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Posted Date: 6 November 2024

doi: 10.20944/preprints202411.0338.v1

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Experimental Study on the Performance Characteristics of a Submersible Pump for Drainage with the Discharge Flow Rate

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Abstract: In this study, an experimental study was conducted on the performance characteristics of large-diameter submersible pumps with 400A and 1350A for drainage according to various flow rate changes. As a result, the total head of the submersible pump with a diameter of 400A decreased by approximately 36.28% from 5.43m to 3.46m, and the pump efficiency also decreased by 7.81% from 83.48% to 76.93%. As the discharge flow rate increased, the input power and the overall efficiency also tended to decrease. It was confirmed that the increase in the discharge flow rate decreased the total head and the input power, and thus the pump efficiency and the overall efficiency decreased. The total head of the submersible pump for the 1350A diameter decreased by about 34.4% from 4.36m to 2.86m, and the pump efficiency decreased by about 3.39% from 76.29% to 73.7%. As with the submersible pump with a diameter of 400A, the input power and overall efficiency tended to decrease as the discharge flow increased. As the diameter increased, the input power of the submersible pump was consumed more, and the total head, pump efficiency, and overall efficiency were lower.

Keywords: discharge flow rate; input power; overall efficiency; pump efficiency; submersible pump

1. Introduction

With the increasing frequency of abnormal weather events driven by climate change, the incidence of agricultural land inundation has been steadily rising. In 2022, heavy rainfall caused three out of the four rainwater pumping stations installed in the Cheongyang region of Chungnam Province to malfunction, resulting in the flooding of over 340 greenhouses and agricultural fields. Consequently, a total of 3.662 billion KRW was required for the emergency restoration of 22 damaged pump stations, while an additional 16.772 billion KRW was necessary for port restoration involving elevation of the pumping station structures. The total infrastructure damage amounted to 20.434 billion KRW, and the estimated flood damage to agricultural land due to pump station failure reached 1.949 billion KRW [1]. In August 2022, heavy rainfall exceeding 80 mm per hour caused rapid flooding in the Cheongcheon-dong area of Bupyeong-gu and the Juan-dong area of Michuhol-gu, Incheon. The significant flooding was attributed to the short duration yet high intensity of rainfall, compounded by the reduced functionality of the road drainage systems, which failed to operate effectively during the event [2]. Submersible pumps employed in drainage pumping stations typically experience short operational periods, with prolonged idle times during which the impellers remain submerged. During these idle periods, foreign materials mixed with the fluid can infiltrate the system, leading to a reduction in pump efficiency and becoming a primary cause of pump failure. Furthermore, motor failures in submersible pumps are often triggered by water ingress due to micro-leakage in the motor chamber or condensation formation resulting from temperature differentials.

To prevent such flood damage, studies are being conducted to improve the flow characteristics of submersible pumps.

