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Modeling the Performance and Frictional Head Losses of the Control Oil Pump at Derna Steam Power Plant

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Abstract:
The objective of this research is to analyze the power and efficiency of the control oil pump (COP) at the Derna steam power plant, focusing on calculating frictional head losses (Hf), volumetric flow rate, and mass flow rate within the pipeline system. The evaluation is based on a computational model and empirical correlations to support performance monitoring and propose maintenance strategies to mitigate degradation caused by aging and operational challenges. Pumping Power Calculator V3.0 and Rotor Zone – Pump Size were employed to simulate hydraulic shaft, and motor power, enabling an assessment of efficiency and performance curves. frictional head losses were calculated using the Darcy–Weisbach (D-W) equation, and the corresponding head loss percentage (Lf %) was determined. Results show that hydraulic power was limited (0.33 KW for mass flow, 0.29 KW for volumetric flow, Hf = 0.8 m, Lf = 0.2%), while mechanical efficiency ( ) remained stable at 78%, indicating effective energy transfer despite low hydraulic performance. The results highlight the significance of optimizing hydraulic pathways and implementing predictive maintenance for the sustainable pump operation of pump..

Keywords: Control Oil Pump, Hydraulic Efficiency, Mechanical Efficiency, Darcy–Weisbach Equation, Frictional Head Losses.

نمذجة أداء وفواقد الاحتكاك الهيدروليكية لمضخة زيت التحكم في محطة درنة البخارية لتوليد الطاقة2024

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الملخص
يهدف هذا البحث إلى تحليل قدرة وكفاءة مضخة التحكم بالزيت (COP) في المحطة البخارية بمدينة درنه، مع التركيز علي حساب فواقد الرفع الاحتكاكية (Hf) ومعدل التدفق الحجمي والكتلي ضمن شبكة الأنابيب. ويعتمد التحليل على نموذج حاسوبي مدعوم بعلاقات تجريبية، بهدف دعم مراقبة الأداء والتنبيه لاستخدام استراتيجيات صيانة تحدَ من التدهور الناتج عن التقادم والتحديات التشغيلية. تم الاعتماد علي برمجيات Pumping Power Calculator V3.0 و Rotor Zone – Pump Size لمحاكاة القدرة الهيدروليكية وقدرة العمود والمحرك، الأمر الذي أتاح تقييم الكفاءة واستخراج منحنيات الأداء. كما جري تقدير فقدان الرأس الاحتكاكي باستخدام معادلة دارسي – وايزباخ (D-W)، وتم تحديد نسبة مفاقيد الاحتكاك (%Lf). أظهرت النتائج أن القدرة الهيدروليكية محدودة؛إذ بلغت (0.33 كيلو وات للتدفق الكتلي، 0.29 كيلو وات للتدفق الحجمي، مفاقيد الاحتكاك = 0.8 متر ، وبنسبة خسائر احتكاكية محدودة تعادل 0.2%). في المقابل، ظلت الكفاءة الميكانيكية ( ) مستقرة عند 78%، مما يعكس أن نقل الطاقة فعال رغم انخفاض الأداء الهيدروليكي. تؤكد هذه النتائج على جدوى تحسين المسارات الهيدروليكية وتطبيق الصيانة التنبؤية لضمان تشغيل مستدام وفعّال للمضخة.

الكلمات المفتاحية: مضخة التحكم بالزيت، الكفاءة الهيدروليكية، الكفاءة الميكانيكية، معادلة دارسي –وايزباخ، فقدان الرأس الاحتكاكي.

