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Original Research Article

Effect of Palm Oil Viscosity on Centrifugal Pump Performance in a Vacuum Dryer System

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ABSTRACT

Centrifugal pumps are critical components in palm oil processing because their hydraulic performance is influenced by the physical properties of the pumped fluid. This study investigates the effect of palm oil viscosity on the performance of a centrifugal pump supplying a vacuum dryer system. A field-based observational and engineering-calculation approach was applied to a centrifugal pump with a nominal capacity of 12 m^3/h and a rated head of 25 m. Three operating temperatures were evaluated: 85, 90, and 95 °C, corresponding to kinematic viscosities of 10.43, 9.45, and 8.61 cSt, respectively. Flow rate, pump speed, fluid density, pressure parameters, velocity head, Reynolds number, pipe losses, total pump head, and shaft-power requirement were determined from operational measurements and hydraulic calculations. As temperature increased from 85 to 95 °C, viscosity decreased by 17.45%, while flow rate increased from 11.64 to 11.71 m^3/h. Pump speed increased from 2814 to 2823 rpm, total calculated head increased from 23.011 to 23.274 m, and shaft-power requirement decreased from 1.354 to 1.339 kW. The calculated mass flow rates were approximately 10 t/h at all three conditions, confirming the intended process throughput. The results indicate that temperature-induced viscosity reduction can maintain the required palm oil throughput while slightly reducing the shaft-power requirement under the investigated operating conditions. The findings provide practical operating evidence for temperature-viscosity management in centrifugal pumping systems used in palm oil vacuum-dryer applications.

Keywords:
centrifugal pump; palm oil; crude palm oil; viscosity; vacuum dryer; hydraulic head; pump performance.

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INTRODUCTION

Background and Engineering Problem

Pumping systems are fundamental to industrial fluid-processing operations because they provide the energy required to transport liquids through piping networks and process equipment (Alabi & Williamson, 2011; Poursharifi et al., 2012). In palm oil processing, centrifugal pumps are used to transfer oil between tanks and process units, including vacuum-drying equipment (Hong, 2023, p. 5; Ravindranath, 2021, p. 2351). Their operating condition directly affects production capacity, energy consumption, and process stability.

The investigated vacuum-dryer system receives palm oil from a clean oil tank through a centrifugal pump (Muarif et al., 2022). The process is designed for approximately 10 t/h of palm oil throughput. Under these conditions, the physical properties of the oil, particularly density and viscosity, are important operating variables (Liu et al., 2008). Viscosity represents the resistance of a fluid to deformation and flow; changes in viscosity therefore affect hydraulic resistance, pipe losses, flow rate, and the energy required by the pumping system.

Centrifugal pumps convert mechanical shaft energy into hydraulic energy through the rotation of an impeller (Al-Zaidi et al., 2023, p. 250). The resulting pressure and velocity changes enable continuous fluid transport through the piping network. Pump selection and operation must consequently be evaluated together with the hydraulic characteristics of the complete system rather than by considering rated pump capacity alone.

Industrial pump studies have emphasized the importance of flow rate, head, and operating speed in centrifugal-pump design and operation (Hovstadius, 1999; Matlakala & Kallon, 2021, p. 25). Studies of process equipment also show that temperature and operating conditions can influence fluid transport and drying performance (Darmadi et al., 2022; Nguyễn & VO, 2022, p. 136).

In palm oil processing, temperature provides a practical means of modifying viscosity because heating generally reduces the resistance of the oil to flow. Consequently, quantifying the relationship between temperature, viscosity, and pump performance is relevant for establishing operating conditions that maintain production capacity while avoiding unnecessary energy demand.

