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Justification of Design Parameters for Efficient Operation of Submersible Pumps to Support Sustainable Development Goals (SDGs)

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ABSTRACT

This study seeks to justify design parameters that enhance the efficient operation of submersible pumps in support of Sustainable Development Goals (SDGs), especially SDG number 6, 7, and 9. Laboratory experiments and flow-path modeling were combined to assess water quality, suspended solids, and energy loss in pipelines. Pump performance under varying conditions was evaluated, including wear impacts on seals and thrust bearings, using vibration diagnostics. Bypass regulation improved efficiency and reduced required head, while valve throttling increased energy loss and caused overheating at low flow. Friction loss rose due to pipe scaling and corrosion. The study shows that performance degradation occurs because of mismatches between hydraulic resistance and impeller load, and insufficient cooling under sediment-rich conditions. The findings offer guidelines for intelligent pump control and predictive maintenance. These improvements are crucial for optimizing water resource infrastructure, reducing energy consumption, and ensuring sustainable irrigation and drainage in line with global development goals.

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1. INTRODUCTION

Submersible pumps are integral components in irrigation and water supply systems, but are known for their high energy consumption, with estimates indicating they account for a significant portion of global electricity use, up to nearly one-fifth [1, 2]. Many reports regarding the pump have been well-documented [3-7]. Improving the operational efficiency of these systems is essential, especially given the increasing demand for sustainable resource management in agriculture and water infrastructure. The performance of submersible pumps is closely tied to flow rate, pressure head, and rotation speed, which are influenced by both mechanical design and environmental conditions.

Previous studies have shown considerable variability in energy consumption across pump types and usage contexts. Energy output/input ratios between 1.6 and 1.8, and energy intensities of 0.7 to 0.8 MJ/kg in agricultural operations have been reported [8]. These figures reflect the critical need to reduce inefficiencies caused by outdated designs, oversized motors, and poor regulation methods. Technological advancements such as frequency inverters and multistage impeller systems have demonstrated potential in boosting pump performance and reducing operational costs [9, 10]. Moreover, predictive models have been developed to estimate energy demand based on flow, dynamic head, and motor power [11, 12].

Nonetheless, empirical studies continue to reveal significant performance degradation due to wear in thrust bearings, impeller seal gaps, and hydraulic friction losses in pipelines. Submersible well pumps, in particular, face challenges related to sedimentation, mineral scaling, and quasi-static loading conditions with frequent starts. These issues contribute to reduced flow rates, increased power draw, overheating, and eventual failure. The modernization of these systems, especially those with high specific cost per kilowatt, is essential to extending service life and improving energy efficiency [13, 14].

This study aims to justify critical design parameters for submersible pumps by integrating diagnostic monitoring, modeling of hydraulic resistance, and empirical evaluation of component wear. The novelty lies in correlating diagnostic signals (such as vibration, temperature, and pressure) with mechanical degradation in seals and bearings. These findings are expected to inform smarter operational strategies and maintenance schedules. Ultimately, the research contributes to broader development goals by supporting efficient water infrastructure and energy conservation, aligning with Sustainable Development Goals (SDGs), especially SDG 6 (Clean Water), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation, and Infrastructure).

2. METHODS

Figure 1 shows the experimental setup used to evaluate the performance characteristics of submersible pumps under various flow and pressure conditions. This setup included a borehole pump, a control station with a pressure regulator, and sensors for measuring pressure, temperature, and electrical parameters.

These components enabled a controlled analysis of how changes in operating conditions influence pump efficiency, wear, and hydraulic resistance. When performing the work, methods of hydraulic research of the flow structure in pump units were used based on refinement in the process of a simulation study of hydraulic processes corresponding to various operating modes. The reliability of the data obtained during theoretical studies was proven by mathematical methods of checking the adequacy of the results of experiments and

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field studies during the operation of pumps. When performing the work, methods were used to determine the quality of pumped water with a set of n-parameters: concentration of suspended particles, floating bodies, chemical properties, density, and temperature. Knowing these parameters enables the construction of a nomogram using the quadratic interpolation method to assess the flow turbidity and saturation with fine materials.

The method for substantiating the optimal parameters of flow paths under conditions of uncertainty in the initial information includes several stages: selection of possible variations of input values, grouping of uncertain parameters for joint optimization, and determination of solution zones that remain economical within bounded input values. The study employed modeling methods to calculate pressure fields in the impeller at each pump stage and included both full-scale and laboratory tests of borehole pumps under real-world operating conditions [15, 16].