In previous studies on submersible pumps, Kim et al. [3] conducted an analytical investigation into the effects of geometric parameters on the hydraulic performance of submersible axial-flow pumps. Their findings revealed that a reduction in sweep angle (θ) increased pump efficiency, although it had minimal impact on total head. Lee et al. [4] performed an analytical study on the flow characteristics of submersible pump impeller blades with varying geometries, confirming that models featuring hemispherical obstacles and dimples only on the pressure side demonstrated relatively higher efficiency. Kim et al. [5] investigated the performance characteristics of submersible axial-flow pumps based on changes in the angle of inlet guide vanes (IGV). The results indicated that, as the IGV angle increased, total head and efficiency showed a corresponding increase across all flow rates. An et al. [6] applied a vortex-reducing impeller design and performed a numerical analysis to evaluate the performance of submersible pumps. The results demonstrated that at a flow rate of 660 m^3/min, the efficiency of the conventional model was 83.7%, while the newly developed model showed an improved efficiency of 87.9%, representing a 4.2% increase. Suh et al. [7] conducted a numerical study on cavitation and clogging phenomena in drainage submersible pumps, demonstrating that their newly designed impeller model significantly enhanced suction performance across the entire flow range compared to conventional pumps. Suh et al. [8] further improved submersible pump performance by optimizing impeller shapes and utilizing a flow balance block in the casing design. The results indicated that power consumption decreased, leading to increased efficiency, and the attachment of the flow balance block further improved efficiency in large flow regions. Seo et al. [9] carried out an analytical study to improve the efficiency of submersible axial-flow pumps by modifying the impeller geometry, selecting dimples and bumps as the geometric variables. The results showed that the application of both dimples and bumps significantly improved efficiency compared to the baseline geometry, with the bump configuration providing the highest efficiency. Park et al. [10] conducted a numerical analysis on the performance characteristics of the suction area in wastewater submersible pumps. Their study revealed that the cutting model, featuring holes in the circular groove of the suction cover, had no significant impact on flow characteristics. Costa et al. [11] investigated an evaluation method for uncertainties in electric submersible pumps (ESP) based on a deep neural network. The proposed model was validated with experimental data, and it successfully predicted key parameters such as choke pressure, intake pressure, and production flow, which are critical to the performance of ESPs. Fang et al. [12] developed a multivariate statistical performance monitoring algorithm for preventing failures and maintaining operational conditions in ESPs used in steam-assisted gravity drainage (SAGD) processes. The proposed algorithm established a novel feature extraction technique based on variable speed drive(VSD) measurements and successfully reflected and evaluated the performance degradation of ESPs. Valdés et al. [13] compared the performance of ESPs in both Newtonian and non-Newtonian fluids using experimental data and CFD simulations. The experiments confirmed a rise in pressure and power consumption in the ESP motor, and the developed CFD model showed a mean square error of 4.91% for head rise and 10.6% for pump efficiency, demonstrating strong agreement with experimental results. Wang et al. [14] investigated the energy characteristics of the hydraulic system of ESPs by analyzing inter-stage variability through numerical simulations and experiments based on entropy generation theory. The study confirmed consistent energy characteristics in ESPs, aligning with the distribution of internal flow structures. However, discrepancies were observed between the energy characterization based on entropy generation theory and the traditional efficiency index when inter-stage differences were considered. Sperlich et al. [15] studied the energy-efficient behavior of variable speed submersible pumps in groundwater wells. Their findings showed that, under simulated well conditions, the total specific energy demand for pumping was significantly lower in partial load operation compared to nominal pump speed operation, achieving up to 20% energy savings in low and medium flow rates. Zhou et al. [16] performed a numerical analysis of high-speed ESPs under various end clearance conditions. The study confirmed that as end clearances increased, turbulent flow developed in the diffuser passage,

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leading to a degradation in pump performance. Han et al. [17] examined the influence of blade outlet angles on the performance and internal flow patterns of high-speed well submersible pumps. The results showed that the outlet angle of the impeller blades significantly affected the static pressure distribution, velocity distribution, and streamline patterns within the impeller and guide vanes, as well as the pump's head, power, and efficiency curves. Wang et al. [18] investigated the pressure pulsation characteristics of the bulb body in submersible tubular pumps. The developed numerical analysis model was compared with experiments, and it was confirmed that the efficiency-head curves were in good agreement.

In previous studies, analytical studies have been mainly conducted to confirm the performance characteristics of submersible pumps, and experimental studies on submersible pumps are insufficient. Therefore, in this study, a performance test of a submersible pump for drainage was performed, and an experimental study on the performance characteristics of the submersible pump under various flow conditions was conducted. The results of this study are expected to provide basic data for performance tests of submersible pumps for flood prevention.