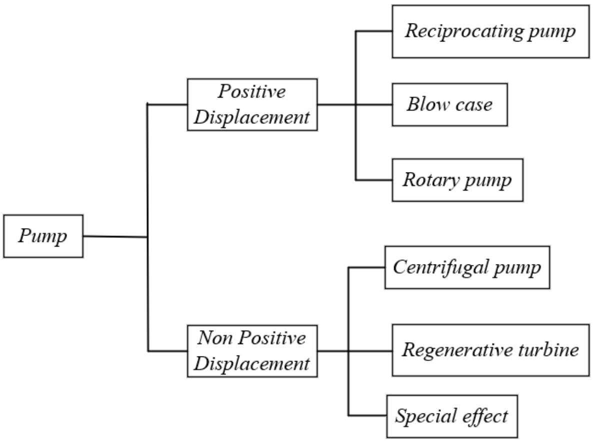

Figure 1. Classification of pump types.

State of the Art

Centrifugal pumps belong to the dynamic-pump group and generate hydraulic energy through impeller rotation. Their performance depends on the interaction between pump characteristics and the resistance of the connected piping system. Previous work has investigated centrifugal-pump design and performance from hydraulic, process, and fluid-property perspectives (Arijanto et al., 2015; RANGGATAMA, 2020).

Research on industrial process systems has also demonstrated that operating conditions such as temperature, fluid properties, and equipment configuration influence transport and process performance (Idris et al., 2022; Schmitt et al., 2020, p. 129). In vacuum and drying applications, the movement of process fluids is particularly important because insufficient or unstable flow can affect the effectiveness of downstream separation and drying operations (Ikbal & Subali, 2020; Nail et al., 2017, p. 2389)

For palm oil processing, equipment performance is closely related to the control of oil properties and the stability of the separation process. Nurulhuda (2009) discussed the importance of controlling crude palm oil processing and separation, while (Wondi et al., 2020) emphasized equipment-related factors affecting water content and CPO quality.

Although previous studies provide useful knowledge regarding centrifugal pumps, process equipment, and palm oil processing, field-based evidence linking temperature-controlled palm oil viscosity to the hydraulic performance of an installed centrifugal pump in a vacuum-dryer system remains limited.

Research Gap

Three practical gaps are addressed in this study. First, existing work frequently discusses pump performance or process equipment separately, whereas the present study evaluates the complete pump-piping arrangement supplying a vacuum dryer. Second, laboratory or generalized pump analyses do not necessarily represent the operating behavior of palm oil in an industrial installation. Third, the combined relationship among temperature, viscosity, flow rate, hydraulic losses, total head, pump speed, and shaft power has not been explicitly characterized for the investigated system.

Novelty and Contribution

The main contributions of this study are: 1) field characterization of an installed centrifugal pump transporting palm oil to a vacuum dryer under three temperature-viscosity conditions; 2) integrated hydraulic analysis involving flow velocity, Reynolds number, major and minor losses, and total pump head; and 3) practical evidence regarding temperature-viscosity control for maintaining approximately 10 t/h palm oil throughput while managing shaft-power demand.

Research Objective

This study aims to quantify the effect of palm oil viscosity, controlled through operating temperature, on the performance of a centrifugal pump used to supply a vacuum dryer. The analysis focuses on changes in flow rate, pump speed, hydraulic losses, total head, and shaft-power requirement.

THEORY AND/OR CALCULATION

Theoretical Framework / Model

The centrifugal pump converts shaft work into hydraulic energy through impeller rotation. The hydraulic requirement of the installation is represented by the sum of static head, pressure head, velocity head, and losses in the suction and discharge piping. The original study used the hydraulic-energy balance approach associated with standard pump-system analysis (Ranggatama, 2020).

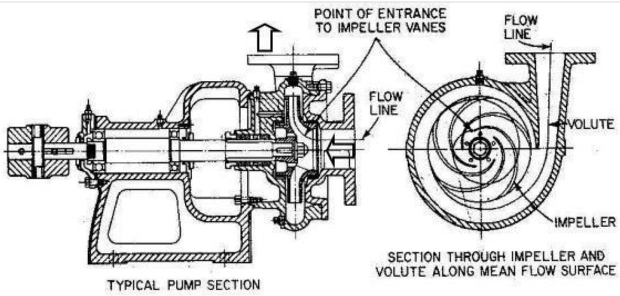

Figure 2. Cross-sectional view of a horizontal-shaft centrifugal pump.

The system static head is determined from the difference between the fluid elevations at the discharge and suction sides. The original installation data give a static head of 1 m.

