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Performance of Different Pumps and Pump Sets for Agricultural Applications Tested by the Agricultural Machinery Testing and Evaluation Center, Philippines

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ABSTRACT

In the Philippines, different sizes and types of pump sets are utilized for shallow tubewells (STW) and low-lift pumps (LLP). Filipino farmers used STW and LLP as main or supplementary sources of irrigation. This study aimed to evaluate the performance of agricultural pumps and pump sets tested by the Agricultural Machinery Testing and Evaluation Center (AMTEC) from 1989 to 2022, based on Philippine Agricultural Engineering Standards (PAES) 115:2000. A total of 486 centrifugal pump sets and 341 bare pumps were used in the study. The selected sizes for both bare pump and pump set (engine-powered) include 50x50mm, 75x75mm, and 100x100mm. These were the common sizes and prime mover used for STWs and LLPs in the Philippines. The performance of the agricultural pumps was evaluated with equal weights using the: a) discharge-to-input power ratio, b) suction lift, c) maximum efficiency, and d) input speed. For all bare pump sizes, non-self-priming (52.99%, 61.05%, 62.21%, respectively) and discharge capacity (7.78lps, 15.78lps, 25.54lps, respectively) have higher pump efficiency than self-priming. All sizes of non-self-priming pumps are driven by diesel engines. Results showed that, generally, for pump sets system efficiency, in general: a) it is relatively higher for non-self-priming than self-priming (same with bare pump efficiency); b) relatively higher for diesel than gasoline engine driven; and c) relatively higher for water-cooled than air-cooled diesel engine. This study has also found that most of the evaluated bare pumps met the criteria of the performance evaluation scheme, including all of the 100x100mm non-self-priming units. On the other hand, most of the 100x100mm self-priming, close-coupled (17/25); 75x75m m self-priming, close-coupled (79/100); 50x50mm self-priming, V-belt drive (6/6); and 50x50mm self-priming, close-coupled (101/109) pump sets did not meet the criteria of the evaluation scheme. Appropriate tools (i.e. statistical) or systems should be utilized to determine the performance parameters and corresponding performance values for the evaluation of the pumps and pump sets.

Keywords: *mechanization, pumps and pump sets, testing and evaluation*

INTRODUCTION

The Agricultural and Fisheries Mechanization (AFMech) Law of 2013 aimed to attain food security and increase farmers' income through agricultural mechanization. Some of the machineries distributed by the government's mechanization program included irrigation pumps and pump sets. Agricultural pumps or irrigation pumps are widely used in the country and installed through the initiatives of different government agencies such as the Department of Agriculture and the National Irrigation Administration (NIA), as well as different local government units (LGUs). As mandated by the AFMech Law, agricultural pump sets are required to be tested by the Agricultural Machinery Testing and Evaluation Center (AMTEC) of the University of the Philippines Los Baños to ensure the quality and safety of machines. However, more comprehensive criteria in determining the acceptability of the pumps' performance, other than what is declared by the manufacturer, have not yet been established and incorporated in the current Philippine National Standards.

Centrifugal pumps are advantageous since they can generally handle large quantities of fluids, and have the ability to adjust their flow rates over a wide range. It can also provide very high flow rates which may vary with the changes in the total dynamic head (TDH) of the particular piping system. Pumps can be classified based on its priming ability. Non-self-priming pump is one that needs to be manually primed. The suction piping and inlet side of centrifugal pumps that are not self-priming must be filled with non-compressible liquid and vented of air and other non-condensable gases before the pump can be started (Volk, 2005). Self-priming pumps are designed to initially remove the air or other gas in the suction line, and then pump in a conventional manner (Volk, 2005). On the other hand, self-priming pumps do not require priming since it create a vacuum that is sufficient for the atmospheric pressure to push liquid through the suction pipe and into the pump casing (PAES 114).

