Report No. IEP-6
February 7, 1983

COMPARATIVE ADVANTAGES OF AXIAL-FLOW PUMPS OVER CENTRIFUGAL PUMPS FOR LOW-LIFT IRRIGATION

The International Rice Research Institute

and

MA-IRRI Industrial Extension Program
for Small Farm Equipment

ABSTRACT

Centrifugal pumps are commonly used in the Philippines for low-lift irrigation whereas axial-flow pumps have proven to be more acceptable in Thailand and Vietnam. This study compares centrifugal and axial-flow pumps in terms of performance and cost.

The pumping efficiency of the axial-flow pump is substantially higher than that of the centrifugal pump for lifts (static heads) of 3 meters or less. Therefore, the fuel required to pump a specified quantity of water is lower for the axial-flow pump than for the centrifugal pump. This, and the fact that the initial costs of the two pumping units are approximately equal, are considered in an economic analysis which demonstrates that axial-flow pumps have significantly lower total annual costs than centrifugal pumps for lifts of 3 meters or less.

It is recommended that a promotional campaign be carried out in the Philippines to inform farmers, manufacturers, and extension workers of the comparative advantages of axial-flow pumps relative to centrifugal pumps for low-lift irrigation.

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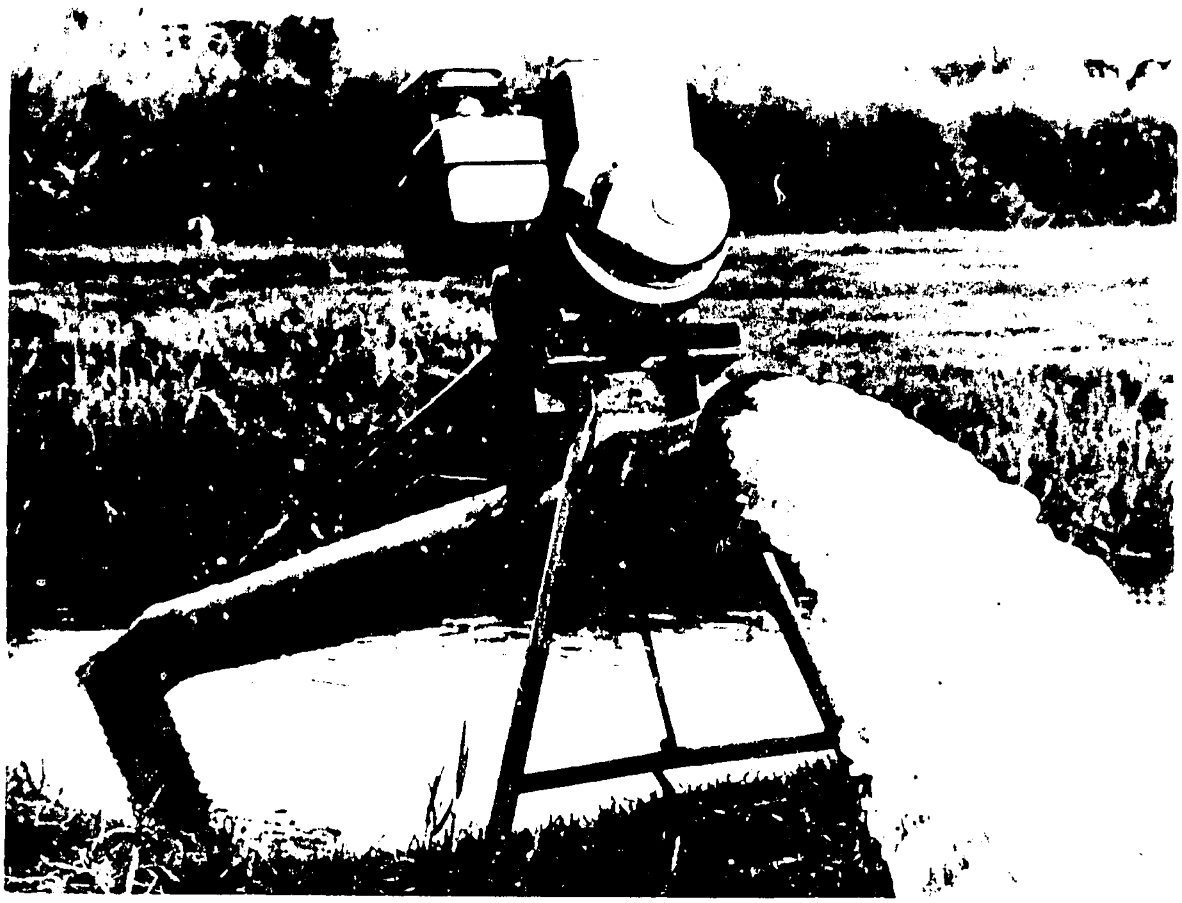
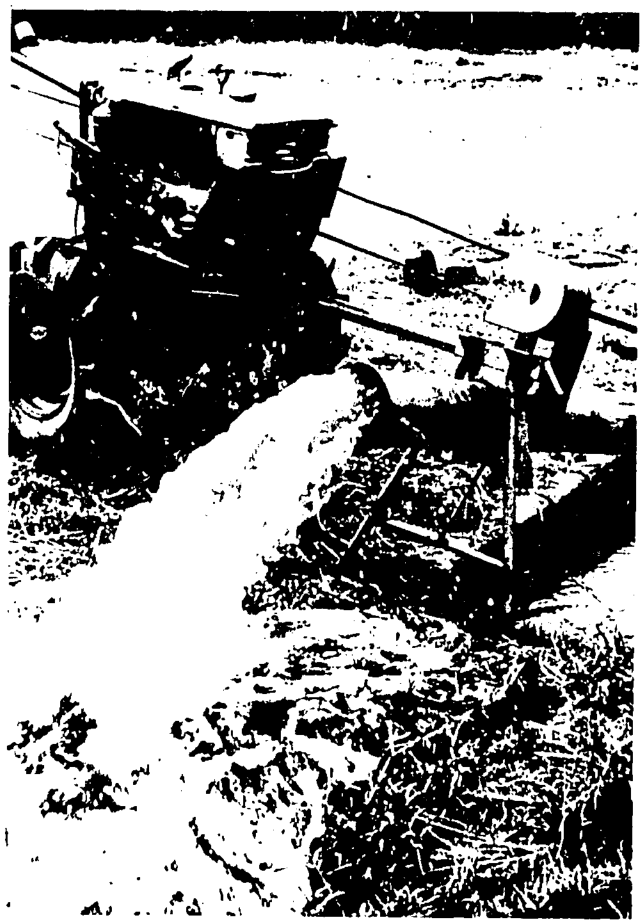