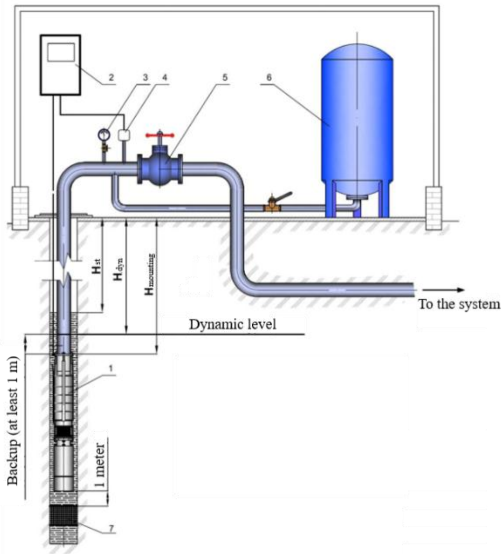

Figure 1. Diagram of the experimental installation of a submersible pump. Note: 1 - Borehole pump; 2 - Control station with pressure regulator; 3- Multimeter; 4- Pressure switch; 5 - Gate valve; 6 - Hydraulic accumulator; 7 - Well filter.

Figure 2 illustrates the performance characteristics of the ECV 6-10-80 pump under varying flow conditions, showing changes in pressure and system response. This experiment was essential for evaluating hydraulic losses and the impact of modernized components.

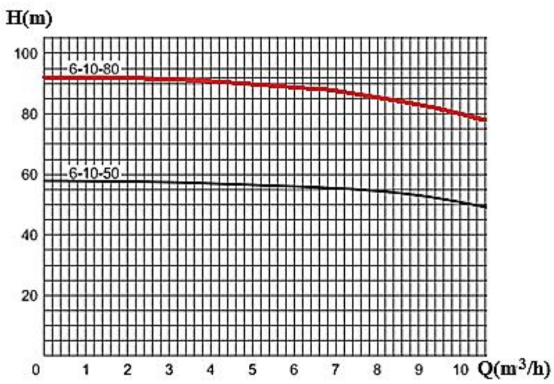

Figure 2. Results of an experiment on the characteristics of a system with a modernized pump ECV 6-10-80.

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Analytical models were also applied to estimate energy loss due to pipeline friction and local resistances. These losses were calculated based on pipeline material roughness, operational wear, and changes in the inner surface condition due to corrosion and mineral scaling. To study the degradation of pump components, controlled wear was introduced into thrust bearings and impeller seals using naturally worn or machined parts. Diagnostic parameters such as pressure, vibration, temperature, and flow were measured at two wear levels (normal and maximum).

All measurements were performed using standard devices such as pressure gauges (class 0.4), IR 51 flow indicators (class I), and the K505 meter integrated into the electric circuit. Temperature was controlled with thermal resistors, and each test condition was repeated to ensure accuracy. The analysis included statistical validation of the observed trends in performance degradation across various submersible pump models.

3. RESULTS AND DISCUSSION

Figure 3 presents the characteristics of submersible pumps under varied flow rates. The experimental data showed that regulating pump flow using a valve often led to unnecessary hydraulic power losses. When the flow was increased beyond the design point, the pump pressure dropped significantly, and when it was reduced, the electric motor experienced overheating, bearing lubrication failure, and reduced overall efficiency.