Centrifugal pump sets consist of a pump that is directly or indirectly coupled to a prime mover, either an engine or an electric motor. An engine pump set may be powered by diesel (water-cooled or air-cooled) or gasoline engines (air-cooled). The common power transmission systems for engine pump sets include close-coupled, direct transmission, and V-belt and pulley transmission. Close-coupled pumps are characterized by a common engine and pump shaft. The engine shaft is longer than ordinary as the pump impeller is attached to its other end. On the other hand, a direct coupling pump set has its engine, and the pump shaft is connected by a flange or universal joint. In a V-belt and pulley transmission, the shaft of the pump and engine are parallel to each other and attached with pulley (commonly V-pulley). The power is transmitted from the engine to the pump using a flexible material called a V-belt.

In the Philippines, the centrifugal pumps and pump sets were tested in accordance with PNS/PAES 115:2000 (Centrifugal, Mixed-Flow, and Axial-Flow Water Pumps – Method of Test). The test shall be conducted by operating the pump at the manufacturer's recommended speed. For the pump performance test, measurements shall be taken on not less than ten different discharge values, starting from no discharge state to the maximum flow rate possible. At least of one these shall be measured at a head lower than the specified head. A cavitation test is also carried out to determine the suction conditions of the pumps.

The main objective of this study was to evaluate the performance of bare pumps and pump sets tested for agricultural applications. Specifically, it aimed to: 1) characterize the bare pumps and pump sets tested, and 2) evaluate the performance of bare pumps and pump sets using a rating scheme.

MATERIALS AND METHODS

The data of bare pumps and pump sets tested by AMTEC from 1989 to 2022 were collated. The pump sizes selected include only 50x50mm, 75x75mm, and 100x100mm for both the bare pumps and pump sets. Some of the 76x76mm and 80x80mm bare pumps and pump sets were grouped under 75x75mm. For the pump sets, only the engine

-powered were selected. These are the common sizes and prime movers being used for shallow tubewells (STW) and low-lift pumps (LLP) in the Philippines (DA, 2022). After which, bare pumps were then grouped according to priming method (non-self-priming and self-priming) for each pump size. On the other hand, the pump sets were grouped based on priming method, engine type (diesel and gasoline), and power transmission system used (close-coupled, V-belt-and-pulley). Direct transmission pump sets were grouped in the close-coupled transmission category. Other bare pump and pump set data that were collated and summarized include: country of manufacture, type of impeller, type of stuffing box, pump speed, pump efficiency, system efficiency, and corresponding head, discharge, and fuel consumption (for pump sets).

With the open impeller, the impeller vanes are clearly visible when viewed from the suction side of the impeller (Volks, 2005). The closed impeller, on the other hand, has a shroud covering the vanes on the suction or front side, and an axially oriented hub that provides the inlet for the liquid into the vane passageways (Volks, 2005). Packing seals are usually formed of a pliable braided fibrous material, often impregnated with a lubricating medium. The packing material is square in cross section, and is formed into rings that are compressed into the stuffing box bore and around the shaft. These rings provide a seal between their outside diameter and the stuffing box (where there is no relative movement when the pump is operating) so that no liquid can leak out this way (Volks, 2005).

Every mechanical seal has in common three sealing points, consisting of two static seals and one dynamic seal. Each mechanical seal has a static seal between the rotating assembly and the sleeve (or shaft if there is no sleeve), and a second static seal between the stationary part of the seal and the gland or seal housing. The dynamic seal is between the two seal faces, one rotating and the other stationary (Volks, 2005). However, some of the data were not included in the evaluation due to unreadable values in the file copies of the test reports.

Performance Rating Scheme of Bare Pumps and Pump Sets

The performance rating scheme adopted from the study of Resurreccion, et. al (2008) was used to evaluate the bare pumps (**Table 1**) and pump sets (**Table 2**) in this study. The performance data of bare pumps and pump sets tested were evaluated using the following parameters: discharge-to-input power ratio, suction lift, maximum efficiency, and input speed. A scale of 2 to 10 was used to rate the parameters, with 10 being the highest rating and 2 being the lowest. The final rating was computed by dividing the total rating points by the number of parameters used. A final rating of six (6) or higher indicates that the pump or pump set meets the minimum performance requirements, while a score of four (4) or lower indicates that it does not. Regardless if the pump met the minimum requirements based on PAES 115 or not, it should be noted that the parameters used have equal weights for determining the final rating.

