained from the principle of torque and angular momentum.

The liquid enters the vane at (1) (Fig.2.1) and leaves the vane at (2), the relative velocities Vr_1 and Vr_2 being tangential to the vane at inlet and outlet respectively, and make angles B_1 and B_2 with the positive direction of the peripheral velocity U is measured clockwise called vane angles. V_1 and V_2 are the absolute velocities of the liquid entering and leaving the vane. The absolute velocity V is the vector sum of the relative velocity and peripheral velocity both at inlet and outlet.

Torque exerted by the impeller on the fluid = Angular momentum at (2) - Angular momentum at (1)

i.e. $T = \rho Q (Vw_2 r_2 - Vw_1 r_1)$ where

ρ - Density of liquid

Q - Mass of liquid entering per second

Vw_1 and Vw_2 are the whirl components of the absolute velocity at inlet and outlet respectively. Since the water enters axial direction there is no whirl at inlet.

OR $Vw_1 = 0$

i.e. $T = \rho Q (Vw_2 r_2)$

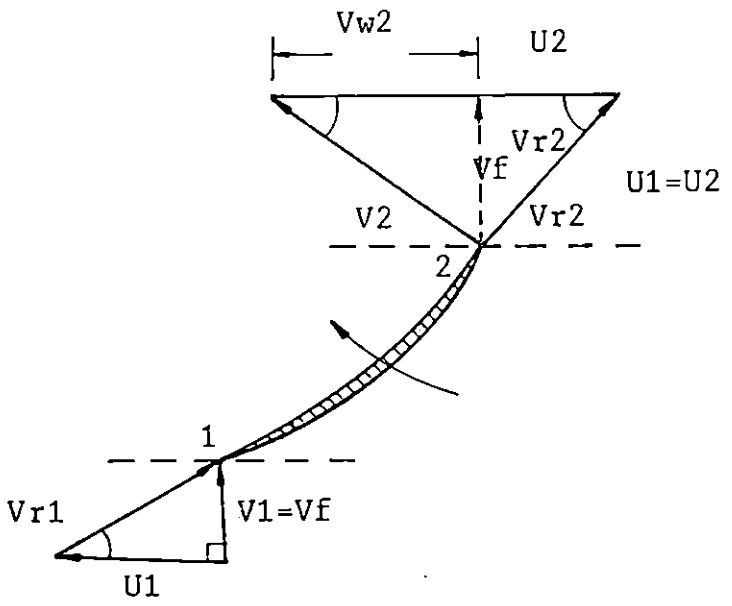


FIG.2.1 VELOCITY TRIANGLES AT INLET AND OUTLET OF AN AXIAL FLOW IMPELLER

Power transferred from impeller to water P $= Tw = \rho Q\,(Vw_2 r_2\, w)$

where

w - Angular velocity

Since $U_2 = r_2 w$

The theoretical head imparted to the fluid Hth $= \frac{P}{YQ} = \frac{1}{g} U_2\, Vw_2$

where

Y - specific weight of liquid

2.2.3 Experimental design factors

There are a number of design elements of axial flow pumps which do not enter into theoretical discussion although they affect directly the performance of the axial flow impeller. These include (1) hub ratio, (2) number of vanes, (3) vane thickness, (4) turning of vanes on the hub and (5) pump casing, with or without diffusion vanes.

Selection of any of these design elements depends upon experience. Correlation of test information, on the basis of specific speed shows a definite pattern consistent with that of lower specific speed centrifugal and mixed fixed flow pump. As more test data are accumulated, it depends upon the skill of the designer to discern the effects of these several variables, leading to the optimum hydraulic performance.

Impeller hub ratio is the ratio of the hub diameter to the impeller outside diameter, which is directly connected with the specific speed of axial flow pumps. This ratio is established experimentally. Higher specific speed pumps have smaller hubs, which give a greater free area for the flow and a smaller diameter to the average stream line, resulting in greater capacity and a lower head. Figure 2.2 gives hub ratios for various specific speeds compiled from a number of modern axial flow pumps and blowers. The hub ratio is the most important design element controlling specific speed of the axial flow impeller. The ratio of the vane chord length to the vane spacing, which is the chord spacing ratio is another important design element, which is selected on the basis of previous experience. For axial flow pumps of specific speeds of 10,000 and higher the chord spacing ratio l/t is less than unity. The ratio varies along the radius, increasing towards the hub. This increase in chord spacing ratio at the hub is desirable for mechanical reasons.

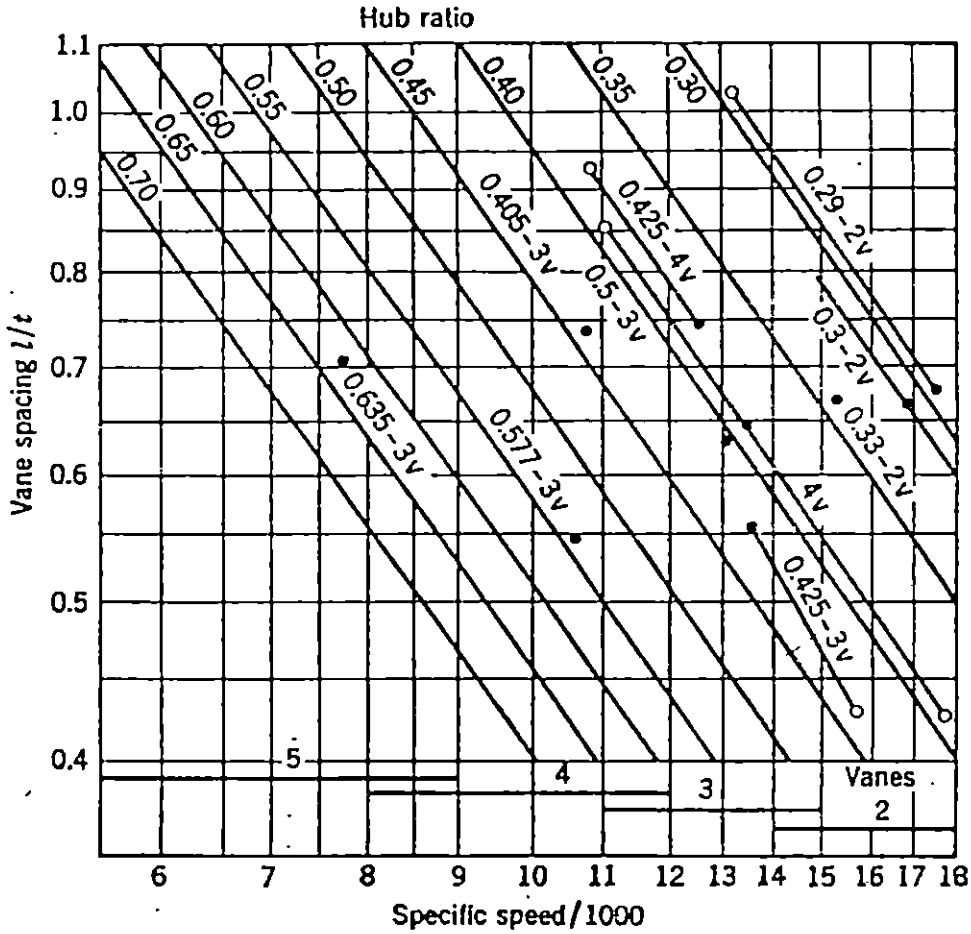


FIG. 2.2 HUB RATIO, NUMBER OF VANES, AND l/t RATIO FOR AXIAL FLOW PUMPS

STEPANOFF (1967)

Materials and Methods

MATERIALS AND METHODS

During the very early part of the twentieth century, dewatering the Kuttanad field was done with the age old manually operated paddle wheel called "Chakram". The device consumed large amount of time and labour to dewater even small blocks of land. The introduction of drainage pumps, 'petti and para' in 1918 AD changed the entire scenario of rice cultivation in Kuttanad. This facilitated reclamation of larger blocks of land and the cultivation extended to larger areas.

3.1 Brief description of 'petti' and 'para'

The 'petti' and 'para' (Fig.3.1) consists of a rotating impeller housed inside a cylindrical wooden drum called 'para'. By the rotation of impeller the accelerated water flows axially upwards through the 'para', takes a 90° turn and flows out through a horizontal rectangular wooden outlet called 'petti'.

The impeller with the shaft is suspended from a thrust bearing which rests on a stand tube (Fig.3.2). Additional wooden planks are provided over the 'petti' to bolt the housing to the 'petti'. Thus the entire axial load is

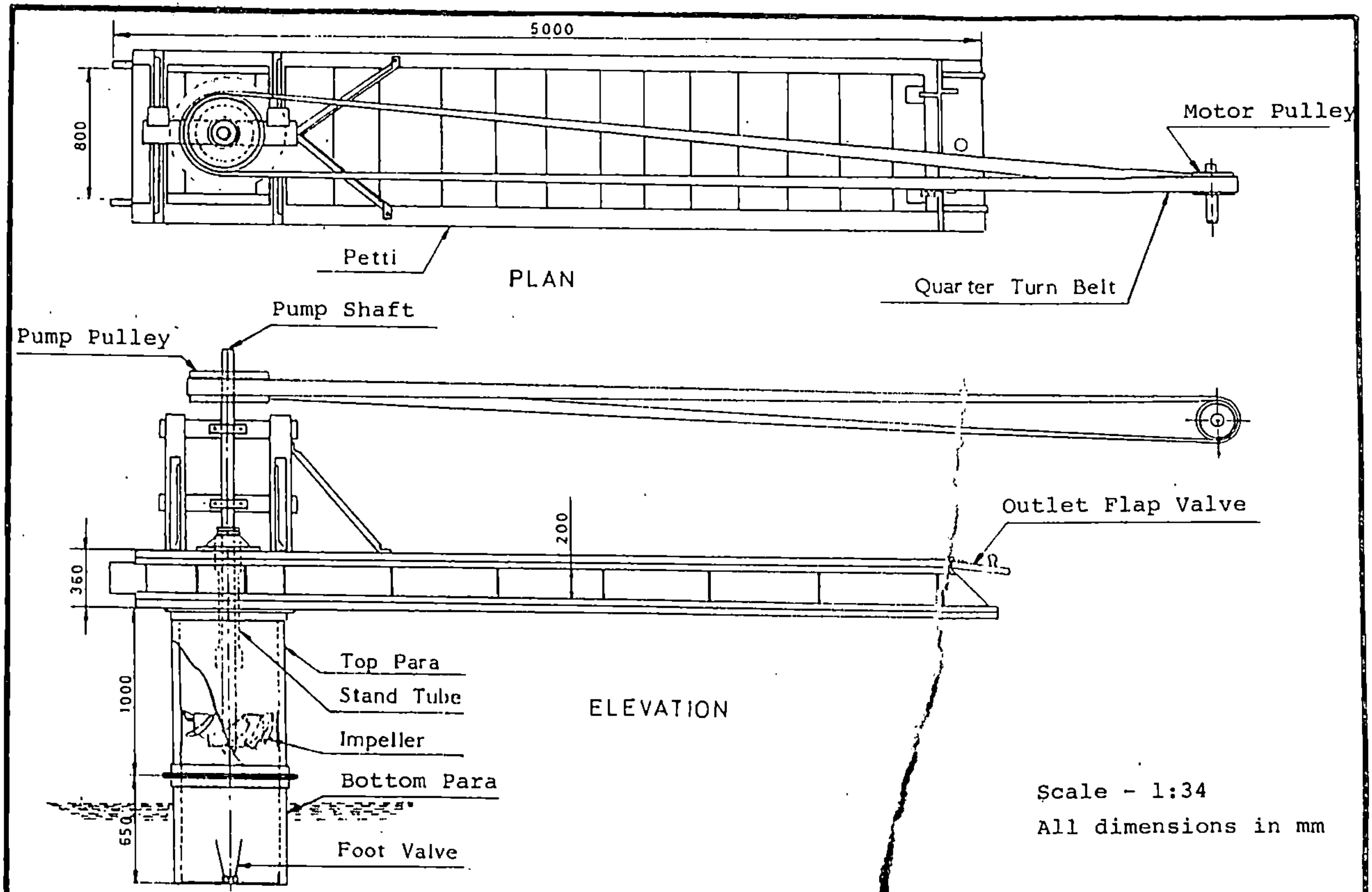
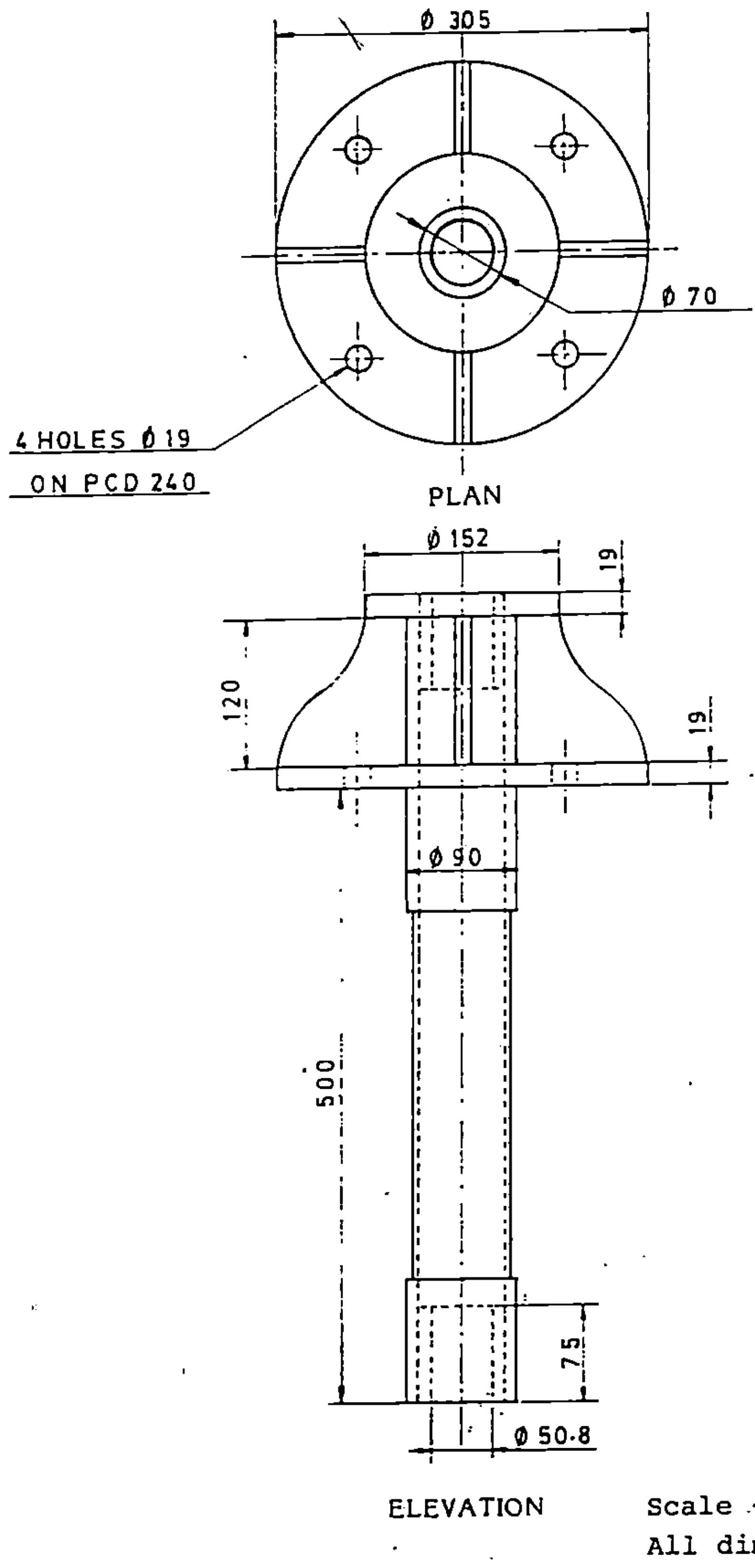


FIG. 3.1 VIEWS OF A TYPICAL PETTI AND PARA



Scale - 1:5
All dimensions in mm

FIG. 3.2 VIEWS OF STAND TUBE

transferred to the pump base. The impeller hub is secured to the shaft with a sunk key and a nut. The vanes are made separately and are bolted to the hub. Two bolts are used to fix each blade to the hub.

The 'para' is in the form of a cylindrical wooden drum and is made out of wooden planks, which are tongued and grooved so as to make the 'para' water tight. The impeller is fixed to the shaft so that it is housed inside the top 'para' (Fig.3.3). The inside of top 'para' is lined with M.S. sheet where the impeller is positioned. This was for protecting the 'para' which is made of wooden planks, from rupture in case of failure of bearing. The bottom 'para' (Fig.3.4) is provided with a butterfly type M.S. foot valve for priming and the details of foot valve are shown (Fig.3.5). For this a M.S. ring is fitted at the bottom of the 'para' to which the foot valve is bolted. The foot valve is seated perfectly over the M.S. ring, without any leakage in order to avoid priming of the pump often.

The power transmission is achieved by means of quarter turn belt. A pulley is fixed on the top of the pump shaft for driving the pump. The shaft is held in position by means of bearings provided for the purpose, which are fixed on wooden planks. For this a wooden superstructure is provided which is bolted to the petty, by providing additional planks. For load

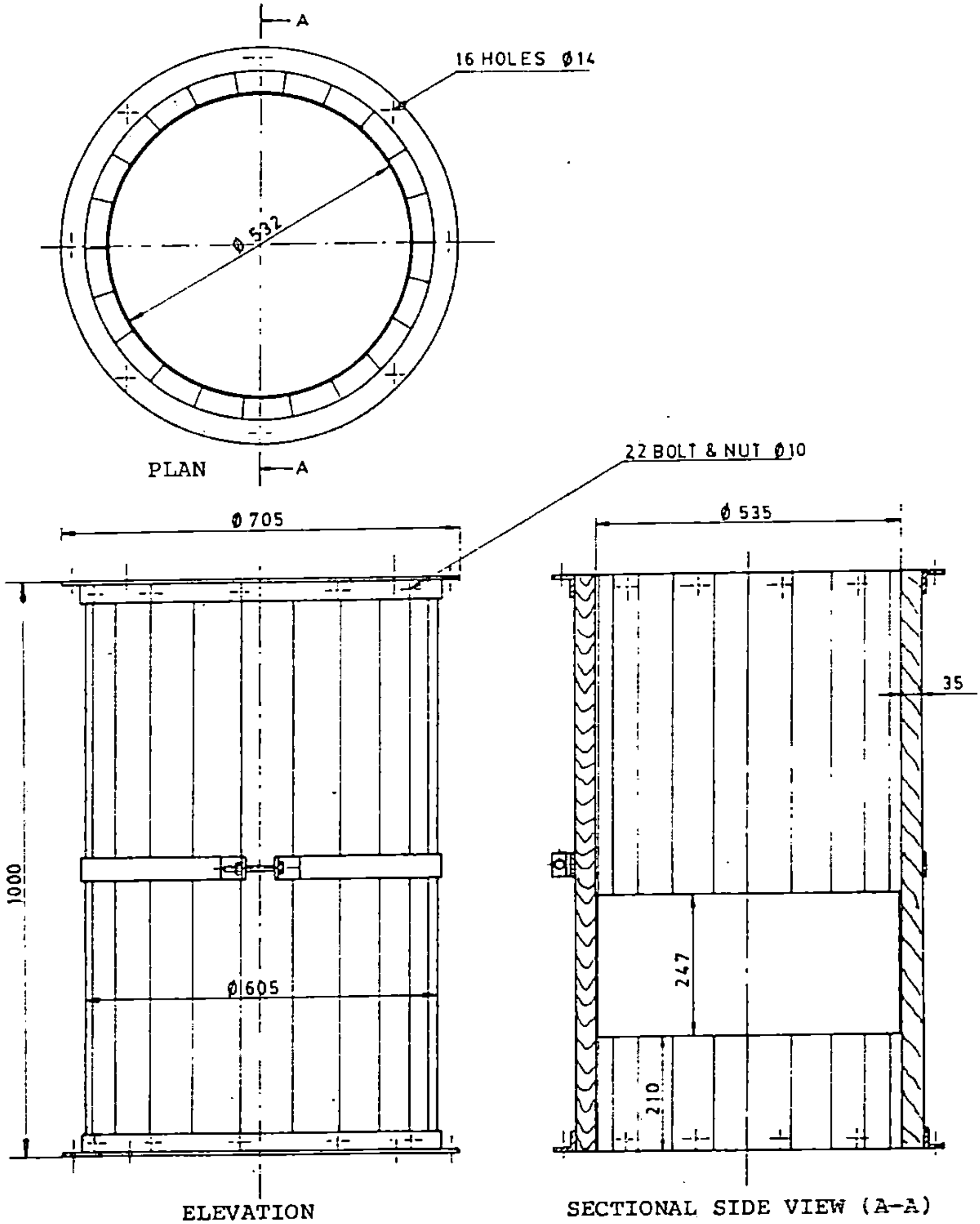


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FIG.3.3 VIEWS OF TOP PARA

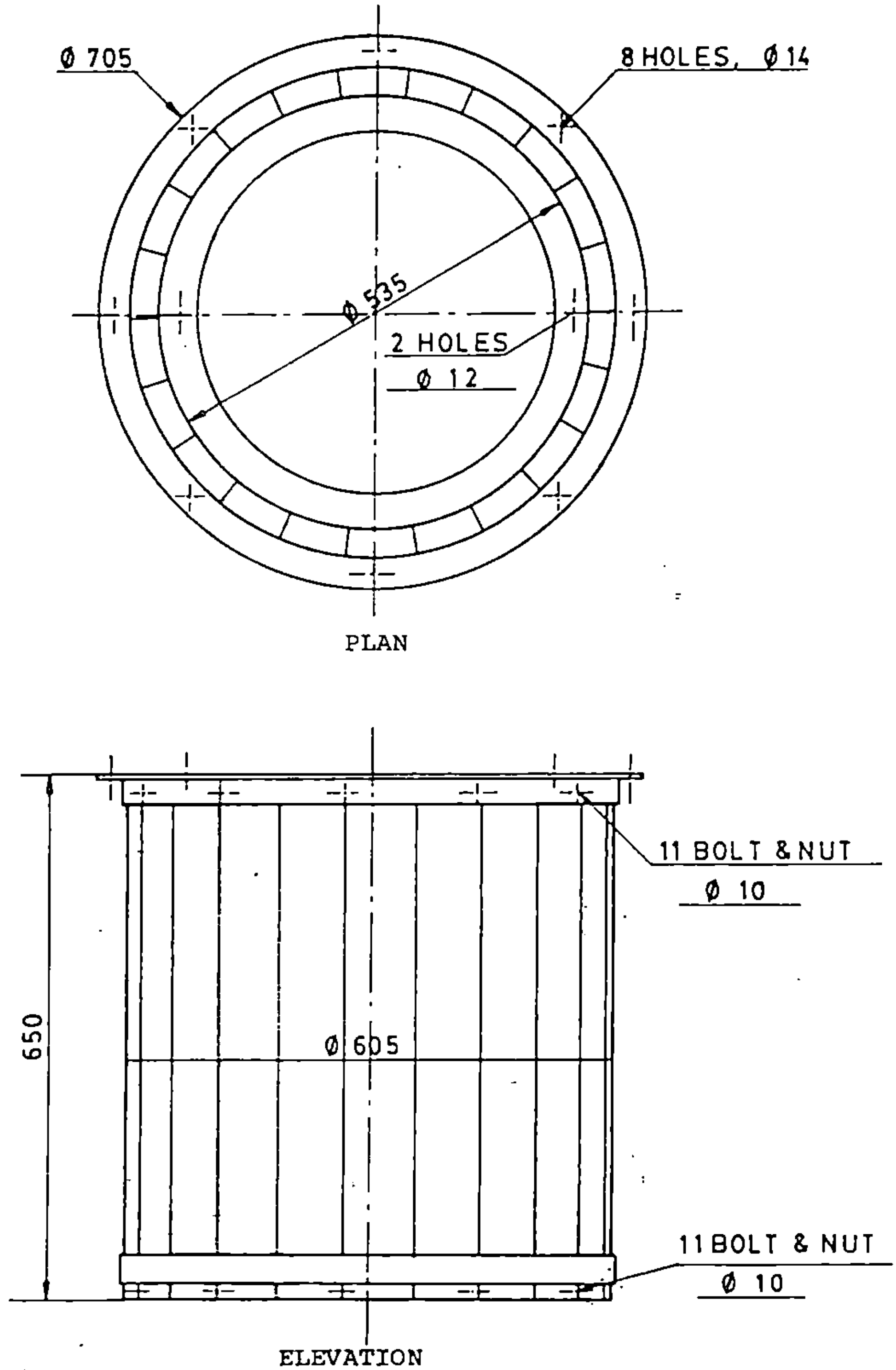

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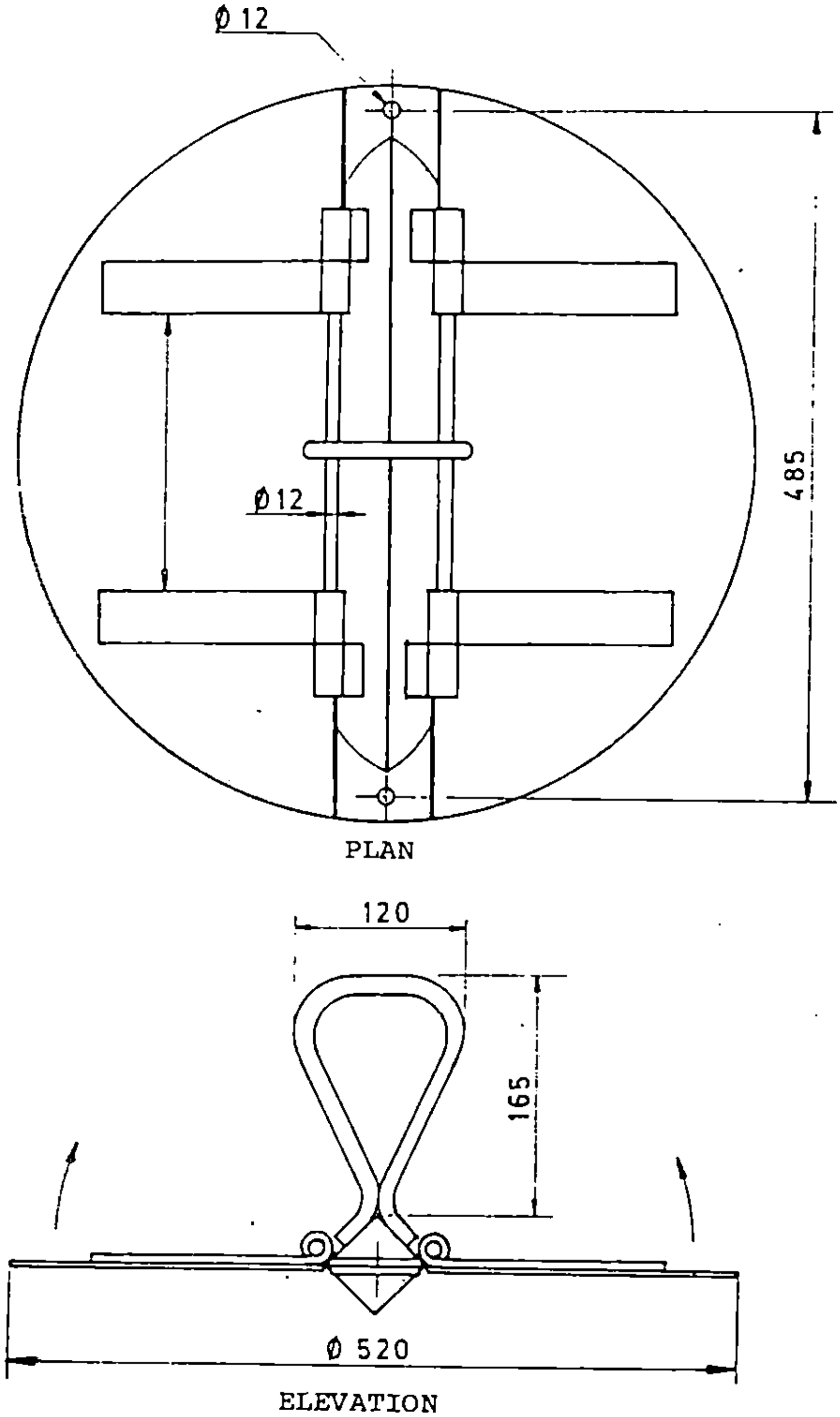
FIG. 3.4 VIEWS OF BOTTOM PARA



Scale - 1:5
All dimensions in mm

FIG. 3.5 VIEWS OF FOOT VALVE

distribution M.S. angles are provided on the wooden superstructure which are also bolted to the 'petti'.

3.2 Constructional details of 'petti' and 'para'

3.2.1 Impeller

The impeller consists of a cast iron hub (Fig.3.6) to which suitably shaped M.S. blades were fixed. The blades were fabricated separately and welded to M.S. pieces, which were then bolted to the hub through the holes provided for the purpose. Three impellers were fabricated with the number of blades four, five and six respectively (Plate 3.1, 3.2 and 3.3). However, for each impeller the hub diameter and impeller outer diameter were kept the same. The hub diameter was 25.4 cm and the impeller outer diameter was 52.9cm.

3.2.2 Shaft

Mild steel shaft of 25 mm diameter was used for the pumping unit. To suit the hub to the shaft the bottom end of the shaft was tapered. Below this, it was threaded to check the impeller by check nut.