MATERIALS AND METHODS

Research Design and Experimental System

This study employed a field-based engineering observational design supported by hydraulic and energy calculations to evaluate the effect of palm oil viscosity on the performance of a centrifugal pump supplying a vacuum-dryer system. The investigation was conducted on an installed pumping system connecting a clean oil tank to a vacuum dryer. Three palm oil operating temperatures, namely 85, 90, and 95 °C, were evaluated to represent different fluid-viscosity conditions under actual operating conditions.

The independent operating variable was palm oil temperature, which was associated with changes in kinematic viscosity and density. The principal pump-performance parameters were volumetric flow rate, pump rotational speed, Reynolds number, suction- and discharge-side hydraulic losses, total pump head, shaft-power requirement, and mass throughput.

Pump and Piping Configuration

The research object was a Southern Cross ISO 50×32-160 centrifugal pump with a nominal capacity of 12 m^3/h, rated head of 25 m, and rated rotational speed of 2825 rpm. The pump was driven by a 1.5-kW, 380-V, three-phase motor operating at 50 Hz.

The suction and discharge lines had nominal diameters of 2 in and 1¼ in, respectively. Their internal diameters were 54.7 and 36.6 mm, while the corresponding pipe lengths were 11.5 and 20.5 m. The piping material was carbon steel, with an absolute roughness of 0.045 mm used in the hydraulic calculations.

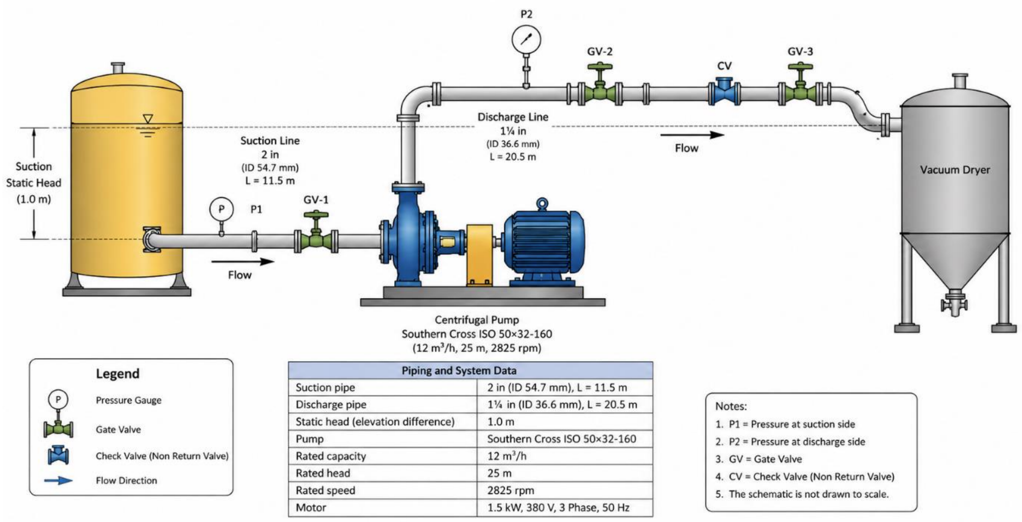

Figure 3. Schematic of the centrifugal-pump installation connecting the clean oil tank and vacuum dryer.

The system schematic defines the suction and discharge sections considered in the hydraulic analysis and illustrates the connection between the clean oil tank, centrifugal pump, piping network, and vacuum dryer.

Fluid Properties and Operating Conditions

Three palm oil temperature conditions were investigated: 85, 90, and 95 °C. The corresponding density values were 858.4, 856.1, and 853.8 kg/m^3, while the corresponding kinematic viscosities were 10.43, 9.45, and 8.61 cSt, respectively. The operating dataset included volumetric flow rate, pressure parameters, electrical voltage, electrical current, fluid density, kinematic viscosity, and pump rotational speed.

