

ANALYSIS OF NPSH INFLUENCE ON PROGRESSIVE CAVITY PUMP PERFORMANCE FOR SUSTAINABLE SLUDGE TRANSFER IN PALM OIL MILL LAND APPLICATION SYSTEMS

Fadlah Kaumenni Sinurat^{1*}, Hendra Susilo², Suardi³

Universitas Tjut Nyak Dhien / Program Studi Tekni Mesin, Medan

Corresponding E-mail: fadlah@utnd.ac.id¹, hendra@utnd.ac.id², suardi@utnd.ac.id³

Received : 01 October 2025

Published : 16 November 2025

Revised : 10 October 2025

DOI : <https://doi.org/10.54443/morfai.v5i5.4420>

Accepted : 05 November 2025

Link Publish : <https://radjapublika.com/index.php/MORFAI/article/view/4420>

Abstract

In palm oil mill land application systems, the efficiency of slurry transfer from aerobic ponds to plantation channels is highly influenced by pump suction performance. This study aims to analyze the suction capability of the Progressive Cavity Pump based on the relationship between the available Net Positive Suction Head ($NPSH_a$) and the required NPSH ($NPSH_r$). Field measurements and calculations were conducted at pond depths ranging from -1 m to -5 m to evaluate pump performance under negative suction conditions. The results indicate that the $NPSH_a$ values consistently exceed the $NPSH_r$ value of 2.56 m across all tested depths. Specifically, at -1 m depth, $NPSH_a$ reached 8.12 m with a margin of 5.56 m, while at -5 m depth, $NPSH_a$ remained at 4.12 m with a margin of 1.56 m. The increasing $NPSH_a - NPSH_r$ margin with shallower suction depths demonstrates that the PCP effectively avoids cavitation and maintains stable operation even under high negative suction pressure. The findings indicate that the PCP provides reliable and energy-efficient performance for transferring aerobic sludge in palm oil mill LA systems. Consequently, the PCP demonstrates significant potential as a superior and sustainable alternative to centrifugal pumps in organic sludge management and liquid fertilizer distribution.

Keywords: *progressive cavity pump, NPSH, suction head, land application, cavitation.*

INTRODUCTION

Indonesia is the world's largest palm oil producer, contributing 59.7% to global demand, with palm oil accounting for 72.9% of the total production of vegetable oils, Jelsma et al. (2024). This condition requires palm oil farmers and industry stakeholders to continuously enhance and develop the growth of palm fruit production. The provision of appropriate nutrients plays a crucial role in improving both yield and fruit quality, Zahir et al. (2025). Fertilization, particularly the use of chemical fertilizers, is one of the methods commonly applied to improve production yield; however, it involves relatively high operational costs. Moreover, excessive fertilizer application may pose risks to ecological balance, soil degradation, water pollution, and the loss of biodiversity, Paliaga et al. (2025). An alternative approach is the utilization of aerobic pond effluent from palm oil mills as liquid fertilizer. The use of green fertilizers derived from waste presents a promising prospect. The addition of nutrients from wastewater to produce renewable fertilizer has the potential to meet up to 13.4% of global fertilizer demand, Shafaghat et al. (2024). This liquid fertilizer is distributed into canal systems within the oil palm plantation through a piping network commonly referred to as land application (LA). Sustainable wastewater management using the LA system requires maintaining a balance between the hydraulic loading rate and the soil's assimilation capacity, Wang et al. (2025). The distance between the palm oil mill effluent (POME) ponds and the oil palm plantation is relatively long, ranging from 1 to 3 km, with an elevation difference of approximately 10–30 m. This distance and elevation can be overcome by using a fluid machine, namely a pump. The term 'pump' is generally used to describe any fluid machine that functions to add energy to a fluid, Çengel dan Cimbala (2006).

As shown in Figure 1, a pump increases the pressure of the fluid, allowing it to flow across the required distance and elevation

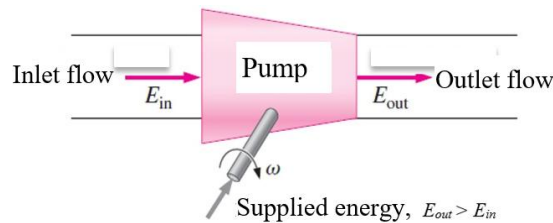


Figure 1. The pump provides energy to the fluid.

The basic parameter for analyzing pump performance is the fluid flow rate, Q , which represents the fundamental performance indicator for incompressible flow. This flow rate, also known as discharge, is expressed in cubic meters per second (m^3/s). Here, v denotes the average fluid velocity (m/s), and A represents the cross-sectional area of the pipe (m^2), which can be expressed by the following equation (1).

$$Q = vA \quad (1)$$

The cross-sectional area of the pipe can be calculated using Equation (2), where D is the pipe diameter (m), and π is a mathematical constant with a value of 3.14.

$$A = \frac{\pi D^2}{4} \quad (2)$$

The pump performance (net head, H) is defined as the change in Bernoulli head between the inlet and outlet sides of the pump, which can be expressed by the following equation (3):

$$H = \left(\frac{P}{\rho g} + \frac{v^2}{2g} + h \right)_{out} - \left(\frac{P}{\rho g} + \frac{v^2}{2g} + h \right)_{in} \quad (3)$$