3.2.3 Pulleys on pump side

The pulleys on the pump side were made from mild steel sheet. It was fixed on the shaft with two keys one at the top

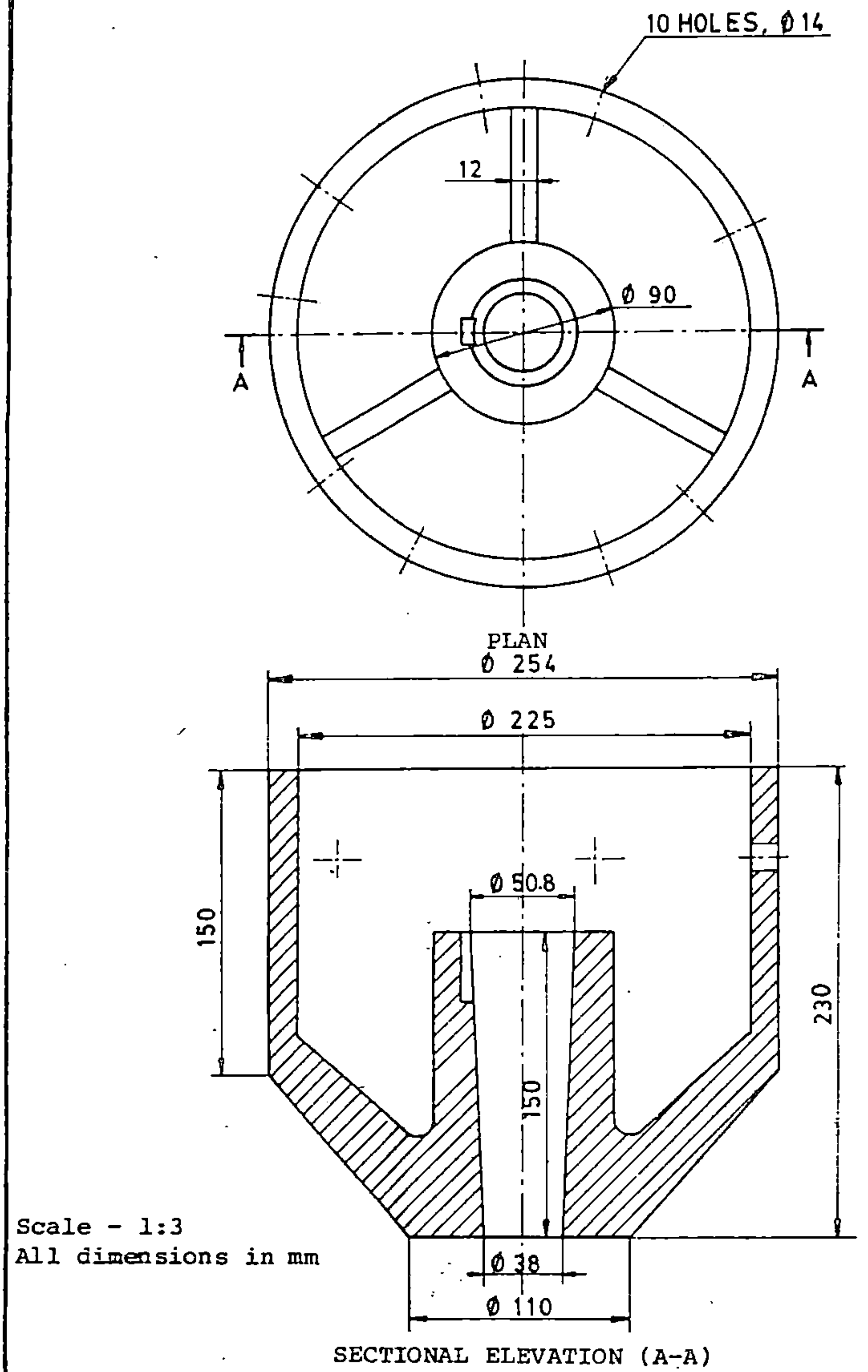


FIG. 3.6 VIEWS OF IMPELLER HUB

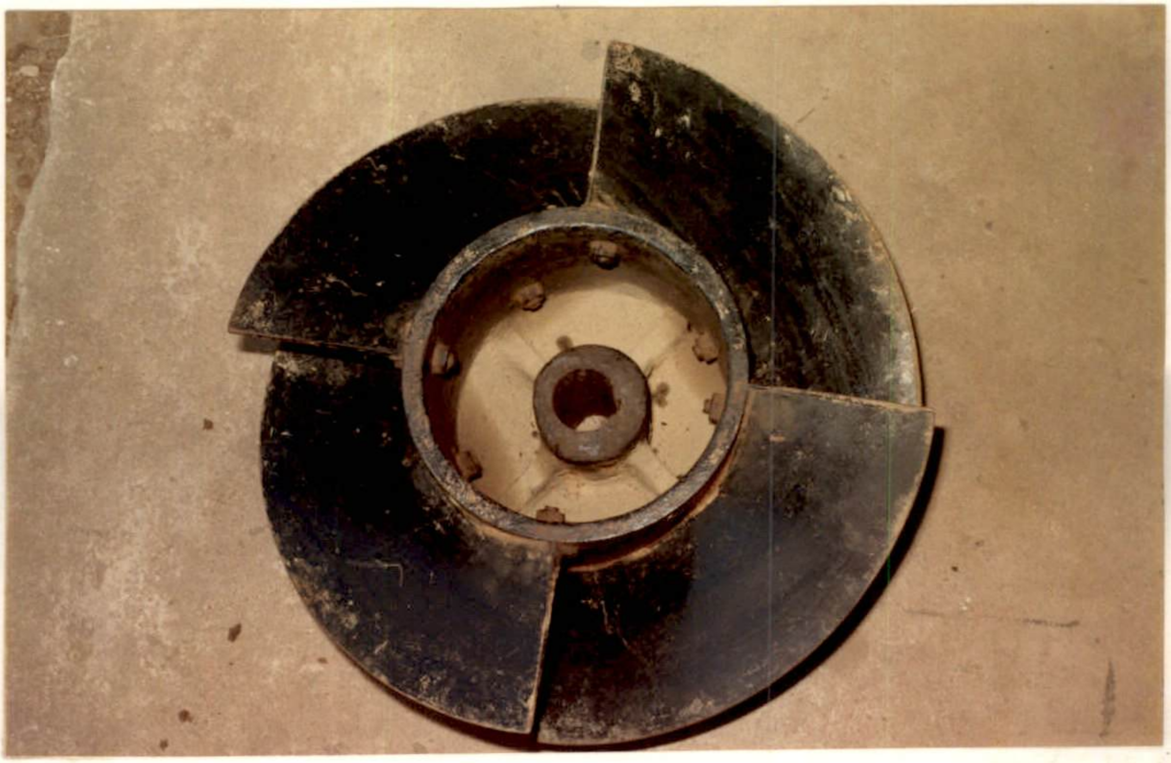
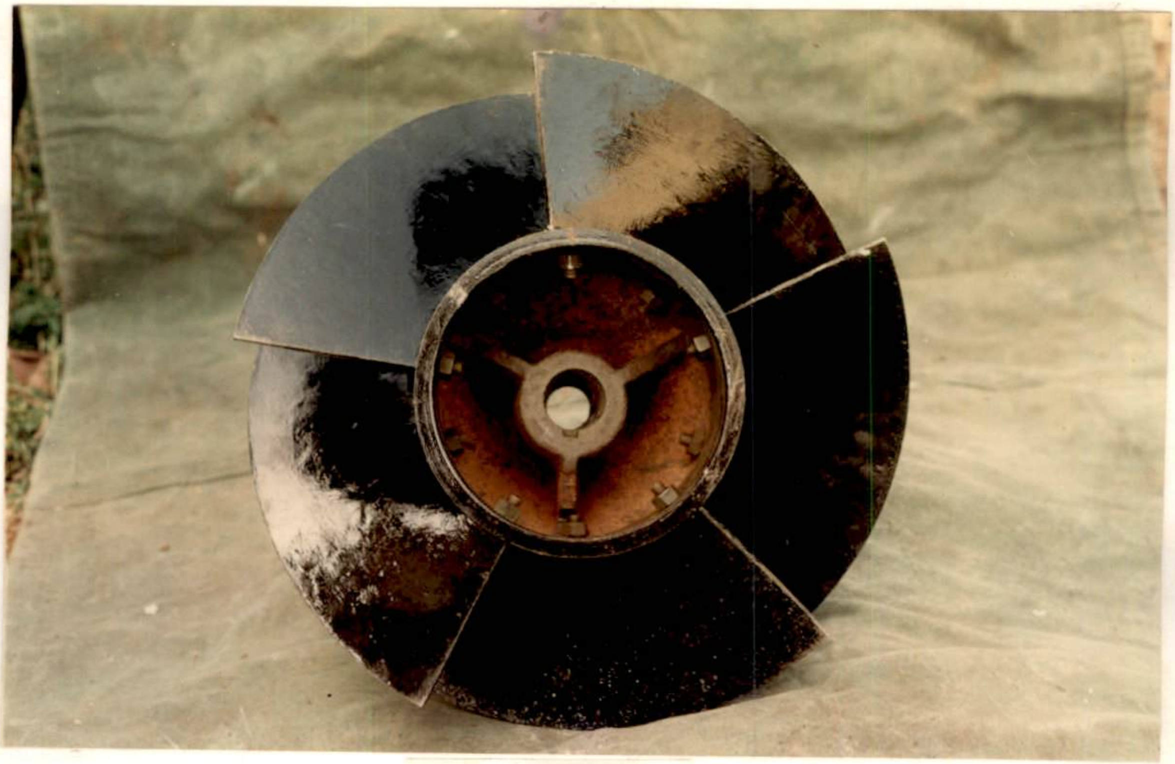


Plate 3.1 Top view of four bladed impeller of a 15 hp 'petti' and 'para'



Top view

Side view

Plate 3.2 Top and side views of five bladed impeller of a 15 hp 'petti' and 'para'

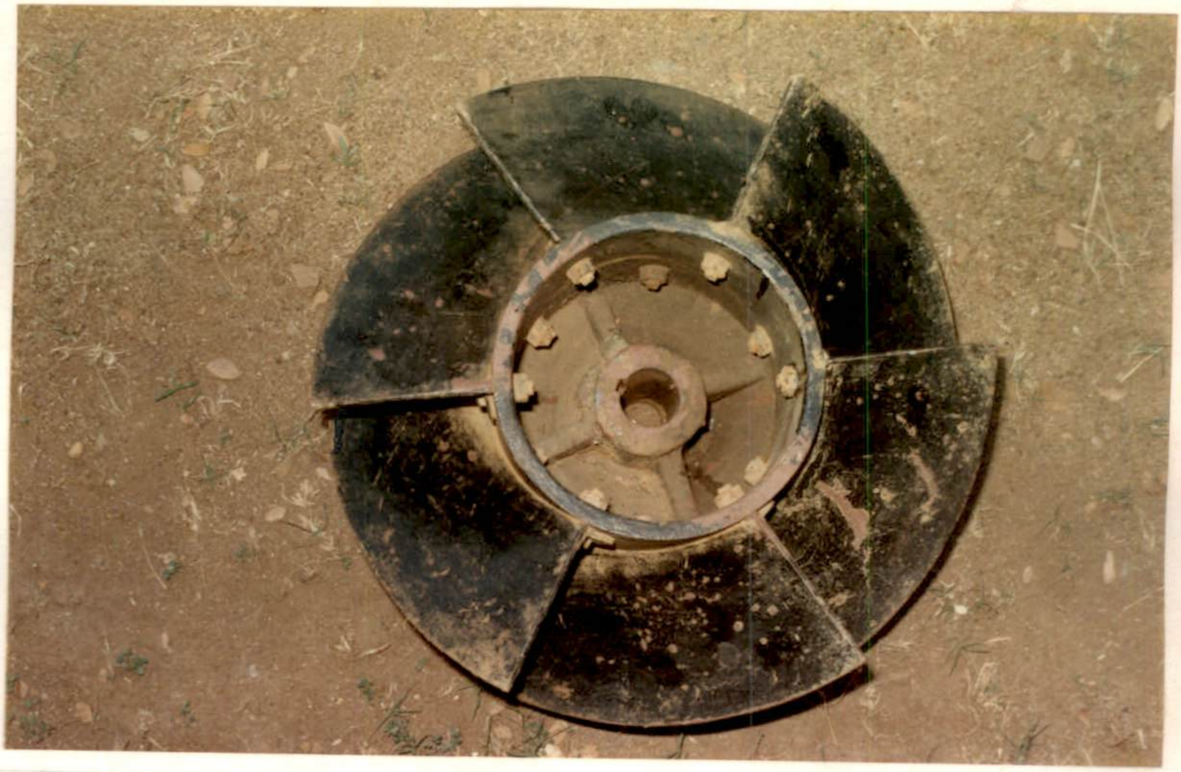


Plate 3.3 Top view of six bladed impeller of a 15 hp 'petti' and 'para'

Plate 3.4 View of 'petti' of a 15 hp 'petti' and 'para'

This was fabricated in the research workshop Mannuthy.

3.2.4 Pulleys on motor side

The pulleys on the motor side were made of cast iron and fixed on the motor with keys. To vary the speeds, different diameter pulleys were fixed to the motor shaft.

3.2.5 Power transmission

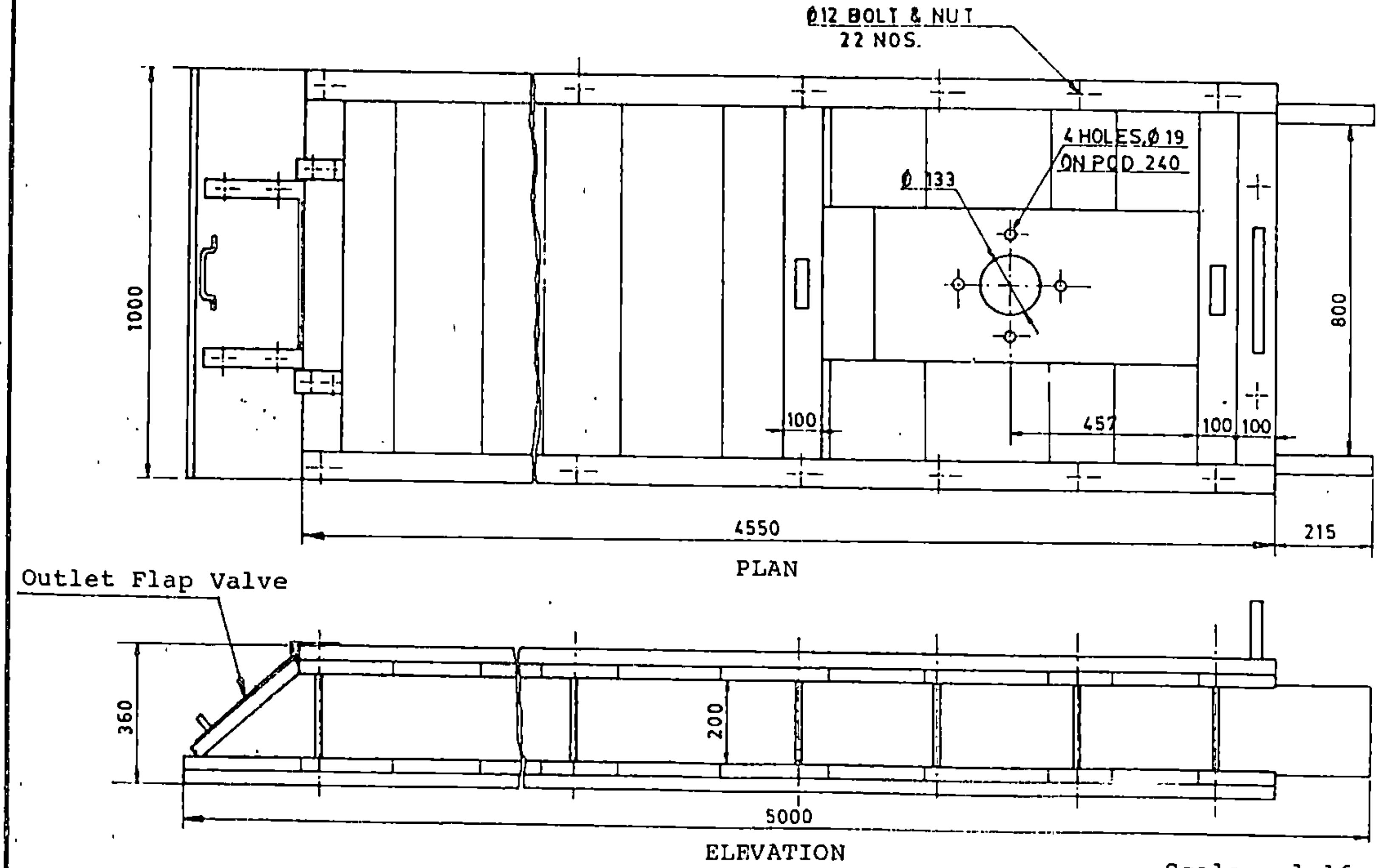
The power for driving the pump was taken from a three phase 15 hp induction motor, through a quarter turn flat belt drive. A 12 m long and 10 cm wide belt with 4 plyrating was used for power transmission. A belt guard was provided, to prevent the belt from falling in water if slipped from the motor pulley.

3.2.6 Bearings

A thrust bearing of roller type was used to suspend the rotor. Thus the entire axial load was transferred to the pump base. In order to hold the shaft in position, two brass metal bush bearings were provided, one at the top and one below the pulley.

3.2.7 'petti'

The top and bottom sides of the 'petti' (Plate 3.4)



Scale - 1:16

All dimensions in mm

FIG.3.7 VIEWS OF PETTI

were made of wooden planks which were tongued and grooved so that it was water tight. The other two sides were made of single piece wooden planks. Then the four sides were joined together in the form of a rectangular box, by bolting the top and bottom sides together (Fig.3.7). For this purpose mild steel bolts of 16 mm diameter were used. A one way valve was fixed on hinges with suitable inclination, on the discharge side of the 'petti', in order to avoid reverse entry of water from the outer channel, when the pumping stopped. A water tight sliding shutter was provided on the rear end of the 'petti' for easier inspection and repair if choking occurred. The dimensions of the 'petti' were as given below.

Size of 'petti' (length x width x height)	-	500 x 80 x 20 cm
Petty plank thickness (top and bottom)	-	4 cm
" " (sides)	-	5 cm

3.2.8 'para'

Two wooden 'paras' were provided, which were connected together. Each 'para' was strengthened by providing M.S. rings one each at the top and bottom which also act as flanges. These were then bolted together through holes provided on the rings. For additional strength, one separate ring was provided at the centre of top 'para', which could be tightened by nut and bolt. The impeller was housed inside the

Plate 3.5 View of top 'para' of a 15 hp 'petti' and 'para'

Plate 3.6 View of bottom 'para' of a 15 hp 'petti' and 'para'

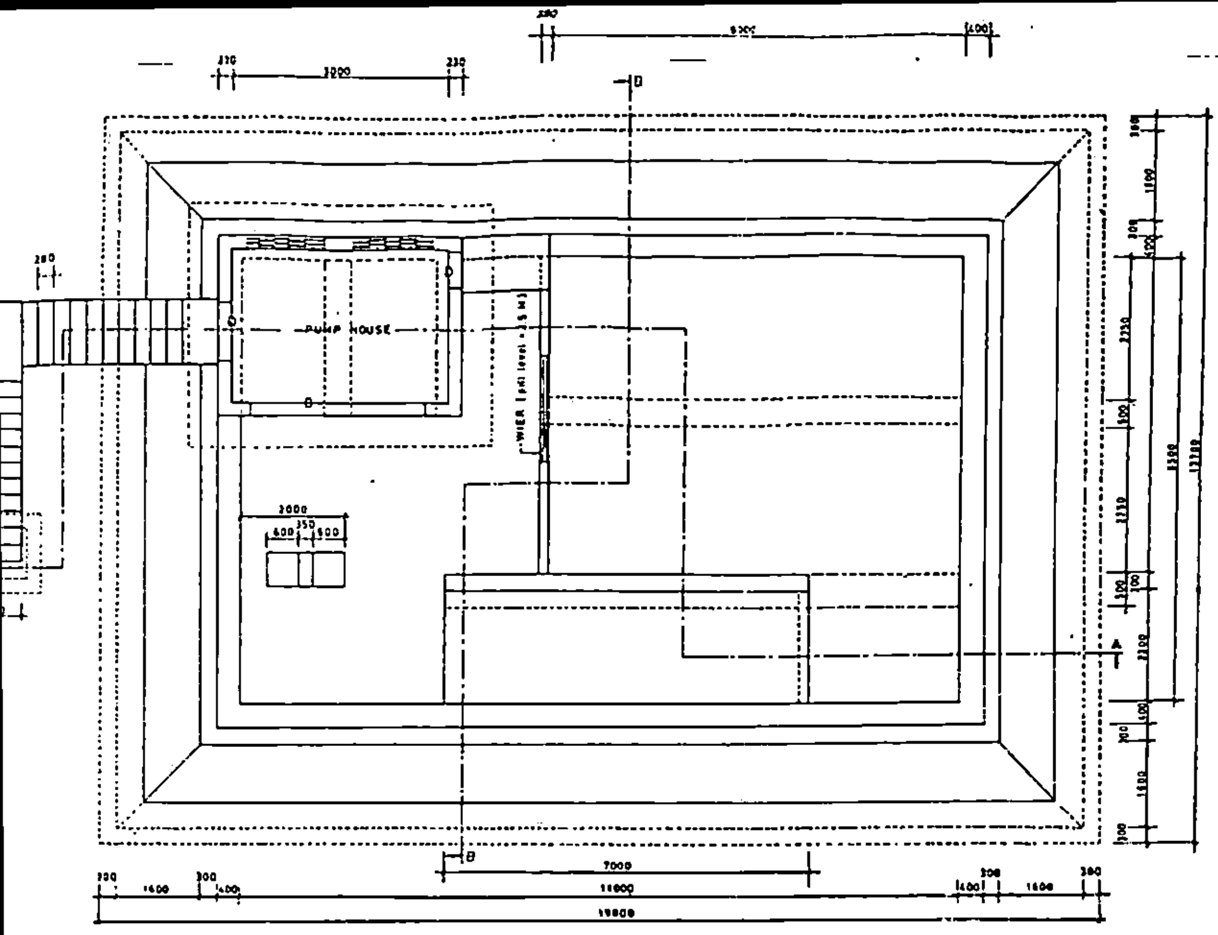
top 'para', where a protective metal cover was provided (Plate 3.5). The foot valve seated over the M.S ring provided at the bottom 'para' (Plate 3.6).

Size of 'para' (top)	-	100 cm x 3.5 cm
" (bottom)	-	65 cm x 3.5 cm
Diameter of 'para'	-	53.5 cm (21")

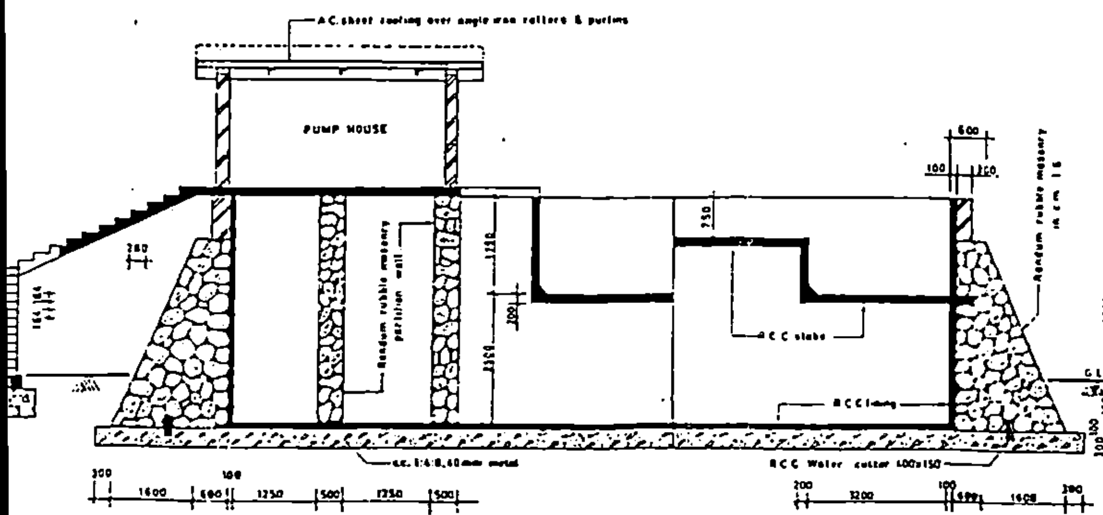
The various parts of the pump were fabricated at Malithara Industries, Changanacherry. It was then installed at the specially designed testing bed at College of Horticulture, Vellanikkara.

3.3 Details of the test bed

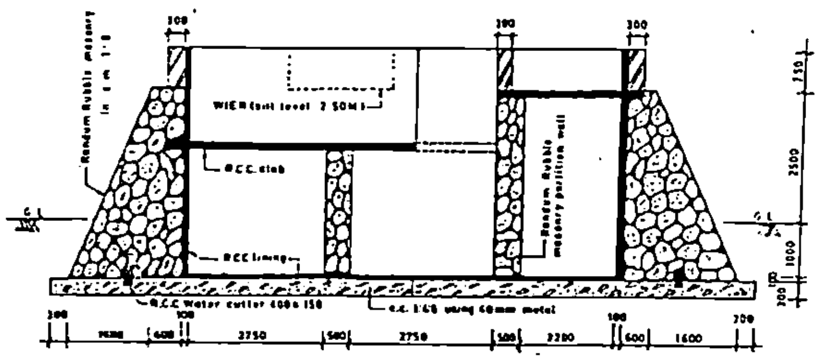
The test bench (Fig.3.8) was designed in such a manner that the discharge of the pump could be recirculated back to the pumping sump. The 'petti' was installed in such a manner that its rear end was on the top of an I-section and the other end over the concrete channel provided in the testing tank. One end the I-section was kept on the top of a concrete column provided inside the tank for the purpose, and the other and was inserted into the drilled hole on the wall of the tank. Clayey soil was spread over the concrete structure which act as a bed, before installing the discharge end of the 'petti', so that it was similar to the general field conditions. The water was pumped from the pumping sump to the discharge



PLAN



SECTION on A-A



SECTION on B-B

channel and then to the tank, where the trapezoidal weir was fixed. The water then flowed back to the pumping sump over the weir crest. The depth of the channel section was lesser than that of the weir tank.

A separate level indicator of M.S. flat was provided on the side wall of the pumping sump, the zero reading of which coincided with the weir crest level.

The power supply was taken from the main line at the pump house, through a new meterboard. A separate starter, main switch, ammeter, voltmeter, energymeter and capacitor were fixed to the new meterboard. A starter of semi-automatic type was provided which was set for tripping at over load. Four gate valves were provided for the testing tank at the bottom, for draining water during pump testing. The test bed was constructed with inner dimensions of 14 x 9 x 4 m which has the provisions for maintaining constant head.

3.4 Performance evaluation of 15 hp 'petti' and 'para'

The testing of 15 hp 'petti and para' was conducted at the specially designed testing bench for three different impellers. For each impeller readings were taken at various speeds by changing the diameter of motor pulleys.

The pump was started when the water level in the pumping sump coincided with the zero reading of the level indicator, that is, at the weir crest level. Since the discharge of the pump was recirculated back to the pumping sump, the pumping water level remained constant. The readings of point gauge, ammeter and voltmeter were noted. Also the time needed for five revolutions of the energy meter disc were taken. The readings were taken when a steady state condition was reached. Once all the readings were taken, the pumping water level was reduced by 10 cm. For this purpose the gate valves provided at the bottom of the tank were opened till the water level was reduced by 10 cm. Then, for this particular level, all the above set of readings were taken as earlier. Then again the water level was lowered by 10 cm and the procedure was repeated. The different speeds were obtained by changing the size of motor pulley. The readings thus taken were tabulated and analysed. Details of other measurements taken were as described below.

3.4.1 Discharge measurement

The discharge was measured by means of a Cipoletti weir fixed in the tank. The Cipoletti weir is a special case of trapezoidal weir, the sloping sides of which have an inclination of 1 horizontal to 4 vertical. This weir was invented by an Italian engineer, Cipoletti in 1887, and named after him. The weir was fabricated from 6 mm M.S. sheet. A coat of anticorrosive paint was applied to it. 3 mm thick rubber packing was provided at the bottom and sides of the tank where the weir was fixed, with the help of stainless steel bolts of diameter 16 mm.

The edge of the weir over which the water flows is known as the sill or crest and its height above the bottom of the tank is known as the crest height. The edge of the weir is bevelled on the downstream side so as to have sharp edged crest resulting in minimum contact with the liquid flowing. Since the sides of the weir cause contraction of nappe, it is said to be a weir with end contraction. It has been indicated by J.B. Francis on the basis of his experiments, that the end contraction has the effect of decreasing the effective length of the crest of the weir due to end contraction of the nappe which results in decreasing the discharge. Further it has been proposed by Francis that the amount by which the crest length decreased depends on the head h and for each end contraction the reduction in the crest length, may be taken to be equal to 0.1 h or h/10. In the case of a Cipoletti weir the slope of 1 in 4 provided for the sides of the weir, results in making the decrease in the discharge over a rectangular weir due to two end contractions, just equal to the increase in the discharge through the two triangular portions. So the discharge over a cipoletti weir is same from a rectangular weir under same head, without correction for end contraction. On the basis of his own experiments and those of Francis, Cipoletti proposed the following equation for the discharge over a Cipoletti weir.

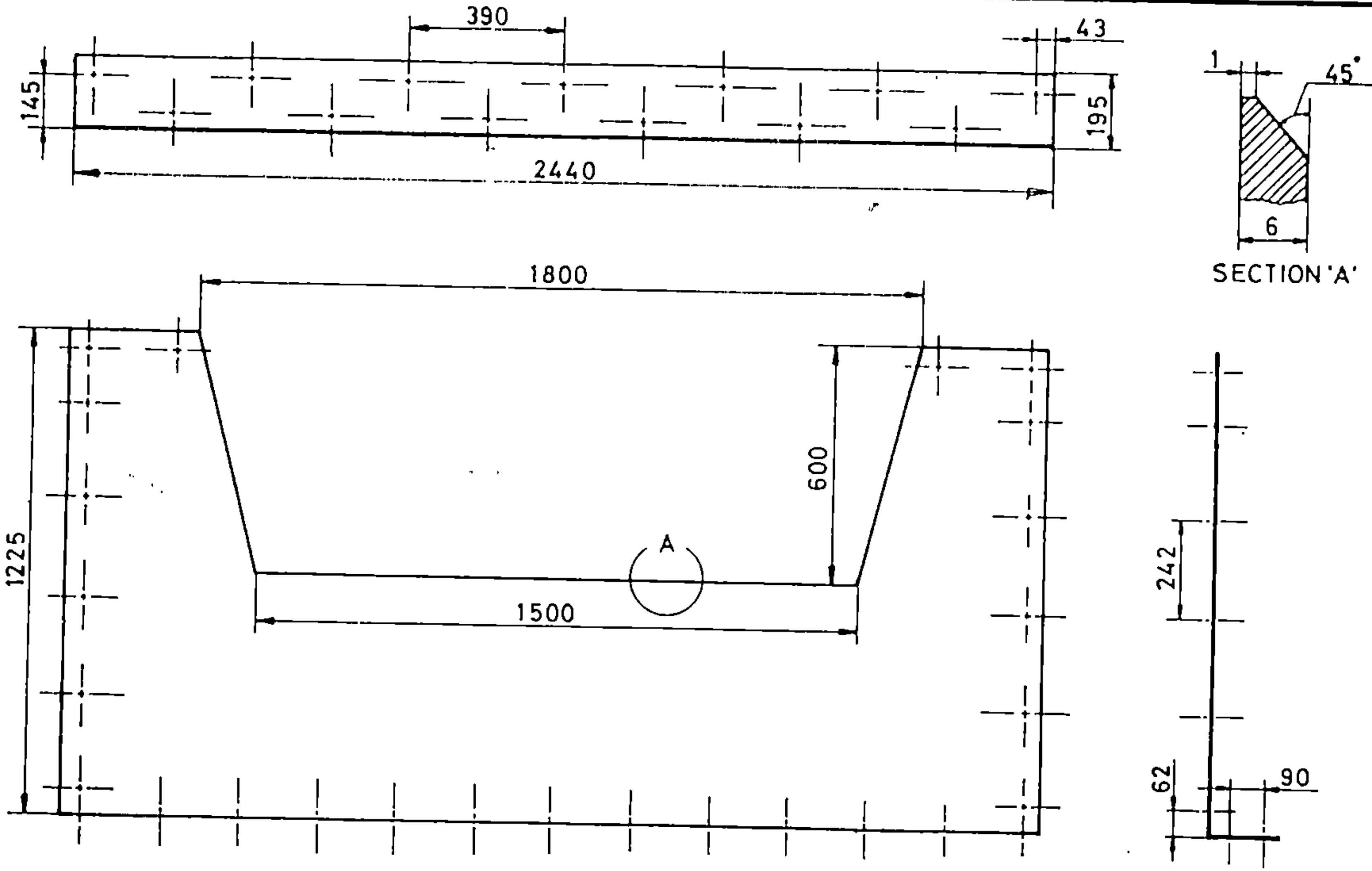
$$Q = 1.86\ Lh^{3/2}$$

where,

L = Length of crest

h = Height of water surface above the crest which is known as the head causing the flow over the weir

Since the water level on the downstream of the weir is well below the weir crest, the nappe emerges well and freely below the weir crest in the atmosphere and hence becomes freely discharging weir. As water flows over the weir, the surface of water over the crest and immediately upstream of it becomes curved. The head h above the crest is therefore measured at a certain distance upstream of the weir, where the water surface may be assumed to be unaffected by the curvature effect. According to IS:9108-1979, the head h above the crest should be measured on the upstream of the weir at a distance of four to five times the maximum head (hmax) above the crest. The head h above the crest level was measured with a point gauge.