Introduction

Pumps, with their various types and operational mechanisms, are a fundamental element in mechanical and energy engineering systems. They play an essential role across residential, agricultural, industrial, and power generation applications by enabling fluid transport, distribution, and thermal management, in addition to supporting cooling and desalination systems. Their performance is especially critical to the efficiency of energy production facilities such as thermal power plants and desalination units. Therefore, the operational reliability, energy efficiency, and overall performance of pumps are crucial factors in the design and enhancement of modern fluid and energy systems. As the second most commonly utilized machines after electric motors, pumps are indispensable for moving fluids between different elevations and delivering them at precise flow rates and pressures. Their operation involves increasing hydraulic energy by transforming electrical energy into kinetic and pressure energy transferred to the fluid as it exits the impeller. This process aligns with Bernoulli's principle, which describes the conversion of fluid velocity into pressure energy within the volute casing and at the outlet. The resulting reduction in velocity and increase in pressure are directly linked to the gradual change in volumetric flow as fluid exits the impeller. In steam power plants, pump efficiency significantly influences overall plant performance. At the Derna steam power plant, operational since 1985 to supply electricity and desalinated water, screw pumps play a vital role in system performance. Investigations into these pumps aim to identify efficiency improvement opportunities and support long-term sustainability (General Electricity Company of Libya [GECOL], 2002). Complementary maintenance efforts at Derna and Al-Bamba power plants seek to boost production capacity (Libya Alaan, 2016), while planned emergency maintenance at North Benghazi Power Plant is projected to cause a two-day outage with a power shortfall of 260–300 MW (Libya Al Mostakbal, 2016).

Understanding Hf and pump-induced stresses is critical for water flow management and pipeline design, where hydraulic efficiency depends on precise design and manufacturing to minimize friction losses and maintain optimal performance. AQUATIM S.A. developed an application-unit programming system tested at the Hydraulic Machinery Laboratory of the Polytechnic University of Timisoara. This system utilizes experimental data on hydraulic and mechanical pump power alongside total head to assess performance and support predictive maintenance (Aline et al., 2022).

In India, reliance on CPHEEO guidelines for pipeline friction loss calculation has been challenged by direct calculations based on flow velocity and discharge, which offer improved accuracy (Pallepati, 2014). Similarly, an energy and exergy analysis of the Derna plant identified major loss areas and assessed component-level efficiency through engineering software, guiding improvement strategies (Adel et al., 2022). Bosch Rexroth (2014) emphasized the hydraulic oil supply system's pressure maintenance for control pumps in turbines, underscoring its role in system stability and reliability. The importance of the Control Oil Pump *COP* for enhancing plant efficiency and dynamic load response was also highlighted by Suryanarayana et al. (2018). Comparative evaluations of head loss methods further contribute to pipeline design knowledge. Jamil (2019) compared Hazen-Williams and Darcy-Weisbach equations for vertical head loss, while Gebremedhin and Tsegay (2018) applied Colebrook-White, Darcy-Weisbach, and Hazen-Williams methods to pipeline pressure losses in Eritrea, determining the most effective model through multiple explicit formulations. Importantly, Zherdev et al. (2021) underscored the necessity of systematic performance evaluation and enhanced filtration to restore oil purity and ensure stable operation of the T-180/210 LMZ steam turbine's oil supply pump. Their study highlighted continuous monitoring of oil flow and cleanliness as essential for protecting control systems and maintaining turbine reliability. Despite these contributions, research utilizing programming and the D-W equation to analyze the *COP* performance and Hf in the Derna power plant's pipeline network remains limited, underscoring the necessity for further in-depth investigation. In response to these challenges, this study aims to address operational and stakeholder concerns by promoting sustainable pump performance and energy efficiency through systematic, continuous monitoring. With increasing integration of digital technologies, practitioners seek cost-effective solutions ranging from complete system replacements to targeted maintenance interventions. Acknowledging the pump's essential role in fluid transfer and system stability, this work proposes a comprehensive framework for monitoring hydraulic, motor, and shaft power to enhance operational performance.

2. Methodology

In this study, a comprehensive numerical modeling approach, supported by advanced mathematical formulations, was employed to analyse the power output, overall efficiency, and Hf of the *COP* at the Derna steam power plant. Operational data were meticulously collected under steady-state conditions to ensure the highest level of accuracy and reliability, accompanied by continuous monitoring of the pump's dynamic performance characteristics. Additionally, critical physical constants, such as gravitational acceleration and the specific density of the oil utilized, were incorporated to enhance the precision and credibility of the computed parameters.

The key performance indicators were systematically derived using a robust and well-structured multi-stage methodology specifically designed to minimize uncertainties and strengthen the validity of the results. This integrated analytical framework not only enabled a detailed evaluation of the pump's operational behavior but also provided a solid foundation for future optimisation and predictive maintenance strategies.