The pump energy (head) derived from pressure is expressed in meters (m), where P is the pressure in pascals (Pa), ρ is the fluid density in kilograms per cubic meter (kg/m^3), and g is the gravitational acceleration with a value of 9.81 m/s^2 , which can be expressed by the following equation (4).

$$H_{atm} = \frac{P}{\rho g} \quad (4)$$

The head due to velocity can be expressed by Equation (5).

$$H_{velocity} = \frac{v^2}{2g} \quad (5)$$

The total head loss is influenced by friction factors, minor losses, and elevation differences under horizontal conditions with an elevation difference of Δz (m), which can be expressed by the following equation (6).

$$H_{pump} = h_f + h_{minor} + \Delta Z \quad (6)$$

Where the friction loss (h_f) represents the head loss due to friction, f is the dimensionless Darcy friction factor, and L is the pipe length measured in meters (m), which can be expressed by the following equation (7).

$$h_f = f \frac{L v^2}{D 2g} \quad (7)$$

Minor losses refer to the energy or head losses in fluid flow that are not caused by friction along a straight pipe but arise due to flow disturbances at pipe components or fittings, such as bends, joints, valves, and pipe inlets or outlets. In certain cases, such as short piping systems with numerous fittings, minor losses can exceed frictional losses. Minor losses result from changes in velocity, direction, and cross-sectional area of the fluid flow, which generate vortices (eddies) and turbulence, leading to the dissipation of part of the kinetic energy. In Equation (8), the coefficient

K represents the loss factor, which depends on the type of fitting, joint configuration, and flow conditions.

$$h_{minor} = K \frac{v^2}{2g} \quad (8)$$

Table 1. Types of Components and Estimated K Values

Type of Component	Estimated K Value
Sharp-edged entrance	0.5
Smooth entrance	0.04
Free exit	1.0
90° sharp bend	0.9 - 1.5
45° bend	0.3 - 0.4

Fully open ball valve	0.05 – 0.15
Fully open gate valve	0.15 – 0.2
Fully open globe valve	8 – 10
Tee (straight-through flow)	0.6 – 0.9
Tee (branch flow)	1.8 – 2.0
Reducer (contraction)	0.1 – 0.4
Expander (enlargement)	0.2 – 1.0

From the total head equation, we can solve for L (the maximum length) when we want to find the length L that makes the frictional head loss h_f equal to the remaining head, which can be expressed by the following equation (9).

$$h_f = H_{pump} - h_{minor} - \Delta Z$$

$$f \frac{L}{D} \frac{V^2}{2g} = H_{pump} - K \frac{V^2}{2g} - \Delta Z$$

$$L = \frac{(H_{pump} - K \frac{V^2}{2g} - \Delta Z) D}{f (V^2/2g)} \quad (9)$$

where f is the Darcy friction factor, ε = absolute roughness of the pipe (m), D = pipe diameter (m). The friction factor f can be obtained using the Swamee–Jain explicit formula, which can be expressed by the following equation (10).

$$f = \frac{0,25}{\left[\log_{10} \left(\frac{\varepsilon}{3,7D} + \frac{5,74}{Re^{0,9}} \right) \right]^2} \quad (10)$$

Where Re is the Reynolds number, a dimensionless number used to determine the characteristics of fluid flow, indicating whether the flow is laminar, transitional, or turbulent. ρ is fluid density (kg.m^{-3}), v is mean velocity (m.s^{-1}), μ is dynamic viscosity (Pa.s), and V is kinematic viscosity ($\text{m}^2.\text{s}^{-1}$), which can be expressed by the following equation (11) and (12).

$$Re = \frac{\rho v D}{\mu} \quad (11)$$

$$Re = \frac{v D}{\nu} \quad (12)$$

The use of centrifugal pumps in the Land Application (LA) station is widely observed in the field, Wang, Tan, Kuang, dan Yu (2024), as centrifugal pumps are relatively economical and spare parts are readily available. However, centrifugal pumps have three main drawbacks, Joko et al. (2021), Wang, Tan, Kuang, dan Yu (2023), Wróbel et al. (2025): (1) a very low negative suction capability, causing the pump to predominantly draw water instead of the organic sludge required by oil palm trees as green fertilizer; (2) the geometric configuration of centrifugal pumps, where the inlet (suction pipe) diameter is larger than the outlet (discharge pipe) diameter, resulting in a pressure drop within the pump. This pressure reduction decreases the discharge distance and total head produced. Moreover, such conditions may induce cavitation, leading to impeller wear and consequently shortening the pump's lifetime; and (3) as the pump rotational speed increases, the pump capacity also increases, thereby requiring higher power consumption.

The Net Positive Suction Head (NPSH) is an important parameter in pumping systems used to prevent cavitation, a condition that must be avoided in pump operation. The available NPSH ($NPSH_a$) represents the actual value available on the suction side of the pump installation, as shown in Equation (13).

$$NPSH_a = \frac{P_{atm}}{\rho g} + h_s - h_L - \frac{P_v}{\rho g} \quad (13)$$

Where h_s is the static head, which is positive when the pump is located below the fluid surface and negative when it is positioned above the fluid surface, measured in meters (m). P_v denotes the vapor pressure of the fluid at the operating temperature, expressed in pascals (Pa)

The energy loss due to internal friction and flow disturbances is expressed as the head loss (h_L) on the suction side of the pump, represented by h_f and h_m , as shown in Equation (14). These two components are crucial because they directly affect the Net Positive Suction Head Available ($NPSH_a$). This energy loss serves to prevent the fluid from vaporizing or experiencing cavitation on the suction side of the pump.