Measurement and Data Collection Procedure

Operational observations were obtained from the installed centrifugal-pump system under the three investigated temperature conditions. At each condition, palm oil temperature, volumetric flow rate, density, kinematic viscosity, electrical voltage, current, and pump rotational speed were recorded. Pressure parameters at the suction and discharge sides were also incorporated into the hydraulic analysis.

The measured volumetric flow rate was converted from m^3/h to m^3/s before calculating flow velocity and hydraulic parameters. The cross-sectional areas of the suction and discharge pipes were calculated from their internal diameters and were 0.00234 and 0.00105 m^2, respectively. The mean fluid velocity was calculated as:

$$V = \frac{Q}{A}$$

where (V) is the mean flow velocity (m/s), (Q) is the volumetric flow rate (m^3/s), and (A) is the internal pipe cross-sectional area (m^2).

For example, at 85 °C, the measured flow rate of 11.64 m^3/h corresponded to approximately 0.00323 m^3/s, resulting in velocities of approximately 1.380 m/s in the suction pipe and 3.076 m/s in the discharge pipe.

Hydraulic Analysis

The hydraulic analysis was based on the energy balance of the complete pumping system. The total pump head was calculated from the static head, pressure head, velocity-head difference, and total hydraulic losses:

$$H_T = H_s + H_p + H_v + h_L$$

where (H_T) is the total pump head (m), (H_s) is the static head (m), (H_p) is the pressure-head contribution (m), (H_v) is the velocity-head contribution (m), and (h_L) is the total hydraulic loss (m). The static head was determined from the elevation difference between the fluid surfaces at the suction and discharge sides. The static head of the investigated installation was 1 m.

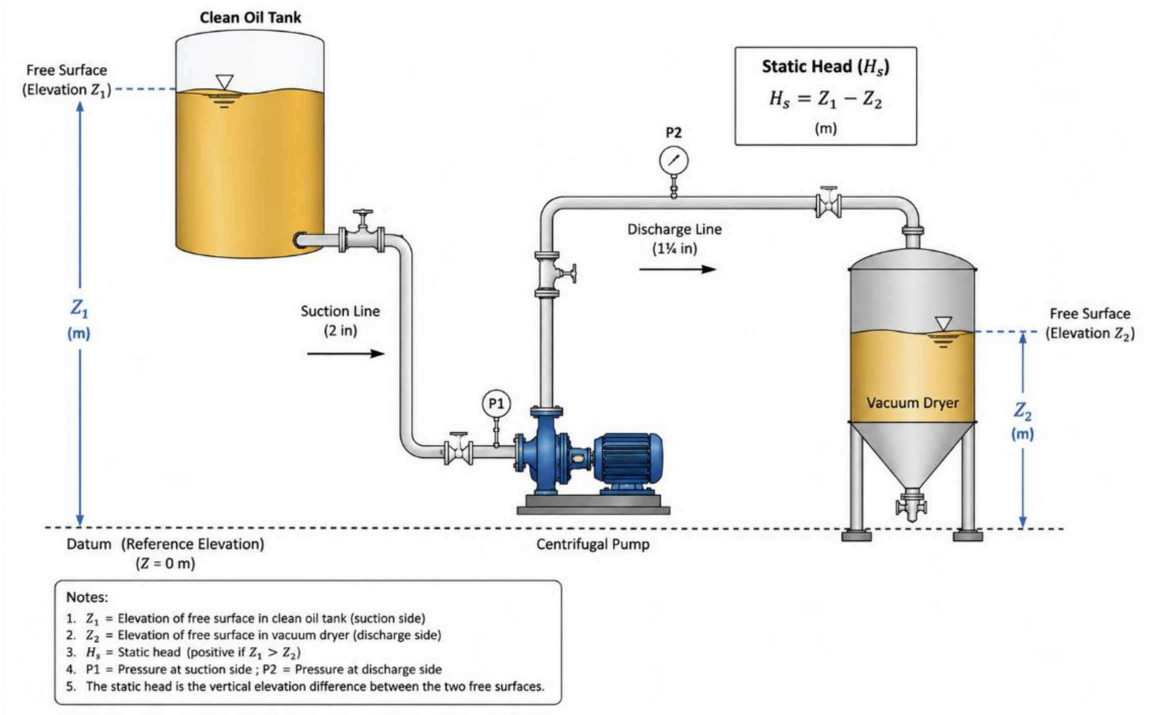

Figure 4. Static-head configuration of the pumping system.