RESULTS AND DISCUSSIONS

The data of tested pump and pump set units in the Agricultural Machinery Testing Evaluation Center (AMTEC), UPLB from 1989 to 2022 were classified into centrifugal pump set, bare pump and submersible pump set testing. The total tested pumps and pump sets were 960 units: 4% of these was submersible pump sets (36), 39% were bare pump (371), and 57% were pump sets (553). The data of centrifugal pump sets (engine) and bare pumps were subject to general statistics analyses and evaluation scheme.

Centrifugal Bare Pumps

Of the 371 AMTEC pump performance test data, a total of 341 bare pumps were collated and analyzed in the study. A total of 49 units of 50x50mm bare pumps were collated which include 31 units self-priming and 18 units non-self-priming. Moreover, there were 114 units of 75x75mm bare pumps. Of the 75x75mm bare pumps, 50 units were self-priming and 64 units were non-self-priming. There were 178 units of 100x100mm bare pump tested as well, which included 72 units self-priming and 106 units non-self-priming. Most of the pumps were manufactured in the Philippines and China (**Table 3**). Others were manufactured in Taiwan, Korea, and Japan. Meanwhile, there were 40 bare pump units that had no information on their country of manufacture (**Table 3**).

Among all self-priming pump sizes, most of the pump shaft speed were in the range of 1901-2100 rpm (**Table 4**). A considerable number (27) of self-priming 100x100mm pumps are in the 1701-1900 rpm range (**Table 4**). On the other hand, most of the non-self-priming across all pump sizes were in the range of 1701 rpm and above range (**Table 5**).

Most of the impellers of self-priming bare pumps across all pump sizes were semi-open type (**Table 6**) while most of the non-self-priming bare pumps for all sizes were enclosed impeller type (**Table 7**).

Mechanical seals are able to seal against higher pressures and can be used with higher-speed pumps than packing (Volks, 2005). From the data of the tested bare pumps, it could be observed that for all pump sizes on both priming methods, most of the pumps have the mechanical seal and packing seal for the stuffing box, with the latter type being the most common (**Tables 8** and **9**)

Summary of Testing Results of Bare Pumps

Table 10 presents the maximum pump efficiency and the corresponding total head and discharge capacity of bare pumps tested at different pipe sizes, which are: 50×50mm, 75×75mm, and 100×100mm, respectively. For all pump sizes, the non-self-priming type has higher pump efficiency (52.99%, 61.05%, 62.21%, respectively) and discharge capacity (7.78L/s, 15.78L/s, 25.54L/s, respectively) than the self-priming (**Table 10**). One factor for the lower pump efficiency of self-priming pumps is the presence of a one-way valve on the suction side. This would lead to head loss and consequently lower output (water power). Generally, a closed impeller pump is more efficient than an open impeller pump of the same size and specific speed (Volk, 2005). Most of the self-priming pumps have open impellers. Pump efficiency and discharge capacity increase with pump size, though the pump efficiencies of the 75×75mm (61.05%) and 100×100 mm (62.21%) pumps have relatively slight differences for each type. It could also be observed from the data that for pumps with 100×100 mm size, the self-priming type has a higher total head (15.90 m) than non-self-priming (14.39 m).

Performance Evaluation Scheme Analysis of Bare Pumps

Four parameters were considered for the performance evaluation scheme adapted from Resurreccion, et al. (2008): discharge-input ratio (0.75), pump efficiency (50% for the self-priming type and 55% for the non-self-priming), total suction lift (8 m), and input speed (1500-1800 rpm). Most of the pumps met the minimum requirement of having a final rating point of 6 and above. All non-self-priming 100×100mm pumps (106/106) passed the minimum requirements while only 71 out of 72 passed for the self-priming 100×100mm pumps. On the other hand, 28 of the 31 self-priming 50×50mm pumps had final rating points above the minimum requirement, while only 16 out of the 18 non-self-priming 50×50mm pumps passed. For the 75×75mm pumps, 48 of 50 met the minimum requirement for the self-priming type and only 60 of 64 for the non-self-priming type.