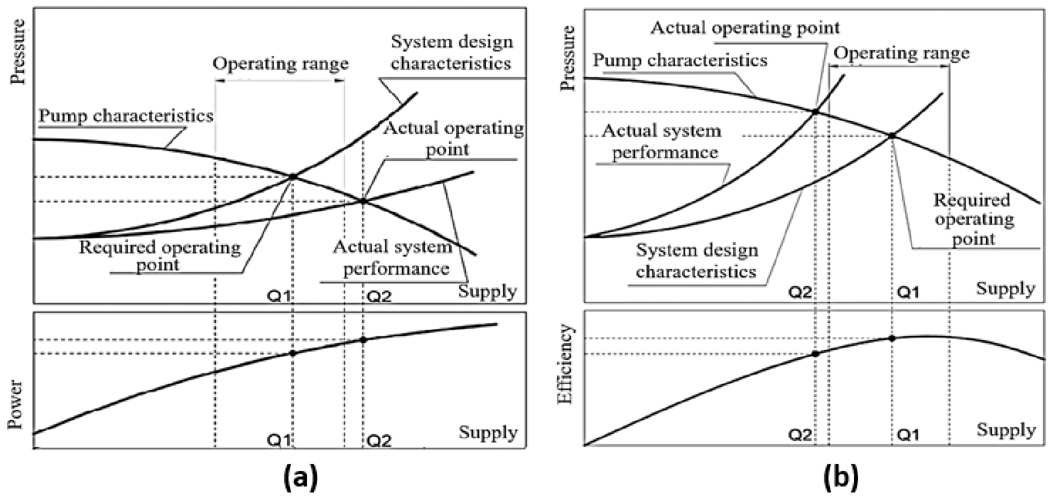

Figure 3. Pump characteristics at increased flow (a) and reduced flow (b).

The analysis of well management for the successful operation of submersible pumps revealed the complexity of modern engineering systems with the need to timely anticipate, diagnose, and control abnormal events and measures to mitigate their consequences. It is necessary to develop intelligent automation systems for assessing and optimizing the parameters of submersible pump systems.

A multi-stage submersible centrifugal pump converts kinetic energy into hydrodynamic pressure necessary to lift water at higher speeds at lower pressures. However, several factors and problems can make it difficult to operate wells to optimize their parameters by increasing efficiency and reducing losses. The objective function should include the main factors associated with the characteristics of the pumped water and pump parameters. Water inflow

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and outflow parameters include well configuration, pressure, temperature, and flow properties [17].

Based on the flow field calculation method and loss model, the performance prediction of the mixed flow pump impeller and the performance curves of the variable blade mixed flow pump model are achieved. Compared with the test data, the mixed flow pump loss model based on iterative calculation can quickly and accurately predict the impeller performance, which is of great significance for engineering applications [18, 19].

Reducing siltation of the inlet chamber is necessary, since deposited sediments seriously disrupt the hydraulic structure of the flow when water is sucked in by pumps, as a result of which their efficiency decreases. To reduce siltation of a well by artificially creating turbulence in the water flow in the bottom layer, the theory of submerged water jets was used to determine their main characteristics. Most existing methods for estimating the operating pressure of pumps under conditions of viscous fluid flow are of an empirical nature by correlating experimental data with correction factors. A new model is proposed that takes into account the influence of the viscosity of working fluids on the hydraulic heads of pumps, which is confirmed using a database collected from various types of submersible pumps [20, 21].

When changing the operating mode of a submersible pump depending on changes in the water level in the well, achieved by changing the rotation speed of the pump and, consequently, its flow, the condition of the submersible equipment may deteriorate. This is explained by the influence of sediment deposition on the working parts, their clogging, silting, and abrasive wear due to the impact of solid particles moved with water, as well as the sticking of the working parts on the supporting surfaces of the pump. Moreover, submersible pumps often operate in a quasi-static load mode with a relatively short-term well development and numerous starts, the number and frequency of which change during operation [22, 23].

The initial data accepted in further calculations of the electricity of borehole pumping units include the static water level in the well, the characteristics of the well according to the relationship S = f (Q) between the dynamic decrease in the water level in the well S and the flow rate Q. The values of the operational parameters of the dynamic decrease in Sex and flow rate Qex, the elevation of the wellhead and the center of the outlet of the outlet pipeline, and the water supply mode are taken into account.

We carried out field and laboratory studies of borehole pumping units [24]. The results of experiments carried out at JSC "SUVMASH" confirmed the influence of hydraulic pressure on the useful power of the pump (equation (1)):

$$P = Q \times \rho \times g \times H \times \ W$$

Where Q is the volumetric flow rate of liquid (m³/s); g is gravitational acceleration (m/s²); ρ is the density of the pumped liquid (kg/m³); and H is the pump head (m). The required pressure was determined by research on an experimental installation of a submersible pump. Pump efficiency η\eta is calculated based on the ratio of useful power (*P*) to the rated power (*Py*) of the selected hydraulic unit (equation (2)):

$$\eta = P/P_N \quad (2)$$

The use of bypass pressure makes it possible to reduce the required pump pressure with an increase in efficiency by 15–20% and reduce energy consumption when placing the pump station on the lower horizon. The individual rate of electricity consumption (H_n) is determined by the equation (3):