2. Experimental setup and method

The submersible pump used in this study is a large submersible pump with a pipe diameters of 400A and 1350A. In this study, the experimental environment for a large submersible pump was implemented. Figure 1 shows a photo of the submersible pump used in this study, and Table 1 shows the specifications of the submersible pump. The performance test for the drainage function of the submersible pump was performed in accordance with KS B 6301:2019 [19], and the experimental conditions for the drainage function of the submersible pump are shown in Table 2. The test items of KS B 6301:2019 [19] are total head, discharge flow rate, rotation speed, shaft power (or input power), and operating status. Based on this, the total head and discharged amount of the submersible pump, shaft power (or input power), pump efficiency, overall pump efficiency, and operating status are checked. Pump efficiency is calculated based on the pump's liquid power (L_w) and shaft power (L), as shown in Equation (1).

$$\eta = \frac{L_w(^{18})}{L} \times 100 \quad (1)$$

Pump overall efficiency (η_{gr}) can be calculated using liquid power (L_{gr}) and input power (L_w) as in Equation (2). Liquid power is as in Equation (3), where ϱ is density, g is gravitational acceleration, Q is discharge flow rate, and H is total head.

$$\eta_{gr} = \frac{L_w(^{18})}{L_{gr}} \times 100 \quad (2)$$

$$L_w = \frac{1}{60 \times 10^3} \rho g Q H \quad (3)$$

In this study, the performance characteristics (total head, input power, pump efficiency, and overall efficiency) of a submersible pump drainage function were experimentally investigated according to various discharge flow rate changes.

 doi:10.20944/preprints202411.0338.v1

Figure 1. Photograph of performance test of the submersible pump for drainage.

Table 1. Specifications of the submersible pump used in this study.

Item		**400A**	**1350A**
Pump	Rotating speed	1167 rpm	438 rpm
	Discharge flow rate	17.0 m^3/min	135 m^3/min
	Consumption power	19 kW	130kW
	Total head	4.0 m	3.5m
	Pump efficiency	70.0%	76.35
Motor	Frequency	60Hz	60
	Volatge	380V	380
	Electric current	41.0A	302.0A
	Number of poles	6P	16P
	Power	19kW	130kW
	Efficiency	86.08%	91.68%

Table 2. Experimental conditions used in this study.

Item	**Specification**
Working fluid	Water
Temperature(°C)	17.2
Density(kg/m^3)	998.738
Discharge flow rate(m^3/min)	(400A)17.26, 18.4, 19.37, 19.96, 20.55
	(1350A)127.16, 132.55, 138.01, 143.36, 149.84

3. Results and discussions

3.1. Performance test results of 400A submersible pump for drainage

In this study, experiments were conducted on the total head and the pump efficiency of a submersible pump with a diameter of 400A according to various discharge flow rates, and the results are shown in Figure 2. In a submersible pump, the total head is the sum total of the pressure that the submersible pump can pump considering various factors such as friction loss, bends, eddies, and vapor pressure in the pipe. Therefore, the total head is an important factor in determining the type

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and capacity of the pump. When the discharge flow rate of the submersible pump was 17.26 m^3/min, the total head was 5.43m. When the discharge flow rate was 18.4 m^3/min, the total head was 4.93m. When the discharge flow rate was 19.37 m^3/min and 19.96 m^3/min, the total heads were 4.06m and 3.86m, respectively. At a discharge flow rate of 20.55 m^3/min, the total head was 3.46m. Overall, as the discharge flow rate increased, the total head tended to decrease. This is because the relationship between the flow rate and the head of the pump is inversely proportional.

The efficiency of a submersible pump is expressed as the ratio of theoretical power to shaft power, and the efficiency of a submersible pump is a measure of energy consumption efficiency. In this study, the pump efficiency of a submersible pump according to various discharge flow rates was analyzed. As shown in Figure 2, when the discharge flow rate of the submersible pump was 17.26 m^3/min, the pump efficiency was 83.45%. At the discharge flow rate of the 18.4 m^3/min, the pump efficiency was 84.4%. When the discharge flow rates were 19.37 m^3/min and 19.96 m^3/min, the pump efficiencies were 81.4% and 81.05%, respectively. In the discharge flow rate of 20.55 m^3/min, the pump efficiency was 76.93%, and overall, as the discharge flow rate increased, the efficiency of the submersible pump tended to decrease. This is because the total head and power consumption decreased as the discharge flow rate increased, and the pump efficiency also decreased accordingly.