SCALE - 1:15
ALL DIMENSIONS IN mm.

FIG.3.9 VIEW OF CIPOLETTI WEIR

The point gage consists of a thin vertical rod, pointed at its lower end, and it was attached to a rack and pinion arrangement. The liquid surface elevation was read from the main scale and vernier scale, attached to the rod. The rod with the main scale and vernier scale was fixed on a mild steel stand and the stand was fixed to the top of the tank wall. A stilling well of 29 cm diameter and 75 cm depth was provided to get more accurate readings. Both the stilling well and Cipoletti weir were fabricated in the Agricultural Research Workshop, Mannuthy.

3.4.2 Power measurement

The input energy to the motor was found out using an energymeter, fixed to the switch board. The time taken by the energymeter disc for five revolutions was noted twice at each reading, using a stopwatch. From these readings, the average time taken for five revolutions was calculated which was then substituted in the formula for power input.

$$\text{Power input} = \frac{n}{t} \times \frac{3600}{k} \times \frac{1000}{746}$$

where,

n - number of revolutions

t - time taken for n revolutions

k - energy meter constant

3.4.3 Speed measurement

The speed of the pump as well as the motor was noted with a tachometer.

3.4.4 Head measurement

The head of the pump can be expressed in two ways.

a. Static head

b. Manometric or total head

The static head is the vertical distance between the liquid surfaces in the sump and the tank to which the liquid is delivered by the pump. During testing the water level below the crest level of the weir was noted from the level indicator attached to the wall of the tank, and the height above the crest level was measured with the point gage. These were added to obtain the total static head. Then the total head calculated

Total head or manoetric head = static head + friction and minor losses losses in suction and delivery pipe + velocity head

Results and Discussion

RESULTS AND DISCUSSION

By conducting tests at a specially designed and constructed test bed, the effects of various parameters on the performance of 'petti' and 'para' pump were determined. The results obtained from these experiments and the analysis of the collected data are presented in this chapter.

4.1 Performance evaluation of 15 hp 'petti' and 'para'

The performance evaluation of the 15 hp 'petti' and 'para' from the tests conducted at the test bed, using four bladed, five bladed and six bladed impellers are described below.

4.1.1 Four bladed impeller

Detailed studies were carried out corresponding to different speeds of operation of the pump at 285, 295, 305, 310, 320, 330, 335, 345 and 350 rpm. The performance of the pump at the various speeds are presented (Appendix I to IX). The maximum efficiency of 23.72 per cent was obtained at a speed of 350 rpm, against a total head of 89.15 cm and a discharge rate of 291.83 lit/set (Appendix IX). The input power corresponding to this efficiency was 14.62 hp. For any other speeds of operation of the pump the efficiency was less than this particular value. The input power varied from 13.18 hp to 16.48 hp indicating that the motor was overloaded at certain speeds. So the upper limit of working speed for the four bladed impeller is 350 rpm beyond which the motor will be considerably overloaded.

By close observations of the input power at various speeds, it is clear that there is considerable difference in the input power to motor at various speeds. At 335 rpm the input power varied from 11.66 to 15.32 hp, at 345 rpm the input power varied from 12.37 to 15.74 hp and at 350 rpm it varied from 13.18 to 16.48 hp. For any particular speed below 310 rpm, the input power to motor was very low (Appendix I, II and III). At 350 rpm the motor of the pump was slightly overloaded. Thus by considering the input power and efficiency it is found, that the optimum working speed ranges from 330 to 345 rpm.

Using the data obtained from laboratory tests curves were fitted for six different speeds, 295, 305, 320, 330, 345 and 350 rpm. These curves give the relation between discharge, efficiency, input power and total head at each speed (Fig.4.1 to 4.6).

The plotted curves of discharge-efficiency relationships are second degree in nature and therefore second degree curves were fitted. The curves are of the form

$$E = K_1 + K_2Q + K_3Q^2$$

where

E - Efficiency

Q - Discharge and

K_1, K_2, K_3 - Constants

The fitted equations for various speeds are presented (Table 4.1).

Table 4.1 Discharge efficiency relationship of 15 hp 'petti' and 'para' with four bladed impeller

Sl. No.	Speed (rpm)	Regression Equation	R^2
1.	295	$E = 2.0056 + 0.2070\ Q - 0.0005\ Q^2$	0.9848
2.	305	$E = 2.1640 + 0.1974\ Q - 0.0005\ Q^2$	0.9486
3.	320	$E = 1.2926 + 0.1967\ Q - 0.0004\ Q^2$	0.9502
4.	330	$E = 1.9940 + 0.1859\ Q - 0.0004\ Q^2$	0.9552
5.	345	$E = 5.2949 + 0.2177\ Q - 0.0004\ Q^2$	0.8048
6.	350	$E = 5.1775 + 0.1437\ Q - 0.0003\ Q^2$	0.9040

In a similar way, the head discharge data were plotted (Fig.4.1 to 4.6) and the head-discharge curves are found semi-logarithmic in nature, of the form

$$LnH = K_1 + K_2 Q$$

where

H - Total head

Q - Discharge

K_1, K_2 - Constants

The fitted equations for the six speeds selected are given (Table 4.2).

Table 4.2 Discharge head relationships of 15 hp 'petti' and 'para' with four bladed impeller

Sl. No.	Speed (rpm)	Regression Equation	R^2
1.	295	LnH = 5.6567 - 0.0065 Q	0.9857
2.	305	LnH = 5.6630 - 0.0059 Q	0.9784
3.	320	LnH = 5.7836 - 0.0058 Q	0.9843
4.	330	LnH = 5.9042 - 0.0059 Q	0.9807
5.	345	LnH = 6.0428 - 0.0060 Q	0.9688
6.	350	LnH = 5.9485 - 0.0052 Q	0.9910

The fitted curves of input power and discharge (Fig.4.1 to 4.6) were found semi-logarithmic in nature and are of the form

$$Hp = K_1 + K_2 \, LnQ$$

where

Hp - Input power

Q - Discharge

K_1, K_2 - Constants

The regression equations are also presented (Table 4.3).

Table 4.3 Discharge input power relationships of 15 hp 'petti' and 'para' with four bladed impeller

Sl. No.	Speed (rpm)	Regression Equation	R^2
1.	295	HP = 21.6858 - 2.3142 LnQ	0.9323
2.	305	HP = 24.7045 - 2.7278 LnQ	0.9452
3.	320	HP = 27.6499 - 2.9588 LnQ	0.9321
4.	330	HP = 31.9539 - 3.5148 LnQ	0.8955
5.	345	HP = 42.9976 - 5.1721 LnQ	0.9252
6.	350	HP = 37.6388 - 4.0973 LnQ	0.9419

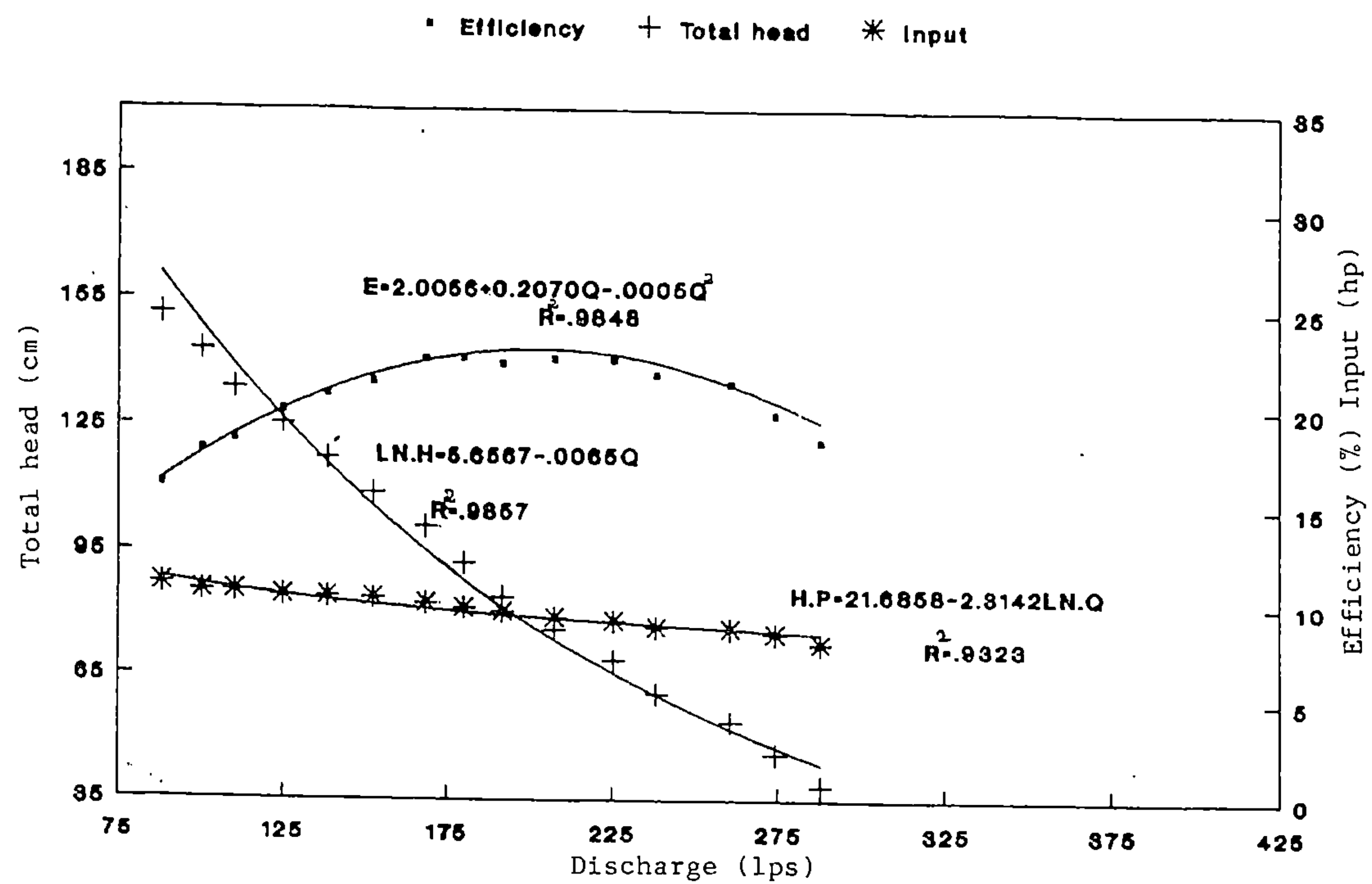


FIG.4.1 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 295 RPM

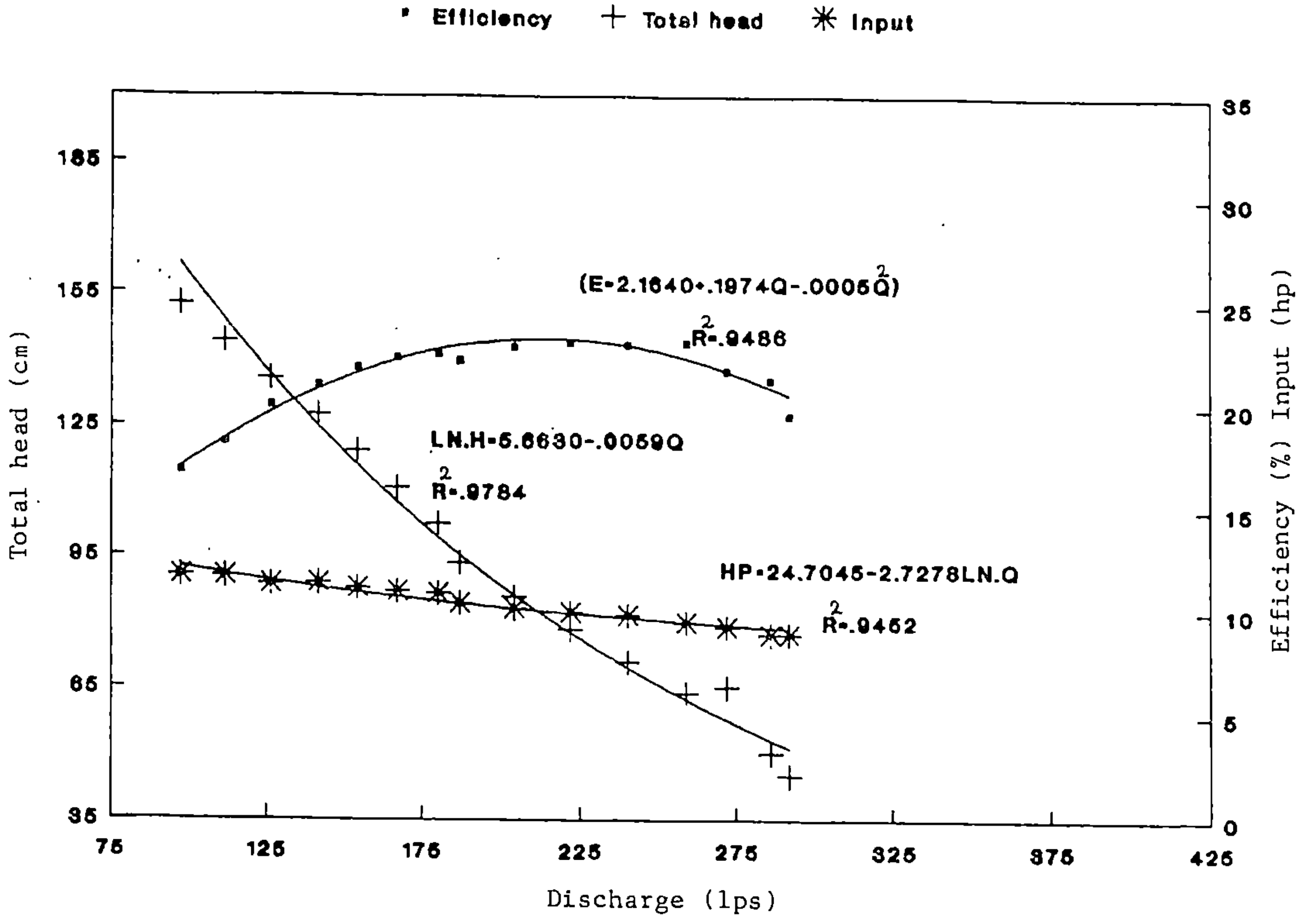


FIG.4.2 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 305 RPM

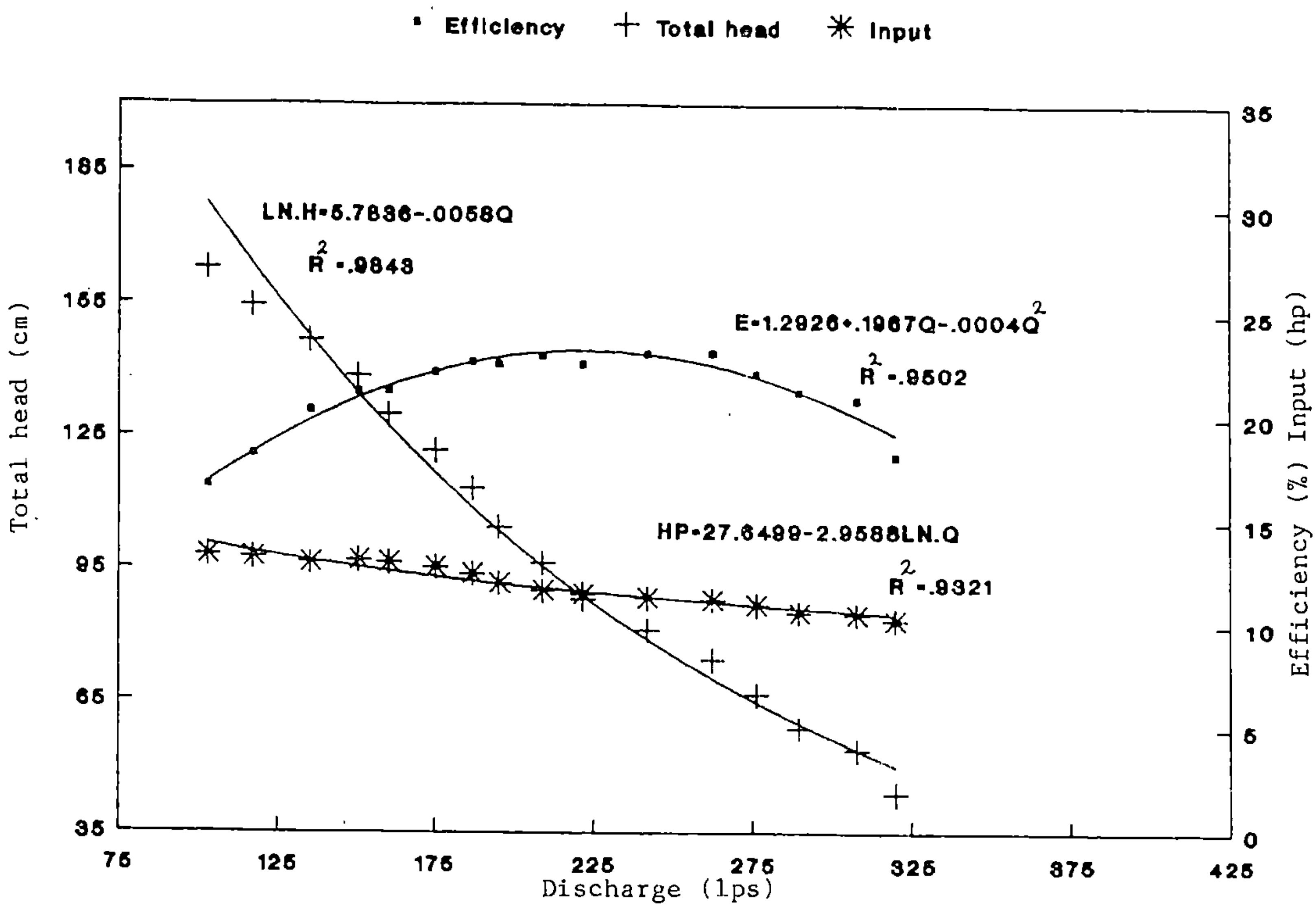


FIG.4.3 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 320 RPM

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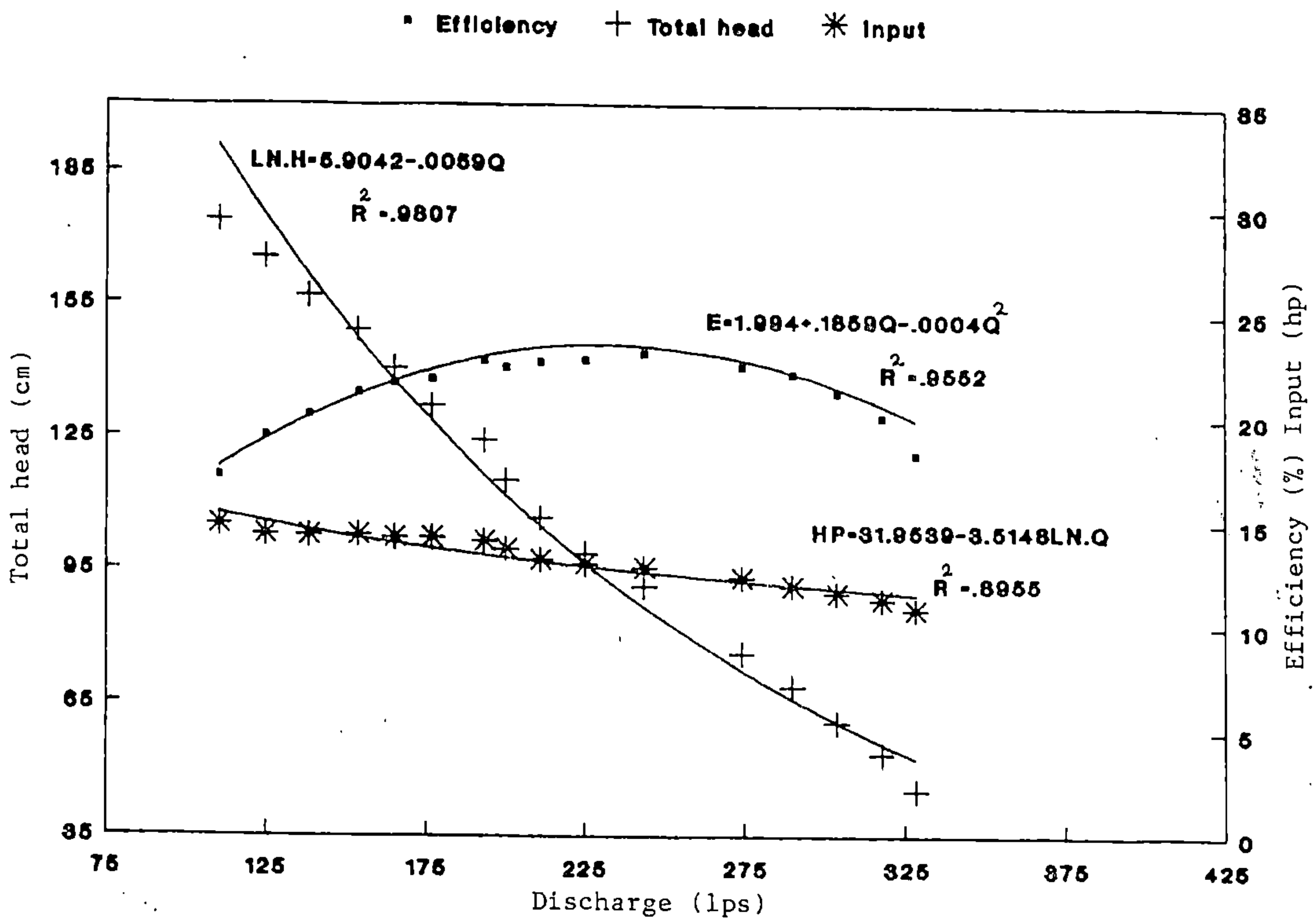

FIG.4.4 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 330 RPM

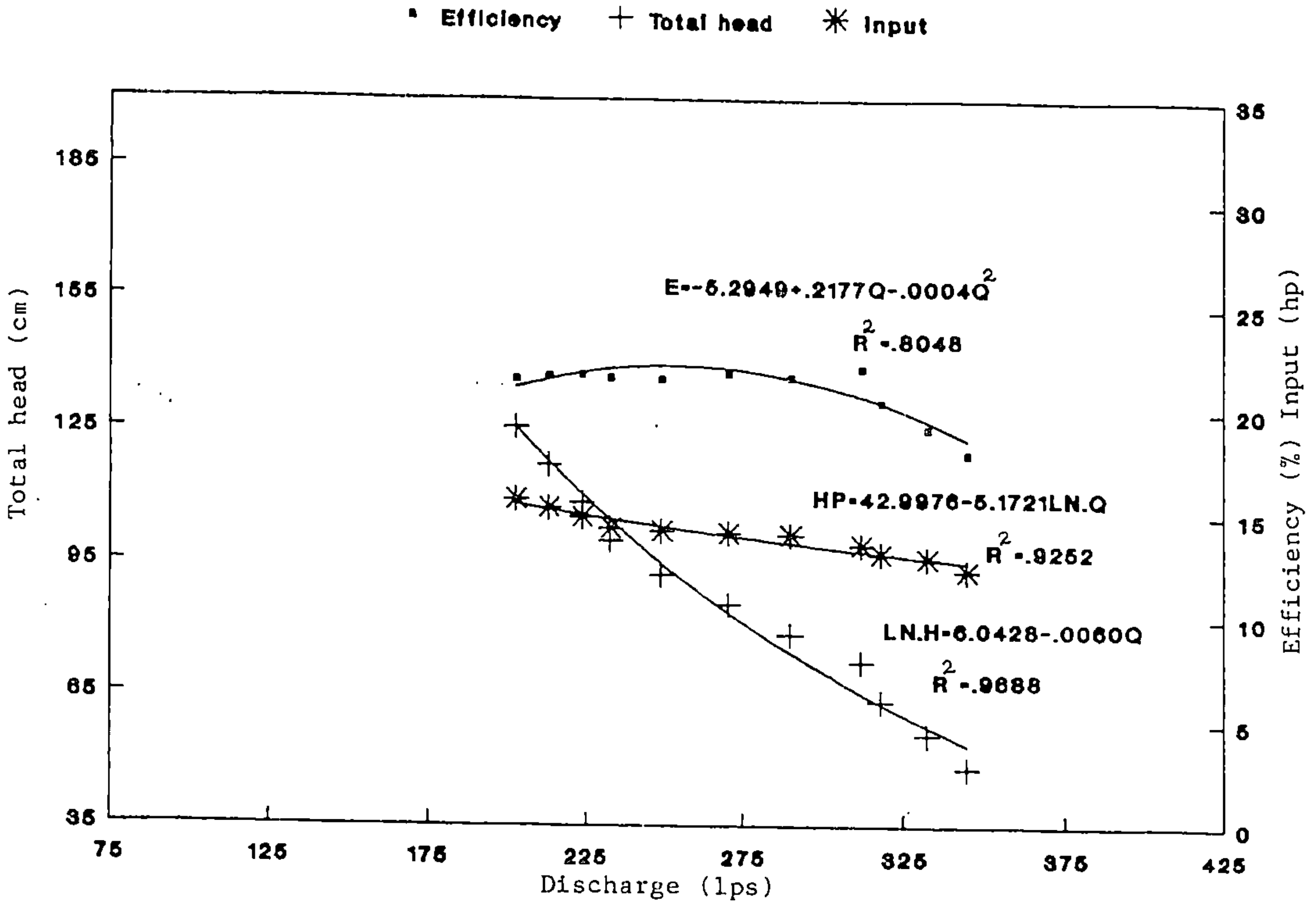

FIG.4.5 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 345 RPM

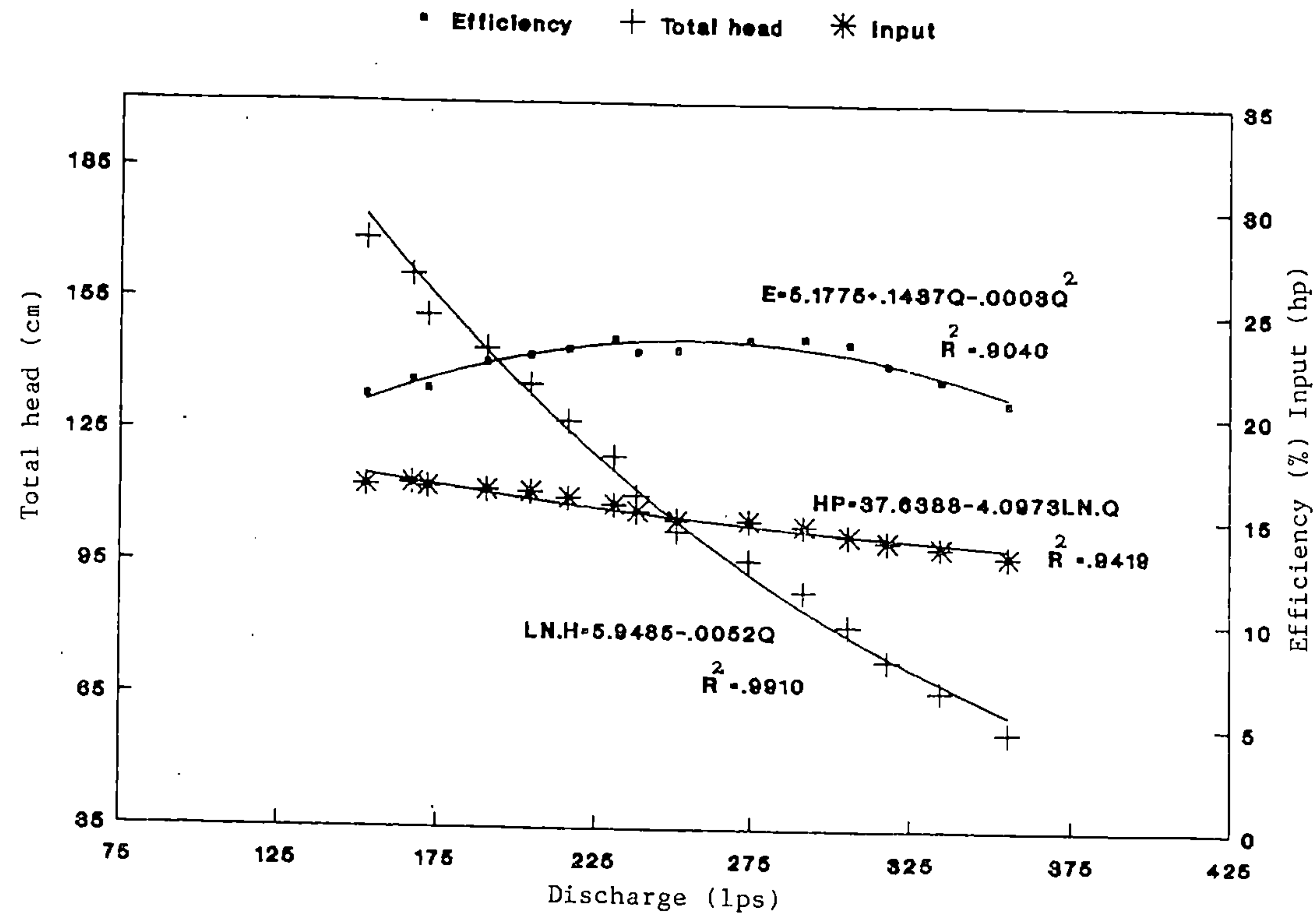

FIG.4.6 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FOUR BLADED IMPELLER AT 350 RPM

4.1.2 Five bladed impeller

The pumping tests were carried out for the five bladed impeller at 285, 295, 300, 305, 310, 320, 330, 340, 345 and 350 rpm. The maximum efficiency of 30.09%was obtained at the speed of 330 rpm (Appendix X to XIX). Also an efficiency of 30.05% was obtained and the corresponding speed was 340 rpm. Test results at various speeds show that the power utilisation was below 13 hp at 285 to 320 rpm. Also the motor was overloaded at 350 rpm. At 345 rpm, the input power varied from 14.36 to 16.25 hp and the maximum efficiency was only 26.48, which is far below that obtained at 330 and 340 rpms. At 330 and 340 rpm the input power was between 10 hp and 15.3 hp, which is reasonably good. Thus when both input power and efficiency are considered, the optimum range of operating speed is between 330 to 340 rpm.