Figure 4 defines the elevation terms used in the hydraulic-energy balance. The Reynolds number was calculated to determine the flow regime: $Re = \frac{VD}{\nu}$. Where (Re) is the Reynolds number, (V) is the mean fluid velocity (m/s), (D) is the internal pipe diameter (m), and (\nu) is the kinematic viscosity (m^2/s). Major pipe losses were calculated using the Darcy-Weisbach relationship: $h\_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$ where (h_f) is the major friction loss (m), (f) is the Darcy friction factor, (L) is the pipe length (m), (D) is the internal pipe diameter (m), (V) is the mean velocity (m/s), and (g) is gravitational acceleration (m/s^2). Minor losses associated with fittings and valves were calculated as: $h\_m = \Sigma K\left(\frac{V^2}{2g}\right)$ where (h_m) is the minor head loss (m) and (K) is the local-loss coefficient.

The suction-side configuration consisted of six 90° elbows, one gate valve, one inlet, and one outlet. The discharge-side configuration consisted of nine 90° elbows, two gate valves, one inlet, and one outlet. The corresponding loss coefficients were incorporated into the calculation of total hydraulic loss.

Performance Indicators and Data Analysis

The principal performance indicators were kinematic viscosity, volumetric flow rate, pump rotational speed, Reynolds number, suction-side hydraulic loss, discharge-side hydraulic loss, total hydraulic loss, total pump head, shaft-power requirement, and mass throughput.

The calculated total pump head was compared with the nominal pump head of 25 m. The calculated mass flow rate was compared with the intended process throughput of approximately 10 t/h.

The analysis was descriptive and engineering-based. The available source dataset consisted of three operating conditions without repeated measurements, standard deviations, or a replicated experimental design. Therefore, no inferential statistical significance testing was performed.

Changes between operating conditions were evaluated using absolute and relative differences in the measured and calculated parameters.

Validation and Methodological Limitations

A basic engineering validation was conducted by comparing the calculated total pump head with the pump's nominal rated head of 25 m and by evaluating the calculated mass throughput against the intended process capacity of approximately 10 t/h. The available source data do not include repeated measurements, instrument calibration records, measurement uncertainty, a complete pump characteristic curve, or experimentally determined hydraulic efficiency. Accordingly, the results should be interpreted as field-based engineering observations and hydraulic calculations for the investigated pump and piping configuration rather than as a statistically generalized pump-performance model.

RESULTS

Operating Conditions and Palm Oil Properties

The measured operating conditions at the three investigated temperatures are summarized in Table 4. Increasing palm oil temperature from 85 to 95 °C was accompanied by a decrease in kinematic viscosity from 10.43 to 8.61 cSt and a decrease in density from 858.4 to 853.8 kg/m^3. The viscosity reduction was 17.45% over the investigated temperature range.

In contrast, volumetric flow rate increased only slightly from 11.64 m^3/h at 85 °C to 11.71 m^3/h at 95 °C, corresponding to an increase of approximately 0.60%. Pump rotational speed increased from 2814 to 2823 rpm.

Table 4. Measured operating conditions of the centrifugal pump

Temperature (°C)	Q (m^3/h)	P1	P2	Voltage (V)	Current (A)	Density (kg/m^3)	Viscosity (cSt)	Speed (rpm)
85	11.64	1.033	0.0407	380	2.69	858.4	10.43	2814
90	11.68	1.033	0.0407	380	2.67	856.1	9.45	2819
95	11.71	1.033	0.0407	380	2.66	853.8	8.61	2823

Note: The notation and units of P1 and P2 should be verified against the original instrumentation record before submission.