2.1 Power Plant Description

Figure 1 below presents the schematic configuration of a single generation unit at the Derna power plant, including the *COP*.

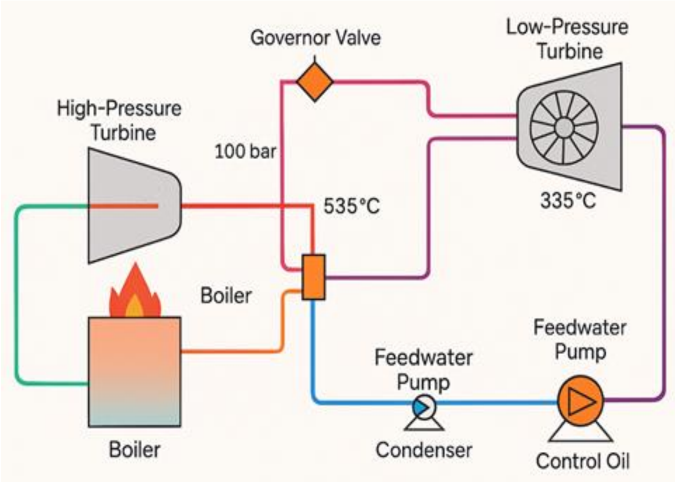

Figure 1. Derna power plant, including the *COP*.

In the schematic presented above, the critical thermal and pressure parameters influencing the performance of the turbine cycle are illustrated. The operating pressure at the high-pressure turbine inlet is 100 bar, with a steam temperature of 535°C, reflecting the elevated thermal energy input to the turbine. After passing through the high-pressure turbine, the steam proceeds to the low-pressure turbine at a reduced temperature of 335°C, indicating a decline in thermal energy while continuing to harness steam for power generation. These values represent the fundamental pressure and temperature levels that govern the thermal efficiency of the power plant cycle, underscoring the significance of precise control over these variables to ensure optimal operation and thermal stability of the system components.

In the preliminary stage of this investigation, data were systematically collected from the *COP* throughout its operational period.

2.2 Background on *COP*

The *COP* examined in this study is a helical rotary pump that circulates oil to control the opening of the main steam valves as well as the turbine load control valves. This ensures rapid valve response and maintains operational stability by providing the necessary hydraulic pressure.

Throughout the study, the *COP's* performance and behavior under operational conditions were closely monitored to assess its efficiency and response characteristics. Figure 2 illustrates a view of the test rig.

Figure 2. View of test rig.

A comprehensive depiction of the *COP's* key operating parameters, which form the basis for the subsequent analysis, is provided in Table 1. In this context, the term Pump Head *(H)* is used to denote the Total Dynamic Head *(TDH)*. Prior to the analysis, the flow rate was properly converted and its units standardized to maintain dimensional consistency. The internal diameter of the pipeline was also converted from millimeters to meters to align with SI unit conventions. Furthermore, the pipeline, constructed from carbon steel, was treated as having dimensionless material properties for simplification purposes within the analytical framework.

Table 1. Operating Characteristics of the *COP*.

Operating characteristics & Unit	Symbol	Value
Flow rate (kg/h) (m^3/h) (m^3/s) (Lpm)	Q	 300 0.3 0.0000833 5
Nominal Shaft Power (KW)	$P_{shaft.nominal}$	32
Pump Head (m)	H	400
Pressure (bar)	P	40
Temperature (°C)	T	36
Pipe Internal diameter (m)	D	0.1
Internal Length of pipeline (m)	L	20
Pipe material (_)	CS	–
Gravitational acceleration (m/s^2)	g	10