$$h_L = h_f + h_m \quad (14)$$

The required $NPSH_r$ is the minimum value needed by the pump to prevent cavitation, and its value is specified by the pump manufacturer according to the relationship given in Equation (15).

$$NPSH_a - NPSH_r \geq (0,5 \text{ s.d } 1) \quad (15)$$

Based on these limitations, this study proposes a new approach by adopting a Progressive Cavity Pump (PCP) as a more suitable technological solution for the sustainable transfer of sludge-based organic fertilizer to plantation fields. The PCP operates on the principle of positive displacement and offers several significant advantages over centrifugal pumps, including: (1) higher suction capability, enabling the transfer of high-viscosity sludge containing beneficial organic matter; (2) stable output pressure, which allows for longer distribution distances without the risk of cavitation or severe head loss; and (3) improved power efficiency within medium to high operational ranges due to its relatively lower rotational speed.

The novelty of this research lies in its approach, methodology, and focus of investigation. From a technological perspective, this study introduces the integration of a Progressive Cavity Pump (PCP) into the Land Application (LA) system, which has rarely been implemented in the palm oil plantation sector. This innovation enables the direct utilization of organic sludge from wastewater ponds as a renewable liquid fertilizer. Furthermore, another aspect of novelty is reflected in the measurement focus. The study not only evaluates the pump's performance but also conducts an in-depth assessment of flow stability, energy efficiency, and fertilizer distribution effectiveness. These aspects have been relatively underexplored in previous studies; therefore, this research is expected to provide a new contribution to the development of renewable fertilizer distribution technology based on palm oil mill effluent.

LITERATURE REVIEW

Relevant previous studies

Research on pump performance and hydrodynamic behavior in complex fluid systems such as sludge and palm oil mill effluent (POME) has been widely examined through experimental, analytical, and computational approaches. Adam et al. (2025) applied Computational Fluid Dynamics (CFD) to investigate failure mechanisms in water injection pumps and found that pressure imbalance and velocity distribution inside the pump casing critically influenced cavitation initiation. This CFD-based diagnostic approach offers valuable insight into the relationship between Net Positive Suction Head (NPSH) and pump performance by allowing detailed visualization of pressure fields and vapor bubble formation regions. In a complementary study, Berli, Niko, and Bambang (2019) proposed an early cavitation detection method in centrifugal pumps using statistical parameter extraction in both time and frequency domains through Principal Component Analysis (PCA). Their results confirmed that pressure fluctuations caused by reduced NPSH could be detected through vibration signatures, reinforcing the strong coupling between hydraulic instability and NPSH variation.

Further investigations by Joko, Kevin, and Rahmat (2021) analyzed the influence of impeller trim diameter on centrifugal pump efficiency. They observed that efficiency and head improved with increasing impeller diameter, but cavitation risks also rose beyond specific thresholds. This finding highlights that geometric design parameters are strongly correlated with NPSH and suction performance. Regarding Progressive Cavity Pumps (PCPs), Kim et al. (2023) utilized CFD modeling to study wax deposition behavior in rotor–stator assemblies. They concluded that uneven pressure distribution from non-Newtonian flow led to localized deposition, efficiency losses, and increased torque demand. Their results emphasize the importance of hydrodynamic balance in PCPs when handling viscous or multiphase fluids. Similarly, Müller et al. (2023) developed an adaptive stator adjustment strategy requiring minimal sensors, achieving up to 12% higher efficiency without elevating cavitation risk. These studies provide substantial contributions to understanding pump fluid dynamics, yet most focus on centrifugal pumps or single-phase fluids. The interaction between NPSH characteristics and non-Newtonian sludge flow within PCP systems remains insufficiently explored, especially under negative suction head conditions relevant to palm oil mill land application (LA) systems.

Theoretical concepts and framework

According to Çengel and Cimbala (2006), NPSH represents the energy available in a liquid above its vapor pressure at the pump suction. It determines whether cavitation will occur when the fluid enters the impeller or suction chamber. NPSH is typically divided into two components: the Net Positive Suction Head Available (NPSH_a), determined by system conditions, and the Net Positive Suction Head Required (NPSH_r), an inherent pump characteristic. Cavitation occurs when NPSH_a falls below NPSH_r, leading to vapor bubble formation, surface erosion, and reduced hydraulic efficiency. In centrifugal pump applications, maintaining a sufficient NPSH_a–NPSH_r margin ensures stable performance. However, in Progressive Cavity Pumps (PCPs), which operate based on the

volumetric displacement principle rather than impeller dynamics, the relationship between NPSH and suction stability is more complex. PCPs handle viscous, shear-sensitive, and multiphase fluids through a continuous sealing line between the rotor and stator, allowing smooth flow even under high suction lift conditions. Hence, evaluating NPSH in PCPs requires considering pressure gradients along the helical cavities and the compressibility of entrained gases.

In palm oil mill operations, Gobi et al. (2011) emphasized the role of stable hydraulic systems in transporting POME for biological treatment, while Imam et al. (2025) highlighted the potential for sustainable resource recovery through sludge transfer and land application. A consistent NPSH balance is crucial to maintaining continuous sludge movement, minimizing cavitation, and improving energy efficiency. Thus, understanding NPSH behavior in PCP systems provides the theoretical foundation for sustainable wastewater management and organic sludge utilization in palm oil industries.