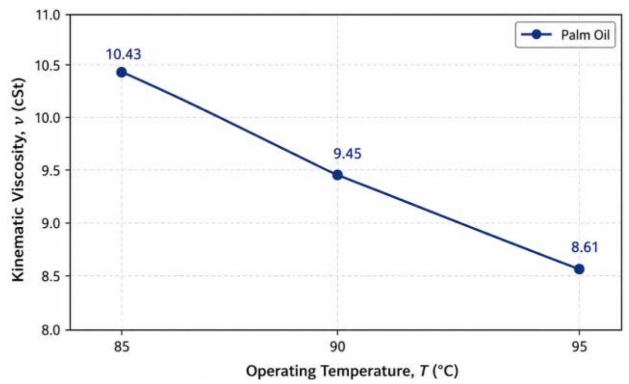

Figure 5. Effect of operating temperature on palm oil kinematic viscosity.

The figure shows a monotonic decrease in kinematic viscosity with increasing palm oil temperature.

Flow Velocity and Flow Regime

The calculated cross-sectional areas of the suction and discharge pipes were 0.00234 and 0.00105 m^2, respectively. At 85 °C, the measured flow rate of 11.64 m^3/h resulted in average velocities of approximately 1.380 m/s in the suction line and 3.076 m/s in the discharge line. The calculated Reynolds numbers were greater than 4000 for both pipe sections throughout the investigated operating conditions, indicating turbulent flow. The turbulent-flow condition was therefore maintained despite the reduction in palm oil viscosity from 10.43 to 8.61 cSt.

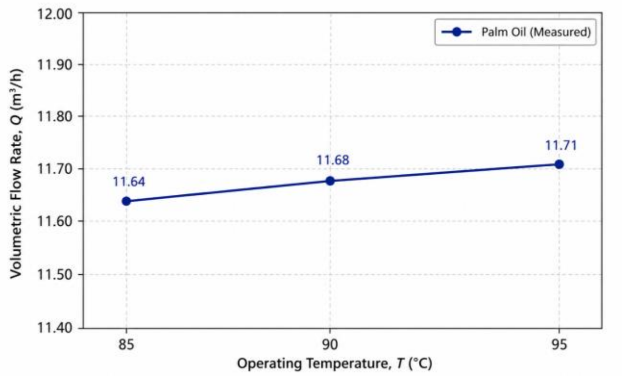

Figure 6. Effect of operating temperature on volumetric flow rate.

The measured flow rate exhibited only a small increase with temperature, indicating relatively stable volumetric throughput over the investigated viscosity range.

Hydraulic Losses

The hydraulic-loss analysis showed that the discharge line was the dominant source of hydraulic resistance in the investigated pumping system. The higher resistance was associated with the smaller internal diameter, greater pipe length, and larger number of fittings on the discharge side. At 95 °C, the calculated suction-side loss was 2.1326 m, whereas the discharge-side loss reached 18.5879 m. Thus, the discharge side accounted for approximately 89.7% of the combined suction- and discharge-side hydraulic losses at this operating condition.

Table 5. Hydraulic-loss configuration of the investigated piping system

Parameter	Suction side	Discharge side
Nominal diameter	2 in	1¼ in
Internal diameter	54.7 mm	36.6 mm
Pipe length	11.5 m	20.5 m
90° elbows	6	9
Gate valves	1	2
Inlet	1	1
Outlet	1	1
Total fitting-loss coefficient, ΣK	13.48	19.55

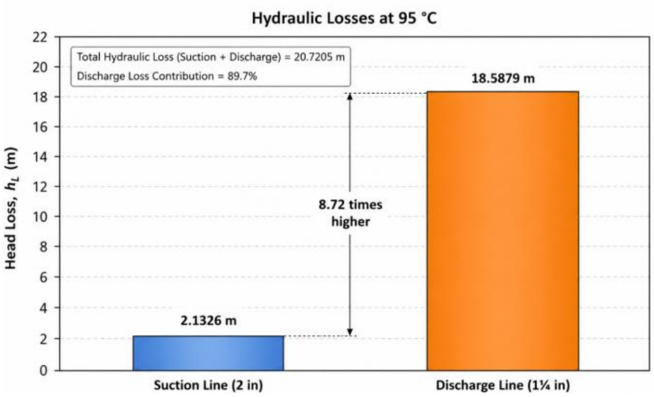

Figure 7. Comparison of calculated hydraulic losses in the suction and discharge lines at 95 °C.