Centrifugal Pump Sets

A total of 485 units of pump sets (out of 553) were considered as shown in **Tables 11** and **12**, including the classification based on transmission mode: 51% were close-coupled while 49% used V-belt and pulley. There were 121 units of 50x50mm pump sets, 111 units of which are close-coupled while 10 units have V-belt and pulley transmission. **Table 11** shows that most of the 50x50mm pump sets are self-priming (115/121), specifically 109 are close-coupled, and 6 units are V-belt-driven. It could be observed that most of the 50x50mm closed-coupled pump sets are driven by gasoline engines (87) while all of the V-belt-driven pump sets are powered by diesel engines (**Tables 11** and **12**). It could also be observed from **Table 12** that all sizes of non-self-priming pump sets are driven by diesel engines. On the other hand, most of the self-priming 50x50mm and 75x75mm pump sets are driven by gasoline engines (**Table 12**).

There were a total of 157 units of 75×75mm pump sets tested, 107 units of which are close-coupled while 50 units have V-belt-and-pulley transmission. It can be observed from **Table 11** that most of the 75×75mm close-coupled pump sets are self-priming (101 units) while most of the V-belt-driven pump sets (29 units) are non-self-priming. In **Table 12**, it is indicated that most of the self-priming, closed-coupled, 75×75mm pump sets are driven by gasoline engines (68) while all of V-belt-driven pump sets are powered by diesel engines (50).

There were 207 units of 100×100mm pump sets, 30 units of which are close-coupled while 177 units have V-belt-and-pulley transmission. Most of the units being distributed by the DA and NIA are 100×100mm diesel engine-powered pump sets with V-belt-and-pulley transmission. Moreveover, most of the V-belt-driven pump sets are non-self-priming (97 units), while for the close-coupled type, it is mostly self-priming (25 units). It can be observed that most of the 100×100mm pump sets are driven by diesel engines, and all of the V-belt-driven are diesel (177).

Most of the pump shaft speed of the non-self-priming pump sets (48 units) were in the range of 2101 rpm and above (**Table 13**) while most of the self-priming pump sets (239 units) were in the range of 2301 rpm and above (**Table 14**). A considerable number (45) of non-self-priming 100x100mm pump sets are in the 1701-1900 rpm range (**Table 13**) and self-priming pump sets (45) were in the 1901-2100 rpm (**Table 14**).

Most of the impellers of all non-self-priming pump sizes were semi-open type (**Table 15**) while most of the self-priming pump sizes were of enclosed type of impeller (**Table 16**). The same was observed on the impeller types of the bare pumps tested.

The most common stuffing box types observed on the non-self-priming pump sets tested were the mechanical and packing seals (**Tables 17** and **18**). However, for the self-priming pump sets tested, the packing seal-type is the most common (**Tables 17** and **18**). It must be noted that the packing seal-type is easy to maintain. It is a similar observation for all bare pumps.
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Summary of Testing Results of Pump Sets

Tables 19 to **21** present the testing results of pump sets tested at different sizes: 50x50mm, 75x75mm, and 100x100mm, respectively. Results showed that, in general, the system efficiency of pump sets is: relatively higher for the non-self-priming types than the self-priming types (the same was observed with bare pump efficiency); relatively higher for diesel engine-driven than the gasoline engine-driven types; and relatively higher for those with water-cooled engines than those powered by air-cooled engines. The highest system efficiency was observed from non-self-priming, water-cooled diesel engine-driven, close-coupled, 75x75mm pump set (18.99%) while the lowest system efficiency was observed from the self-priming, gasoline engine-driven, close-coupled, 50x50mm pump set (7.97%). The lowest fuel consumption for diesel engine-driven pump sets was observed from the self-priming, water-cooled, close-coupled, 75x75mm (0.84L/h). Furthermore, for the gasoline engine-driven pump sets, it was observed from the self-priming, gasoline, close-coupled, 50x50mm (1.30L/h).