2.3 The Calculations of Frictional Losses

Hf was calculated using the modern form of the D-W Equation (eq. 1) to ensure an accurate assessment of flow resistance within the carbon steel pipeline system. To achieve full dimensional consistency and enhance the reliability of the computations, the time component of the flow rate was converted to seconds. The fundamental variables incorporated into the equation—including fluid velocity, density, dynamic viscosity, friction factor, gravitational acceleration, and Reynolds number—are comprehensively summarized in Table 2. This methodological framework provides a precise quantitative estimation of Hf, which is a critical factor for evaluating the overall hydraulic performance and operational efficiency of the pump-pipeline system. The head loss was determined using the equation adopted from Munson et al. (2013):

$$Hf = f.\frac{L}{D}.\frac{v^2}{2g} \qquad (1)$$

To further quantify the impact of frictional losses relative to the total available head, the percentage of frictional head loss as (Lf %), was calculated using (eq. 2):

$$Lf\% = \frac{Hf}{H}\ x\ 100\% \qquad (2)$$

The percentage of frictional head loss Lf % is considered an effective indicator of the system's energy efficiency and provides valuable insight for guiding maintenance strategies and improving overall hydraulic performance, as detailed by Çengel and Cimbala (2014).

Table 2 includes several fundamental parameters and values considered during the analysis and calculation procedures. Specifically, (v) denotes the fluid velocity (Shell Turbo oil), (ρ) represents the fluid density (Shell, 2017), (μ) stands for the dynamic viscosity, (ƒ) refers to the Darcy friction factor, (g) indicates the gravitational acceleration, (Re) denotes the Reynolds number, and (ε) represents the absolute roughness. Moreover, the type of fluid and its operational function in the *COP* revealed specific values in the frictional loss analyses and fluid flow equations, indicating that the flow regime is turbulent. This turbulent behavior is attributed to the need for rapid control response and high operating pressures.

Table 2. Parameters Used in the D-W Equation and Hf.

Variable Description & Unit	Symbol
Frictional head loss (m)	Hf
Fluid velocity (m/s)	υ
Dynamic viscosity (Pa·s)	μ
Reynolds number (dimensionless)	Re
Darcy friction factor (dimensionless)	f
Absolute Roughness (mm)	ε
Fluid density (kg/m³)	ρ
The frictional head loss percentage (%)	Lf

2.4 Pump Motor Power and Efficiency Analysis

The pump motor input power (P_{in}) and shaft power (P_{shaft}) were simulated using the equations and software through modeling in *Rotor Zone.Pump Size* and *Pumping Power Calculator V3.0*, based on the characteristic parameters listed in Table 1. The Hydraulic power (P_{hyd}) was calculated using the classical (eq. 3):

$$P_{hyd=HQ\rho g} \quad (3)$$

Where the flow rate (Q) is expressed in cubic meters per second (Çengel & Cimbala, 2018), and the simulation also confirmed a matching hydraulic power (P_{hyd}). Furthermore, the Efficiencies were calculated using the standard relations:

$$\eta_{mech} = \frac{P_{shaft(nominal)}}{P_{in}} x\ 100\ \% \quad (4)$$

$$\eta_{hyd} = \frac{P_{hyd}}{P_{shaft}} x\ 100\ \% \quad (5)$$

$$\eta_{overall} = \frac{P_{hyd}}{P_{in}} x\ 100\ \% = \eta_{mech\ x}\ \eta_{hyd} \quad (6)$$

Where η_{mech}, η_{hyd} , and $\eta_{overall}$ denote the mechanical, hydraulic, and overall efficiencies, respectively, and all power values are expressed in KW.

These equations and the methodology for power evaluation follow the approaches described by Smith and Patel (2022), Nguyen (2021), and Zhang and Wang (2023).

3. Results and Discussion

This section presents a comprehensive evaluation of the pumping system performance at the Derna steam power plant. The analysis integrates numerical modeling (Equations 3 – 6) and simulations from both software packages. Key performance indicators include hydraulic and mechanical efficiencies, frictional losses, and pump power consumption.

3.1 Hydraulic and Mechanical Performance

Table 3 summarizes preliminary calculations based on pump characteristic parameters:

Table.3 Preliminary Pump Characteristic Parameters.

Parameters (Symbol) & Unit	Value
Hf (m)	0.8
υ (m/s)	2
ρ (kg/m³)	858
μ (Pa·s)	0.05
Re	3432

(dimensionless)	
ε (mm)	0.045
Lf (%)	0.2
f (dimensionless)	0.02

Results indicate that the pump operates with a η_{mech} of approximately 78%. P_{hyd}, determined using (Eq. 3), was found to be consistent, as also confirmed by the software, yielding 0.29 KW in the volumetric flow case.