The substantially greater discharge-side loss indicates that the discharge piping configuration represents the principal hydraulic restriction in the investigated system.

Total Pump Head

The calculated total pump head increased slightly with increasing palm oil temperature. The total head values were 23.0107 m at 85 °C, 23.1360 m at 90 °C, and 23.2739 m at 95 °C.

Table 6. Calculated total pump head

Temperature (°C)	Total pump head (m)	Difference from rated head (25 m)
85	23.0107	1.9893
90	23.1360	1.8640
95	23.2739	1.7261

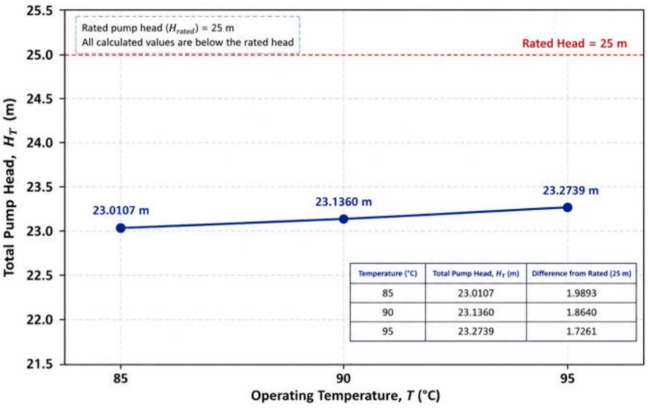

Figure 8. Effect of operating temperature on calculated total pump head.

From 85 to 95 °C, total calculated head increased by approximately 0.2632 m, equivalent to approximately 1.14%. All calculated values remained below the nominal pump rating of 25 m.

Shaft-Power Requirement

The calculated shaft-power requirement decreased from 1.354 kW at 85 °C to 1.339 kW at 95 °C, corresponding to a reduction of approximately 1.11%. This reduction occurred concurrently with a 17.45% decrease in kinematic viscosity and a 0.60% increase in volumetric flow rate. The available source data do not provide a verified shaft-power value for the 90 °C condition. Therefore, no interpolated or estimated value is reported.

Overall Pump Performance

Table 7. Summary of principal pump-performance indicators

Parameter	85 °C	90 °C	95 °C	Change, 85–95 °C
Kinematic viscosity (cSt)	10.43	9.45	8.61	−17.45%
Flow rate (m^3/h)	11.64	11.68	11.71	+0.60%
Pump speed (rpm)	2814	2819	2823	+9 rpm
Total pump head (m)	23.0107	23.1360	23.2739	+1.14%
Shaft-power requirement (kW)	1.354	—	1.339	−1.11%

The combined results indicate that increasing palm oil temperature substantially reduced fluid viscosity while the installed centrifugal pump maintained a relatively stable volumetric throughput. The calculated total pump head remained below the nominal 25-m pump rating over the investigated temperature range.

The results also show that the discharge piping was the dominant contributor to hydraulic loss. Therefore, the hydraulic performance of the complete system was influenced not only by palm oil viscosity but also by the resistance characteristics of the connected piping network. The measured operating conditions corresponded to an estimated mass throughput of approximately 10 t/h at the investigated temperatures, indicating that the intended process throughput was maintained under the evaluated operating conditions.

Overall, the field observations indicate that temperature-induced viscosity reduction can support stable palm oil throughput while being accompanied by a small reduction in calculated shaft-power requirement. Because the study was based on three non-replicated operating conditions, these findings should be interpreted as system-specific engineering observations rather than evidence of statistically significant causal effects.

DISCUSSION

Interpretation of the Main Findings

The main finding is that increasing palm oil temperature reduced viscosity and was accompanied by a small increase in flow rate and a reduction in shaft-power requirement. The 17.45% reduction in viscosity occurred across a relatively narrow temperature interval, while the flow rate changed by only 0.60%. This indicates that the installed pump maintained a relatively stable throughput despite changes in fluid viscosity. The reduction in shaft-power requirement from 1.354 to 1.339 kW is consistent with the interpretation that lower viscosity reduces resistance associated with fluid transport. However, the calculated increase in total head should not be interpreted as a universal effect of lower viscosity. The total head is the system requirement corresponding to the measured pressure, velocity, and loss conditions at each operating point.