It was observed that for the 50x50mm pump sets, there were no self-priming and non-self-priming, air -cooled engine units for all pump sets and no gasoline engine unit for the pump sets with V-belt-and-pulley transmission. Also, from **Table 19,** all the non-self-priming, diesel engine-driven, water-cooled pump sets have relatively higher fuel consumption but with relatively higher system efficiency. The highest system efficiency was obtained with non-self-priming, diesel engine-driven, water cooled, V-belt-and-pulley transmission pump sets at 11.28%.

It can be observed that for the 75x75mm pump sets, there were no gasoline engine unit with V-belt-and-pulley transmission. From **Table 20**, all non-self-priming, diesel, air-cooled pump sets have relatively higher system efficiency than water-cooled pump sets. Moreover, the self-priming, gasoline, close-coupled pump set has relatively higher system efficiency than diesel, air-cooled.

It was observed that for 100x100mm pump sets, there were no gasoline engine units, and no non-self -priming, air-cooled, close-coupled and self-priming, water-cooled, close coupled pump set units. As shown in **Table 21**, all non-self-priming, diesel, water-cooled pump sets have relatively higher system efficiency than air-cooled pump sets. Moreover, the non-self-priming, diesel, water-cooled, close-coupled pump set has the highest system efficiency of 17.49%.

Performance Evaluation Scheme Analysis of Different Pump Sets

The performance evaluation scheme developed by Resurreccion et al. (2008) for agricultural machinery tested in AMTEC includes a performance rating scheme for pump sets. For this study, only the system efficiency (10%), total suction lift (8 m), input speed (1500-1800 rpm) were evaluated using the pump set test data. Discharge to input power was not included, since most of the pump sets test data have no data on input power. Most of the 75x75mm (39/50) and 100x100mm (135/176) V-belt-driven, and 100x100mm close-coupled pump sets passed the rating scheme (6 and above) (**Table 22**). On the other hand, for the 50x50mm pump sets, only 3 out of 10 units passed the rating scheme for belt transmission while only 9 out of 111 units passed for close-coupled (**Table 22**). Most of the non-self-priming V-belt-driven100x100mm pump sets (73/97) passed the performance evaluation while none (0/6) of the self-priming V-belt-driven 50x50mm pump sets did not pass (**Table 22**).

CONCLUSIONS

A total of 49 units 50x50mm bare pump were collated with 114 units of 75x75mm and 178 units of 100x100mm bare pump. Most of the pumps were manufactured in the Philippines and China. There were 121 units of 50x50mm, 157 units of 75x75mm and 207 units of 100x100m pump sets' test data collated and evaluated. Most of the 50x50mm pump sets are self-priming and most of the 50x50mm closed-coupled pump sets are driven by gasoline engine while all of the V-belt-driven pump sets are driven by diesel engine. All sizes of non-self-priming pumps are driven by diesel engine. On the other hand, most of the self-priming 50x50mm and 75x75mm pump sets are driven by gasoline engine. Meanwhile, most of the 75x75mm close-coupled pump sets are self-priming while most of the 75x75mm closed-coupled pump sets are driven by gasoline engine and all of the V-belt-driven pump sets are driven by diesel engine. Most of the V-belt-driven 100x100mm pump sets are non-self-priming while for close-coupled, it is mostly self-priming. Moreover, most of the 100x100mm pump sets are driven by diesel engine with all of the V-belt-driven are diesel.

For all bare pump sizes, non-self-priming has higher pump efficiency and discharge capacity than self-priming. Pump efficiency and discharge capacity increases with pump size, though pump efficiencies of 75x75mm and 100x100mm has relatively slight differences for each type. For 100x100mm size, self -priming pump has higher total head than the non-self-priming. In general, results showed that for pump sets system efficiency, : it is relatively higher for non-self-priming than self-priming (same with bare pump efficiency); relatively higher for diesel than gasoline engine driven; and relatively higher for water-cooled than the air-cooled engine. The highest system efficiency was observed with non-self-priming, diesel, water-cooled, close-coupled, 75x75mm pump set (18.99%) while the lowest was with self-priming, gasoline, close-coupled, 50x50mm pump set (7.97%). The lowest fuel consumption for diesel pump sets was with self-priming, water-cooled, close-coupled, 75x75mm (0.84L/h) while for gasoline was with self-priming, gasoline, close-coupled, 50x50mm (1.30L/h).