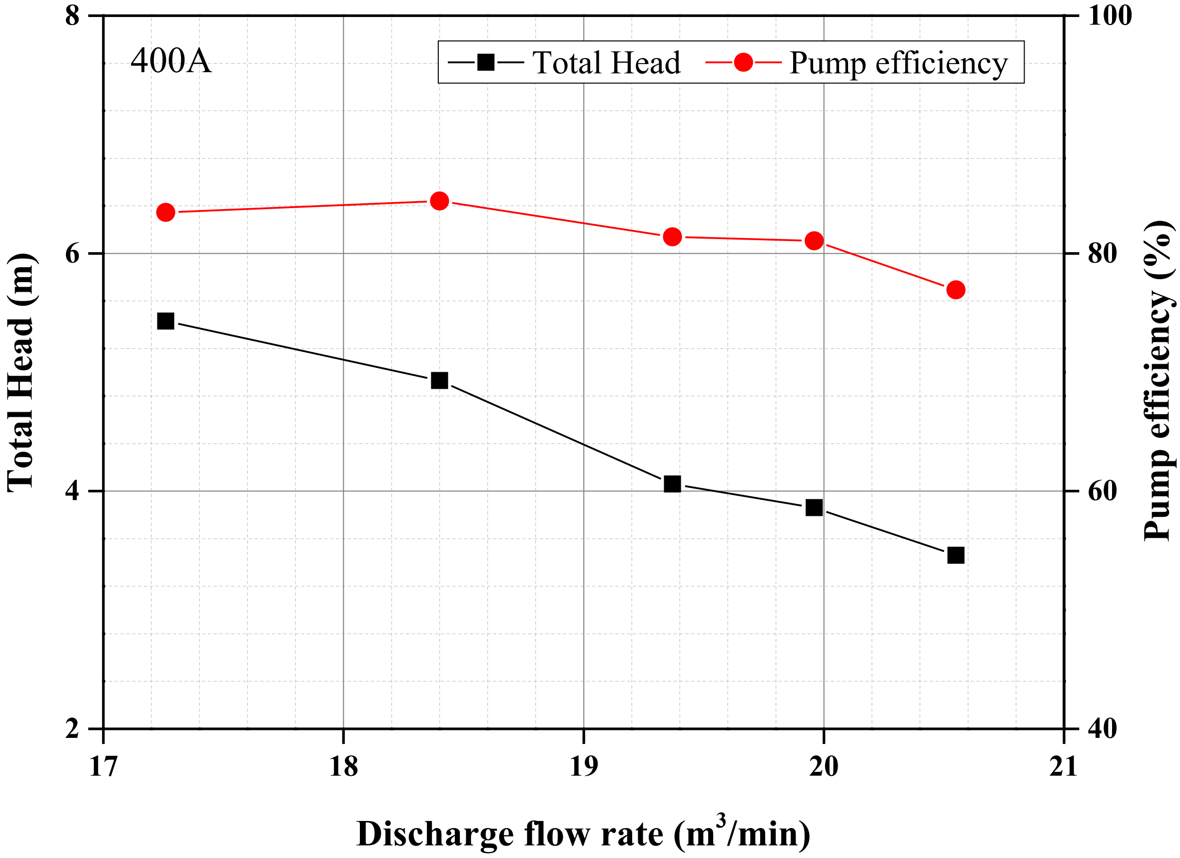

Figure 2. Performance test results for total head and pump efficiency of 400A submersible pump.

In this study, an experiment was conducted on the input power and the overall efficiency of a submersible pump with a diameter of 400A as the various discharge flow rates. Figure 3 are shwon the experimental results fore the input power. The input power of the submersible pump is the power input value for the motor, and based on this, the power consumption of the motor can be checked. In other words, it means the motor power transmitted to the shaft when the electrical energy given to the pump is converted into kinetic energy. The input power of a submersible pump is an important factor in calculating the efficiency of the pump. When the discharge flow rate of the submersible pump motor room drainage function was 17.26 m^3/min, the input power was 21.31 kW. As the discharge flow rate was 18.4 m^3/min, the input power was 20.4 kW. When the discharge flow rates were 19.37 m³/min and 19.96 m³/min, the input powers were 18.34 kW and 18.05 kW, respectively. At a discharge flow rate of 20.55 m³/min, the input power was 17.57 kW, and overall, as the discharge flow rate increased, the input power tended to decrease. The reason is that as the discharge flow rate increases, the total head decreases and thus the power consumption in the motor decreases.