Comparison with Previous Studies

The findings agree with the general conclusion that fluid viscosity is an important factor in centrifugal-pump performance. Arijanto et al. (2015) examined water and coconut oil and showed that changes in fluid properties affect centrifugal-pump performance. The present study extends this practical perspective to palm oil in an operating vacuum-dryer system.

The results are also consistent with studies emphasizing the role of operating conditions in industrial fluid and drying systems. (Demarchi et al., 2018, p. 21) considered operating speed in a washing process, while (Lamidi et al., 2018, p. 395) demonstrated the importance of temperature in dryer operation. In palm oil processing, equipment performance and separation quality are also affected by process conditions (Purwanti, 2019; Tan et al., 2008, p. 645).

The present study differs from purely equipment-design studies because the pump geometry was not modified. Instead, the analysis focuses on operating an existing pump under different palm oil temperatures. This makes the findings directly relevant to industrial operation where process optimization must often be achieved without replacing installed equipment.

Technical and Industrial Implications

The results indicate that temperature can serve as an operational variable for managing palm oil viscosity before pumping. Within the investigated range, the system maintained approximately 10 t/h mass throughput while the shaft-power requirement decreased slightly. This supports simultaneous monitoring of temperature, viscosity, flow rate, and pump power. The discharge line is the dominant source of hydraulic loss. Consequently, future energy-efficiency interventions should consider discharge-pipe diameter, fitting configuration, valve arrangement, pipe routing, and internal condition. Reducing unnecessary discharge-side resistance may provide a larger opportunity for energy saving than focusing exclusively on temperature control. The calculated head remained below the nominal 25-m rating, but the available margin decreased slightly with increasing temperature in the reported calculations. Therefore, operating decisions should consider the complete system curve and not rely solely on viscosity as a predictor of pump performance.

Limitations and Scope

The study has several limitations. Only three temperature-viscosity conditions were evaluated, and the source manuscript does not report repeated measurements, standard deviations, instrument calibration, or measurement uncertainty. The study also concerns one pump and one piping configuration, limiting direct generalization to other installations. In addition, the source data do not provide a complete pump characteristic curve or experimentally determined hydraulic efficiency. Future research should incorporate replicated measurements, torque or shaft-power instrumentation, electrical input power, pump efficiency, uncertainty analysis, and a wider range of viscosity and flow conditions.

CONCLUSION

This study evaluated the effect of palm oil viscosity on the performance of a centrifugal pump supplying a vacuum dryer. Increasing temperature from 85 to 95 °C reduced viscosity from 10.43 to 8.61 cSt, a reduction of 17.45%. Over the same range, flow rate increased from 11.64 to 11.71 m^3/h, pump speed increased from 2814 to 2823 rpm, and calculated total head increased from 23.0107 to 23.2739 m. Shaft-power requirement decreased from 1.354 to 1.339 kW. The measured operating conditions corresponded to approximately 10 t/h of palm oil mass throughput, indicating that the process capacity was maintained. The discharge line produced the dominant hydraulic loss, reaching 18.5879 m at 95 °C compared with 2.1326 m on the suction side.

Overall, the findings show that temperature-induced reduction of palm oil viscosity can support stable process throughput while slightly reducing shaft-power demand under the investigated operating conditions. Future work should strengthen the evidence through repeated experiments, uncertainty analysis, pump-efficiency measurement, and evaluation of a wider viscosity range.

DECLARATION

Competing of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT Authorship Contribution Statement

Golfrid Gultom: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing.
M. Dimas Gunawan: Investigation, Data curation, Validation, Visualization, Writing – review & editing.

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Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for manuscript restructuring, organization according to the JuVoTek format, and language editing. The authors reviewed and edited the content and take full responsibility for the accuracy, interpretation, and final published content.

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