Most of the bare pumps are within the minimum requirements (6 points and above). All non-self-priming 100x100mm pumps passed the minimum requirements. On the other hand, for the 50x50mm pump sets, only 3 out of 10 units passed the rating scheme for belt transmission while only 9 out of 111 units passed for close-coupled. Most of the non-self-priming belt transmission 100x100mm pump sets passed the performance evaluation while none of the self-priming V-belt transmission 50x50mm pump sets did not pass.

RECOMMENDATION

To further improve the results of this study, an analysis of the pumps and pump sets' performance can be done in terms of normalizing the pump shaft speed. This may be done using the pump affinity laws. Furthermore, performance analysis can be done by assigning the optimum values for specific parameters using statistical tools such as the Analytic Hierarchy Process (AHP) or Multi-Criteria Decision Analysis (MCDA) or systems. These may include a revision of the evaluation scheme presented by Resurreccion, et al (2008). The optimum values could be set by the stakeholders as standards for pumps and pump sets.

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Table 1. Criteria for the performance rating of centrifugal pumps.

Item	Minimum Requirement	Range of values	Equivalent Points
1. Discharge-Input power ratio	0.75	1.30 and above	10
		1.00-1.290	8
		0.75-0.99	6
		0.50-0.74	4
		Below 0.50	2
2. Pump Efficiency (%)			
a. Self-priming	50.00	60.00 and above	10
		55.00 to 59.99	8
		50.00 to 54.99	6
		45.00 to 49.99	4
		Below 45.00	2
b. Non-Self-priming	55.00	65.00 and above	10
		60.00 to 64.99	8
		55.00 to 59.99	6
		50.00 to 54.99	4
		Below 50.00	2
3. Total Suction Lift (m)	8	9.0 and higher	10
		8.5 to lower 9.0	8
		8.0 to lower 8.5	6
		7.5 to lower 8.0	4
		7.5 and lower	2
4. Input Speed (rpm)	1500-1800	1800-2400	10
		2400-3000	8
		1500-1800	6
		3000-up	4
		Below 1500	2

Table 2. Criteria for the performance rating of centrifugal pump sets.

Item	Minimum Require-ment	Range of values	Equivalent Points
1. Discharge-Input power ratio	0.75	1.3 and above	10
		1.0-1.29	8
		0.75-0.99	6
		0.5-0.74	4
		Below 0.5	2
2. System Efficiency (%)	10	14 and Above	10
		12-13.9	8
		10-11.9	6
		8-9.9	4
		Below 8	2
3. Total Suction Lift (m)	8	9.0 and Higher	10
		8.5 to lower 9.0	8
		8.0 to lower 8.5	6
		7.5 to lower 8.0	4
		7.5 and lower	2
4. Input Speed (rpm)	1500-1800	1800-2400	10
		2400-3000	8
		1500-1800	6
		3000-up	4
		Below 1500	2

Table 4. Pump shaft speed of the different sizes of self-priming bare pumps

Pump Shaft Speed	50×50 (mm)	75×75 (mm)	100×100 (mm)	TOTAL UNITS
1700 and below	0	1	2	3
1701 to 1900	3	9	27	39
1901 to 2100	18	32	39	89
2101 to 2300	2	2	2	6
2301 and above	7	6	2	15
TOTAL	30	50	72	152

Note: One pump was not included due to unreadable data.

Table 3. Country of manufacture of the different sizes of AMTEC-tested bare pumps.

Country	50×50 (mm)	75×75 (mm)	100×100 (mm)
China	19	42	61
India	0	1	1
Italy	0	1	3
Japan	1	0	2
Philippines	15	38	72
South Korea	0	2	1
Taiwan	7	14	18
Thailand	0	0	1
USA	1	1	0
No data	6	15	19
Total	49	114	178

Table 5. Pump shaft speed of the different sizes of non-self-priming bare pumps

Pump Shaft Speed	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units
1500 and below	1	1	2	4
1501 to 1700	0	0	2	2
1701 to 1900	12	27	49	88
1901 to 2100	1	9	29	39
2101 and above	4	27	23	54
TOTAL	18	64	105	187

Note: One pump was not included due to unreadable data.