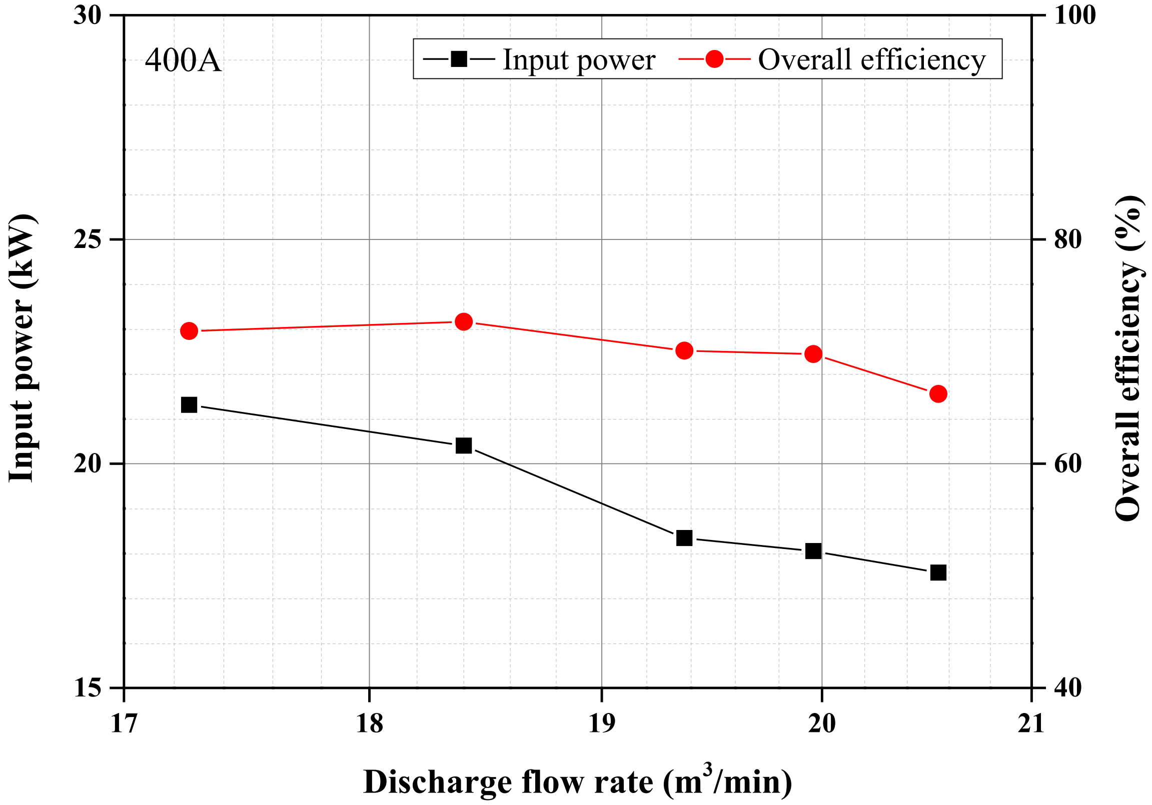

Figure 3. Performance test results for input power and oeverall efficiency of 400A submersible pump.