Curves were fitted for the five bladed impeller for six selected speeds of 295, 305, 320, 330, 345 and 350 rpm using the data obtained from the laboratory tests.

The fitted curves of discharge versus efficiency are of second degree in nature as in the case of four bladed impeller (Fig.4.7 to 4.12). The fitted equations for various speeds are presented (Table 4.4).

Table 4.4 Discharge-efficiency relationships of 15 hp 'petti' and 'para' with five bladed impeller at various speeds

Sl. No.	Speed (rpm)	Regression Equation	R^2
1.	295	$E = 5.8263 + 0.1678\ Q - 0.0003\ Q^2$	0.9509
2.	305	$E = 5.6450 + 0.1692\ Q - 0.0003\ Q^2$	0.7351
3.	320	$E = 4.8304 + 0.1649\ Q - 0.0003\ Q^2$	0.9288
4.	330	$E = 6.0674 + 0.1544\ Q - 0.0003\ Q^2$	0.8912
5.	345	$E = 9.9222 + 0.1116\ Q - 0.0002\ Q^2$	0.8979
6.	350	$E = 9.573 + 0.1055\ Q - 0.0002\ Q^2$	0.715

The fitted curves of total head and discharge (Fig.4.7 to 4.12) are found semi-logarithmic in nature and the regression equations are presented (Table 4.5).

Table 4.5 Discharge-head relationships of 15 hp 'petti' and 'para' with five bladed impeller at various speeds

Sl. No.	Speed	Regression Equation	R^2
1.	295	LnH = 5.4460 - 0.0045 Q	0.9975
2.	305	LnH = 5.5166 - 0.0044 Q	0.9986
3.	320	LnH = 5.6386 - 0.0047 Q	0.9910
4.	330	LnH = 5.7015 - 0.0041 Q	0.9891
5.	345	LnH = 5.7839 - 0.0041 Q	0.9965
6.	350	LnH = 5.8027 - 0.0038 Q	0.9938

The plotted curves of power and discharge (Fig.4.7 to 4.12) are also semi-logarithmic in nature and the equations are fitted are presented (Table 4.6).

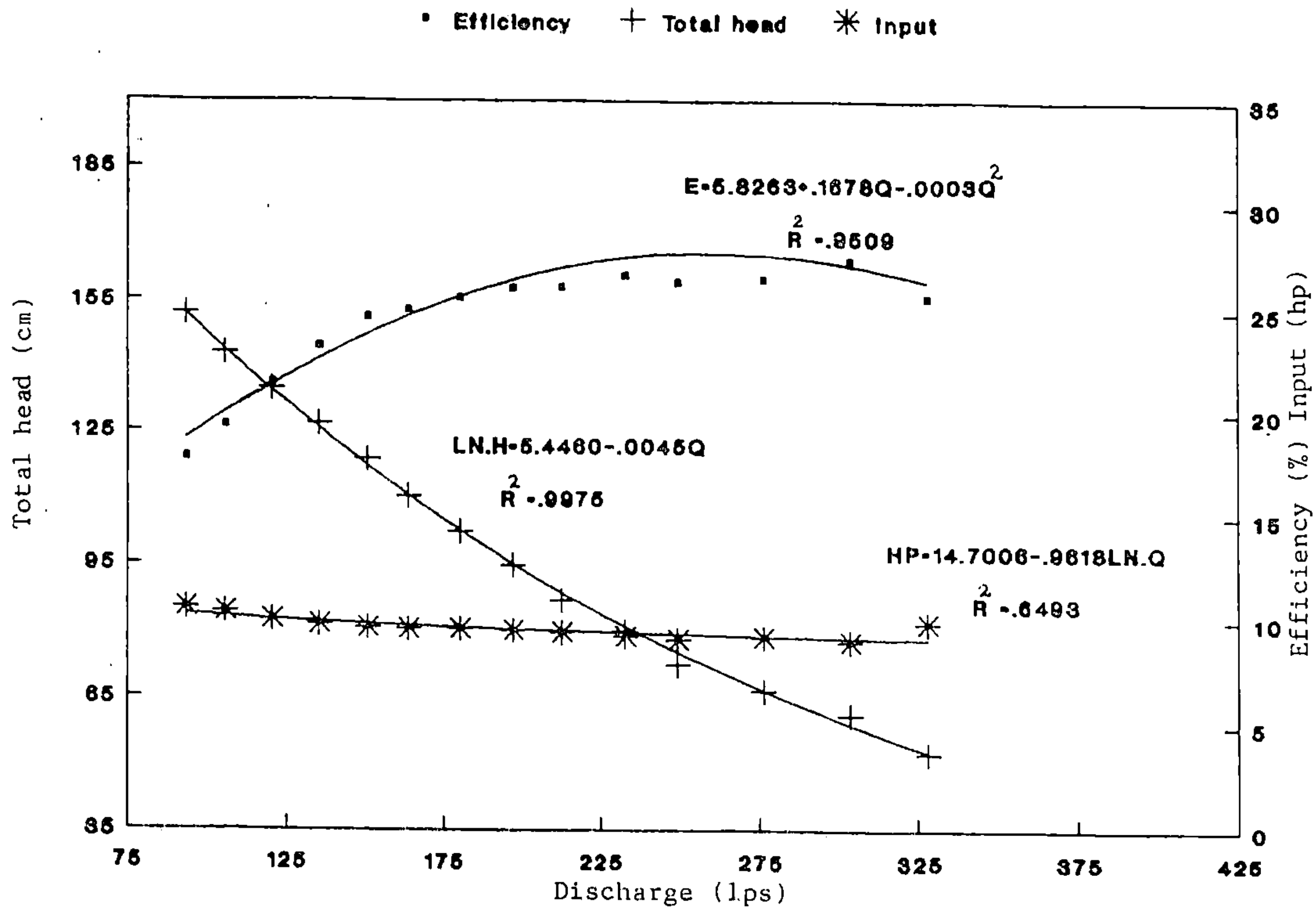

FIG.4.7 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 295 RPM

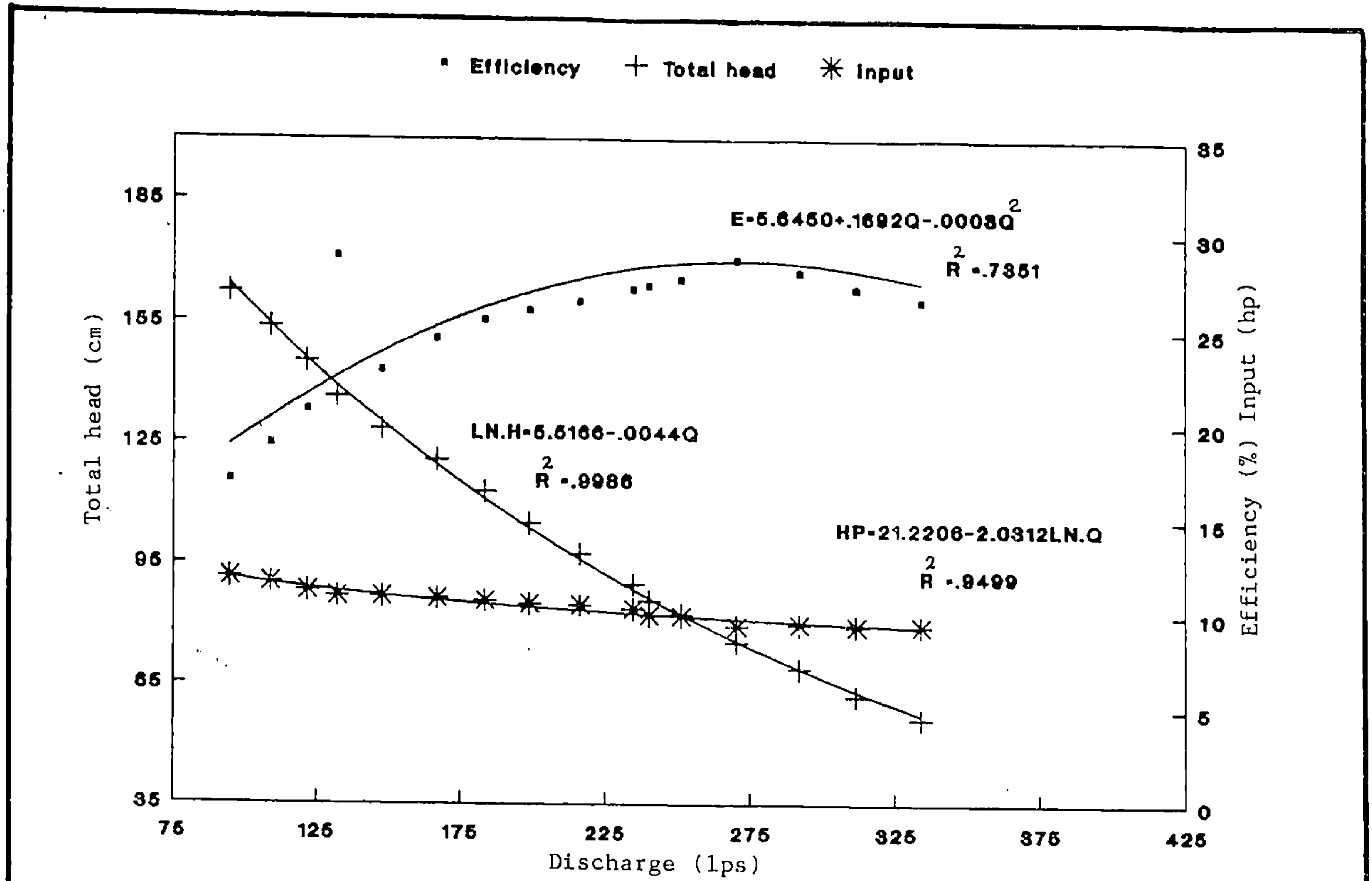

FIG.4.8 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 305 RPM

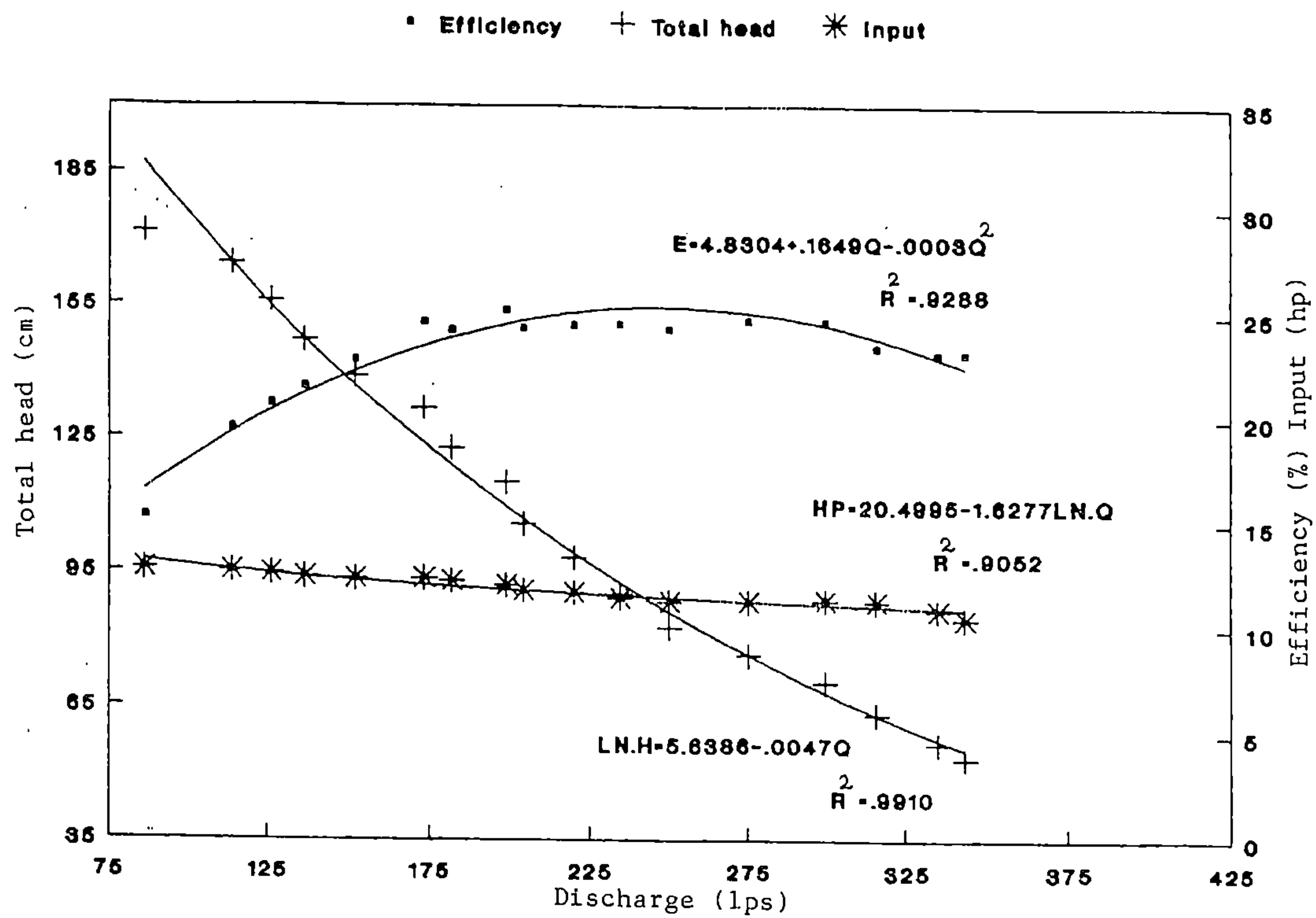

FIG.4.9 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 320 RPM

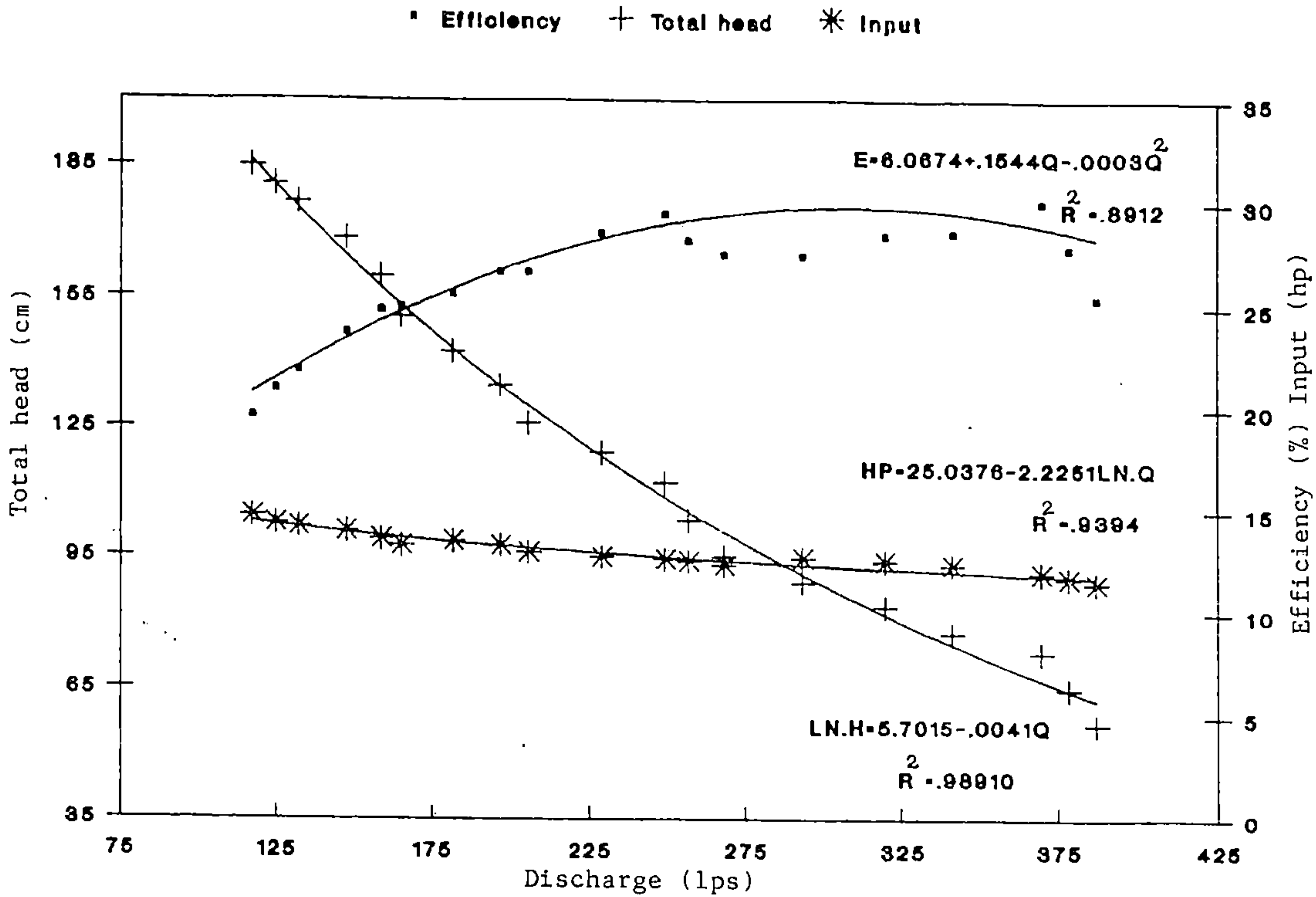

FIG.4.10 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 330 RPM

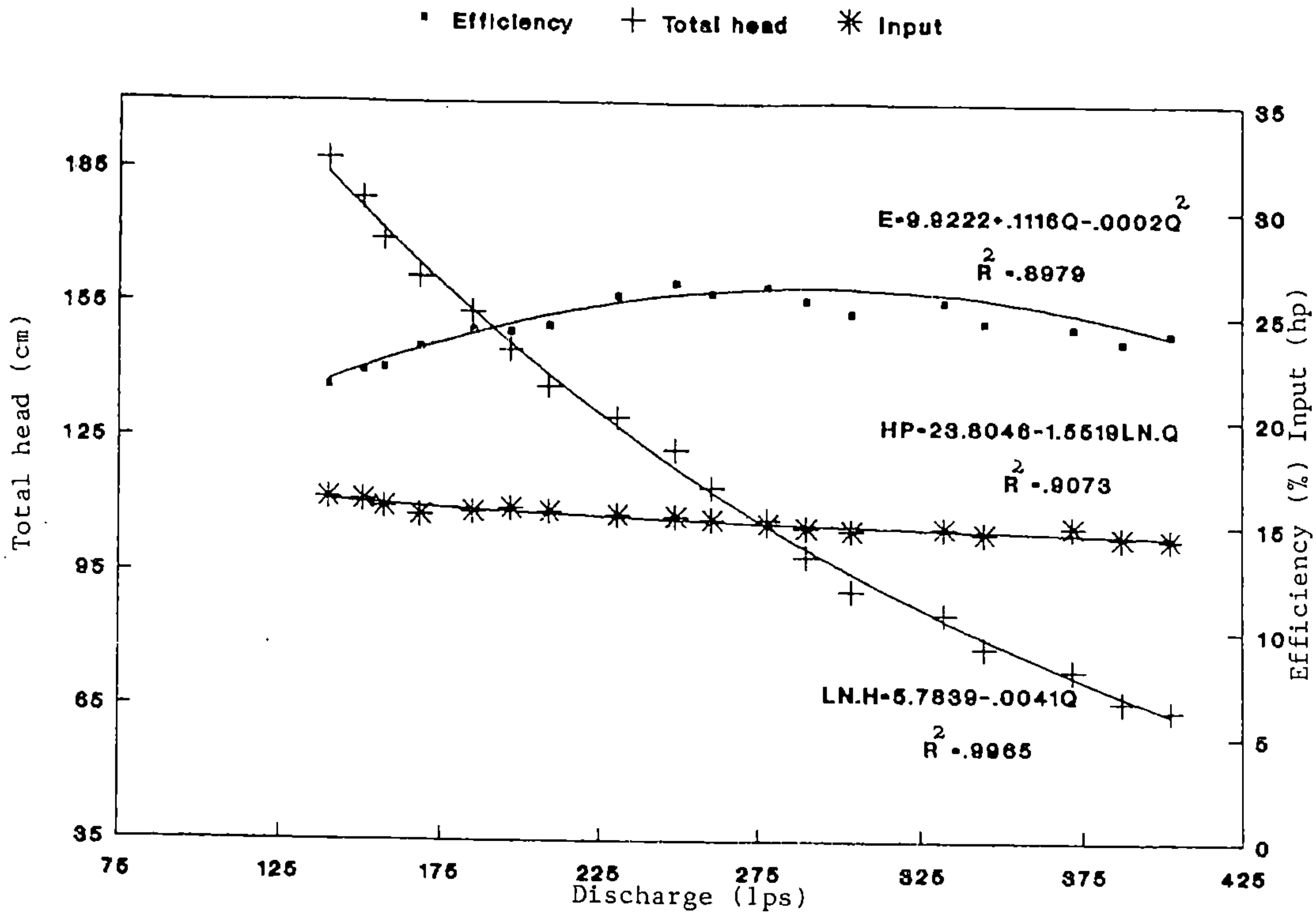

FIG.4.11 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 345 RPM

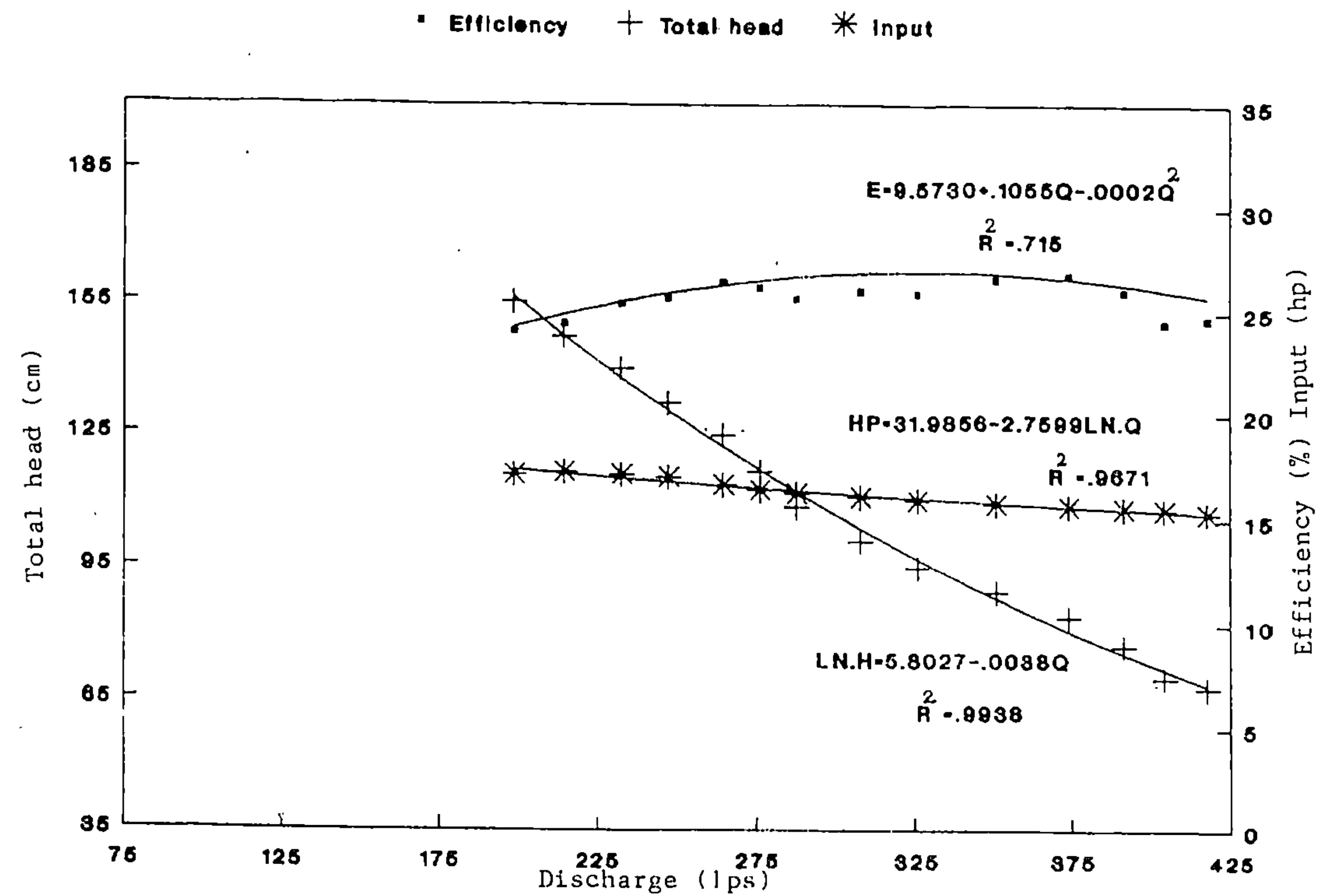

FIG.4.12 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH FIVE BLADED IMPELLER AT 350 RPM

Table 4.6 Discharge-input power ralationships of 15 hp 'petti' and 'para' with five bladed impeller at various speeds

Sl. No.	Speed	Regression Equation	R^2
1.	295	Hp = 14.7006 - 0.9618 LnQ	0.6493
2.	305	Hp = 21.2206 - 2.0312 LnQ	0.9499
3.	320	Hp = 20.4995 - 1.6277 LnQ	0.9052
4.	330	Hp = 25.0376 - 2.2251 LnQ	0.9394
5.	345	Hp = 23.8046 - 1.5519 LnQ	0.9073
6.	350	Hp = 31.9856 - 2.7599 LnQ	0.9671

4.1.3 Six bladed impeller

For the six bladed impeller, tests were conducted at 270, 275, 278, 280, 290, 295 and 305 rpm. The calculated values of discharge, input power and efficiency at various heads for each rpm are presented (Appendx XX to XVI). Eventhough the input power to motor was at the range of 12.4 to 15.23 hp for various speeds of 275, 278, 280 and 290 rpm the efficiency of the pump was very low of the range 18 to 19 per cent (Appendix XX to XIV). At the speeds of 295 and 305 rpm the motor was overloaded (Appendix XXV & XXVI).

Curves were fitted (Fig.4.13 and 4.14) using the data obtained from laboratory tests at 295 and 305 rpm. The efficiency-discharge, head-discharge and input power-discharge curves are of the same nature as in the case of four bladed and five bladed impellers. The regression equations are presented in Table 4.7, 4.8 and 4.9.