Table 6. Type of impeller of the different sizes of self-priming bare pumps.

Impeller	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units
Open	1	0	3	4
Semi-open	28	46	65	139
Enclosed	2	4	4	10
Total	31	50	72	153

Table 7. Type of impeller of the different sizes of non-self-priming bare pumps.

Impeller	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units
Open	0	0	0	0
Semi-open	1	3	3	7
Enclosed	17	61	103	181
Total	18	64	106	188

Table 8. Types of stuffing box of the different sizes of self-priming bare pumps.

Stuffing Box	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units
Mechanical	7	4	9	20
Oil	1	0	0	1
Packing	23	46	63	132
Total	31	50	72	153

Table 9. Type of stuffing box of the different sizes of non-self-priming bare pumps.

Stuffing Box	50×50 (mm)	75×75 (mm)	100×10 0(mm)	Total Units
Mechanical	9	18	24	51
Oil	0	3	3	6
Packing	9	43	79	131
Total	18	64	106	188

Table 10. Total head and discharge capacity of different bare pump sizes at maximum pump efficiency.

Pump Size	Priming Method	Max Pump Eff %	Total Head, m	Discharge Capacity, L/s
50x50, mm	non-self	52.99	16.40	7.78
	self	39.11	15.91	5.37
75x75, mm	non-self	61.05	16.62	15.78
	self	45.14	15.48	10.82
100x100, mm	non-self	62.21	14.39	25.54
	self	47.24	15.90	16.66

Table 11. Engines of different non-self-priming pump set sizes and transmission system.

Engine Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Diesel	2	6	5	13	4	29	97	130	143
Gasoline	0	0	0	0	0	0	0	0	0
Total	2	6	5	13	4	29	97	130	143

Table 12. Engines of different self-priming pump set sizes and transmission system.

Engine Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Diesel	22	33	23	78	6	21	80	107	185
Gasoline	87	68	2	157	0	0	0	0	157
Total	109	101	25	235	6	21	80	107	342

Table 13. Pump shaft speed of different non-self-priming pump set sizes and transmission system.

Shaft Speed	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
1500 and below	0	0	1	1	0	0	2	2	3
1501 to 1700	0	1	0	1	0	1	16	17	18
1701 to 1900	0	1	1	2	0	7	36	43	45
1901 to 2100	0	0	0	0	0	5	22	27	27
2101 and above	2	4	3	9	4	15	20	39	48
Total	2	6	5	13	4	28	96	128	141

Note: Two units have no data.

Table 14. Pump shaft speed of different self-priming pump set sizes and transmission system.

Shaft Speed	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
1700 and below	0	0	0	0	0	0	8	8	8
1701 to 1900	0	1	0	1	0	0	18	18	19
1901 to 2100	1	0	0	1	1	6	37	44	45
2101 to 2300	0	1	0	1	0	11	15	26	27
2301 and above	107	97	24	228	5	4	2	11	239
Total	108	99	24	231	6	21	80	107	338

Note: Three units have no data.

Table 15. Type of impeller of different non-self-priming pump set sizes and transmission system.

Impeller Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Open	0	0	0	0	0	0	2	2	2
Semi-open	0	0	0	0	0	2	6	8	8
Enclosed	2	6	5	13	4	27	89	120	133
Total	2	6	5	13	4	29	97	130	143

Table 16. Type of impeller of different self-priming pump set sizes and transmission system.

Impeller Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Open	0	0	0	0	0	0	2	2	2
Semi-open	106	97	25	228	5	18	74	97	325
Enclosed	3	4	0	7	1	3	4	8	15
Total	109	101	25	235	6	21	80	107	342

Table 17. Type of stuffing box of different non-self-priming pump set sizes and transmission system.

Stuffing Box Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Mechanical	0	5	5	10	3	9	22	34	44
Oil	0	0	0	0	0	0	1	1	1
Packing	2	1	0	3	1	20	74	95	98
Total	2	6	5	13	4	29	97	130	143

Table 18. Type of stuffing box of different self-priming pump set sizes and transmission system.