Differences in perspectives and conflicting findings

Scholars have presented varying interpretations regarding the dominant mechanisms of pump degradation under slurry and viscous fluid conditions. Peng, Fan, and Ma (2021) identified impeller erosion as the principal factor in efficiency decline, primarily influenced by solid particle impact and flow turbulence. Conversely, Wróbel et al. (2025) argued that material fatigue induced by cyclic pressure fluctuations had a more significant effect than erosion, especially in prolonged operations. These contrasting viewpoints indicate that pump degradation depends not only on fluid abrasiveness but also on transient hydraulic pressures associated with NPSH instability.

Wang, Tan, Kuang, and Yu (2023; 2025) further demonstrated through the Discrete Phase Model (DDPM) that inlet geometry profoundly affects suction stability and NPSH maintenance, emphasizing that optimized inlet designs can suppress cavitation inception. In contrast, Adam et al. (2025) focused mainly on internal pressure distributions without considering inlet boundary conditions. Such methodological differences highlight the need for integrated modeling approaches combining CFD-based pressure field analysis with system-level suction dynamics. Overall, discrepancies in findings suggest that the relationship between NPSH, flow regime, and mechanical performance is not yet fully characterized, particularly for positive displacement pumps such as PCPs operating with non-Newtonian sludge. These research inconsistencies underscore the need for experimental validation under real industrial conditions to better define NPSH performance thresholds.

Research gap

Although numerous studies have explored NPSH phenomena in centrifugal and submersible pumps, only limited quantitative research has focused on Progressive Cavity Pumps handling high-viscosity, non-Newtonian fluids such as palm oil mill sludge. Existing works have yet to integrate NPSH analysis with CFD-based or experimental evaluations under negative suction head conditions typical in land application (LA) systems.

Furthermore, current literature lacks a clear understanding of how NPSH variations affect volumetric efficiency, cavitation onset, and energy stability in PCP-driven sludge transfer. The absence of such studies restricts the development of design standards for sustainable sludge management systems in palm oil industries. Therefore, this study titled “Analysis of NPSH Influence on Progressive Cavity Pump (PCP) Performance for Sustainable Sludge Transfer in Palm Oil Mill Land Application Systems” addresses these gaps by:

1. Quantitatively examining the relationship between NPSH variation and volumetric efficiency of PCPs in sludge transfer operations.
2. Determining the critical NPSH threshold that marks the transition from stable flow to cavitation onset under negative suction conditions.

By bridging theoretical principles with empirical observations, this research contributes to improving pump selection, reducing cavitation risk, and enhancing energy efficiency in sustainable wastewater reuse systems in palm oil mills.

METHOD

The research method involves direct observation and field measurements conducted at the aerobic pond of a palm oil mill, focusing on the piping installation system at both the suction side and the inlet section of the PCP pump. The study utilizes liquid waste generated as a by-product of palm oil mill production as a renewable fertilizer. This renewable fertilizer is transferred through a piping system using a Progressive Cavity Pump (PCP) to the distribution channels within the oil palm plantation area, as illustrated in Figure 2.

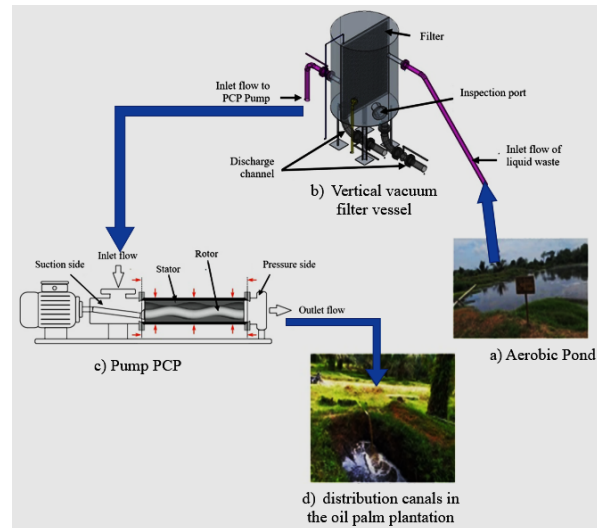


Figure 2. Schematic diagram of the PCP pump system in the land application

Figure 2. Illustrates the process flow scheme of the PCP pump system within the Land Application (LA) system. The process begins with measuring the specific gravity of the liquid waste in the aerobic pond of the palm oil mill. To determine the density of the sludge being pumped, the calculation of specific gravity is carried out by directly weighing the mass of the thickened sludge from the aerobic pond and the mass of water using a 500 mL measuring cylinder. The comparison between the mass of clean sludge and clean water is then used to determine the specific gravity of the sludge. To obtain the sludge density, the measured specific gravity is multiplied by the water density of 1000 kg/m³, as shown in Figure 3 and the equation (16), (17), (18) and (19).