- AXIAL-FLOW PUMP -

- PORTABLE -



- POWERED BY TILLER -

INTRODUCTION

The majority of small farms in developing countries are not serviced by irrigation systems and therefore must rely on rainfall which, in many instances, is supplemented by pumps or other small-scale irrigation technologies. For centuries, pumps have been an economically and culturally accepted technology in many areas (Wood, 1976), especially where the water source lies only a few meters below the field level. Consequently, there is a wide variety of designs of low-lift irrigation pumps, i.e., pumps for lifting water less than 3 m.

Low-lift pumps are powered by a wide range of power sources, including man, animal, wind, water, sun, internal combustion engines, and electric motors. Utilization of engine-powered pumps has increased markedly, partly because these units are generally more economical than human, animal, or solar powered pumps and have broader areas of potential application than wind, water, or electrically powered pumps (Eckaus and Potter, 1977).

For low-lift applications, the most efficient engine-powered pump is the axial-flow "propeller" pump (Streeter and Wylie, 1975). Because of its efficiency and ease of fabrication, the axial-flow pump has become popular in Vietnam and Thailand where there are extensive areas suitable for low-lift pumps and the technology is similar to that of boat engines which are serviced by thousands of workshops in both countries. The axial-flow pump is essentially an outboard motor with its propeller reversed and placed inside a tube which serves as the casing of the pump. (See Fig. 1). The pump is mounted so that it cannot move, hence the power delivered to the propeller goes to moving (pumping) water rather than to propelling a boat.