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$$H_n = \frac{2\times72\times H}{\eta_N} \times \frac{kW,h}{thousand\ m^3} \qquad (3)$$

Where η_N is the efficiency of the electric pump at the operational flow rate of the well, with a change in the efficiency of the pump during operation. Energy losses in the pressure pipeline occur as the fluid overcomes hydraulic resistance along the pipe's length and through local resistances (equation (4)):

$$h_w = \mathrm{K} \cdot h_w^e + h_w^M \text{, m} \qquad (4)$$

Where h_w is the amount of energy loss in the pressure pipeline; $h^e{}_w$ is the amount of energy loss due to friction in the first year of pipeline operation; K is a coefficient representing changes in roughness over time; $h^M{}_w$ is the energy loss in local resistances.

During long-term operation, corrosion, mineral scaling, and sedimentation increase the internal roughness of pressure pipelines, thereby increasing friction losses. These changes can significantly reduce overall pump efficiency, especially in systems with extended pipeline lengths. Our studies show that the formation of deposits is influenced by the chemical composition of water, pipe material, and flow dynamics.

The studies were carried out on pumping units with pumps ETsV 10-160-35 and ETsV12-255-30G with a submersible electric motor 6PEDV32-230. These pumps are suitable for lifting water with a temperature not exceeding 25°C and with a mechanical impurity content of not more than 0.05% by weight and mineralization below 25 g/l. During initial start-up, a higher sand content (up to 0.1% by weight) was tolerated for a limited period.

Figure 4 is presented to illustrate the dependencies between pressure, power, and efficiency as a function of seal clearance in the ECV 10-160-35 submersible pump. This diagnostic analysis allowed for a visual evaluation of how mechanical wear in impeller seals leads to significant performance degradation.

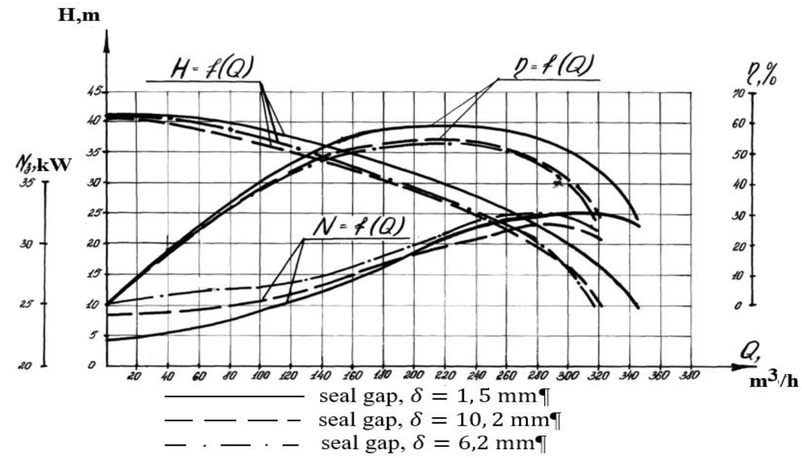

Figure 4. Dependencies between the functions of pressure, power, and efficiency, and clearances in seals (Q).

Currently, vertical drainage systems with submersible pumps are being modernized in Uzbekistan. The structural parameters of the technical condition of a submersible pump can be divided into basic ones, the change of which within the limits of values determined by technological and operational factors has a significant impact on the output characteristics and reliability indicators of the unit, and additional ones, the value of which, within the specified limits, has a slight effect on its performance. The question of which class should be

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assigned to certain parameters was decided on the basis of an analysis of the relationship between them and the performance criteria of the pumps.

The variable factors during the implementation of the experiments were the gaps in the radial bearings of the ECV 10-120-60 submersible pump and the power parts of the unit, wear of the thrust bearing, and the impeller. Their change was carried out by installing corresponding parts with natural (removed from failed electric pumps) or artificial (after machining) wear of the working surfaces into experimental pumps of the ETsV 12-255-30 G and ETsV 10-120-60 brands.

The performance criteria of the unit (flow, efficiency, temperature in the cavity of the electric motor) were determined from the readings of the corresponding instruments and calculated using the given formulas. During the experiments, the temperature of the pumped liquid was maintained at 20±1°C and controlled by a thermal resistance installed in the suction zone of the pumps. The pump pressure was measured with standard pressure gauges of class 0.4.