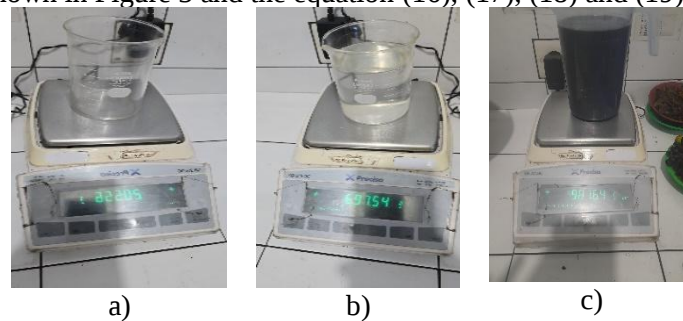


Figure 3. (a) Measurement mechanism of sludge specific gravity using the mass of a measuring cylinder, (b) water mass, and (c) sludge mass.

$$m_{\text{bersih lumpur}} = m_{\text{total lumpur}} - m_{\text{gelas ukur}} \quad (16)$$

$$m_{\text{bersih air}} = m_{\text{total air}} - m_{\text{gelas ukur}} \quad (17)$$

$$SG_{\text{Lumpur}} = \frac{m_{\text{bersih lumpur}}}{m_{\text{bersih air}}} \quad (18)$$

$$\rho_{\text{Lumpur}} = SG_{\text{Lumpur}} \times \rho_{\text{air}} \quad (19)$$

Knowing the actual density of the sludge is essential to determine its classification, whether the sludge intended for fertilizer use is dilute, medium, or thick. This information is required to calculate the flow characteristics within the pipeline, specifically to identify whether the flow is laminar, transitional, or turbulent, as represented by the Reynolds number.

The PCP pump is positioned on land, above the surface of the aerobic wastewater pond. The negative suction capability of the PCP pump is a crucial qualification, as it enables the suction of sludge containing essential nutrients that can enhance palm oil production and serve as an alternative to commercial chemical fertilizers. This negative suction capability cannot be achieved by centrifugal pumps, where the NPSH_a value represents the pump's actual negative suction head performance. In this study, the suction depth reaches the bottom of the pond at approximately –5 m, ensuring that the fluid transferred to the plantation area is nutrient-rich organic sludge. To protect the pump from contaminants and solid objects such as wood, metal, and stones which could shorten the lifespan of the PCP pump components—a vertical vacuum filter tank is installed. This tank functions as a solid particle separator,

extending the service life of critical pump components such as the stator, rotor, and universal cardan joint. Figure 4 illustrates the placement of the vertical vacuum filter tank between the PCP pump and the aerobic wastewater pond.



Figure 4. Position of the PCP Pump and the Vertical Vacuum Filter Tank

The PCP pump was selected because it possesses a negative suction capability, can operate effectively with high-viscosity fluids, and maintains a stable flow rate. The working principle of the PCP pump relies on the interaction between the rotor and stator, which produces a continuous flow with stable discharge pressure. To measure the volume of liquid fertilizer transferred to the land application (LA) canals, an electromagnetic flowmeter is used. Additionally, a pressure gauge is installed to ensure that the pump operates under safe conditions at all times, as illustrated in **Figure 5**.



Figure 5. Flowmeter and Pressure gauge

With the implementation of the Land Application (LA) system, palm oil mills (POMs) no longer need to discharge liquid waste into water bodies or rivers Wang et al. (2025), but can instead reuse it as fertilizer for oil palm plantations. The palm oil industry produces a large volume of liquid waste known as Palm Oil Mill Effluent (POME), In-chan et al. (2024). POME from the mill can be utilized as a green fertilizer and considered a renewable resource, Imam et al. (2025). This renewable or green fertilizer is derived from the aerobic pond, which has undergone biological treatment systems combined with adsorption systems, Gobi et al. (2011). The Progressive Cavity Pump (PCP) is capable of pumping media with high viscosity and high solid fractions, Müller et al. (2023). The main components of the PCP are the rotor and stator Kim et al. (2023), as shown in Figure 2(c). The PCP demonstrates high accuracy in transferring fluid, Ugurluoglu et al. (2023) to the irrigation channels of oil palm plantations, as illustrated in Figure 2(d).

RESULTS AND DISCUSSION

Based on the specifications and operational parameters of the PCP pump applied in the field for transferring organic sludge from the aerobic pond of the palm oil mill, as presented in Table 2 below.

Table 2. Specifications and Operational Parameters of the PCP Pump

Parameter	Symbol	Value	Unit
Pump Capacity	Q	0,0167	m ³ /s
Pump Pressure	P	1.000.000	Pa
Suction Pipe Diameter	D	0,1524	m
Type of Pipe: HDPE (High-Density Polyethylene)	ϵ	1,5x10 ⁻⁶	m
Horizontal Suction Pipe Length	L_h	2	m
Vertical Suction Pipe Length	L_v	-3	m
Type of Fluid		Lumpur	
Fluid Temperature	T	30	°C
Atmospheric Pressure	P_{atm}	101,325	Pa
Dynamic Viscosity of Sludge	μ	0,000798	Pa.s

Based on the parameters shown in Table 2, the capacity of the PCP pump is 60 m³/hour, which when converted to SI units becomes 0.00167 m³/s. The suction pipe diameter is 6 inches, converted to SI units as 0.1524

m. Using Equation (2), the cross-sectional area of the HDPE pipe is calculated as 0.018249 m^2 . Applying Equation (1), the flow velocity of the sludge inside the pipe is obtained as 0.9133 m/s . Using the dynamic viscosity of the sludge at 30°C ($\mu = 0.000798 \text{ Pa}\cdot\text{s}$), and the measured specific gravity (S.G.) of sludge from the aerobic pond at the palm oil mill, determined from Equations (16–18), the S.G. value is found to be 1.078. Therefore, using Equation (19), the sludge density is calculated to be $1,078 \text{ kg/m}^3$. It can be concluded that the sludge in the aerobic pond is classified as dilute sludge, since its density is below $1,200 \text{ kg/m}^3$. To obtain the Reynolds number, Equation (12) is used, resulting in $\text{Re} = 1.67445 \times 10^5$. This indicates that the flow inside the suction pipe is turbulent, as the Reynolds number (Re) exceeds 4,000.