Table 4.7 Discharge-efficiency relationships of 15 hp 'petti' and 'para' with six bladed impeller at various speeds

Sl.No.	Speed (rpm)	Regression equation	R^2
1.	295	$E = 1.3432 + 0.1354Q - 0.0003Q^2$	0.9305
2.	305	$E = -0.2184 + 0.1348Q - 0.0003Q^2$	0.5509

Table 4.8 Discharge-input power relationships of 15 hp 'petti' and 'para' with six bladded impeller at various speeds

Sl.No.	Speed (rpm)	Regression equation	R^2
1.	295	$HP = 21.32 - 1.0132 \, Ln.Q$	0.4530
2.	305	$HP = 33.96 - 2.917 \, Ln.Q$	0.567

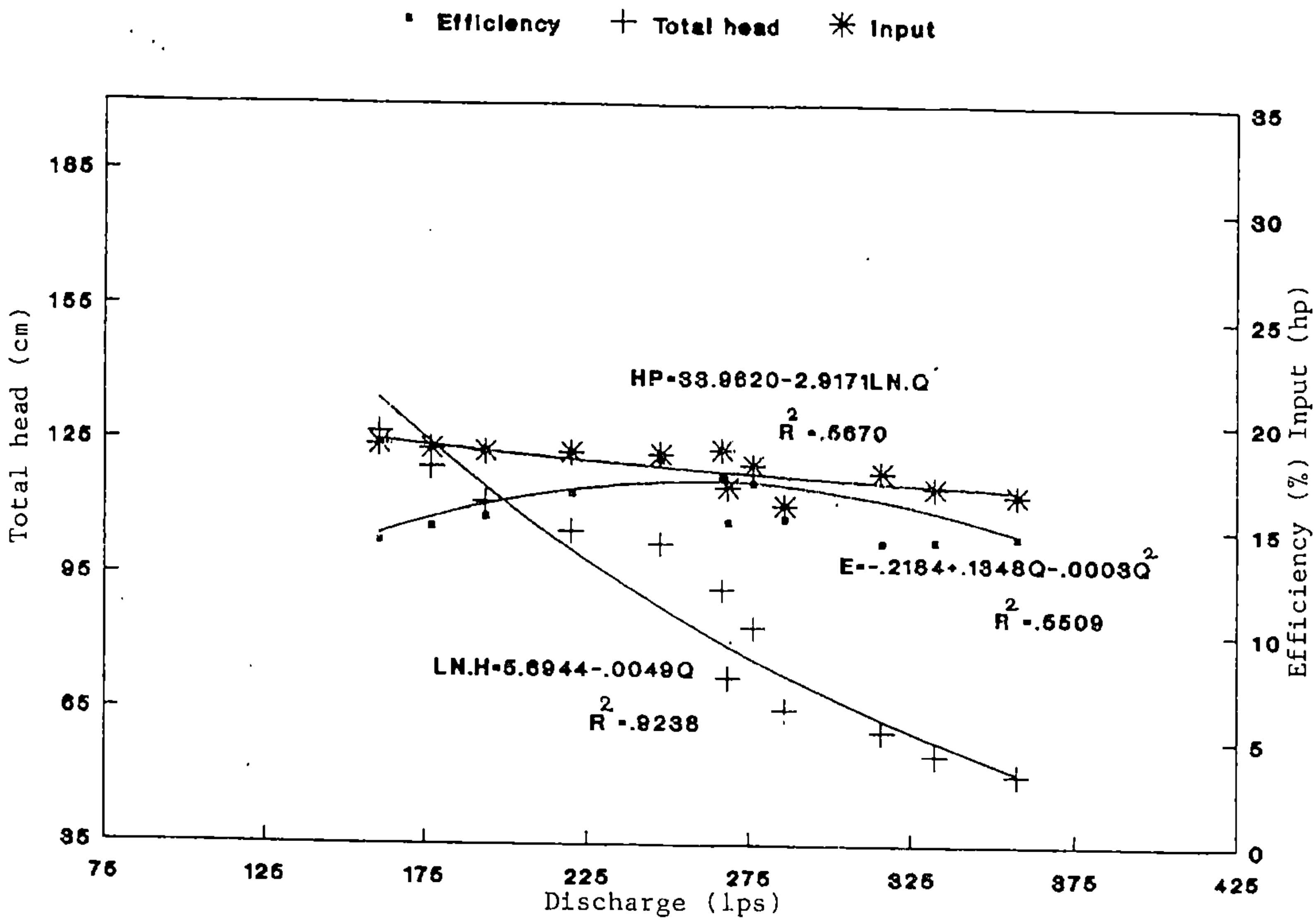

FIG.4.14 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH SIX BLADED IMPELLER AT 305 RPM

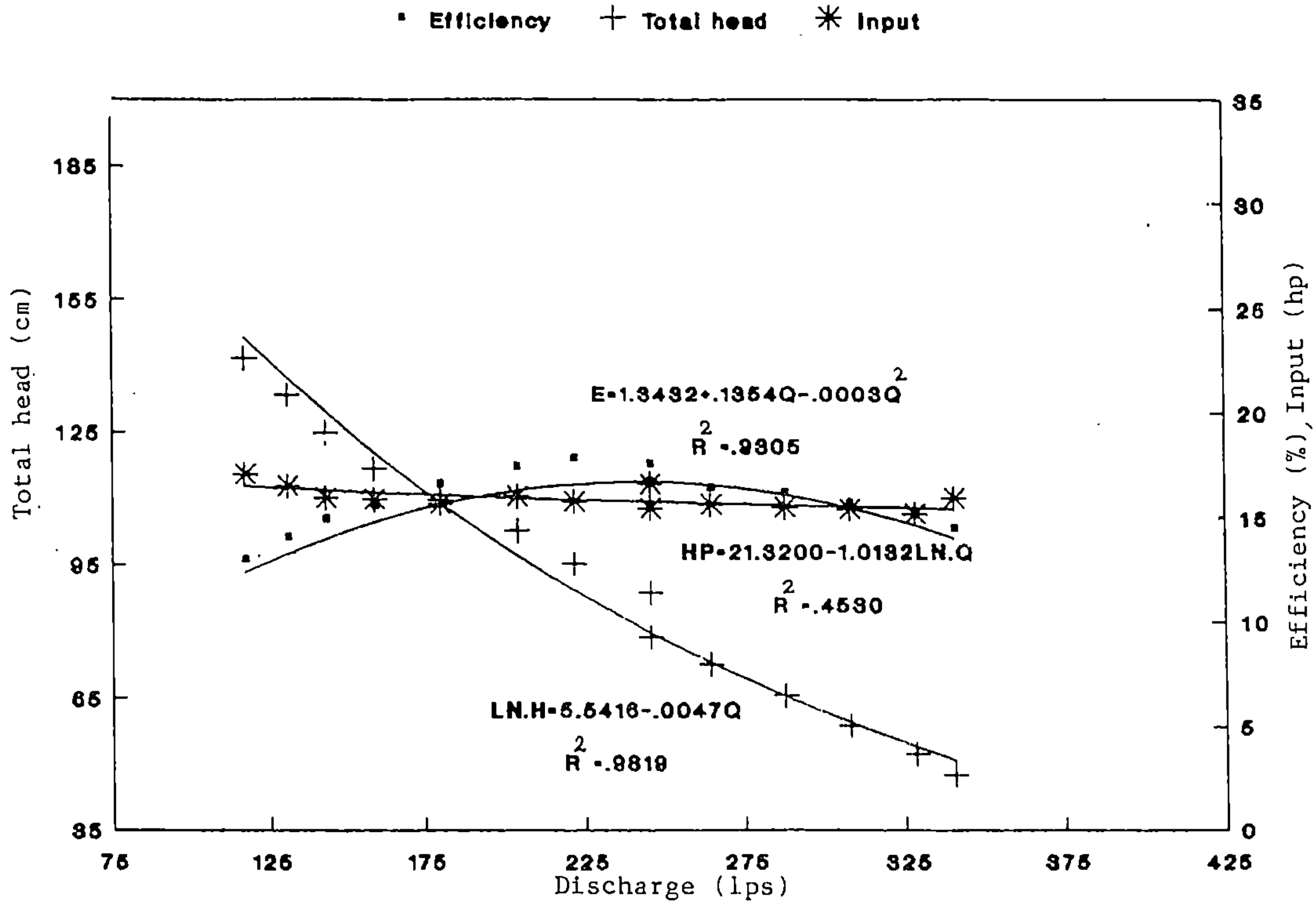

FIG.4.13 HEAD, HP, EFFICIENCY AND DISCHARGE RELATIONSHIPS OF 15 HP 'PETTI' AND 'PARA' WITH SIX BLADED IMPELLER AT 295 RPM

Table 4.9 Discharge-head relationships of 15 hp 'petti' and 'para' with six bladded impeller at various speeds

Sl.No.	Speed (rpm)	Regression equation	R^2
1.	295	Ln H = 5.5416 - 0.0047 Q	0.9819
2.	305	Ln H = 5.6944 - 0.0049 Q	0.9238

The above derived functional relationships for the three impellers have high values of coefficient of determination except for a few cases which indicates that the data can very well be relied upon.

4.2 Comparison of the three impellers

The comparison of the 15 hp 'petti' and 'para' for three impellers was necessary to find out the effect of number of blades on the impeller on pump performance.

The performance tests of the pump with four bladed impeller indicates that it can pump water at total heads ranging from 36.89 cm to 174.0 cm (Appendix I to IX), and the maximum head of 174.0 cm was developed at 330 and 335 rpm. The maximum total head that was developed by the five bladed impeller was 187.5 cm at 345 rpm (Appendix XVII). The maximum total head produced by the six bladed impeller was the least and it was only 137 cm (Appendix XXIII). Thus if the performance of the pump is considered by evaluating total head only, the five bladed impeller is found to be superior to four bladed and six bladed impellers.

It is seen from (Appendix I to IX) that the maximum efficiency obtained at various speeds for the four bladed impeller varied from 21.81 to 23.72 per cent, the maximum being noted at 350 rpm. For the five bladed impeller the corresponding variation was from 25.25 to 30.09 per cent for various speeds of operation of pump (Appenx X to XIX) and for the six bladed impeller the maximum efficiency was found to lie between 17.83 and 18.98 per cent. That is, the least maximum efficiency of the five bladed impeller (25.25%) is higher than the highest maximum efficiency of four bladed (23.72%) and six bladed (18.98%) impellers. Thus it is advantageous to use the five bladed impeller owing to its high efficiency.

The comparison curves were plotted for the three impellers from the estimated values of efficiency, total head and input power for selected discharge rates. As the six bladed impeller was heavily overloaded beyond 305 rpm, pumping tests were not done beyond this speed. So at speeds above 305 rpm characteristic curves were drawn for the four bladed and five bladed impellers for the performance evaluation.

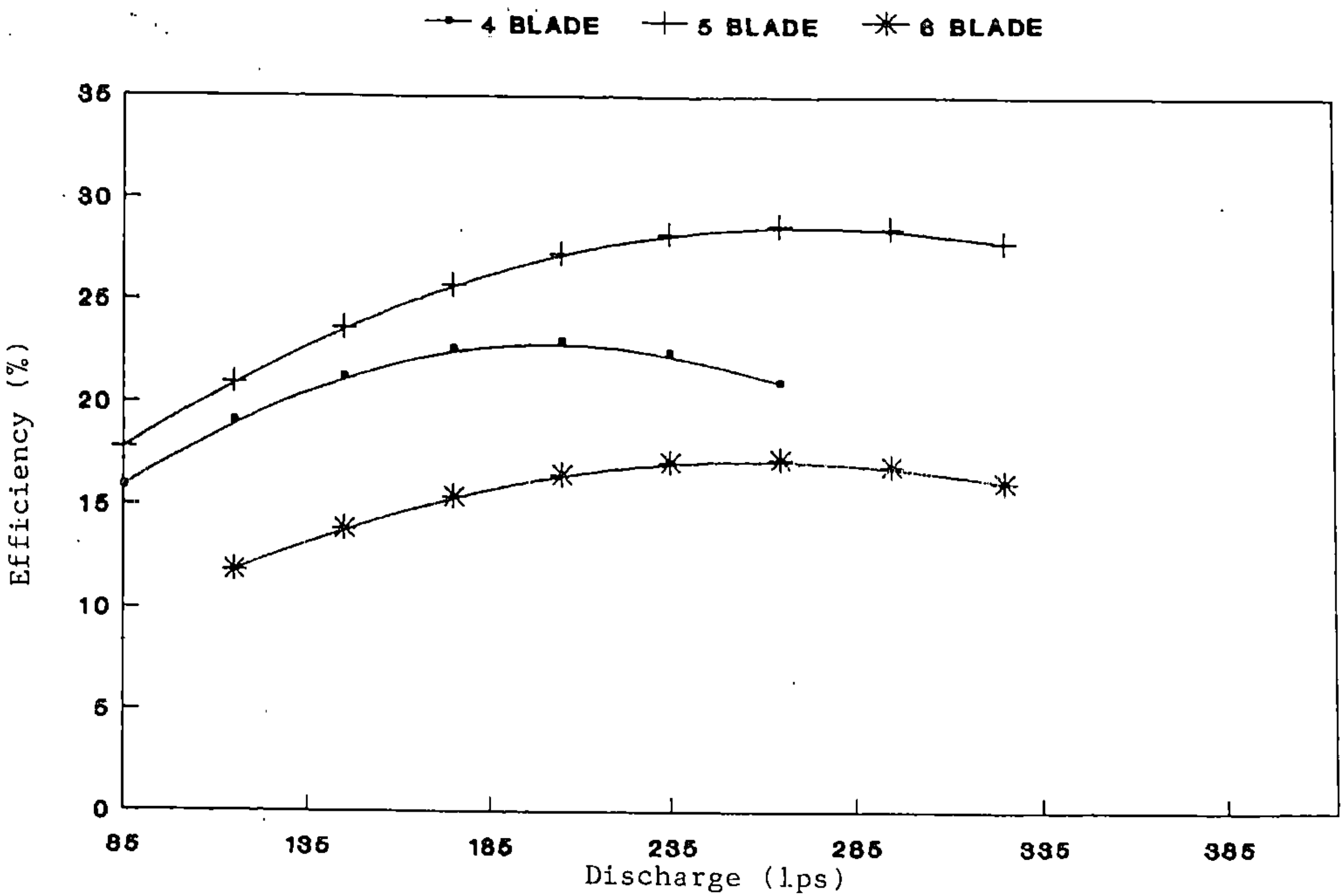

FIG.4.15 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 295 RPM

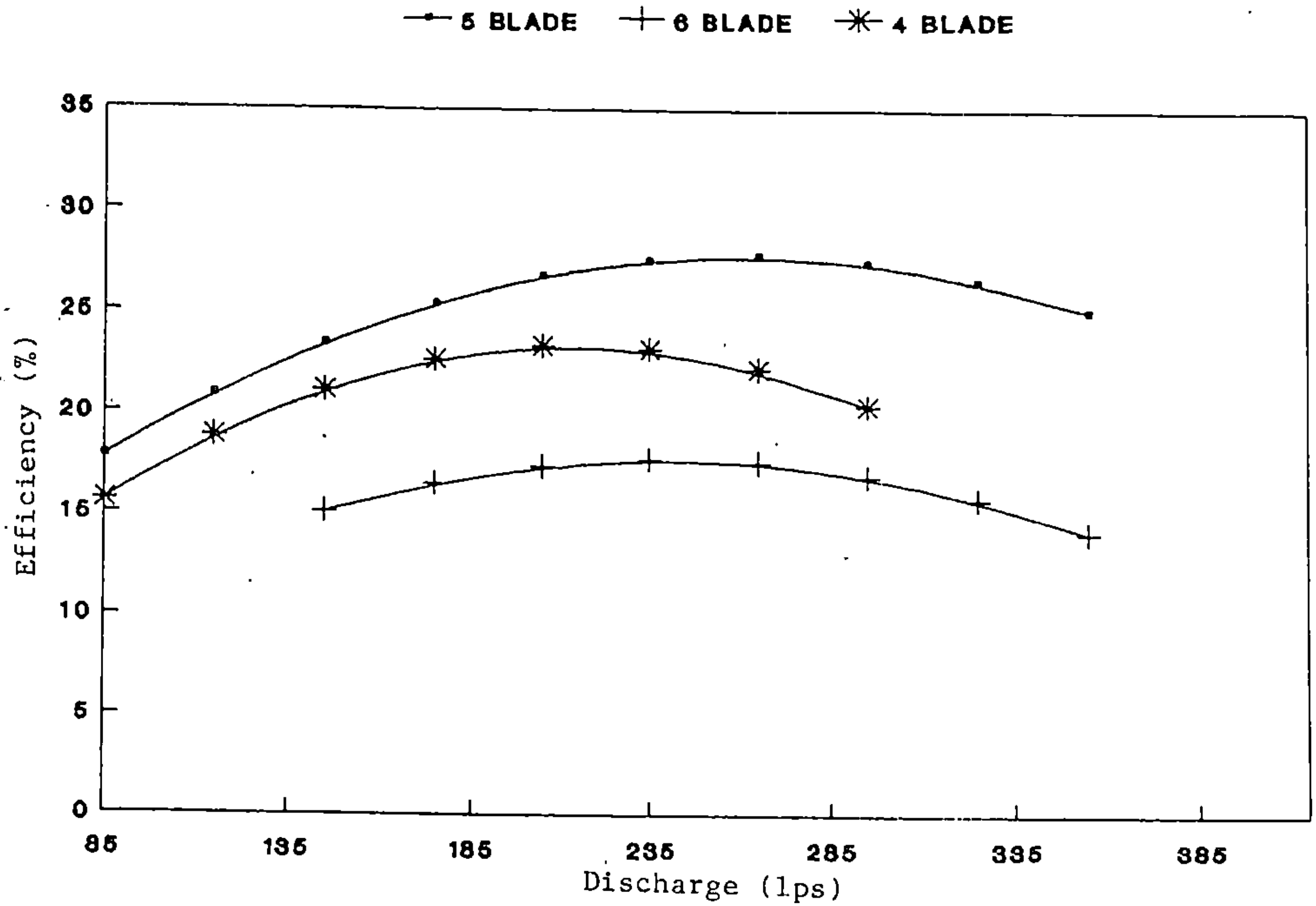

FIG.4.16 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 305 RPM

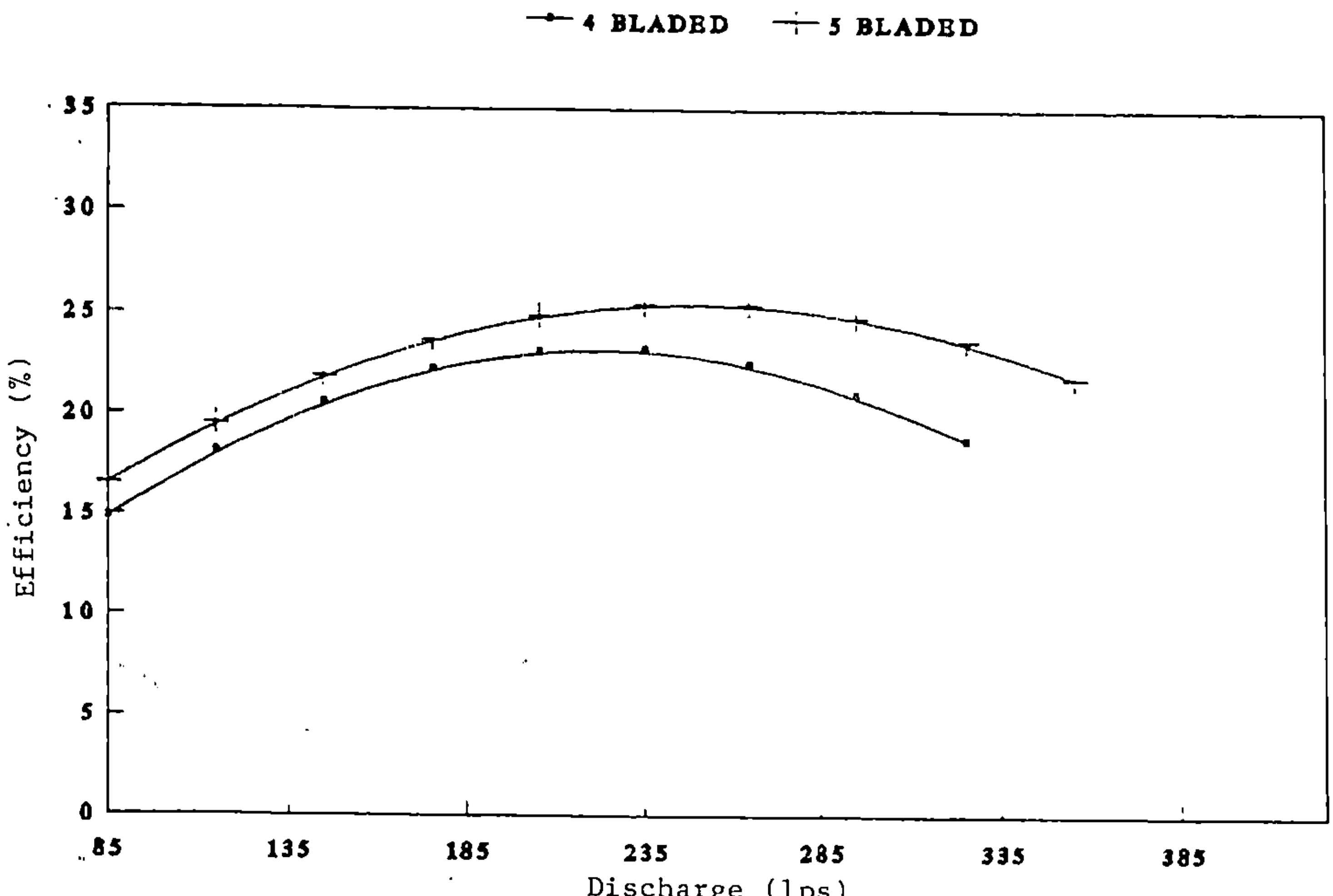

FIG.4.17 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 320 RPM

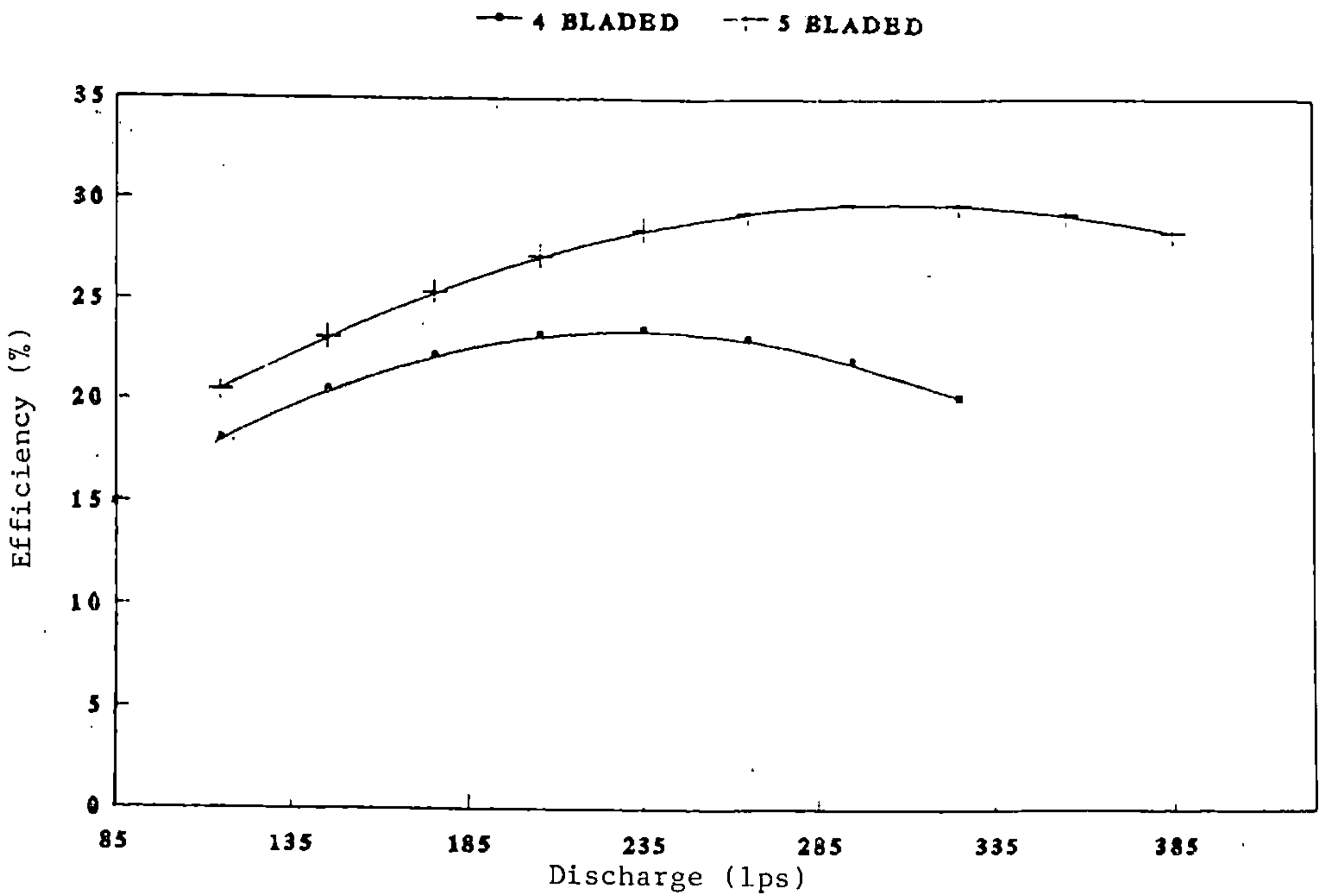

FIG.4.18 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 330 RPM

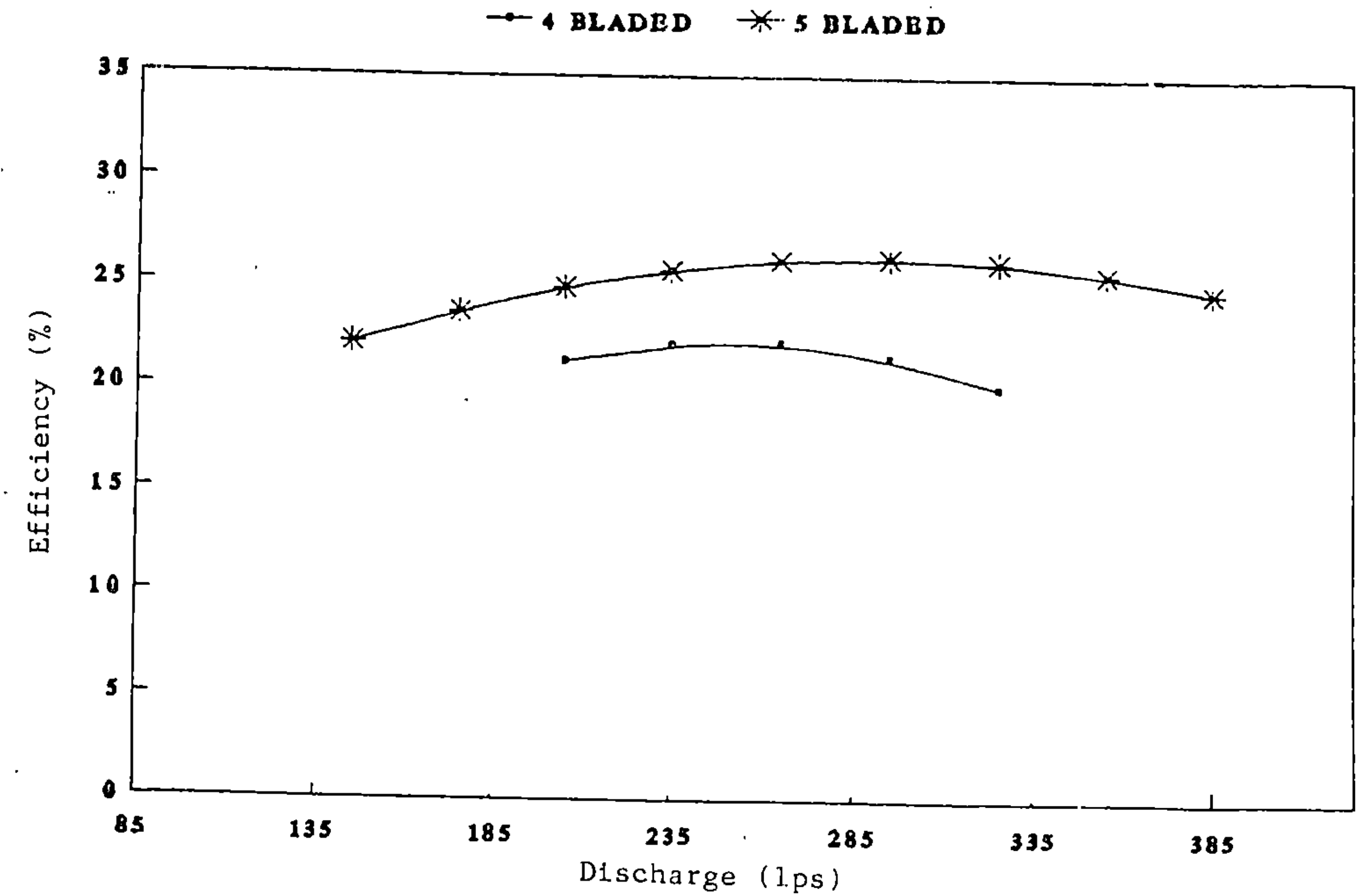

FIG.4.19 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 345 RPM

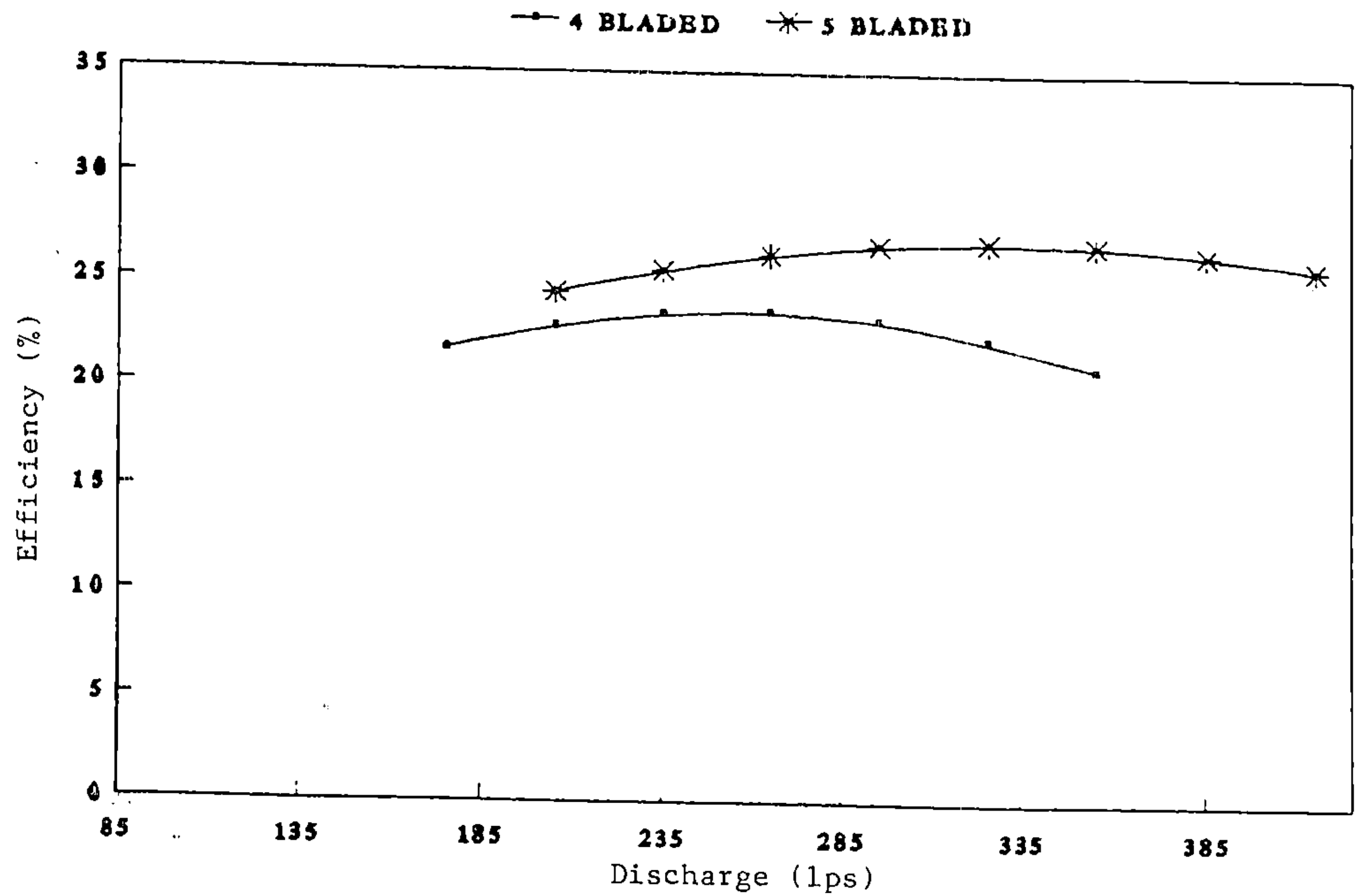

FIG.4.20 CURVES OF EFFICIENCY-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 350 RPM

The efficiency discharge curves were plotted for the three impellers at 295 and 305 rpm (Fig.4.16 and 4.17) and it can be observed from these curves that corresponding to any particular discharge, the efficiency of the five bladed impeller is higher than that of both four bladed and six bladed impellers, and the efficiency of the six bladed impeller is the least among the three. Also, in terms of discharge, the working range of five bladed impeller is found to be the maximum for all operated speeds. Observing the efficiency-discharge curves for the four bladed and five bladed impellers drawn at 320, 330, 345 and 350 rpm (Fig.4.17 to 4.20) it is obvious that the efficiency curves of the five bladed impeller lies above that of the four bladed impeller for all discharge rates, indicating its better performance in terms of power utilization.