The pump flow was measured by primary induction transducers installed in pressure pipelines with limits of 0 to 200 m^3/h and determined by indicating instruments IR 51 of accuracy class I installed on the control station panel. The current characteristics of the pumps under study were determined according to the readings of the K505 measuring device built into the power circuit of the electric pump. All measurements were performed twice, at certain time intervals, and then the data were averaged.

During the experiments, each parameter was varied at two levels, corresponding to its values during normal running-in during 20 hours of operation of the unit and maximum wear, determined based on the results of controlled operation of the electric pumps. Based on these experiments, the dependences of the operating characteristics of electric pumps on the SP values were obtained. Their analysis showed that the least impact of the specified parameters on the performance of electric pumps is exerted by the clearances in the radial bearings of the pumps. This is explained by the fact that when the bearing surfaces wear out, their function can be performed by other elements (floating seals, spacers). The influence of gaps in radial bearings of electric motors is more significant; if they exceed the gap between the rotor and stator, it leads to failure of the stator winding insulation.

The rear seals of the impellers of the ECV 10-120-60 pumps serve mainly to unload the unit from axial force, which significantly affects the performance of the unit when operating in a high-pressure area. The main purpose of the front seals of the impellers is to prevent the flow of pumped liquid from the pressure to the suction area. As the gaps in them increase, the volume of water circulating in the pump increases and, accordingly, its flow and efficiency decrease. Analysis of the characteristics showed that when the gaps in the specified seals change from nominal to maximum values, the flow and efficiency of the units at nominal pressures decrease by more than 50% for ECV 10-120-60 and by about 25% for ECV 12-255-30 G, which is a parametric failure.

Wear of the elements of the thrust bearing of a submersible pump and the thrust bearing leads to deterioration of the lubrication conditions of their rubbing surfaces, which contributes to an increase in mechanical losses, resulting in a decrease in efficiency. The temperature in the cavity of its electric motor increases. Experimental data showed that when the total wear of the heel and thrust bearing changed from 0.2 (running wear) to 4 mm, the efficiency of the unit decreased by about 30% in the working area, while its feed changed slightly, only in the high-pressure zone. At the same time, the temperature increased in the thrust bearing housing by 40–50°C, in the stator winding by 30–40°C. At the same time, the wear rate increased significantly. A thrust bearing with wear of 4 mm was built into the

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experimental pump, and after operating for 20 hours under various conditions, it had worn to 9 mm. Thus, wear of the thrust bearing elements leads to first parametric and then functional failure of the unit.

Experimental studies of the selected main components varied at several levels, which made it possible to determine the dependence of the operating characteristics of the pumps on them under various operating modes. For pump elements, diagnostic parameters (DP) were used as a response function. They included: feed, load current, pressure, rotor speed, temperature, and vibration characteristics. Analysis of the experimental results showed that changing the gaps in the impeller seals led to unambiguous changes in the pressure characteristics of the pumps. In this case, the unit pressure with the valve fully closed was taken as a diagnostic parameter. Based on experimental data, relationships were obtained between changes in pressure, power, and efficiency and gaps in seals.

The selected diagnostic parameter was conditional, where subsequent checks depended on the results of previous ones. If the diagnostic parameters had unacceptable values, the diagnosis was stopped, and routine repairs of the unit were scheduled. If the limit value is exceeded, there is no need to evaluate the diagnostic parameters during the thrust bearing restoration process. The use of the described diagnostic technique made it possible to prevent a significant part of functional (more than 70%) and almost all parametric failures [25]. As additional data is accumulated on the factors that determine the performance of reclamation pumps and on the processes occurring in them during operation, in order to increase the efficiency of their diagnosis, it is advisable to clarify the accepted wear, structural, and diagnostic models.

Continued experimental studies confirmed that each worn component contributes uniquely to pump degradation. Among them, thrust bearing wear had the most critical impact, not only reducing efficiency but also accelerating damage to the stator and increasing internal temperature. The diagnostic system proposed in this study, which monitors multiple technical parameters, allows for early intervention before irreversible damage occurs. Such preventative maintenance frameworks can significantly extend the service life of submersible pumps in irrigation systems.