The flow within the suction pipe is classified as turbulent flow. Using Equation (10), the Swamee Jain correlation, the friction factor (f) is calculated as 0.01617, with the internal surface roughness (ϵ) of the HDPE pipe being $1.5 \times 10^{-6} \text{ m}$. The total suction pipe length, consisting of vertical and horizontal sections, is varied at 3 m, 4 m, 5 m, 6 m, and 7 m. Using Equation (7), the frictional head loss (h_f) for a total pipe length of 5 m is obtained as 0.0226 m. If we take a sample configuration with a total suction pipe length of 5 m and one 45° elbow at the pump inlet, the corresponding loss coefficient (K) from Table 1 is 0.9. Therefore, the minor loss on the suction side, calculated using Equation (8), is 0.0383 m. To determine the atmospheric head (h_{atm}), Equation (4) is used, yielding a value of 9.581 m, while the vapor pressure head (h_v) is 0.401 m. Based on all the above parameters, the Net Positive Suction Head Available (NPSH_a) can be calculated using Equation (13) for various suction depths of -1 m , -2 m , -3 m , -4 m , and -5 m .

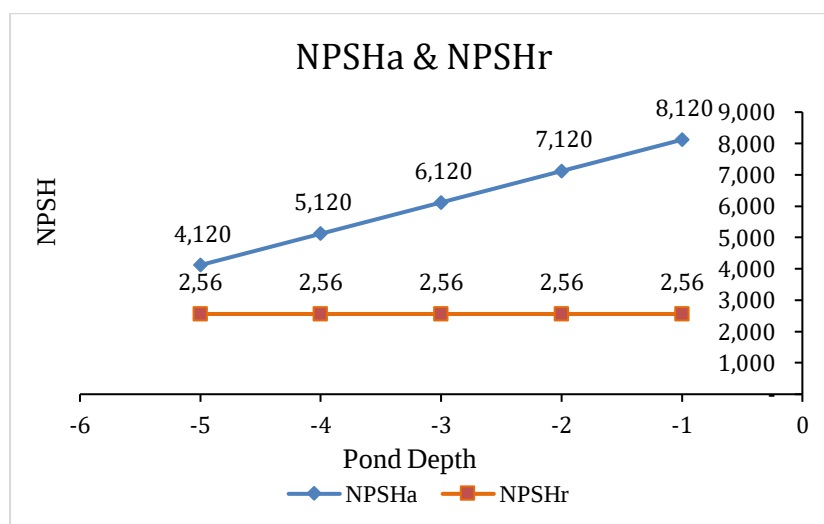


Figure 6. Graph of the Relationship between NPSH_a and NPSH_r.

In Figure 6 below, it is clearly shown that the NPSH_a curve lies above the NPSH_r line. At a suction depth of -1 m , the NPSH_a value is 8.120 m, while at the deepest point of -5 m , the NPSH_a value decreases to 4.120 m. However, the required NPSH (NPSH_r) for the PCP pump with a capacity of $60 \text{ m}^3/\text{h}$, discharge pressure of 10 bar, and pump diameter of 6 inches is 2.56 m.

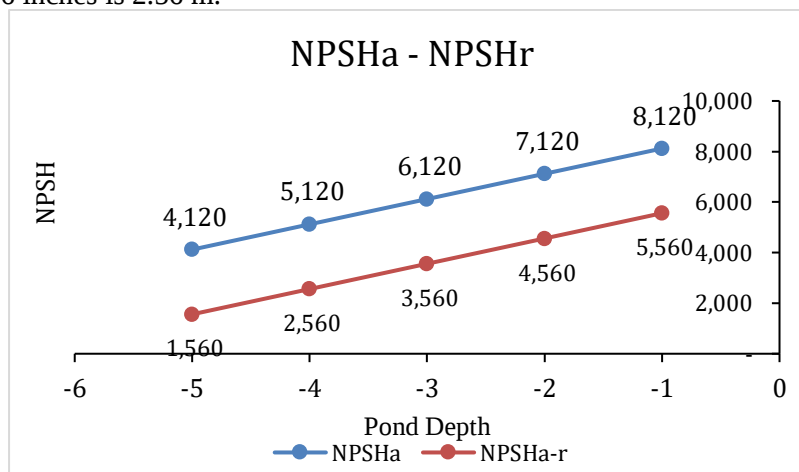


Figure 7. Graph of the Relationship Between NPSH_a and the Difference Between NPSH_a and NPSH_r.

Figure 7 illustrates the relationship between $NPSH_a$ and the difference between $NPSH_a$ and $NPSH_r$, where the value of $NPSH_a$ is relatively higher than its difference. At the shallowest depth of -1 m, the difference is 5.560 m, indicating excellent performance where the pump can safely operate to suction the sludge. At the deepest depth of -5 m, the difference is 1.560 m, showing that the pump can still operate effectively and normally, capable of drawing and lifting the organic sludge from the aerobic pond and delivering it efficiently to the land application (LA) canals.