The overall efficiency of a submersible pump is calculated by the parameters of flow rate, total head, specific gravity, and power consumption of the pump and motor. Based on the overall efficiency, it can see how efficient the submersible pump is in converting electricity into electromechanical work. In this study, the overall efficiency of a submersible pump according to various discharge flow rates was analyzed. As shown in Figure 3, when the discharge flow rate for the submersible pump drainage function was 17.26 m³/min, the overall efficiency of the pump was 71.83%, and at 18.4 m³/min, the overall efficiency was 72.65%. When the discharge flow rates were 19.37 m³/min and 19.96 m³/min, the overall efficiencies of the pump were 70.07% and 69.77%, respectively. At a discharge flow rate of 20.55 m³/min, the pump efficiency was 66.22%, and the overall efficiency of the submersible pump tended to decrease as the discharge flow rate increased. Accordingly, it was confirmed that an increase in the discharge flow rate decreased the efficiency of the pump's electromechanical work conversion.

3.2. Performance test results of 1350A submersible pump for drainage

In this study, a performance test was conducted on the total head and pump efficiency of a submersible pump for drainage with a diameter of 1350A, and the results are shown in Figure 4. When the discharge flow rate of the submersible pump was 127.16 m3/min, the total head was 4.36m. When the discharge flow rate was 132.55 m³/min, the total head was 4.09m. When the discharge flow rates were 138.01 m³/min and 143.36 m³/min, the total heads were 3.9m and 3.53m, respectively. At a discharge flow rate of 149.84 m³/min, the total head was 2.86m.Overall, as the discharge flow rate

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increased, the total head tended to decrease. This is because the more fluid that needs to be transported, the less total head can be produced at the same rotational speed.