In practice, using diagnostic thresholds for seal clearance and thrust bearing wear helps operators identify parametric failures before they become functional failures. This not only minimizes downtime but also reduces energy waste by ensuring the pump operates within its optimal range. As found in these experiments, exceeding the limit value in any one component often leads to a chain reaction of wear and energy inefficiency across the system.

Moreover, the results demonstrate that smart monitoring systems can replace reactive repair models with predictive diagnostics. By evaluating flow, pressure, temperature, and vibration as interconnected signals, it is possible to develop a real-time performance monitoring system. This approach aligns with the broader goal of smart water management and supports decision-making in both rural and industrial-scale irrigation projects.

From the perspective of sustainable development, these findings contribute directly to SDG 6 by ensuring more reliable access to clean water through improved pump infrastructure. By reducing energy loss and optimizing pump operation, the work also advances SDG 7, promoting energy efficiency and sustainability. Additionally, the implementation of diagnostic systems and performance-based design modernization reflects innovation in water infrastructure, supporting SDG 9 through the enhancement of industry and resilient technologies. Finally, this study adds new information regarding SDGs, as reported elsewhere (**Table 1**).

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Table 1. Previous studies on SDGs.

No	Title	Ref
1	Dataset on the number of schools, teachers, and students in Sulawesi, Indonesia	[26]
2	A bibliometric insight into materials research trends and innovation	[27]
3	Techno-economic analysis of sawdust-based trash cans	[28]
4	Education on diversification of food using infographic	[29]
5	Sustainable packaging: Bioplastics as a low-carbon future step	[30]
6	Enhancing innovative thinking through a theory-based instructional model	[31]
7	Environmentally friendly packaging and zero waste interest	[32]
8	HIRADC for workplace safety in manufacturing	[33]
9	Enhancing job satisfaction through HRIS and communication	[34]
10	Analysis of student's awareness of sustainable diet	[35]
11	Professional readiness in vocational education	[36]
12	Smart learning as transformative impact of technology	[37]
13	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	[38]
14	Optimizing lemon commodities and community empowerment	[39]
15	Integrating generative AI-based multimodal learning	[40]
16	Application of Mediterranean diet patterns on sustainability	[41]
17	Definition and role of sustainable materials	[42]
18	Safe food treatment technology	[43]
19	Wet organic waste ecoenzymes for environmental conservation	[44]
20	Techno-economic analysis of production ecobrick	[45]
21	Self-efficacy on affective learning outcomes	[46]
22	School feeding program and SDGs in education	[47]
23	Physical adaptation of college students in high-altitude training	[48]
24	Enhancing occupational identity and self-efficacy	[49]

4. CONCLUSION

This study justified critical design parameters that significantly affect the efficiency and operational reliability of submersible pumps. The experimental findings demonstrated that seal clearance, thrust bearing wear, and pipeline roughness are the main contributors to reduced performance. Diagnostic techniques based on vibration, temperature, and pressure readings enabled the early detection of both parametric and functional failures.

Modernization of vertical drainage systems using real-time diagnostics and performance modeling has been shown to enhance pump efficiency by 15–20% and reduce energy consumption. Moreover, empirical data confirmed that predictive maintenance strategies are more effective than reactive repair approaches in prolonging pump lifespan.

These improvements directly support Sustainable Development Goals, particularly SDG 6 (Clean Water) by improving water delivery systems, SDG 7 (Affordable and Clean Energy) by reducing power loss in irrigation infrastructure, and SDG 9 (Industry, Innovation, and Infrastructure) through the application of intelligent control technologies to pump systems.The experimental results demonstrate the significant enhancement in freshwater productivity and efficiency achieved by the MSS compared to the CSS. The incorporation of modifications, likely involving nanofluids, led to consistently higher outer and inner glass

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temperatures, indicating improved solar energy absorption and heat retention within the MSS. Consequently, the water temperature in the MSS reached a peak of approximately 73°C, notably higher than the 65°C peak observed in the CSS. This resulted in a substantially greater accumulated freshwater yield of around 1050 mL for the MSS by the end of the day, representing an approximate 66.67% improvement over the CSS, which produced about 630 mL. Furthermore, the peak energy conversion efficiency of the MSS reached approximately 57%, significantly outperforming the CSS peak efficiency of around 32%, with an estimated average efficiency improvement of about 85.7%. These findings underscore the effectiveness of the implemented modifications in the MSS for enhancing solar distillation performance under the specific environmental conditions of the study.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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