Eventhough the five bladed impeller is found superior to the other two impellers in terms of efficiency, in order to have a clear idea of the overall performance, comparison curves of input-discharge (Fig.4.27 to 4.32) and total head-discharge relationships (Fig.4.21 to 4.26) were also drawn from the estimated values of head and input power. From close observations of the total head discharge curves at the speed of 295 rpm (Fig.4.21) of the three impellers it is very clear that at 295 rpm the total head developed by the five bladed

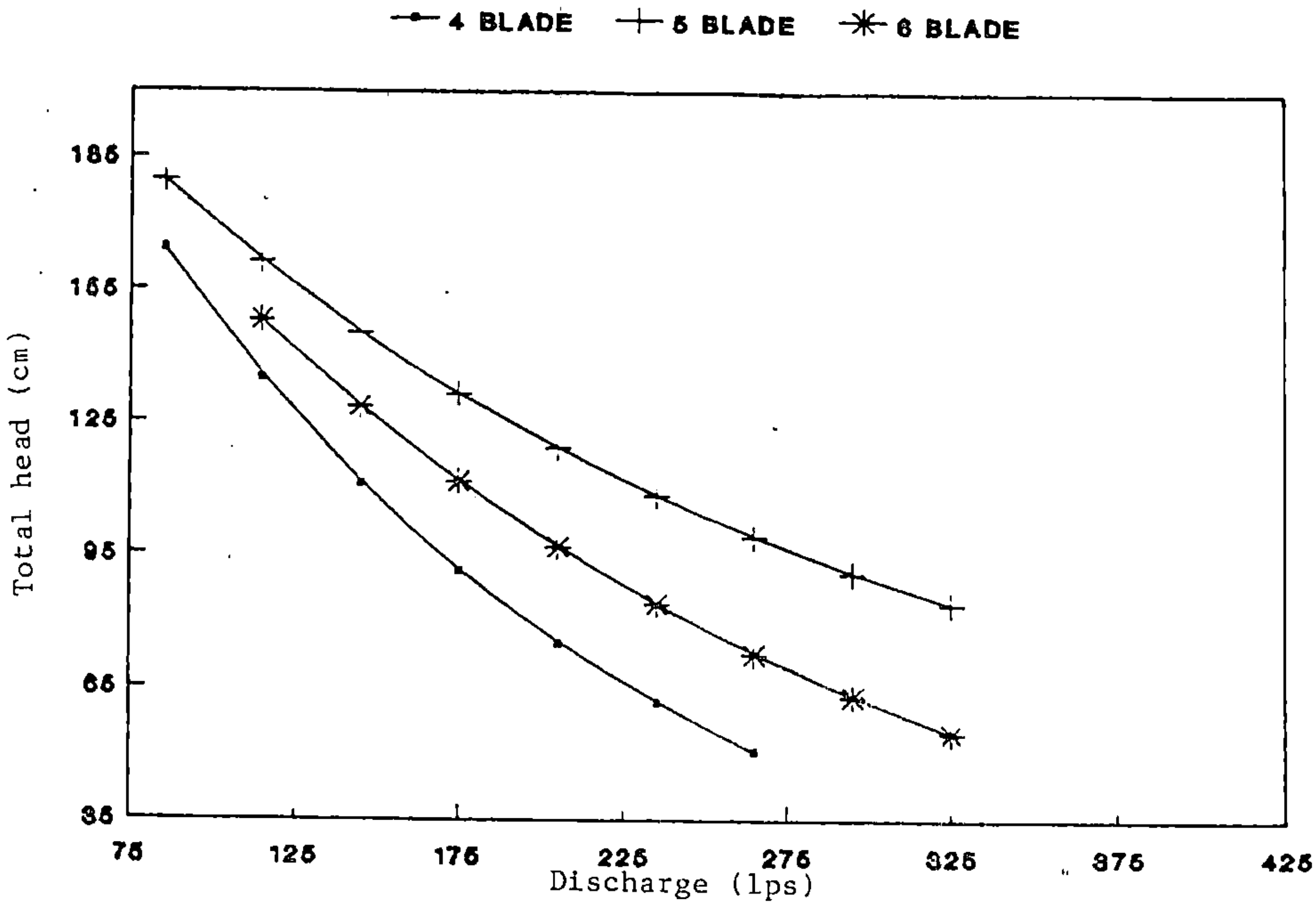

FIG.4.21 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 295 RPM

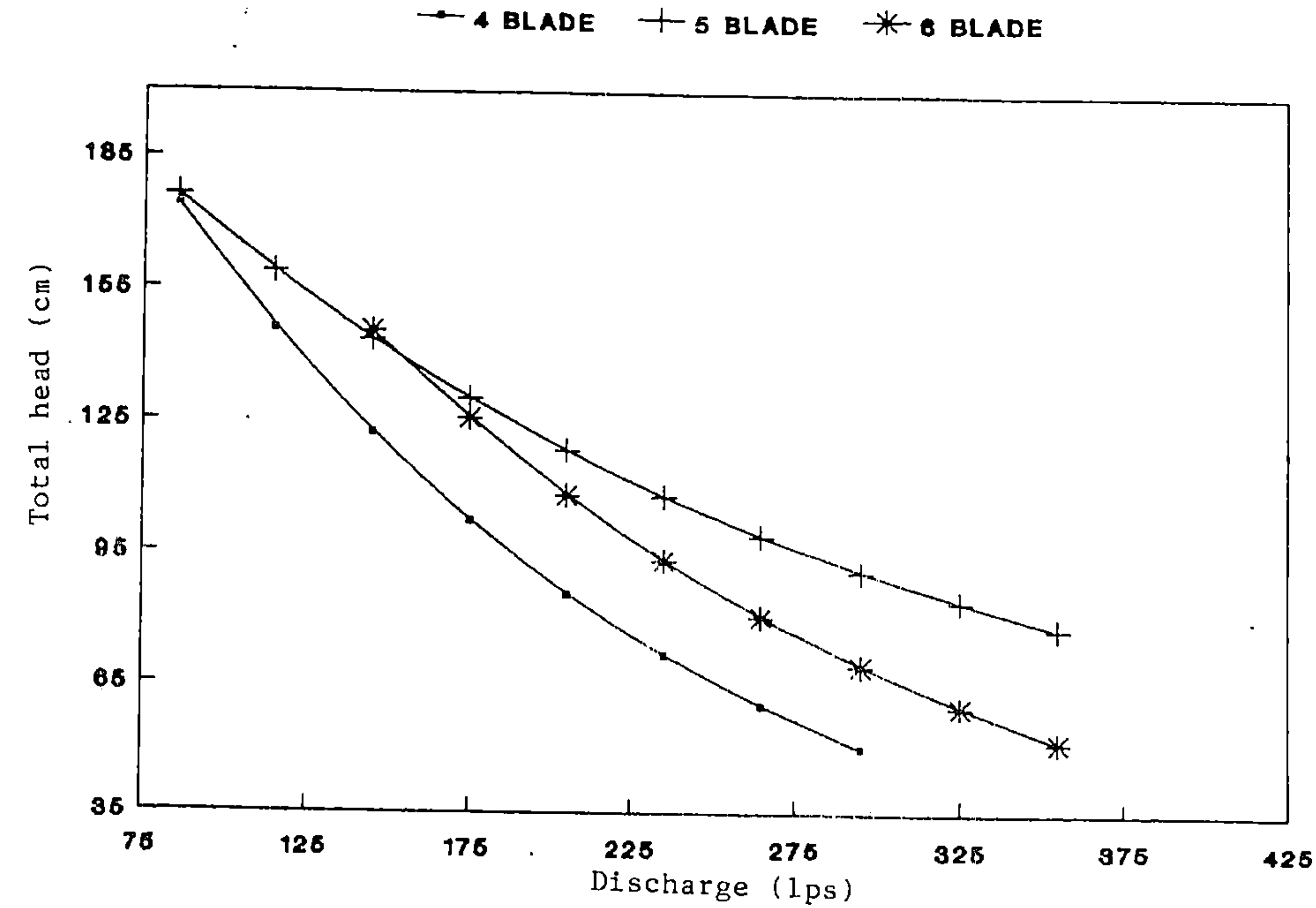

FIG.4.22 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 305 RPM

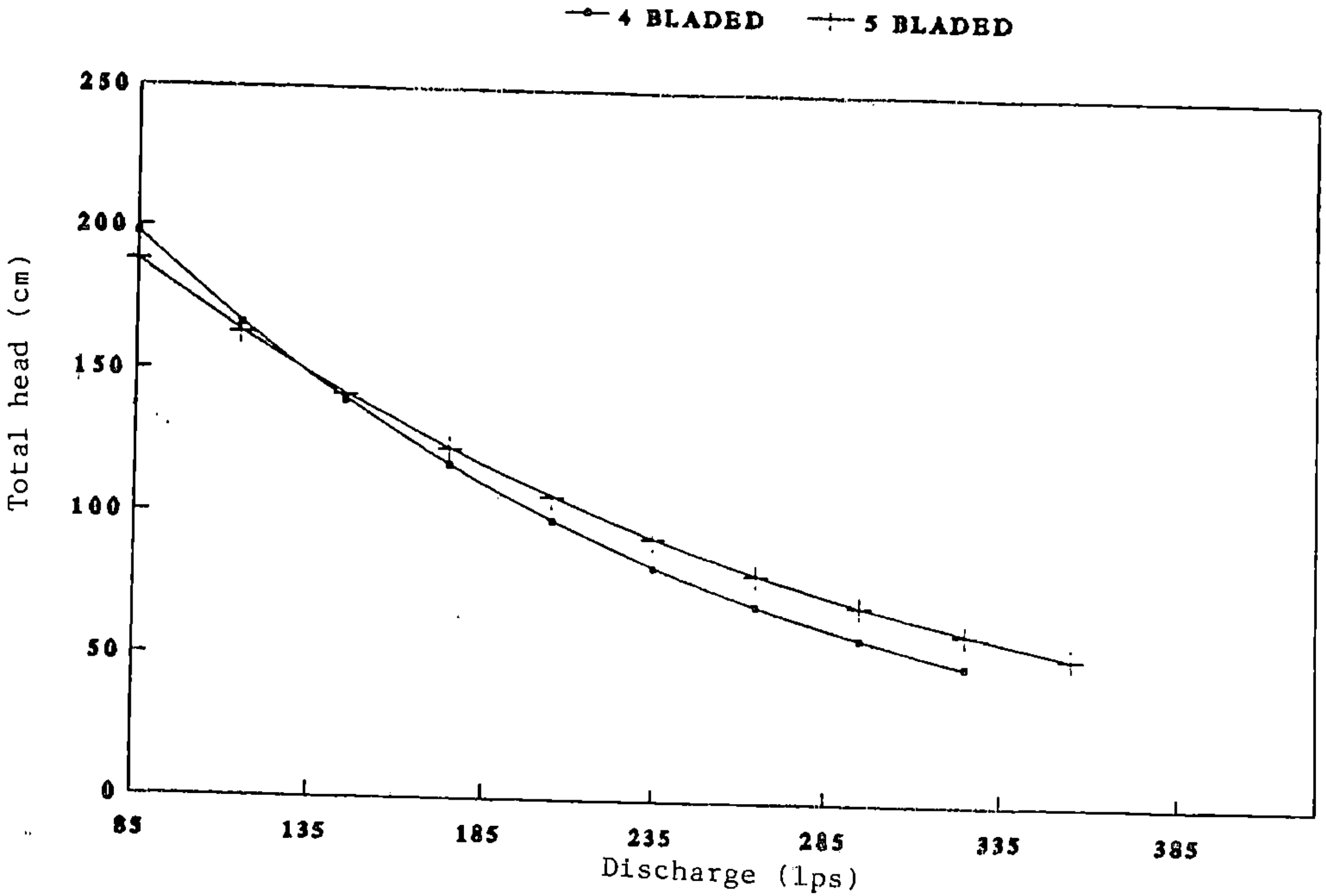

FIG.4.23 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 320 RPM

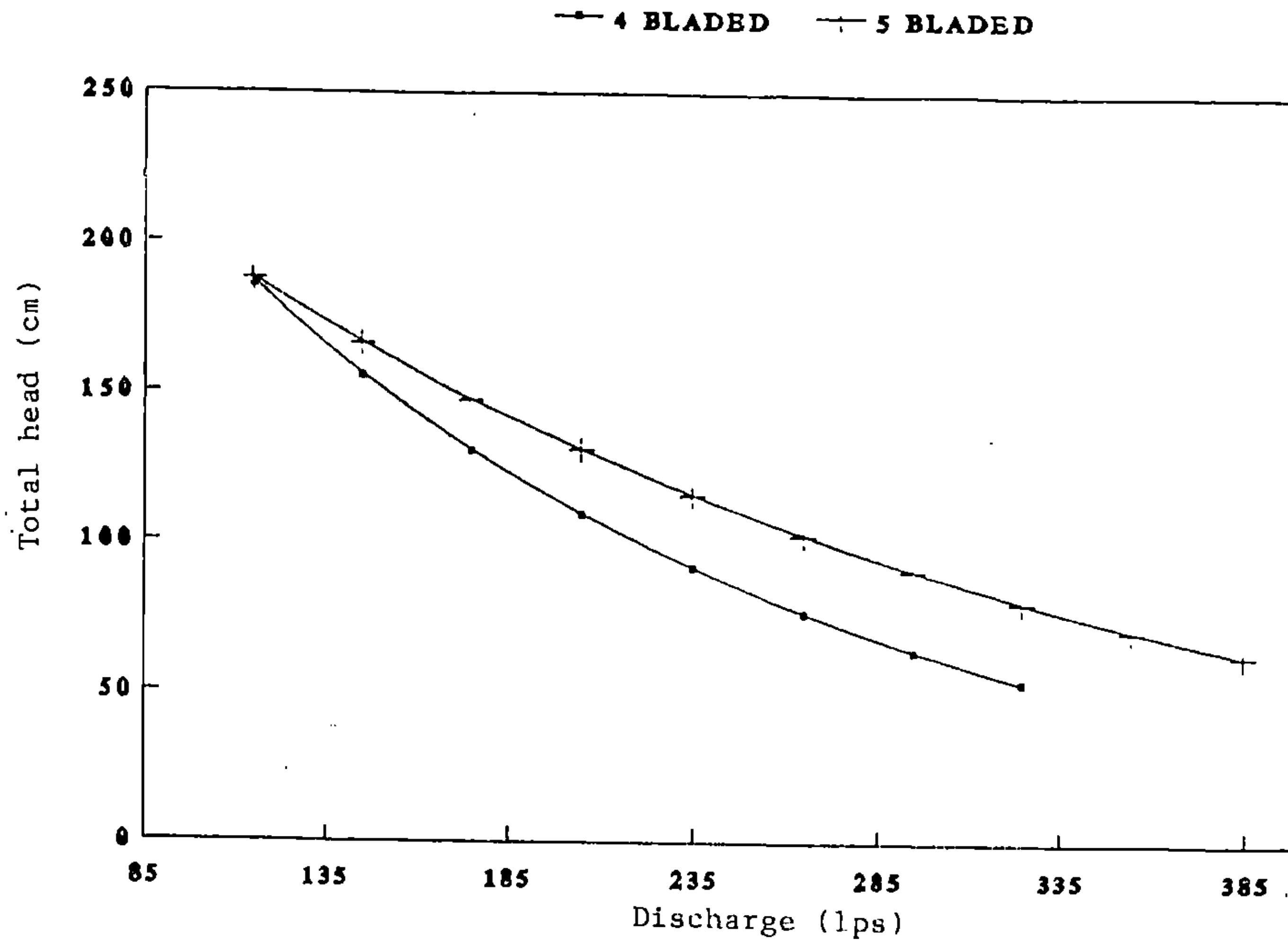

FIG.4.24 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 330 RPM

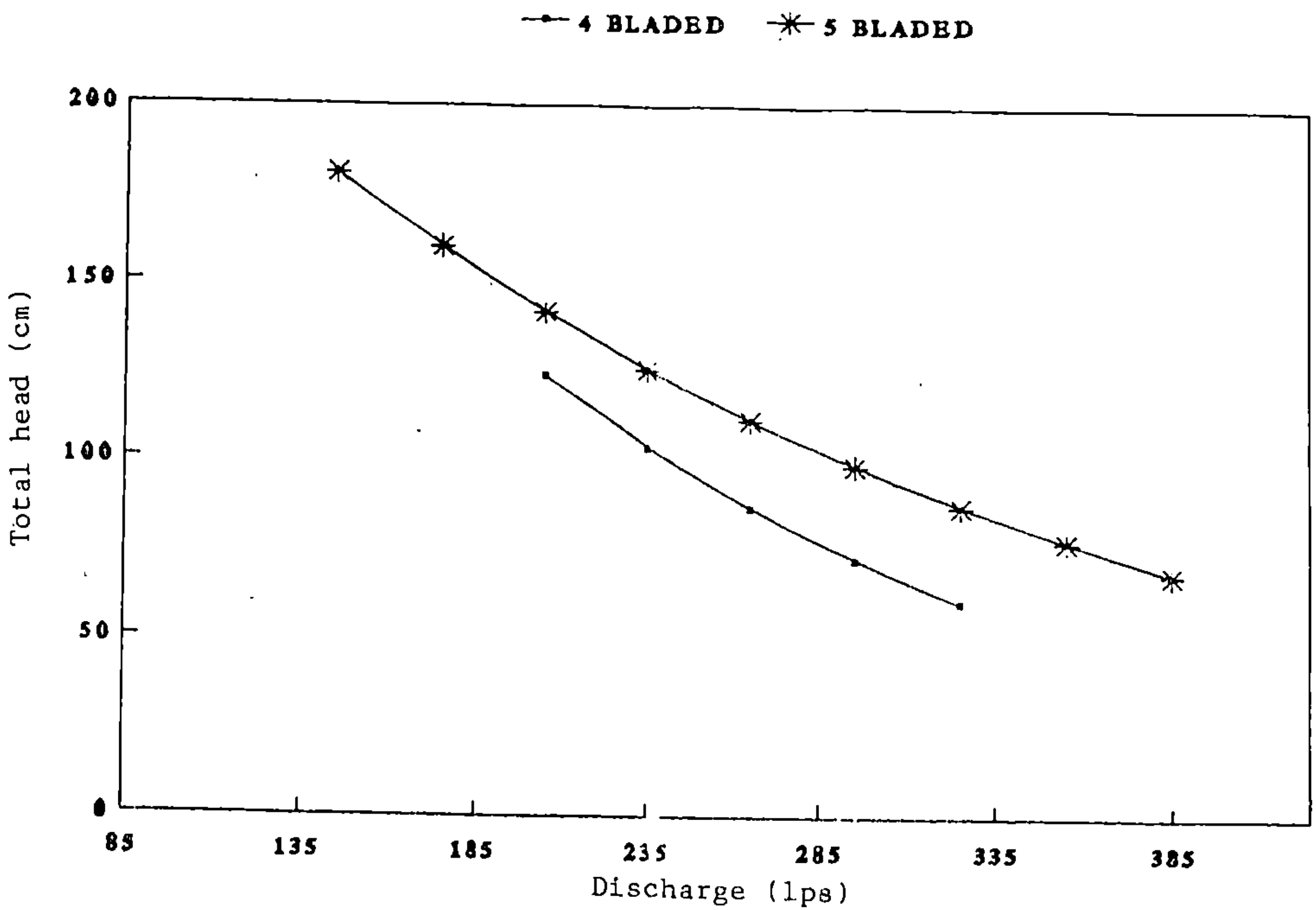

FIG.4.25 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 345 RPM

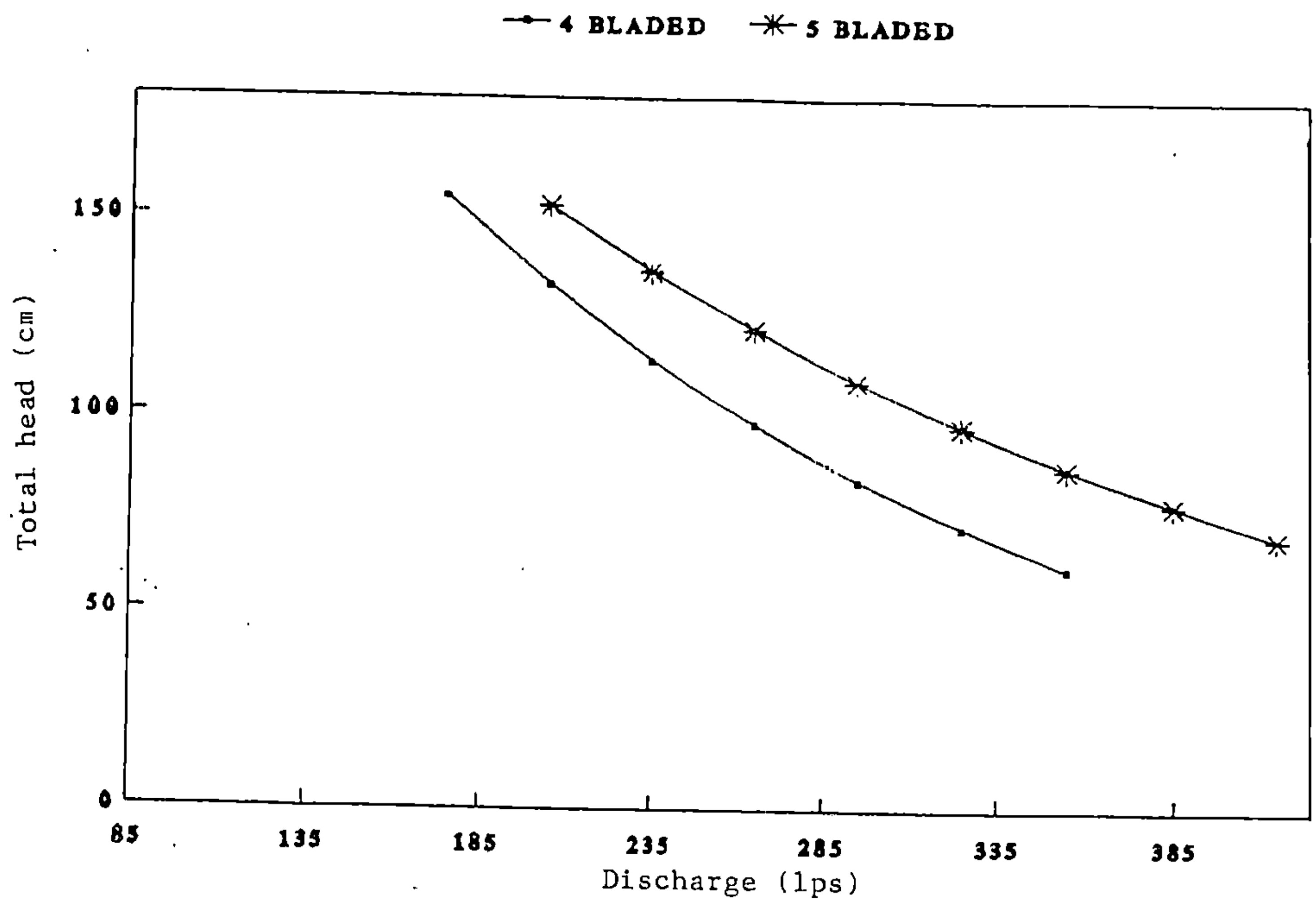

FIG.4.26 CURVES OF TOTAL HEAD-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 350 RPM

impeller was above that of the other two impellers, indicating that corresponding to any head, the discharge was more for this impeller. Also it is seen that the curve for the six bladed impeller lies above that for the four bladed impeller, which implies that for any particular head the discharge was more for the six bladed impeller than that for the four bladed impeller. While examining the curves at 305 rpm (Fig.4.22) the same trend as that at the speed of 295 rpm is observed, except that, the same maximum head is produced by both the four bladed and five bladed impellers at 305 rpm. The discharge corresponding to 140 cm was the same for the five bladed and six bladed impellers, that is, the two curves intersect corresponding to this head. At 320 rpm the curves intersect and above 149 cm, the discharge was more for the four bladed impeller than the five bladed impeller (Fig.4.23). From the observations of the curves drawn at 330, 345 and 350 rpm (Fig.4.24 to 4.26) it is clear that for any particular head, the discharge rate was more for the five bladed impeller. Thus when considering both the head and efficiency the five bladed impeller is found to be the best one.

As the head-discharge and efficiency-discharge curves the input power-discharge curves were also drawn for various speeds (Fig.4.27 to 4.32) to realise whether the motor was overloaded. Input-discharge curves drawn at 295 and 305 rpm