In Vietnam, the impact of the axial-flow pump has been remarkable. Four years after the pump was introduced in 1963, about 50,000 units were being used in the upper delta region of the Mekong Delta, and it has been estimated that these pumps were responsible for a 40% increase in agricultural production (Sansom, 1969). By increasing cropping intensity, the pumps were extremely profitable (e.g., the initial cost was recovered in the first year of operation) and significantly increased the demand for farm labor. In Thailand, 1969 data indicate that the sales price of the axial-flow pump was approximately 1/3 that of a centrifugal pump of equivalent size, and the production was estimated to be 47,000 units per year (USOM, 1970). In Vietnam and Thailand, the pumps are produced locally with keen competition between a large number of manufacturers.

In the Philippines, low-lift irrigation pumps are economically attractive for certain areas and conditions (Moya et al., 1981). The axial-flow pump is almost completely unknown, and farmers use centrifugal pumps for low-lift applications, even though these pumps are designed for medium lift and become increasingly inefficient at lower lifts. The purpose of this study is to compare the technical and economical characteristics of axial-flow and centrifugal pumps under conditions of low lift (1 to 3 m), thereby providing a more concrete basis for pump selection.

IRRI AXIAL-FLOW PUMP

In 1977, the Engineering Department of the International Rice Research Institute (IRRI) initiated a project to improve the efficiency of the axial-flow pump and to simplify the design in a manner that would reduce the cost and simplify fabrication by workshops in rural areas. The design illustrated in Figure 1 was developed and made available to interested manufacturers in late 1979. The principal components are:

- high efficiency propeller, which may be fabricated by bending and welding, rather than by casting and grinding,
- vanes for straightening the spiral flow induced by the propeller, thereby increasing efficiency by reducing losses due to fluid friction,
- improved bearing for longer life in dirty or sandy water,
- tube fabricated from iron sheet by simple rolling and welding techniques, thereby avoiding the weight and expense of commercially available pipes or tubes, and
- direct-coupling of the propeller shaft to an engine mounted on the pump tube. (Alternatively, a pulley and V-belt may be used to power the pump by an engine mounted separately, such as the engine of a hand tractor).

Detailed information on technical specifications, fabrication procedures, and operations of this pump may be obtained from IRRI. Design drawings are available for two sizes:

Inside Diameter of Pump Tube		Recommended Engine Size	Capacity at 1.5 m lift	
cm	in	hp	liters/sec	gal/min
15	6	5	50	790
25	10	8	100	1,580

TEST PROCEDURE AND RESULTS

The pumping capacities of axial-flow and centrifugal pumps were measured for three levels of lift using the same engine. The axial-flow pump was a 15-cm (6-inch) diameter unit (IRRI Design #PU-4). The centrifugal pump was representative of those manufactured in the Philippines, and the size was 10-cm (4-inch) diameter of inlet and discharge ports. {A 15-cm (6-inch) unit would have required a larger engine than needed for the axial-flow pump.} The same 5-hp gasoline engine was used to drive each pump during test runs.

The diameters of the V-belt pulleys on the pumps were adjusted to attain the desired pump speed (2200 to 2400 rpm) for engine speeds in the range of 3100 to 3300 rpm. To attain approximately equal engine power for both pumps at a particular lift, the carburetor throttle was adjusted to give the same value of vacuum pressure in the intake manifold.

Test runs were conducted for three values of the lift (or static head), which is the vertical distance measured from the surface of the water source to the center of the discharge tube. Each run lasted for 60 minutes, with the capacity (pump discharge) measured every 10 minutes by means of a calibrated cut-throat flume, and the fuel consumption measured before and after the run. The results were observed to be highly reproducible except for an unexplainable variation (±20%) in measurement of fuel consumption.

The results shown in Table 1 are averages of three runs made for each value of lift. Note that at the lowest lift (1.07 m), the capacity of the axial-flow pump is 3 times that of the centrifugal pump. At the highest lift (2.8 m), the capacity of the axial-flow pump is 2 times that of the centrifugal pump. Based on linear extrapolations of the data plotted in Figure 2, it is estimated that the capacities of the two pumps will become equal at a lift of about 4 m. At higher lifts, the capacity of the centrifugal pump should exceed that of the axial-flow pump. It should be emphasized, however, that the lift at which the capacities of the two pumps are equal depends upon the design and operation details of the pumps (e.g., pitch of the propeller, shape of rotor passages, RPM, etc.). Consequently, the value of 4 m is not a general result for axial-flow and centrifugal pumps.