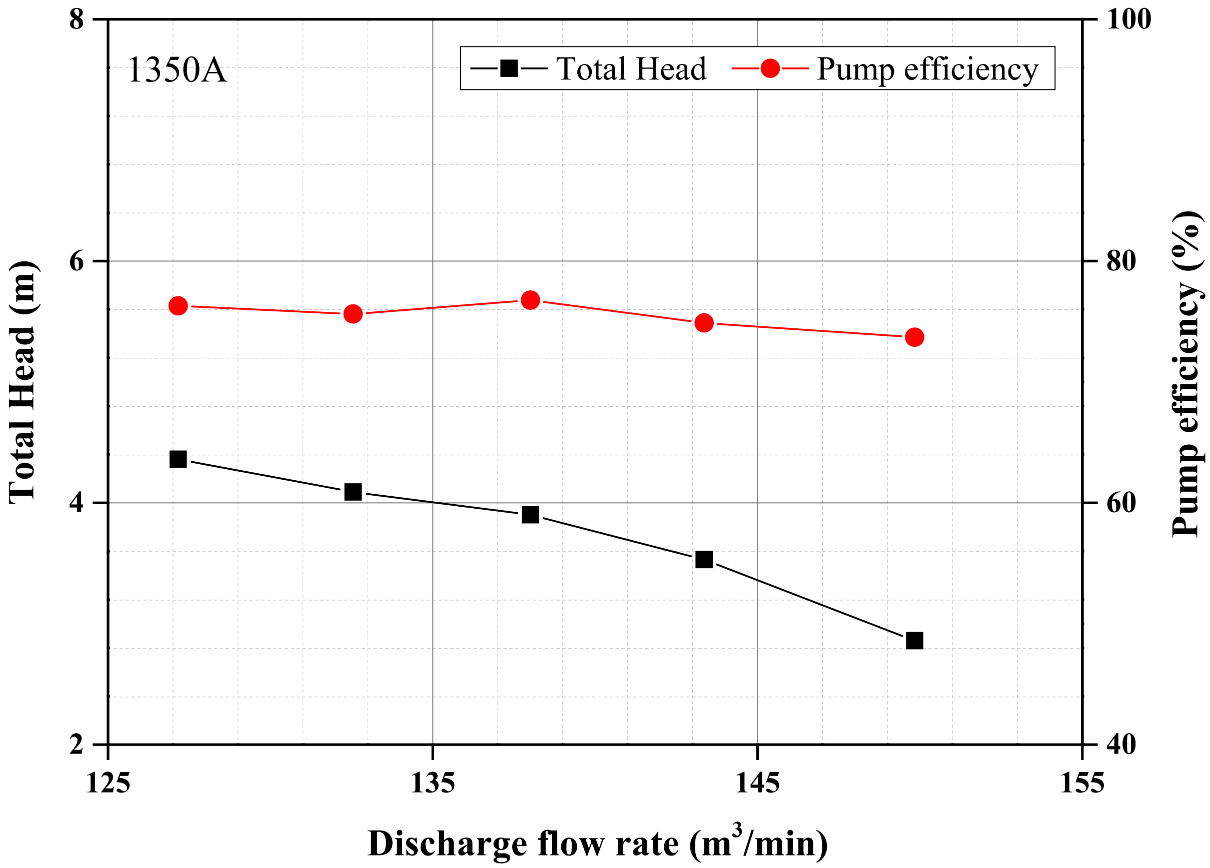

Figure 4. Performance test results for total head and pump efficiency of 1350A submersible pump**.**

The pump efficiency of a submersible pump with the diameter of 1350A according to various discharge flow rates was analyzed. As shown in Figure 4, when the discharge flow rate of the submersible pump was 127.16 m^3/min, the pump efficiency was 76.29%. At the discharge flow rate of the 132.55 m^3/min, the pump efficiency was 75.62%. When the discharge flow rates were 138.01 m^3/min and 143.36 m^3/min, the pump efficiencies were 76.77% and 74.87%, respectively. In the discharge flow rate of 149.84 m^3/min, the pump efficiency was 73.7%.

In this study, an experiment was conducted on the input power and the overall efficiency of a submersible pump with a diameter of 1350A as the various discharge flow rates. Figure 5 are shwon the experimental results fore the input power. When the discharge flow rate of the submersible pump motor room drainage function was 127.16 m^3/min, the input power was 129.49 kW. As the discharge flow rate was 132.55 m^3/min, the input power was 127.63 kW. When the discharge flow rates were 138.01 m^3/min and 143.36 m^3/min, the input powers were 124.99 kW and 120.41 kW, respectively. At a discharge flow rate of 149.84 m^3/min, the input power was 105.68 kW, and overall, as the discharge flow rate increased, the input power tended to decrease. The reason is that as the flow rate increases, the total head decreases and the discharge flow rate and input power value are inversely proportional.

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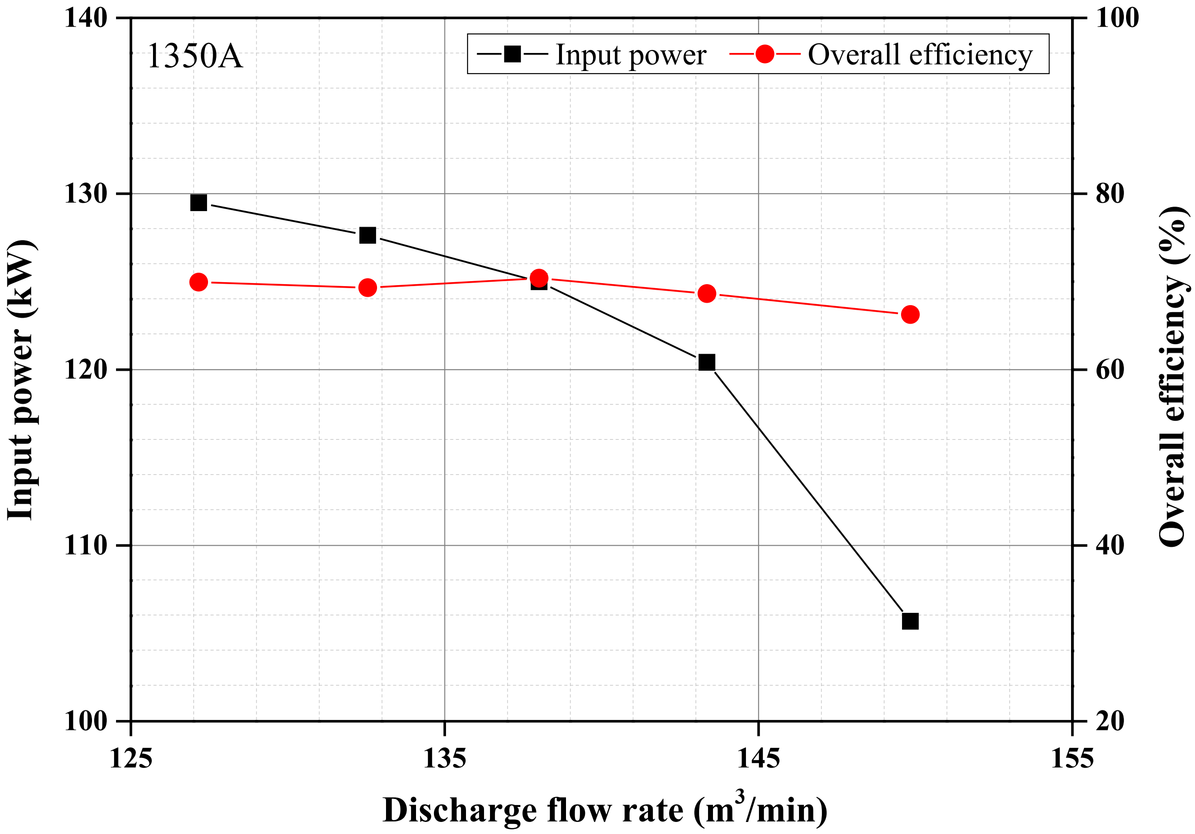