The analysis revealed that the $\eta_{overall}$ is 7.73% for the mass-flow case and 7.90% for the volumetric-flow case. The absolute difference is 0.17 percentage points, corresponding to a relative increase of approximately 2.20% for the volumetric case. Despite this small discrepancy, both values are close to 8%, confirming that hydraulic losses—mainly due to internal friction and minor leakage—are the primary limiting factor, while the mechanical components operate with high efficiency.

It is worth noting that under turbulent flow conditions (*Re* = 3432), which involve high pressure levels and require rapid control responses, the relationship between *Re* and key hydraulic parameters was analyzed to provide a comprehensive understanding of flow behavior within the system. As shown in Figures 3 – 5, variations in *Re* directly influence Hf and frictional effects. The low value of $Lf\%$ indicates negligible frictional pressure loss, thereby allowing efficient conversion of mechanical power into hydraulic power. Figure 3 illustrates the variation of *Re* with Hf.

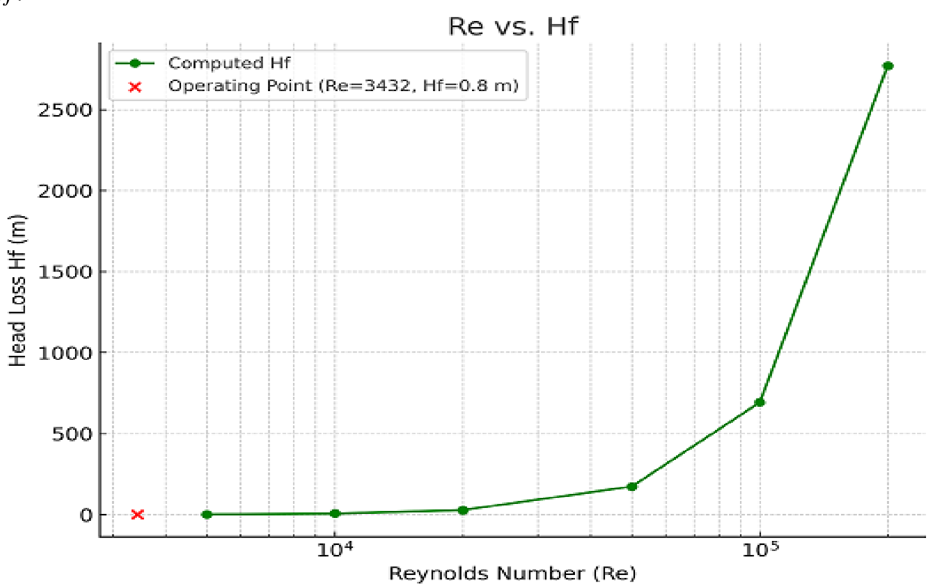

Figure 3. *Re* vs. Hf highlighting turbulent flow influence.

Furthermore, Figure 4 presents the correlation between *Re* and *Q*, highlighting the impact of flow velocity on turbulence, where the vertical axis represents the f and the horizontal axis corresponds to the *Re*. The curve illustrates the variation of f with changing flow conditions, emphasizing the transition from laminar to turbulent flow.