The capacity of the axial-flow pump is larger than that of the centrifugal pump in these test runs because: (1) for low lift, a propeller is basically more efficient than a centrifugal rotor; and (2) the fluid friction losses are greater for the centrifugal pump because it has higher resistance due to smaller diameter tubing, a 90°elbow, and a foot valve. These friction losses have been estimated using standard hydraulic tables (Berkeley Pump Catalogue, 1959) and the results are presented in Table 2 as the "friction head" (H_f), together with the static head (H_s) from Table 1, and calculated values for the velocity head (H_v) and the total head ($H_t = H_s + H_f + H_v$).

Also included are calculations of the power transmitted to the water:

$$P_w \text{ (horsepower)} = 0.0131\ Q\ H_t$$

where Q is the measured pump capacity in liters/sec (Table 1) and H_t is the total head in meters.

The results in Table 2 illustrate that: (a) the fluid friction losses, represented by H_f, are 2.7 to 3.6 times higher for the centrifugal pump than for the axial-flow pump; and (b) for approximately the same power input to both pumps, the power transmitted to the water (P_w) is significantly greater for the axial-flow pump than for the centrifugal pump, indicating a higher efficiency for the axial-flow pump. It is not possible to calculate the pump efficiencies because the power input was not measured in these tests. However, based on power measurements for similar engines, we expect that the actual power output of the 5-hp engine was less than 2 hp for the present test conditions.

ECONOMIC COMPARISON

Although the purchase price of the 10-cm centrifugal pump is less than that of the 15-cm axial-flow pump, the total prices of the two are about equal if one adds the accessories required for the centrifugal unit (i.e., foot valve, pipe elbow, 10-cm hose or tubing, base plate). For example, in Iloilo City in January 1982, the price of similar centrifugal and axial-flow pumps were both about P1,800, excluding cost of engine. The price of a 5-hp engine ranges from about ₱1,500 for an air-cooled gasoline to ₱6,000 for a water-cooled diesel engine.

Because the initial costs of the two units are essentially equal, the principal factors to consider in an economic comparison are differences in their operating costs and in their usable lives. In terms of operating costs, the main difference is that for low-lift applications the axial-flow pump requires less fuel than the centrifugal pump to pump the same quantity of water. For example, assume that the pump will be used to irrigate 5 ha at an average rate of 10,000 m^3/ha per year (100 ha-cm), which means the average quantity of water pumped per year for 5 ha would be 50,000 m^3. If the lift were 1.51 m, then the data in Table 1 indicate that the capacities of the 10-cm centrifugal pump and the 15-cm axial-flow pump would be 14.3 l/sec (51.5 m^3/hour) and 40 l/sec (144 m^3/hour), respectively. Therefore, the centrifugal pump would have to operate 971 hours per year to provide the requirement of 50,000 m^3/yr, whereas the corresponding value for the axial-flow pump would be only 347 hours per year - a savings of 624 hours per year. Based on the average fuel consumption of 1.4 liters/hr, the fuel savings will be 874 liters/yr. At the current price of gasoline (about ₱5/liter), this amounts to a savings of ₱4,370 per year. In this case, the savings in one year alone is greater than the initial cost of the pump and engine.

Similar calculations have been made for a range of lifts and water requirements, and the results are summarized in Table 3. The savings are most impressive at low lifts and high water requirements, although the dependence on lift is smaller than expected.

An approximate economic comparison of the annual fixed costs of the two pumps is presented in Table 4. For each pump component the corresponding initial cost and useful life have been estimated. Other fixed costs, such as taxes, insurance, and maintenance, have not been included because these are of secondary importance in this comparison. The centrifugal pump is assumed to have longer life (15 years) than the axial-flow pump (5 years) because of its heavier construction. On the other hand, the life of the engine is estimated to be longer for the axial-flow pump (5 years) than for the centrifugal pump (2.5 years) because, as seen in Table 3, the operating time required to pump a given quantity of water is substantially less for the axial-flow pump. These estimates have been used to compute the values shown for the annual fixed costs.[1/] These costs represent the annual payments that have to be made, assuming initial costs were financed by a loan at 15% annual interest for the life of each component. Note that the total annual fixed costs for the two pumps are nearly equal because the longer life of the centrifugal pump is counterbalanced by its shorter engine life.