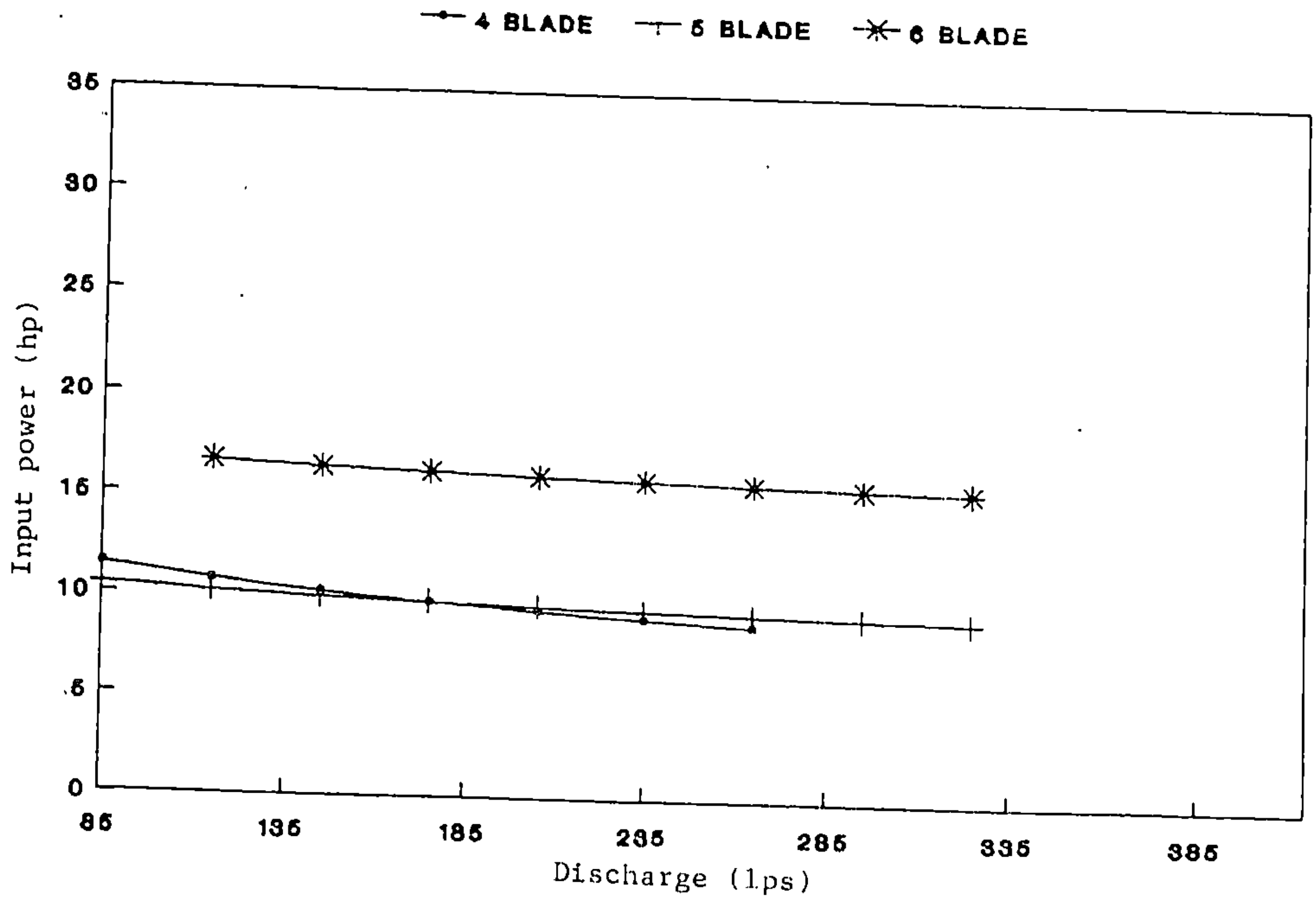

FIG.4.27 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 295 RPM

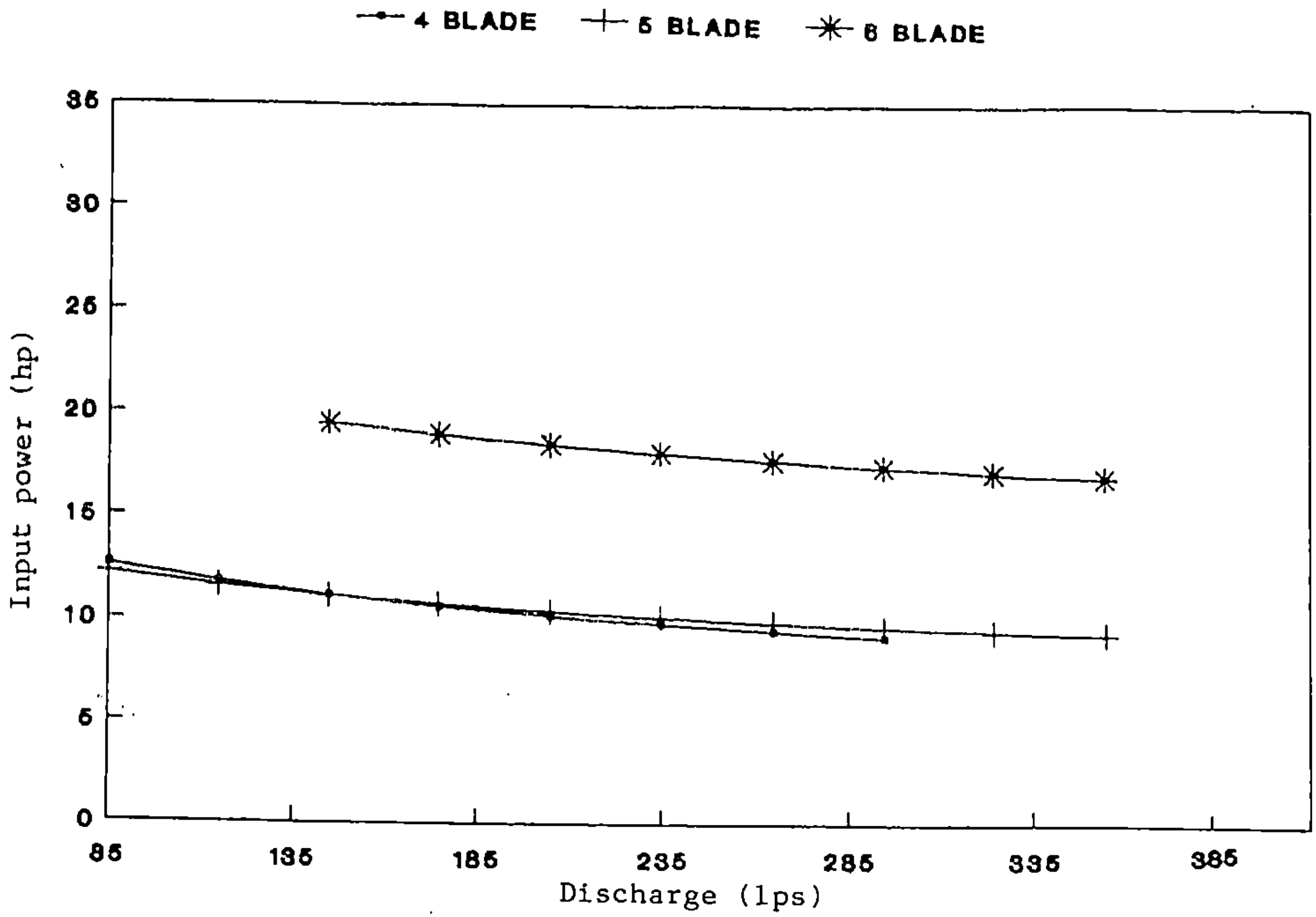

FIG.4.28 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED, FIVE BLADED AND SIX BLADED IMPELLERS AT 305 RPM

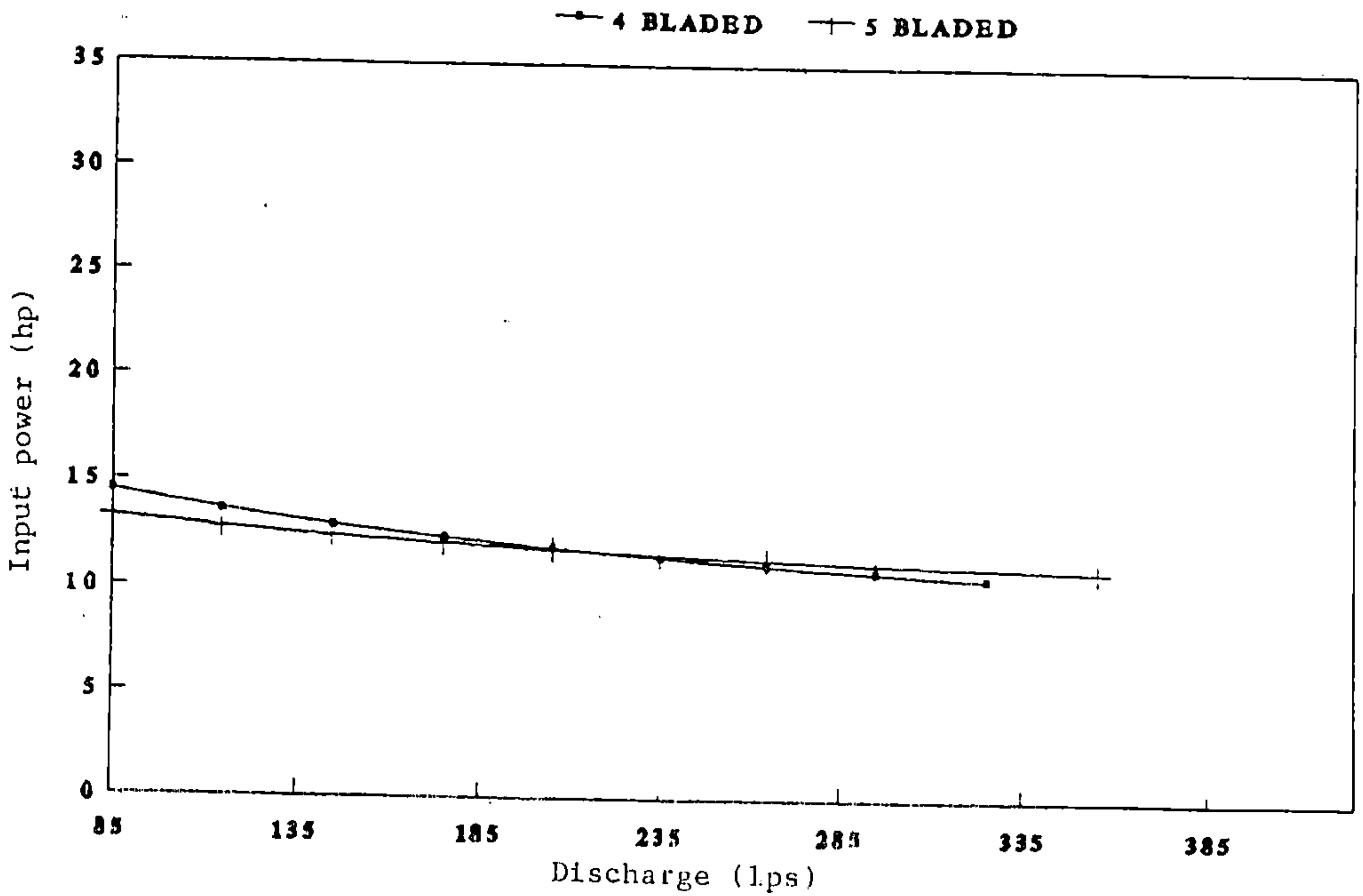

FIG.4.29 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 320 RPM

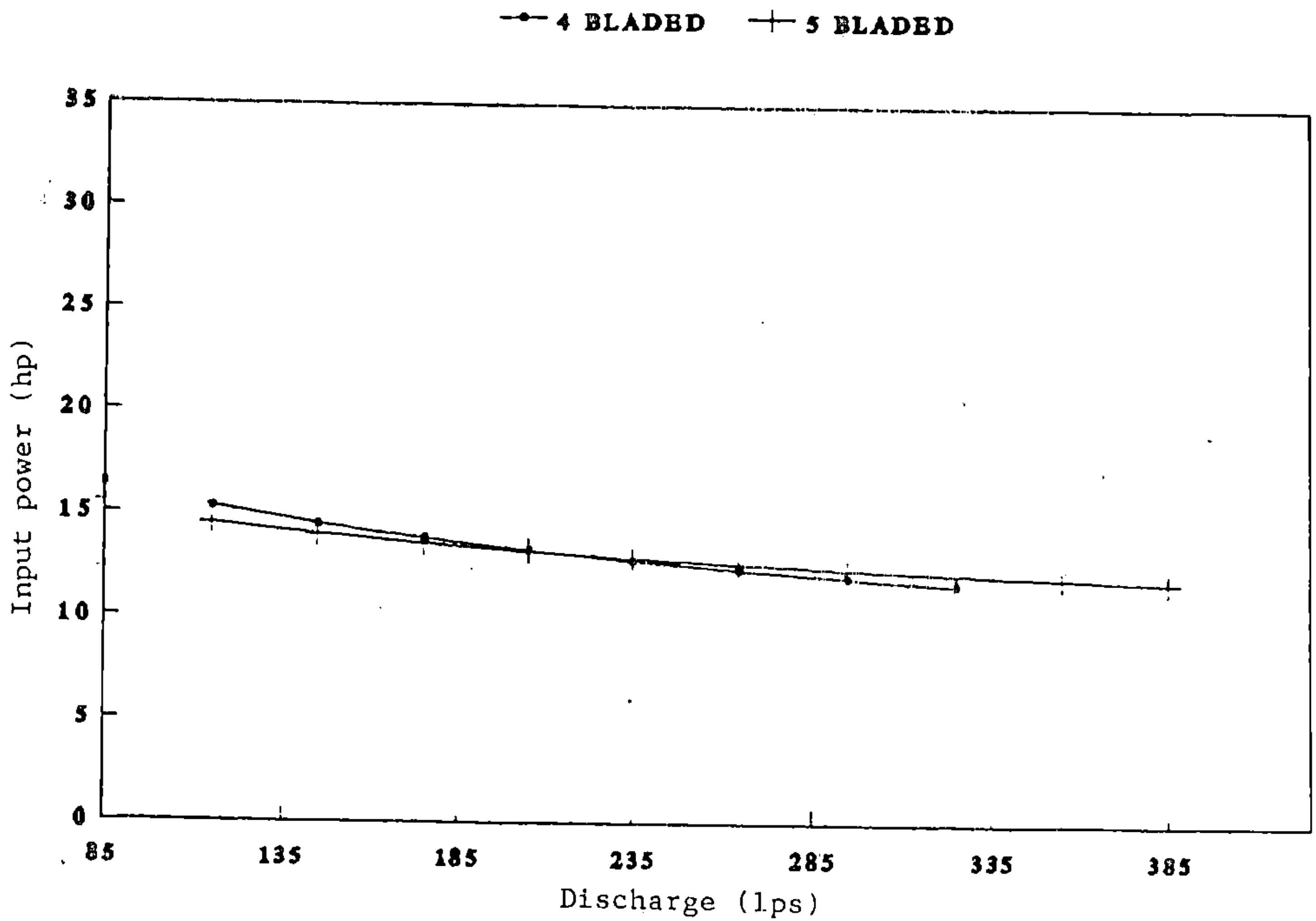

FIG.4.30 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 330 RPM

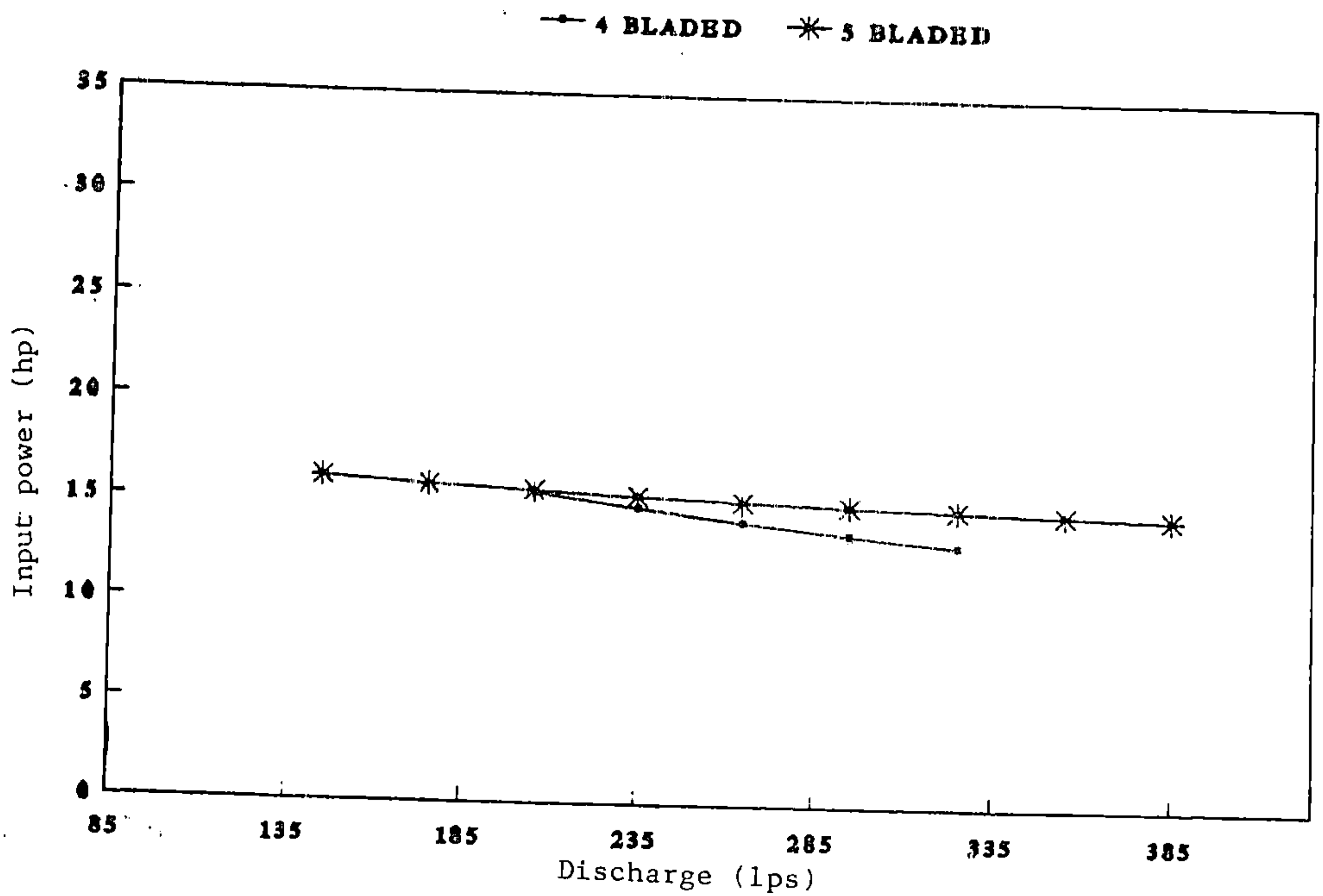

FIG.4.31 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 345 RPM

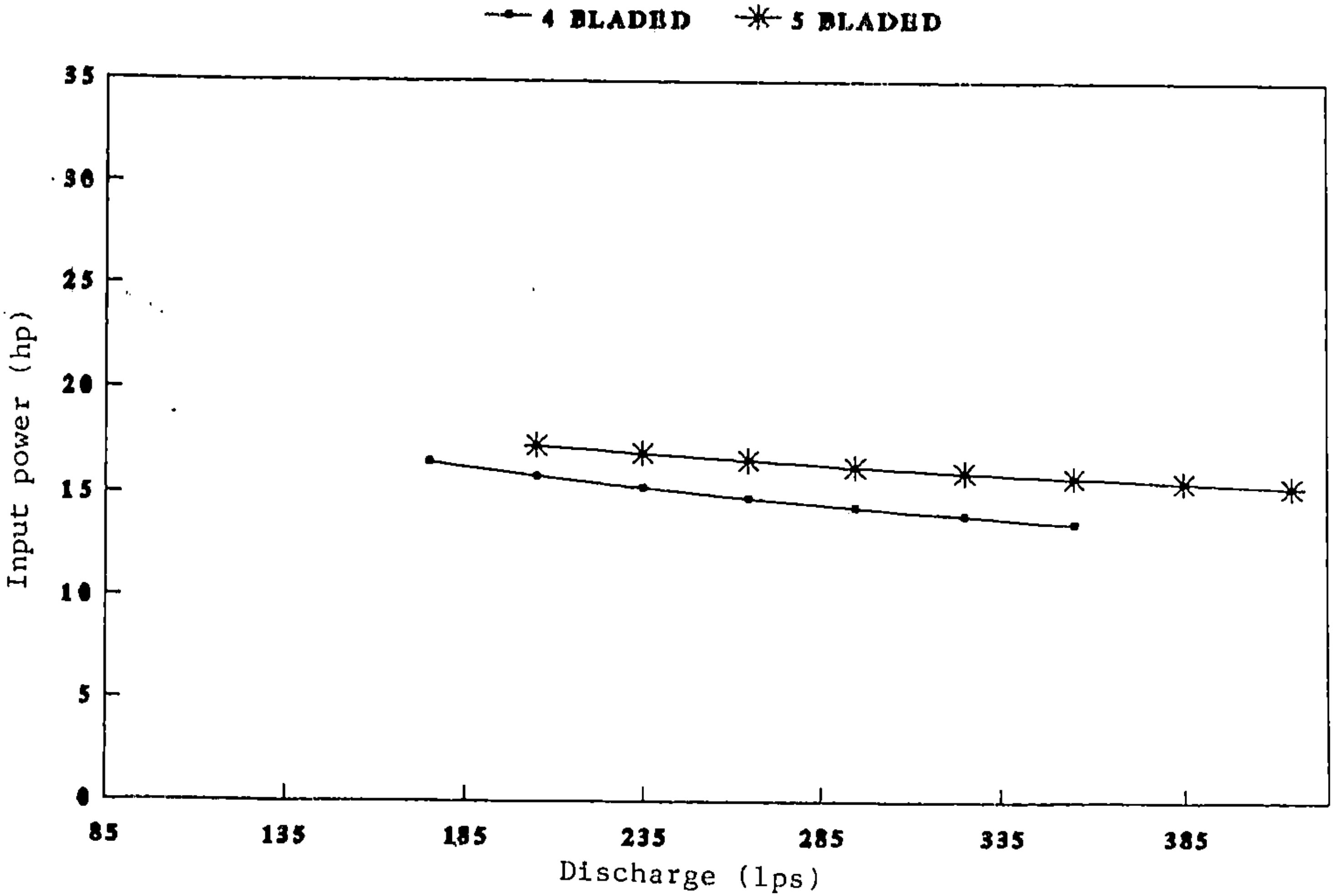

FIG.4.32 CURVES OF INPUT POWER-DISCHARGE RELATIONSHIPS OF FOUR BLADED AND FIVE BLADED IMPELLERS AT 350 RPM

(Fig.4.27 and 4.28) clearly indicate that the motor of 15 hp 'petti and para' with six bladed impeller was overloaded, and in the case of four bladed and five bladed impellers, the input power to motor was very low. The input curves at the speed of 350 rpm indicates that the motor was overloaded for both the four bladed and five bladed impellers (Fig.4.32). At 345 rpm the motor of the five bladed impeller was slightly overloaded (Fig.4.31). At 320 rpm the maximum input power was found to be below 14 hp (Fig.4.29). However at 330 rpm the input power to the motor is found in the desirable range (Fig.4.30). These observations implies that the high efficiency values of the four bladed and five bladed impellers at 295, 305 and 320 rpm was due to the low input power. The high input power together with the high efficiency values obtained at the speed of 330 rpm indicates the better performance of the five bladed impeller.

The above detailed evaluation of the performance of the four vaned, five vaned and six vaned impellers at various speeds establishes the supremacy of the five bladed impeller over the four bladed and six bladed impellers. Also analysis of the head-discharge, efficiency discharge and input power-discharge curves at various speeds indicates that the optimum working speed is 330 rpm.

Summary

SUMMARY

'Petti' and 'para', the widely used pumping device in Kuttanadu and kole lands of Kerala, for dewatering, has got high discharge capacity under low head conditions. It is less efficient for not being properly designed and since it is locally fabricated. However detailed hydraulic evaluation in a test bench, to reduce the power requirement, has not been done till now.

Considering the above aspects it was decided to study the performance of a 15 hp 'petti' and 'para' using three different impellers. The objective of the project was to evaluate the performance of the pump for various designs of the impeller and to suggest the optimum number of blades on the impeller and the optimum working speed for better efficiency.

The laboratory tests were conducted at a properly designed and constructed test bench at the head quarters of the Kerala Agricultural University, Vellanikkara, Trichur. The test bench has the facility for testing pumps with discharge up to 2000 lps and heads upto 3.5 m. The tests were conducted for the 15 hp 'petti and para' using four bladed, five bladed and six bladed impellers for various speeds of

operation of the pump. The hub ratio of all the three impellers was the same. For each test, from the observed readings, discharge, input power and efficiency were calculated.

The four bladed impeller was tested at different speeds, 285, 295, 305, 310, 320, 330, 335, 345 and 350 rpm and the total head developed varied from 37 cm to 174 cm, the minimum head and maximum head being different for different speeds. The maximum efficiency obtained for different speeds were found to vary from 21.81 to 23.72 per cent. Beyond 350 rpm the motor was found to be overloaded.

Pumping tests for the five bladed impeller were carried out at 285, 295, 300, 305, 320, 330, 340, 345 and 350 rpm. The total heads produced varied from 45 cm to 187 cm and the maximum efficiency values ranged from 25.25 to 30.09 per cent, the highest maximum efficiency was noted at 330 rpm.

Pumping tests for the six bladed impeller were done at 270, 275, 278, 280, 290, 295 and 305 rpm. Since the motor was heavily overloaded beyond 305 rpm, speeds above this value were not selected. The total head varied from 43 cm to 137 cm, and the maximum efficiency values for the operated speeds ranged between 17.88 and 18.98 per cent.

Characteristic curves were fitted for the three impellers at selected speeds using the data obtained from the pumping tests. For the four bladed impeller curves were fitted at 295, 305, 320, 330, 345 and 350 rpm; for the five bladed impeller at 295, 305, 320, 330, 345 and 350 rpm and for the six bladed impeller at 295 and 305 rpm.

The plotted curves of discharge-efficiency relationship for the three impellers were second degree in nature and therefore second degree curves were plotted, which are of the form

$$E = K_1 + K_2Q + K_3Q^2$$

where

E - Efficiency

Q - Discharge and

K_1, K_2, K_3 - Constants

The fitted curves of input power and discharge showed a relationship of semi-logarithmic nature as

$$HP = K_1 + K_2 \text{Ln } Q$$

where

HP - Horsepower

Q - Discharge

K_1 K_2 - Constants

In the same manner head discharge data were plotted which were also semi-logarithmic in nature, of the form

$$\ln H = K_1 + K_2 Q$$

where

H - Total head

Q - Discharge

K_1 K_2 - Constants

For easy comparison of the performance of the three impellers, input-discharge, head-discharge and efficiency-discharge curves were plotted from the estimated values of total head, input power and efficiency for various discharge rates. The comparison curves for the three impellers together were drawn at 295 and 305 rpm. Besides these, for the four bladed and five bladed impeller curves were also drawn at 320, 330, 345 and 350 rpm. For the six bladed impeller these curves were not drawn since it could not be operated beyond 305 rpm, being heavily overloaded.

Analysis of the efficiency-discharge curves indicated that for all the speeds compared the efficiency of the five bladed impeller was maximum and that of the six bladed impeller was the minimum.

Comparison of the total head-discharge curves indicated that at 295 rpm the maximum head was developed by the five bladed impeller. At 305 rpm the same maximum total head was developed by the four bladed and five bladed impellers. Observations of the curves at 330, 345 and 350 rpm indicated that for any particular head the discharge rate was more for the five bladed impeller.

The comparison of the input-discharge curves indicated that at 295 and 305 rpm, pump motor was heavily overloaded for six bladed impeller, whereas for the four bladed and five bladed impellers the input power to the pump motor was found very low. At 345 and 350 rpm motor was slightly overloaded for five bladed and four bladed impellers. At 330 rpm the input power to the motor was in the optimum range, for the five bladed impeller.

At speeds of 295 and 305 rpm the input power to the motor was very low for the four bladed and five bladed impeller. At the speed of 320 rpm, eventhough the input power to the motor was between 13 and 14.5 hp for the four bladed and five bladed impellers, efficiency was low. At 330 rpm input power to the motor was in the optimum range. High efficiency values were also found for this particular speed. Thus the best performance of the five bladed impeller was noted at 330 rpm.

The detailed analysis of the performance curves of the pump with four bladed, five bladed and six bladed impellers clearly established that the optimum number of blades on the impeller is five for the 15 hp 'petti and para' and the optimum speed of operation is 330 rpm.

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Appendices

Appendix-I

Performance of 15 hp petti and para with four bladed impeller at 285 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	21.50	15.00	36.89	21.50	278.13	1.36	7.46	18.37
2.	32.90	14.08	46.90	20.90	266.57	1.67	8.05	20.74
3.	40.10	12.58	52.60	20.10	251.41	1.76	8.19	21.56
4.	48.90	10.40	59.35	18.90	229.24	1.81	8.42	21.53
5.	57.90	8.00	66.78	17.90	211.29	1.88	8.78	21.42
6.	66.90	7.47	74.37	16.90	193.84	1.92	8.95	21.46
7.	76.10	6.46	82.56	16.10	180.23	1.98	9.11	21.78
8.	85.40	5.60	91.00	15.40	168.61	2.04	9.38	21.81
9.	94.40	4.60	99.00	14.40	152.45	2.01	9.49	21.16
10.	103.60	3.89	107.40	13.60	139.93	2.00	9.69	20.60
11.	112.60	3.09	115.60	12.60	124.78	1.92	9.79	19.63
12.	121.50	2.35	123.85	11.50	108.80	1.79	9.96	18.02
13.	130.80	1.95	132.75	10.80	99.02	1.75	9.96	17.58
14.	139.90	1.50	141.40	9.90	86.90	1.63	10.28	15.92

Appendix-II

Performance of 15 hp petti and para with four bladed impeller at 295 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	22.00	16.50	38.50	22.00	287.89	1.47	8.06	18.32
2.	31.30	14.90	46.20	21.30	274.26	1.69	8.59	19.69
3.	40.60	13.45	54.05	20.60	260.85	1.88	8.83	21.27
4.	49.40	11.30	60.71	19.40	238.40	1.92	8.88	21.70
5.	58.70	10.10	68.80	18.70	225.61	2.07	9.22	22.44
6.	67.70	8.59	76.29	17.70	207.76	2.11	9.39	22.48
7.	76.80	7.34	84.14	16.80	192.11	2.15	9.69	22.23
8.	86.10	6.46	92.56	16.10	180.23	2.22	9.86	22.53
9.	95.40	5.65	101.06	15.40	168.61	2.27	10.11	22.45
10.	104.40	4.62	109.00	14.40	152.45	2.21	10.39	21.32
11.	113.50	3.81	117.30	13.50	138.39	2.16	10.45	20.69
12.	122.60	3.09	125.60	12.60	124.78	2.09	10.52	19.86
13.	131.60	2.41	134.00	11.60	110.22	1.96	10.72	18.36
14.	140.90	2.00	142.90	10.90	100.40	1.91	10.72	17.84
15.	150.00	1.54	151.50	10.00	88.22	1.78	11.06	16.10

Appendix-III

Performance of 15 hp petti and para with four bladed impeller at 305 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	28.20	16.90	45.15	22.20	291.83	1.75	8.96	19.60
2.	33.90	16.27	50.17	21.90	285.93	1.91	8.96	21.32
3.	41.20	14.76	55.90	21.20	272.33	2.03	9.33	21.78
4.	50.50	13.35	63.80	20.50	258.96	2.20	9.53	23.13
5.	59.50	11.49	70.99	19.50	240.24	2.27	9.88	23.01
6.	68.50	9.81	78.30	18.50	222.00	2.31	10.02	23.14
7.	77.50	8.30	85.80	17.50	204.24	2.33	10.19	22.92
8.	86.50	6.96	93.46	16.50	186.99	2.33	10.47	22.25
9.	96.10	6.46	102.50	16.10	180.23	2.46	10.93	22.56
10.	105.30	5.55	110.80	15.30	166.97	2.46	11.03	22.36
11.	114.50	4.72	119.20	14.50	154.04	2.44	11.17	21.91
12.	123.70	3.98	127.68	13.70	141.47	2.40	11.42	21.08
13.	132.70	3.17	135.87	12.70	126.27	2.28	11.38	20.10
14.	141.70	2.48	144.10	11.70	111.65	2.14	11.74	18.30
15.	150.40	1.89	152.50	10.70	97.65	1.98	11.77	16.87

Appendix-IV

Performance of 15 hp petti and para with four bladed impeller at 310 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	22.70	18.10	40.80	22.70	301.75	1.64	9.35	17.57
2.	32.30	17.10	49.40	22.30	293.81	1.93	9.82	19.74
3.	41.80	16.10	57.80	21.80	283.98	2.19	10.11	21.65
4.	50.90	14.10	65.00	20.90	266.58	2.31	10.44	22.14
5.	59.90	12.20	72.10	19.90	247.68	2.38	10.54	22.60
6.	68.90	10.50	79.40	18.90	229.24	2.42	10.82	22.41
7.	78.00	9.00	87.00	18.00	213.07	2.47	10.98	22.51
8.	87.20	7.90	95.10	17.20	199.02	2.52	11.31	22.31
9.	96.90	7.48	104.40	16.90	193.84	2.70	11.71	23.04
10.	106.20	6.60	112.70	16.20	181.92	2.74	12.13	22.55
11.	115.50	5.80	121.30	15.50	170.26	2.75	12.28	22.42
12.	124.70	5.00	129.60	14.70	157.25	2.72	12.45	21.83
13.	133.70	4.00	138.00	13.70	141.48	2.60	12.57	20.70
14.	142.60	3.00	146.00	12.60	124.78	2.42	12.47	19.44
15.	151.70	2.00	154.20	11.70	111.66	2.29	12.86	17.84
16.	160.80	2.00	163.00	10.80	99.02	2.14	12.76	16.83

Appendix-V

Performance of 15 hp petti and para with four bladed impeller at 320 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	23.60	20.30	43.96	23.60	319.86	1.87	10.31	18.18
2.	35.00	18.80	53.85	23.00	307.74	2.20	10.58	20.87
3.	42.10	16.70	58.82	22.10	289.86	2.27	10.68	21.28
4.	51.40	15.18	61.50	21.40	276.20	2.45	11.04	22.19
5.	60.70	13.70	74.40	20.70	262.76	2.60	11.26	23.15
6.	69.60	11.65	81.25	19.60	242.09	2.62	11.36	23.08
7.	78.50	9.80	88.30	18.50	222.00	2.61	11.57	22.58
8.	87.80	8.70	96.50	17.80	209.52	2.69	11.72	23.04
9.	97.00	7.60	104.60	17.00	195.55	2.72	12.07	22.58
10.	106.50	6.96	113.40	16.50	186.99	2.82	12.46	22.68
11.	115.80	6.11	121.90	15.80	175.22	2.84	12.82	22.20
12.	124.90	5.12	130.02	14.90	160.46	2.78	13.05	21.29
13.	134.30	4.50	138.80	14.30	150.87	2.79	13.14	21.24
14.	143.30	3.60	146.90	13.30	135.32	2.65	13.03	20.33
15.	152.10	2.74	154.80	12.10	117.43	2.42	13.29	18.23
16.	161.10	2.11	163.20	11.10	103.17	2.24	13.40	16.74

Appendix-VI

Performance of 15 hp petti and para with four bladed impeller at 330 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	24.00	21.40	45.40	24.00	328.03	1.98	10.87	18.28
2.	33.50	20.11	53.60	23.50	317.83	2.27	11.32	20.05
3.	42.90	18.40	60.76	22.80	303.74	2.47	11.65	21.25
4.	52.10	16.70	68.80	22.10	289.86	2.65	12.00	22.17
5.	61.30	14.97	76.30	21.30	274.27	2.78	12.37	22.54
6.	79.70	11.84	91.50	19.70	243.95	2.98	12.86	23.14
7.	88.70	10.10	98.80	18.70	225.60	2.97	13.03	22.81
8.	97.90	8.80	106.79	17.90	211.29	3.00	13.25	22.71
9.	107.30	8.00	115.30	17.30	200.76	3.08	13.74	22.45
10.	116.90	7.50	124.40	16.40	193.84	3.21	14.11	22.78
11.	125.90	6.20	132.10	15.40	176.89	3.11	14.23	21.89
12.	135.20	5.40	140.60	15.20	165.34	3.10	14.28	21.70
13.	144.50	4.70	149.20	14.50	154.05	3.06	14.41	21.26
14.	153.50	3.80	157.00	13.50	138.39	2.89	14.36	20.17
15.	162.60	3.10	165.60	12.60	124.78	2.75	14.41	19.12
16.	171.60	2.40	174.00	11.60	110.23	2.56	14.89	17.17