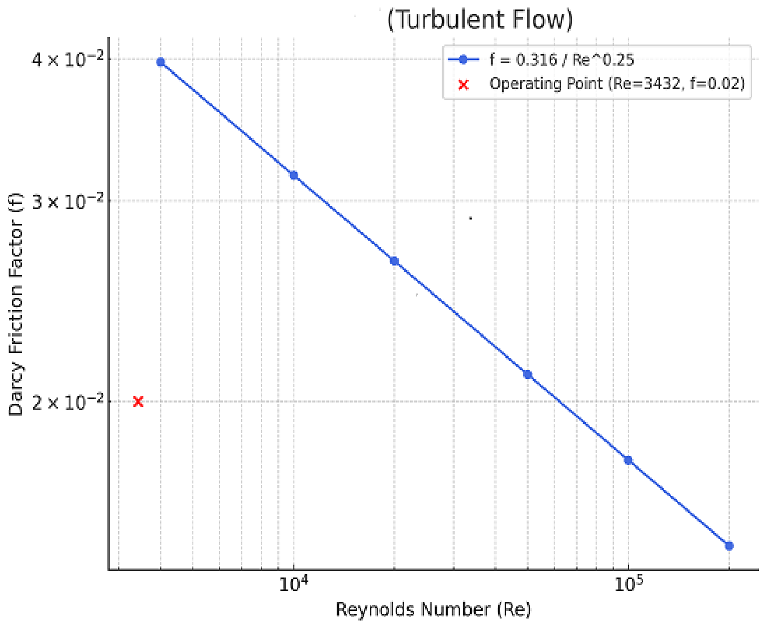

Figure 4. *Re* vs. *Q* and *f*, illustrating laminar-to-turbulent transition.

Finally, Figure 5 depicts the relationship between *Q* and *H*, which reflects the system's performance under various operating scenarios.

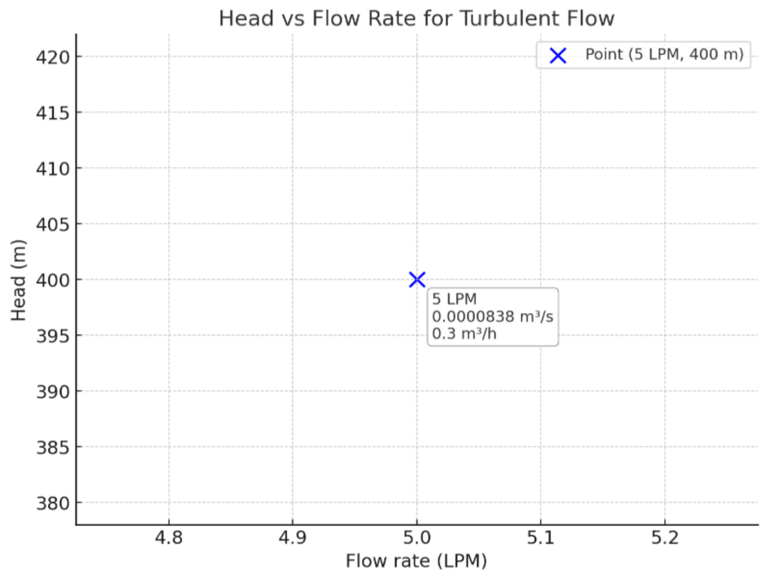

Figure 5. *Q* - *H* Characteristic Curve, system performance across operating.

Understanding the dynamics of turbulent flow and its impact on hydraulic parameters is fundamental for optimizing system performance and ensuring operational stability under challenging conditions. Turbulent flow induces velocity and pressure fluctuations that significantly affect *Re* and key hydraulic parameters, increasing friction and energy losses. This necessitates rapid control responses and robust system design to maintain efficiency and stability under high-pressure conditions. These findings highlight the need for precise monitoring and analysis of *Re* relationships to optimize performance, reduce losses, and ensure reliable operation through informed design and control strategies.

3.2 *Rotor Zone.Pump Size* Simulation Results

Simulations align well with theoretical calculations P_{in}= 41 KW, showing stable pump performance across the expected range. However, the *Pumping Power Calculator V3.0* reported lower P_{in} (36.73 – 37.33 KW) for both mass and volumetric flows, reflecting software assumptions and real operating conditions that reduce the actual power requirement.

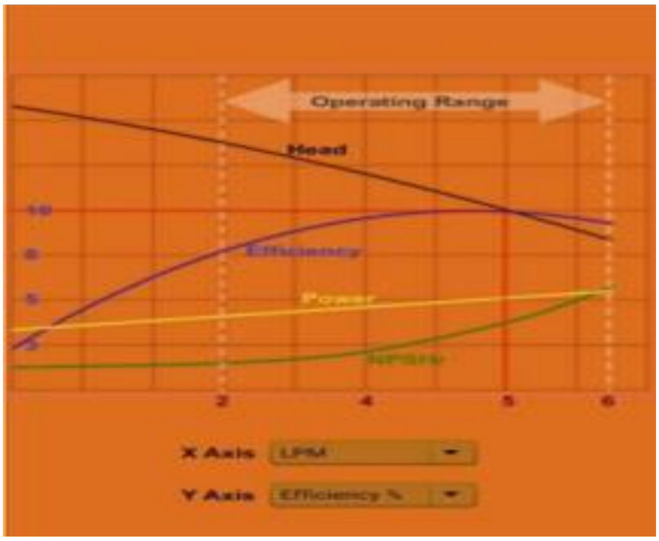

Figure 6. Operating range curves of the pump, confirming stability.