If a diesel engine had been used instead of a gasoline engine in these tests and economic comparisons, the magnitude of the results would be altered but the axial-flow pump would still be more economical than the centrifugal pump at low lift.

[1/] Annual fixed cost = $i \cdot C \cdot (1+i)^n/\{(1+i)^n - 1\}$, where i = interest rate, C = initial cost, and n = usable life in years. (De Neufville and Stafford, 1971)

DISCUSSION AND CONCLUSIONS

Because this study was limited to a single model of centrifugal pump, the quantitative results apply only to the specific pumps and conditions of the tests. On the other hand, it is expected that the economic advantage of the axial-flow pump over the centrifugal pump at low lifts is a qualitative result which will be generally valid for various designs of axial-flow and centrifugal pumps, although the quantitative magnitudes of the capacities, costs, and critical lift will depend on design details and operating conditions.

The axial-flow pump has other advantages relative to the centrifugal pump: (1) it is easily fabricated in small workshops; and (2) it is suitable for operation in dirty and sandy water.

For these reasons, it is recommended that a campaign to promote the use of axial-flow pumps for low-lift irrigation be initiated in the Philippines. This promotional campaign should reach manufacturers, distributors, farmer organizations, and agricultural and bank officials who recommend and/or approve equipment selections.

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TABLE 1. TEST RESULTS FOR COMPARISON OF AXIAL-FLOW AND CENTRIFUGAL PUMPS AT LOW LIFT[a]

STATIC HEAD (meters)	CAPACITY (liters/second)	
	CENTRIFUGAL	AXIAL-FLOW
1.07	15.0	46.0
1.51	14.3	40.0
2.80	13.4	26.8

[a] Average fuel consumption for all runs: 1.4 liters/hour

TABLE 2. ESTIMATES OF HEADS AND POWERS CORRESPONDING TO TEST CONDITIONS OF CENTRIFUGAL AND AXIAL-FLOW PUMPS[a]

ESTIMATED VALUES[a]	H_s, STATIC HEAD					
	1.07m		1.51m		2.80m	
	CENT.	AXIAL	CENT.	AXIAL	CENT.	AXIAL
H_f, Friction Head (m)	0.73	0.21	0.62	0.23	0.62	0.17
H_v, Velocity Head (m)	0.17	0.31	0.15	0.23	0.13	0.11
H_t, Total Head (m)	1.97	1.59	2.28	1.97	3.55	3.11
P_w, Water Power (hp)	0.39	0.96	0.43	1.03	0.63	1.09

[a] See text for definitions of terms and estimation procedures.

TABLE 3. ESTIMATED FUEL SAVINGS OF AXIAL-FLOW PUMP VS. CENTRIFUGAL PUMP FOR THREE LEVELS OF LIFT AND WATER REQUIREMENT

LIFT (Meters)	ANNUAL WATER REQUIREMENT[1] (M^3/YR)	ANNUAL OPERATING TIME (HOURS)[2]			ANNUAL FUEL SAVINGS[3]	
		CENTRIFUGAL PUMP	AXIAL-FLOW PUMP	DIFFERENCE	(Liters)	(Pesos)
1.07	10,000	185	60	125	175	875
	50,000	926	302	624	874	4,370
	250,000	4,630	1,510	3,120	4,368	21.840
1.51	10,000	194	69	125	175	875
	50,000	971	347	624	874	4,370
	250,000	4,854	1,736	3,118	4,365	21,825
2.80	10,000	207	104	103	144	720
	50,000	1,037	518	519	727	3,635
	250,000	5,187	2,591	2,596	3,634	18,170

1/ Assumed levels for representing low, medium, and high usage of pumps.

2/ Computed from data on pump capacities (Table 1).

3/ Based on average fuel consumption of 1.4 liters/hour (Table 1) and fuel cost of 5 pesos per liter of gasoline.

Note: Exchange rate in mid-1982 was approximately 8 pesos per U.S. dollar.