Appendix-VII

Performance of 15 hp petti and para with four bladed impeller at 335 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	24.40	22.50	46.90	24.40	336.27	2.10	11.66	18.04
2.	34.00	21.40	55.40	24.00	328.03	2.42	12.19	19.89
3.	43.50	20.11	63.60	23.50	317.84	2.69	12.47	21.62
4.	52.80	18.40	71.20	22.80	303.74	2.88	12.87	22.39
5.	62.80	16.90	79.00	22.20	291.83	3.08	13.29	23.16
6.	71.10	14.60	8.50	21.10	270.41	3.09	13.52	22.84
7.	80.40	13.20	93.00	20.40	257.07	3.21	13.63	23.52
8.	89.40	11.30	100.20	19.40	238.40	3.20	13.75	23.30
9.	98.50	9.80	108.30	18.50	222.00	3.20	13.92	23.03
10.	108.10	9.20	117.30	18.10	214.84	3.36	14.36	23.40
11.	117.40	8.20	125.60	17.40	202.50	3.39	14.62	23.20
12.	126.40	6.80	133.20	16.40	185.29	3.29	14.76	22.30
13.	135.40	5.60	141.00	15.40	168.61	3.17	14.62	21.69
14.	144.50	4.70	149.20	14.50	154.05	3.06	14.54	21.10
15.	153.40	3.70	157.00	13.40	136.85	2.87	14.54	19.72
16.	162.40	2.95	165.00	12.40	121.82	2.69	14.89	18.04
17.	171.70	2.48	174.20	11.70	111.65	2.59	15.32	16.92

Appendix-VIII

Performance of 15 hp petti and para with four bladed impeller at 345 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	24.80	23.60	48.40	24.80	344.57	2.32	12.37	17.99
2.	34.20	21.90	56.00	24.20	332.14	2.48	12.97	19.17
3.	43.50	20.10	63.60	23.50	317.84	2.69	13.18	20.45
4.	53.20	19.35	72.50	23.20	311.77	3.02	13.63	22.13
5.	62.10	16.70	78.80	22.10	289.86	3.05	14.06	21.67
6.	71.10	14.50	85.60	21.10	270.41	3.09	14.14	21.84
7.	80.00	12.39	92.40	20.00	249.54	3.07	14.26	21.56
8.	89.10	10.80	99.90	19.10	232.89	3.10	14.36	21.60
9.	98.60	9.90	108.60	18.60	223.81	3.24	14.89	21.76
10.	108.00	9.00	117.00	18.00	213.07	3.32	15.35	21.71
11.	117.40	8.00	125.60	17.40	202.50	3.39	15.74	21.54

Appendix-IX

Performance of 15 hp petti and para with four bladed impeller at 350 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	32.30	25.00	57.39	25.30	355.04	2.71	13.18	20.60
2.	44.30	22.20	66.50	24.30	334.20	2.96	13.60	21.75
3.	53.50	20.10	73.60	23.50	317.83	3.11	13.89	22.45
4.	62.90	18.60	81.50	22.90	305.74	3.32	14.16	23.46
5.	72.20	16.95	89.15	22.20	291.83	3.46	14.62	23.72
6.	81.30	14.97	96.27	21.30	274.26	3.52	14.89	23.63
7.	90.10	12.58	102.68	20.10	251.41	3.44	14.89	23.10
8.	99.40	11.30	110.70	19.40	238.40	3.51	15.29	23.01
9.	109.00	10.62	119.62	19.00	231.06	3.68	15.58	23.64
10.	118.20	9.33	127.50	18.20	216.62	3.68	15.92	23.12
11.	127.50	8.30	135.80	17.50	204.24	3.69	16.21	22.80
12.	136.70	7.20	143.91	16.70	190.40	3.65	16.28	22.43
13.	145.60	5.88	151.48	15.60	171.90	3.47	16.41	21.15
14.	155.30	5.55	160.85	15.30	166.97	3.58	16.58	21.58
15.	164.40	4.60	169.00	14.40	152.45	3.43	16.48	20.84

Appendix-X

Performance of 15 hp petti and para with five bladed impeller at 285 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	25.40	19.80	45.20	23.40	315.81	1.90	7.96	23.92
2.	32.60	17.89	50.48	22.60	299.75	2.61	8.04	25.08
3.	41.10	14.55	55.65	21.10	270.41	2.01	7.86	25.53
4.	50.30	12.96	63.26	20.30	255.18	2.15	7.84	27.45
5.	59.30	11.10	70.44	19.30	236.56	2.22	7.96	27.91
6.	68.30	9.40	77.70	18.30	218.41	2.26	8.12	27.90
7.	77.40	8.16	85.56	17.40	202.50	2.31	8.16	28.29
8.	86.40	6.80	93.20	16.40	185.29	2.30	8.31	27.69
9.	95.10	5.30	100.40	15.10	163.70	2.19	8.45	25.94
10.	104.50	4.72	109.20	14.50	154.05	2.24	8.51	26.32
11.	113.35	3.68	117.00	13.35	136.09	2.12	8.55	24.82
12.	122.70	3.17	125.8	12.70	126.27	2.11	8.83	23.97
13.	131.90	2.60	134.50	11.90	114.53	2.05	9.18	22.37
14.	140.85	1.97	142.80	10.85	99.71	1.89	9.46	20.06

Appendix-XI

Performance of 15 hp petti and para with five bladed impeller at 295 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	31.00	21.40	52.40	24.00	328.03	2.29	8.93	25.65
2.	42.80	18.30	61.16	22.80	303.74	2.47	9.04	27.39
3.	51.40	15.10	66.50	21.40	276.20	2.45	9.24	26.52
4.	60.00	12.40	72.40	20.00	249.54	2.41	9.14	26.35
5.	69.10	10.79	79.90	19.10	232.89	2.48	9.30	26.68
6.	78.00	9.00	87.00	18.00	213.06	2.47	9.46	26.13
7.	87.10	7.70	94.80	17.10	197.28	2.49	9.57	26.07
8.	96.10	6.40	102.56	16.10	180.24	2.46	9.63	25.59
9.	105.10	5.30	110.40	15.10	163.71	2.41	9.63	25.03
10.	114.30	4.50	118.80	14.30	150.87	2.39	9.69	24.67
11.	123.30	3.60	126.90	13.30	135.32	2.29	9.84	23.27
12.	132.30	2.80	135.10	12.30	120.35	2.17	10.08	21.52
13.	141.10	2.20	143.20	11.30	105.98	2.02	10.44	19.38
14.	150.40	1.70	152.10	10.40	93.57	1.89	10.65	17.82

Appendix-XI

Performance of 15 hp petti and para with five bladed impeller at 295 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	31.00	21.40	52.40	24.00	328.03	2.29	8.93	25.65
2.	42.80	18.30	61.16	22.80	303.74	2.47	9.04	27.39
3.	51.40	15.10	66.50	21.40	276.20	2.45	9.24	26.52
4.	60.00	12.40	72.40	20.00	249.54	2.41	9.14	26.35
5.	69.10	10.79	79.90	19.10	232.89	2.48	9.30	26.68
6.	78.00	9.00	87.00	18.00	213.06	2.47	9.46	26.13
7.	87.10	7.70	94.80	17.10	197.28	2.49	9.57	26.07
8.	96.10	6.40	102.56	16.10	180.24	2.46	9.63	25.59
9.	105.10	5.30	110.40	15.10	163.71	2.41	9.63	25.03
10.	114.30	4.50	118.80	14.30	150.87	2.39	9.69	24.67
11.	123.30	3.60	126.90	13.30	135.32	2.29	9.84	23.27
12.	132.30	2.80	135.10	12.30	120.35	2.17	10.08	21.52
13.	141.10	2.20	143.20	11.30	105.98	2.02	10.44	19.38
14.	150.40	1.70	152.10	10.40	93.57	1.89	10.65	17.82

Appendix-XII

Performance of 15 hp petti and para with five bladed impeller at 300 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	33.90	21.10	55.00	23.90	325.98	2.39	9.46	25.29
2.	42.60	17.90	60.48	22.60	299.75	2.41	9.52	25.39
3.	51.70	15.80	67.50	21.70	282.03	2.53	9.75	26.04
4.	60.50	13.35	73.80	20.50	258.96	2.54	9.77	26.09
5.	69.40	11.30	80.70	19.40	238.40	2.56	9.81	26.15
6.	78.50	9.80	88.30	18.50	222.00	2.61	9.87	26.48
7.	87.40	8.16	95.56	17.40	202.50	2.58	10.05	25.67
8.	96.60	7.08	103.60	16.60	188.69	2.61	10.24	25.46
9.	105.50	5.70	111.20	15.50	170.25	2.52	10.44	24.17
10.	114.80	5.00	119.80	14.80	158.85	2.53	10.37	24.45
11.	123.90	4.10	128.10	13.90	144.59	2.46	10.44	23.63
12.	133.10	3.40	136.50	13.10	132.28	2.40	10.79	22.31
13.	142.50	3.00	145.50	12.50	123.30	2.39	11.01	21.71
14.	151.30	2.20	153.50	11.30	105.98	2.16	11.28	19.23
15.	160.50	1:79	162.20	10.50	94.92	2.05	11.74	17.49

Appendix-XIII

Performance of 15 hp petti and para with five bladed impeller at 305 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	34.30	22.20	56.50	24.30	334.21	2.51	9.47	26.58
2.	43.20	19.18	62.30	23.20	311.77	2.58	9.46	27.27
3.	52.20	16.95	69.15	22.20	291.83	2.69	9.57	28.09
4.	61.10	14.51	75.61	21.10	270.41	2.72	9.46	28.75
5.	70.10	12.58	82.68	20.10	251.41	2.77	10.00	27.70
6.	74.50	11.49	85.99	19.50	240.24	2.75	10.05	27.36
7.	79.20	10.96	90.16	19.20	234.72	2.82	10.37	27.17
8.	88.20	9.34	97.54	18.20	216.62	2.81	10.58	26.55
9.	97.20	7.88	105.08	17.20	199.02	2.78	10.65	26.09
10.	106.30	6.71	113.01	16.30	183.60	2.76	10.79	25.57
11.	115.30	5.55	120.85	15.30	166.97	2.69	10.94	24.58
12.	124.10	4.34	128.44	14.10	147.71	2.52	11.01	22.95
13.	133.10	3.48	136.58	13.10	132.28	2.41	11.01	21.87
14.	142.40	2.95	145.35	12.40	121.82	2.36	11.32	20.84
15.	151.50	2.35	153.85	11.50	108.80	2.23	11.74	19.01
16.	160.50	1.79	162.29	10.50	94.92	2.05	12.00	17.11

Appendix-XIV

Performance of 15 hp petti and para with five bladed impeller at 310 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	23.00	18.84	41.80	23.00	307.74	1.71	10.18	16.86
2.	31.90	16.27	48.17	21.90	285.93	1.83	10.31	17.80
3.	40.50	13.35	53.85	20.50	258.96	1.85	10.44	17.79
4.	49.70	11.80	61.50	19.70	243.95	2.00	10.65	18.77
5.	58.20	10.46	69.36	18.90	229.24	2.12	10.94	19.37
6.	68.20	9.30	77.50	18.20	216.62	2.23	11.09	20.10
7.	77.35	8.09	85.44	17.35	201.63	2.29	11.17	20.55
8.	87.10	7.74	94.89	17.10	197.29	2.49	11.48	21.72
9.	96.00	6.34	102.34	16.00	178.56	2.43	11.74	20.74
10.	105.10	5.33	110.43	15.10	163.70	2.41	11.74	20.52
11.	113.60	3.80	117.40	13.60	139.93	2.19	11.48	19.06
12.	122.90	3.32	126.22	12.90	129.26	2.17	11.57	18.79
13.	132.25	2.84	135.09	12.25	119.62	2.15	11.65	18.47
14.	141.20	2.10	143.30	11.20	104.57	1.99	11.74	17.01
15.	150.20	1.60	151.80	10.20	90.88	1.83	12.00	15.25

Appendix-XV

Performance of 15 hp petti and para with five bladed impeller at 320 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	29.75	23.50	53.25	24.75	343.53	2.43	10.51	23.19
2.	34.35	22.37	56.72	24.35	335.23	2.53	10.94	23.16
3.	43.40	19.85	63.25	23.40	315.81	2.66	11.32	23.48
4.	52.60	17.89	70.49	22.60	299.75	2.81	11.40	24.71
5.	61.35	15.10	76.45	21.35	275.23	2.80	11.32	24.77
6.	70.05	12.50	82.55	20.05	250.48	2.75	11.32	24.33
7.	79.20	10.97	90.17	19.20	234.72	2.82	11.48	24.56
8.	88.40	9.65	98.05	18.40	220.21	2.87	11.74	24.52
9.	97.50	8.30	105.80	17.50	204.25	2.88	11.82	24.35
10.	107.20	7.89	115.09	17.20	199.02	3.05	12.09	25.25
11.	116.20	6.59	122.79	16.20	181.92	2.97	12.28	24.25
12.	125.70	5.99	131.69	15.70	173.56	3.04	12.37	24.63
13.	134.40	4.62	139.02	14.40	152.46	2.82	12.37	22.85
14.	143.40	3.72	147.12	13.40	136.86	2.68	12.47	21.53
15.	152.70	3.17	155.87	12.70	126.27	2.62	12.66	20.72
16.	161.85	2.50	164.35	11.85	113.81	2.49	12.77	19.53
17.	169.85	1.48	17.33	9.85	86.25	1.97	12.87	15.31

Appendix-XVI

Performance of 15 hp petti and para with five bladed impeller at 330 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	26.80	29.98	56.70	26.80	387.08	2.92	11.48	25.42
2.	36.40	28.50	64.90	26.40	378.45	3.27	11.74	27.85
3.	46.00	27.20	73.20	26.00	369.88	3.61	12.00	30.09
4.	54.65	23.20	77.80	24.65	341.45	3.54	12.37	28.60
5.	63.60	20.30	83.90	23.60	319.87	3.58	12.56	28.49
6.	72.30	17.20	89.40	22.30	293.81	3.50	12.73	27.49
7.	81.00	14.30	95.30	21.00	268.49	3.41	12.37	27.59
8.	90.40	13.20	103.60	20.40	257.07	3.54	12.56	28.25
9.	100.00	12.39	112.39	20.00	249.54	3.73	12.66	29.52
10.	108.90	10.46	119.36	18.90	229.24	3.64	12.77	28.57
11.	117.60	8.40	126.04	17.60	206.00	3.46	12.97	26.69
12.	127.10	7.70	134.80	17.10	197.29	3.54	13.29	26.69
13.	136.20	6.58	142.70	16.20	181.92	3.46	13.52	25.61
14.	145.20	5.40	150.60	15.20	165.37	3.32	13.29	24.99
15.	154.80	5.00	159.80	14.80	158.85	3.38	13.63	24.83
16.	164.10	4.30	168.44	14.10	147.72	3.32	13.99	23.73
17.	173.10	3.40	176.60	13.10	132.29	3.11	14.23	21.89
18.	177.60	3.09	180.69	12.60	124.78	3.00	14.36	20.99
19.	182.10	2.70	184.80	12.10	117.43	2.89	14.75	19.62

Appendix-XVII

Performance of 15 hp petti and para with five bladed impeller at 340 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	27.20	31.00	58.34	27.20	395.78	3.08	12.09	25.47
2.	36.90	30.16	67.10	26.90	389.25	3.48	12.57	27.68
3.	46.20	27.80	74.10	26.20	374.16	3.69	12.87	28.67
4.	55.60	26.00	81.60	25.60	361.38	3.93	13.07	30.05
5.	64.20	21.90	86.20	24.20	332.15	3.82	13.29	28.59
6.	72.50	17.60	90.20	22.50	297.77	3.58	12.97	27.60
7.	82.30	17.20	99.50	22.30	293.81	3.89	13.29	29.32
8.	91.80	16.00	107.70	21.80	283.98	4.08	13.63	29.93
9.	100.60	13.50	114.10	20.60	260.86	3.97	13.92	28.52
10.	110.00	12.39	122.30	20.00	249.55	4.07	14.23	28.60
11.	119.40	11.39	130.70	19.40	238.40	4.15	14.49	28.67
12.	128.40	9.60	138.10	18.40	220.21	4.05	14.62	27.72
13.	137.40	8.16	145.50	17.40	202.50	3.93	14.62	26.81
14.	146.80	7.34	154.10	16.80	192.12	3.94	14.84	26.60
15.	155.90	6.22	162.10	15.90	176.88	3.82	14.62	26.15
16.	165.00	5.20	170.20	15.00	162.08	3.67	14.89	25.31
17.	174.30	4.50	178.80	14.30	150.87	3.59	15.06	23.88
18.	183.50	3.80	187.30	13.50	138.39	3.45	15.32	22.56

Appendix-XVIII

Performance of 15 hp petti and para with five bladed impeller at 345 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	32.50	32.20	64.00	27.50	402.35	3.47	14.36	24.16
2.	36.80	29.80	66.60	26.80	387.09	3.43	14.46	23.77
3.	46.10	27.50	73.60	26.10	372.02	3.65	14.95	24.42
4.	54.80	23.60	78.40	24.80	344.57	3.60	14.62	24.64
5.	64.20	21.90	86.10	24.20	332.15	3.81	14.89	25.61
6.	72.80	18.40	91.20	22.80	303.74	3.69	14.75	25.04
7.	82.10	16.70	98.80	22.10	289.86	3.81	14.89	25.64
8.	91.50	15.40	106.90	21.50	278.14	3.96	15.06	26.32
9.	100.60	13.54	114.10	20.60	260.86	3.96	15.26	26.01
10.	110.00	12.39	122.39	20.00	249.55	4.07	15.38	26.48
11.	119.00	10.63	129.60	19.00	231.06	3.99	15.44	25.86
12.	127.80	8.74	136.50	17.80	209.52	3.81	15.62	24.42
13.	137.10	7.74	144.80	17.10	197.29	3.81	15.77	24.16
14.	146.40	6.84	153.24	16.40	185.30	3.78	15.62	24.23
15.	155.40	5.66	161.10	15.40	168.61	3.62	15.46	23.42
16.	164.70	4.90	169.60	14.70	157.24	3.55	15.83	22.40
17.	174.30	4.50	178.80	14.30	150.87	3.59	16.15	22.27
18.	183.60	3.89	187.49	13.60	139.93	3.49	16.25	21.53

Appendix-XIX

Performance of 15 hp petti and para with five bladed impeller at 350 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	33.20	34.70	67.80	28.20	417.81	3.77	15.32	24.66
2.	37.60	32.58	70.18	27.60	404.54	3.78	15.47	24.47
3.	47.00	30.40	77.40	27.00	391.43	4.04	15.55	25.99
4.	56.20	27.80	84.00	26.20	374.15	4.19	15.65	26.79
5.	65.10	24.50	89.60	25.10	350.84	4.19	15.77	26.58
6.	73.90	21.15	95.00	23.90	325.98	4.13	15.93	25.90
7.	83.00	18.85	101.00	23.00	307.75	4.17	16.08	25.99
8.	92.00	16.50	108.50	22.00	287.89	4.16	16.25	25.63
9.	101.40	15.20	116.50	21.40	276.20	4.29	16.41	26.16
10.	110.80	13.90	124.70	20.80	264.67	4.40	16.65	26.43
11.	119.90	12.20	132.00	19.90	247.67	4.36	17.00	25.66
12.	129.10	10.70	139.80	19.10	232.89	4.34	17.11	25.37
13.	138.10	9.18	147.18	18.10	214.84	4.21	17.26	24.43
14.	147.20	7.88	155.00	17.20	199.02	4.11	17.11	24.05

Appendix-XX

Performance of 15 hp petti and para with six bladed impeller at 270 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	28.80	21.00	49.70	23.80	323.94	2.15	12.22	17.56
2.	33.10	19.10	52.20	23.10	309.76	2.15	12.09	17.83
3.	41.30	14.90	56.30	21.30	274.27	2.05	11.74	17.53
4.	49.90	12.20	62.10	19.90	247.68	2.05	11.57	17.73
5.	58.90	10.50	69.40	18.90	229.24	2.29	11.60	18.27
6.	67.90	8.90	27.00	17.90	211.30	2.16	11.55	18.72
7.	76.60	7.10	83.60	16.60	188.70	2.10	11.52	18.27
8.	85.30	5.50	90.80	15.30	166.97	2.02	11.54	17.53
9.	94.00	4.20	98.20	14.00	146.15	1.91	11.60	16.50
10.	103.00	3.40	106.40	13.00	130.88	1.85	11.79	15.74
11.	111.60	2.40	114.00	11.60	110.23	1.67	12.09	13.85
12.	120.70	1.80	122.60	10.70	97.65	1.59	12.13	13.16

Appendix-XXI

Performance of 15 hp petti and para with six bladed impeller at 275 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	35.10	16.70	51.80	22.10	289.86	2.00	12.60	15.88
2.	41.40	15.18	56.60	21.40	276.20	2.08	12.48	16.68
3.	50.40	13.16	63.56	20.40	257.06	2.17	12.53	17.38
4.	59.20	10.97	70.20	19.20	234.72	2.19	12.41	17.69
5.	68.40	9.65	78.05	18.40	220.20	2.29	12.85	17.83
6.	77.50	8.30	85.80	17.50	204.25	2.33	12.97	18.01
7.	86.10	6.47	92.60	16.10	180.23	2.22	13.01	17.09
8.	95.00	5.23	100.20	15.00	162.08	2.16	12.97	16.70
9.	103.70	3.98	107.68	13.70	141.47	2.03	12.99	15.64
10.	112.70	3.20	115.87	12.70	126.27	1.95	13.18	14.80
11.	121.60	2.40	124.00	11.60	110.23	1.82	13.52	13.50

Appendix-XXII

Performance of 15 hp petti and para with six bladed impeller at 278 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	24.90	23.90	48.80	24.90	346.65	2.25	13.68	16.49
2.	30.80	20.89	51.69	23.80	323.94	2.23	13.63	16.38
3.	39.80	18.36	58.16	22.80	303.74	2.35	13.54	17.39
4.	49.10	16.70	65.80	22.10	289.86	2.54	14.26	17.84
5.	58.10	14.58	72.60	21.10	270.41	2.61	14.06	18.63
6.	67.00	12.39	79.39	20.00	249.54	2.64	13.91	18.98
7.	75.70	10.13	85.80	18.70	225.61	2.58	14.11	18.29
8.	84.80	8.74	93.54	17.80	209.52	2.61	14.18	18.42
9.	93.50	6.96	100.46	16.50	186.99	2.50	13.91	18.01
10.	102.60	5.88	108.48	15.60	171.91	2.48	14.13	17.59
11.	111.10	4.34	115.44	14.10	147.72	2.27	13.98	16.25
12.	119.90	3.32	123.22	12.90	129.26	2.12	14.16	14.99
13.	128.80	2.54	131.34	11.80	113.09	1.98	14.36	13.79

Appendix-XXIII

Performance of 15 hp petti and para with six bladed impeller at 280 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	31.20	21.96	53.10	24.20	332.14	2.35	13.51	17.42
2.	35.10	19.09	54.20	23.10	309.75	2.23	13.75	16.28
3.	44.00	16.50	60.50	22.00	287.89	2.32	13.81	16.80
4.	53.00	14.35	67.35	21.00	268.49	2.41	14.06	17.14
5.	62.40	13.75	75.55	20.40	257.06	2.58	14.49	17.87
6.	71.60	11.62	83.22	19.60	242.09	2.68	14.75	18.20
7.	80.50	9.80	90.30	18.50	222.00	2.67	14.92	17.91
8.	89.90	8.88	98.79	17.90	211.29	2.78	15.40	18.06
9.	99.10	7.74	106.80	17.10	197.28	2.81	15.61	17.99
10.	108.20	6.59	114.90	16.20	181.91	2.78	15.92	17.48
11.	117.00	5.23	122.20	15.00	162.08	2.64	15.61	16.91
12.	125.60	3.90	129.50	13.60	139.93	2.41	15.52	15.56
13.	134.00	3.04	137.00	12.00	115.97	2.11	15.46	13.70

Appendix-XXIV

Performance of 15 hp petti and para with six bladed impeller at 290 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	33.50	20.10	53.60	23.50	317.83	2.27	13.91	16.32
2.	39.60	17.88	57.48	22.60	299.75	2.29	14.28	16.08
3.	48.80	16.05	64.85	21.80	283.98	2.45	14.49	16.94
4.	58.50	15.40	73.90	21.50	278.13	2.74	15.61	17.54
5.	67.70	13.74	81.44	20.70	262.76	2.85	15.34	18.59
6.	75.70	10.13	85.83	18.70	225.61	2.58	14.31	18.04
7.	84.60	8.45	93.04	17.60	206.00	2.55	14.49	17.63
8.	93.50	6.88	100.38	16.50	186.99	2.50	14.70	17.02
9.	102.60	5.88	108.48	15.60	171.90	2.48	15.03	16.53
10.	111.50	4.70	116.22	14.50	154.05	2.38	15.11	15.79
11.	120.50	3.80	124.31	13.50	138.39	2.29	15.06	15.22
12.	129.30	2.83	132.18	12.30	120.35	2.12	15.23	13.92

Appendix-XXV

Performance of 15 hp petti and para with six bladed impeller at 295 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	24.60	23.06	4.67	24.60	340.41	2.16	14.92	14.49
2.	31.00	21.40	52.40	24.00	328.05	2.29	15.14	15.14
3.	40.00	18.85	58.80	23.30	307.74	2.41	15.37	15.70
4.	49.00	16.50	65.50	22.00	287.89	2.51	15.49	16.22
5.	58.00	13.90	72.74	20.80	264.66	2.56	15.61	16.43
6.	66.80	12,03	78.88	19.80	245.81	2.55	15.41	16.74
7.	76.80	12.03	88.80	19.80	245.81	2.91	16.58	17.55
8.	85.50	9.80	95.30	18.50	222.00	2.82	15.77	17.88
9.	94.50	8.30	102.80	17.50	204.24	2.79	16.02	17.47
10.	103.10	6.46	109.56	16.10	180.23	2.63	15.83	16.63
11.	111.80	5.02	116.80	14.80	158.85	2.47	15.86	15.59
12.	120.80	4.07	124.80	13.80	143.02	2.38	15.92	14.95
13.	130.00	3.40	133.40	13.00	130.77	2.32	16.48	14.10

Appendix-XXVI

Performance of 15 hp petti and para with six bladed impeller at 305 rpm

Sl. No.	Static head (Hs+Hd) (cm)	Velocity head $Vd^2/2g$ (cm)	Total head H (cm)	Flow over weir crest h (cm)	Discharge Q (lps)	Output (hp)	Input (hp)	Efficiency (%)
1.	25.40	25.39	50.79	25.40	357.15	2.41	16.58	14.58
2.	33.20	21.96	55.16	24.20	332.14	2.44	16.93	14.42
3.	40.40	19.80	60.25	23.40	315.81	2.53	17.67	14.35
4.	48.90	16.27	65.20	21.90	285.93	2.48	16.08	15.44
5.	58.00	14.29	72.29	21.00	268.49	2.58	16.93	15.28
6.	68.40	15.18	83.58	21.40	276.20	3.07	17.99	17.11
7.	77.90	14.14	92.04	20.90	266.57	3.27	18.70	17.49
8.	89.90	12.20	102.10	19.90	247.67	3.37	18.48	18.24
9.	95.40	9.65	105.00	18.40	220.20	3.08	18.53	16.64
10.	103.90	7.48	113.80	16.40	193.83	2.87	18.57	15.49
11.	112.90	6.22	119.10	15.90	176.88	2.80	18.70	15.02
12.	121.90	5.12	127.02	14.90	160.46	2.71	18.92	14.36

Sample Calculation

Data taken is 8th set reading of Appendix **XVII** (performance of 15 hp) 'Petti' and 'Para' with 5 bladed impeller at 340 rpm)

Head over weir crest h = 21.8 cm

Total static head = 91.8 cm

Length of weir crest L = 1.5 m

Flow over weir crest Q $= 1.86 \ L \ h^{3/2}$

$= 1.86 \times 1.5 \times (21.8)^{3/2}$

$= 283.98$

284 lps $= 0.284 \ m^3/s$

Total head = static head + velocity head

Velocity head $= \frac{Vd^2}{2g}$

Velocity Vd $= \frac{Q}{A} = \frac{284}{A}$

Cross sectional area of petti A $= 80 \times 20 = 1600 \ cm^2$

$= 0.16 \ m^2$

Vd $= \frac{Q}{A} = \frac{0.284}{0.16}$

$= 1.77$ m/s

$\frac{Vd^2}{2g} = \frac{(1.77)^2}{2 \times 9.81} = 0.159$ m

Total head H $= 0.918+0.159 = 1.077$ m

Output $= \frac{QH}{75} = \frac{284 \times 1.078}{75}$

$= 4.08$ hp

Input power $= \frac{n}{t} \times \frac{3600}{k} \times \frac{1000}{746}$

where,

n = number of revolutions of energy meter disc = 5

t = time taken for 5 revolutions = 98.5 sec

Energy meter constant k = 18

Input power $= \frac{5 \times 3600 \times 1000}{98.3 \times 18 \times 746} = 13.63$ hp

Efficiency $= \frac{\text{Output}}{\text{Input}} = \frac{4.08}{13.63}$

$= 29.93\%$

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ABSTRACT

The most peculiar feature of paddy cultivation in Kuttanadu is the system of drainage of water from the bunded rice fields during the crop season. 'Petti' and 'para' is the most commonly used pump for this purpose. It has been observed that though the discharge rate of the pump is very high under low head conditions, its efficiency is dismally low. So the present study was undertaken with the express purpose of optimising the number of blades on the impeller and its working speed for maximum efficiency for a 15 hp 'petti' and 'para'.

The study included testing of the 15 hp 'petti' and 'para' at the specially designed and constructed test bench, using impeller with four blades, five blades and six blades keeping the hub ratio same. Using data obtained from the laboratory tests, efficiency-discharge, head-charge and input power-discharge curves were fitted and regression equations were developed. From the estimated values of head, input power and efficiency corresponding to various discharge rates curves were also drawn at selected speeds, for comparing the performance of different impellers at various speeds.

The analysis of the performance curves clearly showed that for obtaining maximum efficiency the optimum number of vanes on the impeller is five and the optimum working speed is 330 rpm for the commonly used 15 hp 'petti' and 'para'.