Experimental Analysis of Water Jet Pump Performance and Throat Diffuser Loss Coefficient: An Empirical Correlation

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Abstract: Water jet pumps are widely used in industry, with performance influenced by geometric parameters such as angle, length, and diameter. This study investigates the effects of projection and throat aspect ratios on pump efficiency and diffuser loss coefficient. Nine experimental cases were conducted, and two predictive correlations were developed using nonlinear regression. The correlations were validated against experimental results within the dimensionless range of projection ratio (1-3) and throat aspect ratio (5-9), with marginal errors of 5% for performance and 10% for the loss coefficient. The results have a good agreement with the experiment, offering performance enhancement in design framework.

Keywords: projection ratio; throat aspect ratio; throat diffuser loss coefficient; water jet pump performance

1. Introduction

Water jet pumps are categorized as an artificial lift method. A specific type of subsonic ejector uses liquid as both the motive and additional flows. It facilitates the momentum transfer from a stream with a higher velocity to one with a lower velocity[1)]. It finds widespread application across various industries such as chemical processing, energy conversion, agriculture, and even the food sector. The key attributes of this system encompass no moving parts, simplicity, reliability, long-lasting durability, and a relatively affordable cost. Among its main drawbacks is its relatively low efficiency[2)]. Jet pump inefficiency is frequently a result of friction, the dynamics of jet flow, the mixing of fluid streams, recirculation phenomena, and the subsequent pressure recovery [3)]. In addition, it also appears due to poor design, manufacturing process, and system installation. Nonetheless, it can be effectively controlled through a suitable combination of operational parameters[4)], structural configurations[5–8)], fluid characteristics[9,10)], and the positioning of the jet pump installation[11–14)].

Water jet pumps are widely used in various industries due to their simple construction and reliable operation. A typical jet pump consists of a primary and secondary fluid inlet, a suction chamber, a converging mixing section, a throat, and a diverging section (diffuser), as shown in Figure 1. Among the many design parameters, five key dimensionless groups govern the jet pump's performance: (a) the nozzle-to-throat area ratio (A_{on-t}^{*}), (b) the throat aspect ratio (L_t^{*}), (c) the converging–diverging section angle ratio (θ_{cd}^{*}), (d) the projection ratio or nozzle tip offset (L_x^{*}), and (e) the suction chamber area ratio (A_{s-on}^{*})[15,16)].

Among these, L_t^{*} and L_x^{*} are independent geometric parameters that significantly affect flow development and diffuser performance. However, Cunningham's classical one-dimensional model[17)] only accounts for vertical (y-direction) dimensions such as diameters, neglecting longitudinal effects (x-direction). This simplification leads to limited predictive capability, especially for configurations where projection and throat length play a dominant role. Consequently, most researchers have relied on experimental studies to understand the effects of L_t^{*} and L_x^{*} [18–20)].

Over the last several decades, experimental studies have investigated how these two parameters influence performance. For instance, Hammoud and Naby[21)] and Mekhail and Teaima[22)] analyzed the effect of L_x^{*} at various motive pressures, identifying optimum L_x^{*} values ranging between 0.5 and 1.25. El-Sawaf et al., reported optimal performance at L_x^{*} = 1 and L_t^{*} = 7.25[23)]. Helios and Asvapoositkul confirmed that small values of L_x^{*} and L_t^{*} yielded the highest efficiency, around 23.4%[24)]. Despite

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these findings, there is no general correlation or regression model that quantifies the combined effect of L_x^* and L_t^* on efficiency or pressure losses. To sump up, the optimal L_x^* and throat aspect ratio for water jet pumps are typically found within the intervals of 0.5 to 1.25 and 5 to 10, respectively[17,20,21,25,26].

In addition to affecting performance, repositioning components and extending parts can lead to increased energy losses. Losses in mechanical energy, which are converted into internal energy, are the primary source of energy losses within a flow field. From a thermodynamic perspective, the conversion process of both energy forms maintains the total energy conservation, in accordance with the principles outlined in the first law of thermodynamics[27]. From a fluid mechanics standpoint, individual components within an internal flow lane, such as expansion channels, bends, straight tubes, and contraction channels, are denoted as head loss coefficients (K). By measuring the pressure decrease when internal flows occur in the conduit, the K can be calculated.[28]. Nonetheless, this equality occurs solely when there is no change in kinetic and potential energies between the two cross sections, signifying that it corresponds solely to a loss of mechanical energy[29]. Water jet pump performance is directly influenced by the throat diffuser head loss coefficient (K_{td}). This coefficient is a combination of the loss coefficients at the throat (K_t) and the diffuser (K_d). The assumed value is utilized in the design process and needs to be reassessed following testing[17,25]. Cunningham[17] noted that a longer or persistent mixing procedure modified the actual K_t with rising ratio of volumetric. In addition, the pump's efficiency is progressively declining as the throat loss coefficient rises[30]. The abrupt increase in K_d within the diffuser may suggest a separation phenomenon occurring in the diffuser wall. However, previous studies often neglected to include pressure taps on the throat section, which restricted the assessment of K_{td} solely through practical examination.