TABLE 4. COMPARISON OF ESTIMATED ANNUAL FIXED COSTS FOR AXIAL-FLOW AND CENTRIFUGAL PUMPS[1/]

COMPONENTS	AXIAL-FLOW PUMP			CENTRIFUGAL PUMP		
	INITIAL COST (PESOS)	LIFE (YEARS)	ANNUAL COST[4/] (PESOS)	INITIAL COST (PESOS)	LIFE (YEARS)	ANNUAL COST[4/] (PESOS)
PUMP[2/]	1,800	5	537	1,300	15	222
ENGINE (5HP GASOLINE)	1,500	5	448	1,500	2.5	764
PIPE ELBOW & FITTINGS[3/]	-	-	-	200	15	34
FLEXIBLE HOSE[3/]	-	-	-	200	2.5	102
FOOT VALVE[3/]	-	-	-	100	5	30
TOTAL ANNUAL FIXED COSTS (PESOS)			985			1,152

[1/] Based on interest rate of 15% per year.

[2/] For 15-cm axial-flow pump and 10-cm centrifugal pump.

[3/] Components needed for centrifugal pump only.

[4/] See text for explanation.

Note: Exchange rate in mid-1982 was approximately 8 pesos per U.S. dollar.

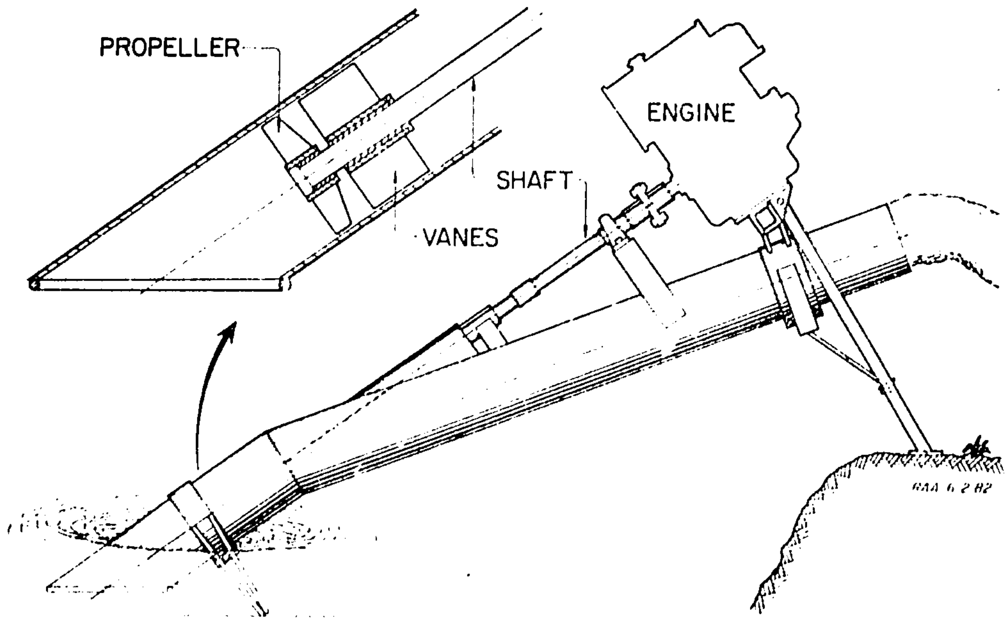

FIGURE 1. SCHEMATIC DRAWING OF AXIAL-FLOW PUMP

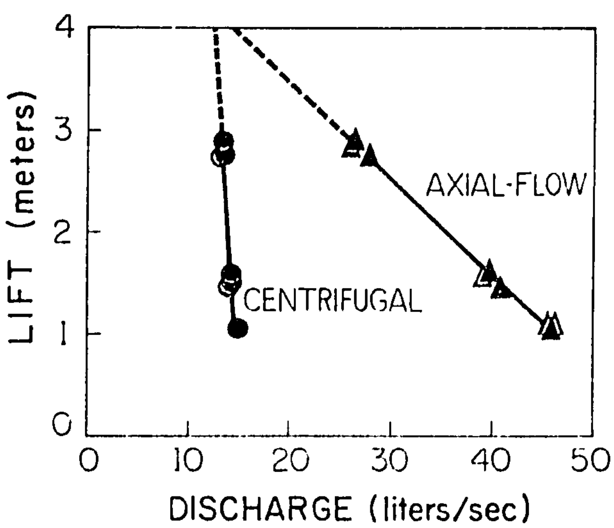

FIGURE 2. TEST RESULTS ON PUMPING CHARACTERISTICS OF 15-CM AXIAL-FLOW PUMP AND 10-CM CENTRIFUGAL PUMP.