Figure 8 shows that the difference between $NPSH_a$ and $NPSH_r$ remains above 1, in accordance with Equation (15). This demonstrates that the PCP pump is highly suitable for handling negative suction conditions, even at a depth of -5 m, where the sludge can still be effectively drawn and lifted. Therefore, the PCP pump can also be utilized for sludge pond draining operations without the need for an excavator. The PCP pump is capable of performing suction lift without cavitation since the difference between $NPSH_a$ and $NPSH_r$ remains greater than one at a depth of -5 m.

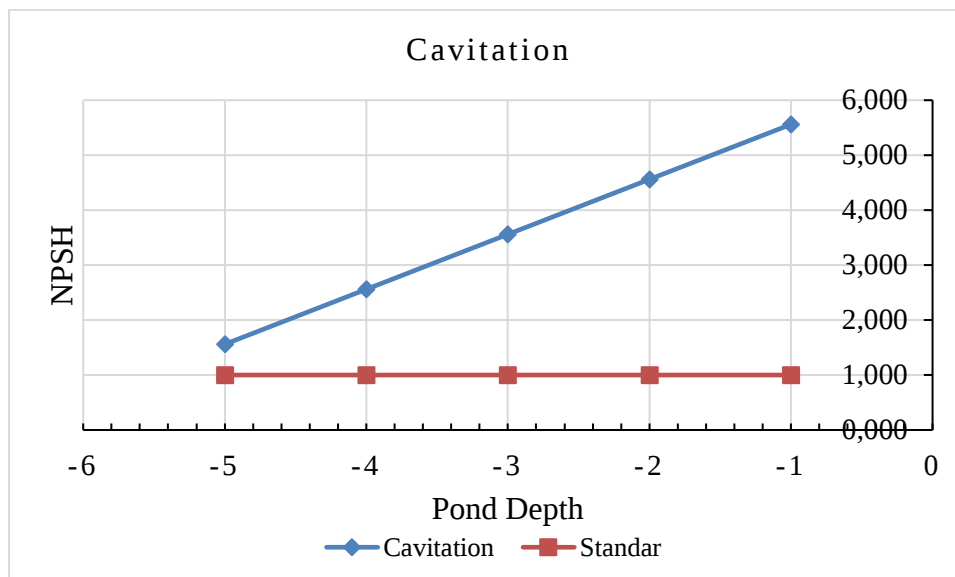


Figure 8. Graph of the Relationship Between $NPSH_a$ and $NPSH_r$ with respect to cavitation

Based on the inspection and observation results shown in Figure 7, the measured capacity of the PCP pump is **57 m³/h at a pressure of 4 bar**. This indicates that the PCP pump operates well within its specified range, which is **60 m³/h at 10 bar**, and is therefore highly suitable for pumping liquid sludge from the aerobic pond effectively into the oil palm plantation canals through the **land application piping system**.

CONCLUSION

Based on the data analysis and the relationship graph between $NPSH_a$ and $NPSH_r$, it can be concluded that the Progressive Cavity Pump (PCP) demonstrates excellent negative suction capability in the land application (LA) system of palm oil mills. Field measurements and calculations show that the $NPSH_a$ and values obtained at suction depths ranging from -1 m to -5 m consistently remain above the $NPSH_r$ value of 2.56 m, with a margin greater than 1 m. At a depth of -1 m, the $NPSH_a$ reaches 8.120 m, resulting in a difference of 5.560 m, while at -5 m the $NPSH_a$ is 4.120 m, with a difference of 1.560 m. These results indicate that the PCP effectively performs suction and lifting of organic sludge from aerobic ponds without cavitation, even under negative suction conditions up to -5 m. Therefore, the PCP has proven to be both effective and reliable in transferring organic sludge to palm oil plantation canals through the LA pipeline system. This capability positions the PCP as a suitable technological alternative to centrifugal pumps for distributing renewable liquid fertilizer derived from palm oil mill effluent, thereby supporting sustainable waste utilization in the plantation sector.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Ministry of Education, Culture, Research, and Technology (KEMENDIKBUDRISTEK) of the Republic of Indonesia for funding this research through the Beginner Lecturer Research Grant Program (Hibah Penelitian Dosen Pemula). Special thanks are also extended to PT. ANJ Binangan for their collaboration and support during data collection, as well as to Universitas Tjut Nyak

Dhien for serving as the authors' home institution. Finally, the authors convey their appreciation to all colleagues who have provided encouragement, assistance, and support, enabling the successful completion of this research and article.