3.3 Pumping Power Calculator V3.0 Simulation Results

Table 4 and Table 5 summarize the extracted power values and calculated efficiencies.

A. Mass Flow Rate Operation

Table 4. Pumping Power Results Under Mass Flow Rate Input Conditions (Via *Pumping Power Calculator V3.0*).

Parameter	Symbol	Value & Unit (KW, %)
Pump Hydraulic Power	P_{hyd}	0.33
Shaft Power	P_{shaft}	3.33
Motor Power	P_{in}	4.27
Hydraulic Efficiency	η_{hyd}	9.91
Mechanical Efficiency	η_{mech}	77.99
Overall Efficiency	η_{overall}	7.73

B. Volumetric Flow Rate Operation

Table 5. Pumping Power Results Under Volumetric Flow Rate Input Conditions (Via *Pumping Power Calculator V3.0*).

Parameter	Symbol	Value & Unit (KW, %)
Pump Hydraulic Power	P_{hyd}	0.29
Shaft Power	P_{shaft}	2.86
Motor Power	P_{in}	3.67
Hydraulic Efficiency	η_{hyd}	10.14
Mechanical Efficiency	η_{mech}	77.93
Overall Efficiency	η_{overall}	7.90

In general, the η_{mech} remains stable at approximately 78% in both mass and volumetric flow cases, indicating minimal mechanical losses, while the relatively low η_{hyd} suggests that most energy losses occur within the hydraulic pathways due to design limitations, internal wear, or fluid viscosity. The η_{mech} aligns closely with theoretical predictions, reflecting accurate modeling of pump geometry and operating conditions. In contrast, the η_{overall} shows a significant difference: theoretical calculations yield only 0.7% due to idealized assumptions that neglect hydraulic losses, flow deviations, and minor imperfections, whereas the software based result for the flow cases are around 8%, , providing a more realistic estimate by accounting for internal pump dynamics and real operating conditions.

3.3.1 Analysis of Mass Flow Rate and Volumetric Flow Rate Curves

Figures 7 and 8 show approximately linear relationships between inlet flow and extracted hydraulic power for both mass and volumetric flow conditions. Mechanical efficiency remains nearly constant, while hydraulic efficiency slightly varies, demonstrating the sensitivity of hydraulic performance to flow measurement method and operational parameters. The combined analysis confirms that while the *COP* operates within expected mechanical parameters, attention should be given to improving hydraulic efficiency to enhance overall system performance.

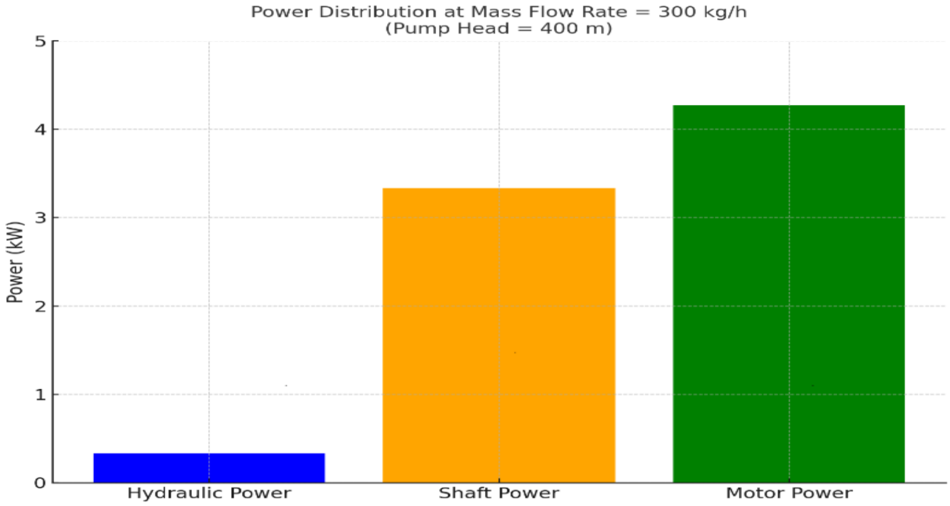

Figure 7. Mass flow rate vs. hydraulic power, showing efficiency trends.