Stuffing Box Type	Close-coupled				V– belt and Pulley				Total
	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	50×50 (mm)	75×75 (mm)	100×100 (mm)	Total Units	
Mechanical	106	99	25	230	4	5	20	29	259
Oil	0	0	0	0	0	0	0	0	0
Packing	0	1	0	1	2	16	60	78	79
Total	106	100	25	231	6	21	80	107	338

Table 19. 50x50mm pump set performance parameters at maximum system efficiency.

Type	Maximum System Efficiency, %	Fuel Consumption, L/	Total Head, m	Discharge Capacity, L/s	Range of Engine Rated Power (kW)
Close-coupled					
Non-self-priming, Water-cooled diesel engine	10.70	1.48	28.50	6.19	3.73 – 5.97
Self-priming, Air-cooled diesel engine	10.18	0.94	16.86	5.89	2.24-5.22
Self-priming, Gasoline engine	7.97	1.30	16.63	5.70	2.24 -5.22
V-belt and pulley					
Non-self-priming, Water-cooled diesel engine	11.28	1.76	30.09	6.73	5.10 – 5.27
Self-priming, Water-cooled diesel engine	8.45	1.48	23.63	5.92	5.10 – 6.18

Table 20. 75x75mm pump set performance parameters at maximum system efficiency.

Type	Maximum System Efficiency, %	Fuel Consumption, L/h	Total Head, m	Discharge Capacity, L/s	Range of Engine Rated Power, kW
Close-coupled					
Non-self-priming, Air-cooled diesel engine	18.99	1.34	15.60	17.30	4.80
Non-self-priming, Water-cooled diesel engine	14.95	1.80	13.78	17.05	3.73 – 5.22
Self-priming, Air-cooled diesel engine	11.47	1.33	16.12	9.84	2.80 – 8.96
Self-priming, Water-cooled diesel engine	8.36	0.84	10.7	7.07	5.10
Self-priming, Gasoline engine	10.01	1.56	15.63	9.97	2.83 – 5.60
V-belt and pulley					
Non-self-priming, Air-cooled diesel engine	15.25	1.26	14.09	13.85	4.90 – 9.00
Non-self-priming, Water-cooled diesel engine	13.87	1.81	19.19	13.33	4.48 – 7.09
Self-priming, Air-cooled diesel engine	10.08	1.72	16.18	11.27	4.90 – 7.46
Self-priming, Water-cooled diesel engine	11.79	1.49	15.00	12.30	5.12 – 7.09

Table 21. 100x100 mm pump set performance parameters at maximum system efficiency.

Type	Maximum System Efficiency, %	Fuel Consumption, L/h	Total Head, m	Discharge Capacity, L/s	Range of Engine Rated Power, kW
Close-coupled					
Non-self-priming,Water-cooled diesel engine	17.49	1.32	12.79	18.77	3.73 – 5.97
Self-priming, Air-cooled diesel engine	11.99	1.48	14.83	12.87	4.00-7.50
Self-priming, Gasoline engine	8.44	2.46	16	11.55	5.20 – 5.60
V-belt and pulley					
Non-self-priming, Air-cooled diesel engine	11.90	2.41	13.24	20.61	6.62 – 9.00
Non-self-priming, Water-cooled diesel engine	13.38	2.08	14.06	20.75	5.10 – 8.96
Self-priming, Air-cooled diesel engine	9.51	2.14	14.40	14.94	7.30 – 7.46
Self-priming, Water-cooled diesel engine	10.62	2.59	16.53	15.25	5.10 – 10.30

Table 22. Performance of different pump set sizes and transmission system.

Priming Method	Close-Coupled			V-Belt & Pulley		
	50×50 (mm)	75×75 (mm)	100×100 (mm)	50×50 (mm)	75×75 (mm)	100×100 (mm)
Non-self	½	5/6	4/5	3/4	24/29	73/97
Self	8/109	21/100	8/25	0/6	15/21	62/79