REFERENCES

- Adam, et al. (2025). Studi computational fluid dynamics (CFD) untuk mendiagnosa kegagalan pompa injeksi air. *Jurnal Rekayasa Mesin*, 16(1), 507–520. <https://doi.org/10.21776/jrm.v16i1.2131>
- Berli, P., Niko, P., & Bambang, R. (2019). Ekstraksi parameter statistik domain waktu dan domain frekuensi untuk mendeteksi kavitas pada pompa sentrifugal berbasis principal component analysis (PCA). *Jurnal Rekayasa Mesin*, 10(2), 165–176. <https://doi.org/10.21776/ub.jrm.2019.010.02.8>
- Çengel, Y. A., & Cimbala, J. M. (2006). *McGraw-Hill series in mechanical engineering* (1st ed.). McGraw-Hill.
- Gobi, K., Mashitah, M. D., & Vadivelu, V. M. (2011). Development and utilization of aerobic granules for the palm oil mill (POM) wastewater treatment. *Chemical Engineering Journal*, 174(1), 213–220. <https://doi.org/10.1016/j.cej.2011.09.002>
- Imam, S. S., Sani, S., Mujahid, M., & Adnan, R. (2025). Valuable resources recovery from palm oil mill effluent (POME): A short review on sustainable wealth reclamation. *Waste Management Bulletin*, 3(1), 1–16. <https://doi.org/10.1016/j.wmb.2024.12.002>
- In-chan, S., Mamimin, C., Phruksaphithak, N., & O-Thong, S. (2024). Enhancement of biohythane production from palm oil mill effluent by *Thermoanaerobacterium thermosaccharolyticum* PSU-2 and methanogenic mixed cultures using a thermophilic two-ring bioreactor. *Carbon Resource Conversion* (August 2024). <https://doi.org/10.1016/j.crcon.2024.100273>
- Jelsma, I., Turinah, F., Gay, F., Ollivier, J., & Rapidel, B. (2024). Collective action, replanting and resilience: Key lessons from 40 years of smallholder oil palm cultivation in the Ophir plantation, Indonesia. *Agricultural Systems*, 213(June 2022). <https://doi.org/10.1016/j.agry.2023.103801>
- Joko, W., Kevin, M., & Rahmat, W. (2021). Analisis kinerja pompa sentrifugal pada variasi trim diameter menggunakan simulasi numerik. *Jurnal Rekayasa Mesin*, 12(2), 467–474. <https://doi.org/10.21776/ub.jrm.2021.012.02.23>
- Kim, D. Y., Kim, W. B., Choi, J., Sim, H. S., & Moon, J. H. (2023). Modeling consolidation of wax deposition for progressive cavity pump using computational fluid dynamics. *Engineering Science and Technology, an International Journal*, 41, 101384. <https://doi.org/10.1016/j.jestch.2023.101384>
- Müller, J., Leonow, S., & Mönnigmann, M. (2023). Optimal stator adjustment with minimal sensor requirements for variable stator progressing cavity pumps. *IFAC-PapersOnLine*, 56(2), 4614–4619. <https://doi.org/10.1016/j.ifacol.2023.10.969>
- Paliaga, S., et al. (2025). Resource recovery from wastewater treatment: Effects of water reuse and slow-release fertilizers on faba bean within Palermo University (Italy) case study. *Journal of Environmental Management*, 373(June 2024). <https://doi.org/10.1016/j.jenvman.2024.123839>
- Peng, G., Fan, F., Zhou, L., Huang, X., & Ma, J. (2021). Optimal hydraulic design to minimize erosive wear in a centrifugal slurry pump impeller. *Engineering Failure Analysis*, 120(November), 105105. <https://doi.org/10.1016/j.engfailanal.2020.105105>
- Shafaghat, A. H., Merenda, A., Seccombe, D., Phuntsho, S., & Shon, H. K. (2024). From waste to high-value fertilisers: Harvesting nutrients from liquid anaerobic digestate for a circular bioeconomy. *Desalination*, 596(October), 118266. <https://doi.org/10.1016/j.desal.2024.118266>
- Ugurluoglu, Y. F., Ferreira, A. M., Gentile, P., & Munguia, J. (2023). Conceptual design and development of a progressive cavity pump for extrusion-based additive manufacturing applications. *CIRP Journal of Manufacturing Science and Technology*, 46, 191–203. <https://doi.org/10.1016/j.cirpj.2023.08.011>
- Wang, H., Chen, X., Chen, B., Yang, M., & Zhang, B. (2025). Switchable biomaterials for wastewater treatment: From material innovations to technological advancements. *Chemical Engineering Journal*, 509(December 2024), 160928. <https://doi.org/10.1016/j.cej.2025.160928>
- Wang, H., Tan, Z., Kuang, S., & Yu, A. (2023). Systematic investigation of centrifugal slurry pump under different operating condition by DDPM method. *Powder Technology*, 430(September), 119024. <https://doi.org/10.1016/j.powtec.2023.119024>
- Wang, H., Tan, Z., Kuang, S., & Yu, A. (2025). DDPM investigation on centrifugal slurry pump with inlet and sideline configuration retrofit. *Powder Technology*, 449(August 2024), 120386. <https://doi.org/10.1016/j.powtec.2024.120386>

- Wang, S., Li, Z., Wu, L., Shi, L., Yang, H., & Yu, H. (2025). Assessing rainfall infiltration dynamics and effluent assimilation capacity for land application of treated wastewater. *Desalination and Water Treatment*, 321(November 2024), 100971. <https://doi.org/10.1016/j.dwt.2024.100971>
- Wróbel, J., Pietrusiak, D., Rozmus, R., Roicki, R., Zarzycki, B., & Stefanek, P. (2025). Failure analysis and guidelines for further exploitation of centrifugal slurry pumps used for copper flotation waste transport: A case study. *Engineering Failure Analysis*, 174(February). <https://doi.org/10.1016/j.engfailanal.2025.109479>
- Zahir, S. A. D. M., et al. (2025). Quantifying the impact of varied NPK fertilizer levels on oil palm plants during the nursery stage: A Vis-NIR spectral reflectance analysis. *Smart Agricultural Technology*, 11(November 2024), 100864. <https://doi.org/10.1016/j.atech.2025.100864>