Figure 5. Performance test results for input power and oeverall efficiency of 1350A submersible pump.

The overall efficiency of a submersible pump according to various discharge flow rates was analyzed. As shown in Figure 5, when the discharge flow rate for the submersible pump drainage function was 127.16 m³/min, the overall efficiency of the pump was 69.95%, and at 132.55 m³/min, the overall efficiency was 69.32%. When the discharge flow rates were 138.01 m³/min and 143.36 m³/min, the overall efficiencies of the pump were 70.07% and 69.77%, respectively. At a discharge flow rate of 149.84 m³/min, the pump efficiency was 66.22%, and the overall efficiency of the submersible pump tended to decrease as the discharge flow rate increased.

4. Conclusion

In this study, a performance test of the large-diameters(400A and 1350A) submersible pump for drainage to prevent flooding was performed, and an experimental study on the performance characteristics of the submersible pump under various flow conditions was conducted. As a result, the following conclusions were arrived at:

The total head of a submersible pump with a diameter of 400A decreased by about 36.28% from 5.43 m to 3.46 m as the discharge flow increased from 17.26 m³/min to 20.55 m³/min, and the pump efficiency decreased by approximately 7.81% from 83.48% to 76.93%. As the discharge flow increased, the input power decreased by 17.55% from 21.31 kW to 17.57 kW, and the overall efficiency decreased by about 7.81% from 71.83% to 66.22%. The increase in discharge flow reduced the total head, which in turn reduced the power consumption of the submersible pump motor. As a result, the pump efficiency and overall efficiency decreased.

The total head of a submersible pump with a diameter of 1350A decreased by about 34.4% from 4.36 m to 2.86 m as the discharge flow increased from 127.16 m³/min to 149.84 m³/min, and the pump efficiency decreased by about 3.39% from 76.29% to 73.7%. As the discharge flow increased, the input power decreased by 18.37% from 129.47 kW to 105.68 kW, and the overall efficiency decreased by approximately 5.28% from 69.95% to 66.26%. It is important to determine the diameter of the submersible pump with the discharge flow rate. As the diameter increased, the input power of the submersible pump was consumed more, and the total head, pump efficiency, and overall efficiency were lower.

Acknowledgments: This study was conducted with the support of the regional demand-tailored research and development project of Jeollanam-do and JEONNAM TECHNOPARK in 2022.

Nomenclature

L	Pump shaft power, kW
L_{gr}	Input power, kW
g	gravitational acceleration, 9.8 m/s^2
H	Total head, m
Q	Discharge flow rate, m^3/min
Greek symbols	
η	Pump efficiency, %
η_{gr}	Overall efficiency, %
ρ	Density of liquid, kg/m^3

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