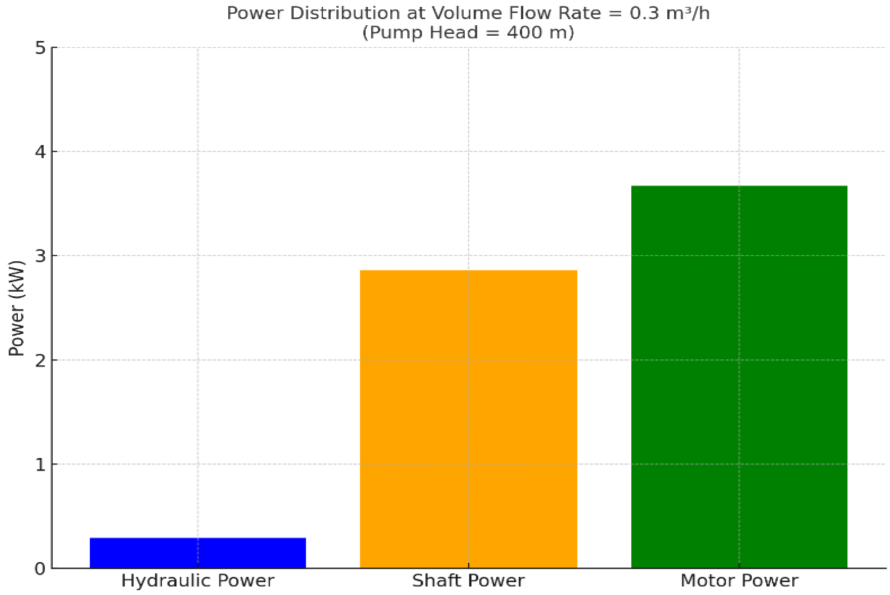

Figure 8. Volumetric flow rate vs. hydraulic power, showing efficiency trends.

4. Conclusion

This study presents an integrated framework combining theoretical modeling, computational simulations, and programming to improve pump performance analysis and support industrial facilities in monitoring, maintenance reduction, and cost optimization. Results show a stable mechanical efficiency of ≈ 78% and low hydraulic efficiency of ≈ 10%, indicating that energy losses primarily occur within hydraulic pathways due to friction, turbulence, and fluid viscosity rather than mechanical limitations. Nominal shaft power is 32 KW, while a 41 kw estimate may overstate real operating demand; hydraulic power (≈ 0.29 KW for volumetric flow) accurately reflects energy transferred to the fluid.

Comparison of mass and volumetric flow scenarios reveals minor efficiency differences (7.73% vs. 7.90%), confirming mechanical reliability while highlighting the need to optimize hydraulic efficiency through pump design, flow control, and fluid property management. Integrating computational and theoretical approaches is essential for effective performance monitoring, particularly in power generation facilities facing operational challenges, such as those in Libya. Generating reliable local data supports preventive maintenance, operational strategy improvement, and project planning, ensuring efficient and stable pump operation.

5. Recommendations

Based on this study's findings, the following recommendations are proposed to enhance pump performance and operational efficiency: optimize internal pump design to reduce losses and improve hydraulic efficiency; implement predictive and digital maintenance programs to maintain mechanical efficiency (≈78%); and integrate real-time monitoring systems to ensure operational reliability.

Additionally, adopting this approach systematically across other power plants can further improve performance, expand a localized database to support the government and the General Electricity Company, promote monitoring and simulation technologies, and strengthen personnel capabilities in integrated experimental, theoretical, and computational methods.

Acknowledgement

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