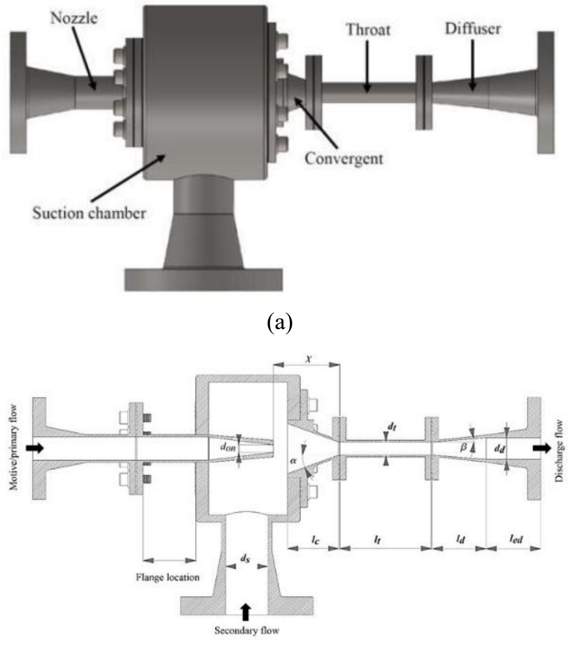
Recent literature has explored various additional factors such as throat shape, mixing length, and nozzle spacing[31–34], but still lacks an integrated regression model that links key geometric ratios to both efficiency and head loss coefficients. Therefore, this study aims to develop a new regression equation that quantifies the influence of L_t^* and L_x^* on water jet pump performance, focusing specifically on optimum efficiency and the throat-diffuser head loss coefficient.

Based on the author's understanding, there is no further exploration or discussion regarding the link between these parameters and the optimal performance and loss coefficient of the throat diffuser. Therefore, it is still necessary to investigate both independent parameters in order to improve and promote performance. Furthermore, this research aims to get the highest performance and estimates the loss coefficient of a water jet pump through experimentation by adjusting the projection and throat aspect ratios. Later, two regression equations were linked to Cunningham's model for enhancing the accuracy of performance, throat diffuser loss coefficient, and proper L_x^* prediction and reducing time of water jet pump design framework.

2. Methods

2.1. Water jet pump and parameters of study

The original water jet pump dimensions were obtained from the National Research and Innovation Agency's Technology Laboratory for Thermodynamics, Engines, and Propulsion in Indonesia. The design is developed in accordance with ESDU standards[35,36], with a multipurpose focus to support Indonesia's power generation and agricultural sectors. The finalized design parameters for the centrally driven water jet pump are summarized in Table 1. Based on established literature, L_x^* and L_t^* are set to 1 and 7 times the throat diameter, respectively. Fabrication and testing of the jet pump assembly are permitted in order to acquire the actual performance. It is built of stainless steel (SS-304) because of its great resilience and endurance for prospective research studies. Essentially, the suitable L_x^* and L_t^* selection plays crucial role in attaining the performance outlined in the design. Both parameters are specifically chosen due to their crucial role in affecting the flow behavior. The transfer of momentum and cavitation are associated with L_x^*, whereas the mixing process and friction loss are linked to the throat aspect ratio. Hence, L_x^* and L_t^* have been selected as parameters of this experiment as presented in



(a)

(b)

Fig. 1: Geometry of water jet pump: 3D Assembly (a) and Schematic parameters of study (b)

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Table 1*:* Dimension and non-dimension parameters of the water jet pump[37)]

Parameter	Unit	Value
d_{on}	mm	7.1
d_s	mm	35.0
d_t	mm	12.7
d_d	mm	18.9
x	mm	12.7
l_c	mm	49.0
l_t	mm	88.9
l_d	mm	51.5
l_{ed}	mm	52.4
α	º	20.0
β	º	3.5
$A^*_{on-t} = \left(\frac{d_{on}}{d_t}\right)^2$	-	0.303
$L^*_t = \frac{l_t}{d_t}$	-	7.0
$\theta^*_{cd} = \frac{\alpha}{\beta}$	-	5.7
$L^*_x = \frac{x}{d_t}$	-	1.0
$A^*_{s-on} = \left(\frac{d_s^2}{d_t^2 A^*_{on-t}} - 1\right)$	-	47.61
$A^*_{d-t} = \left(\frac{d_d}{d_t}\right)^2$	-	2.21

Table 2. To achieve the objective of this paper, the experimental setup comprising both the schematic design and the instrumentation has been adopted from our previous research. This approach ensures continuity in methodology and allows for consistent comparison with earlier findings[24)].

2.2. Evaluation of performance and loss coefficient

Principally, the jet pumps function by capturing the secondary fluid (Q_s) with the primary liquid (Q_p) at lower pressure levels, subsequently transporting it to the discharge point under specific pressure conditions. Two performance parameters, specifically the ratio of volumetric (Q^*) and ratio of pressure (P^*), are launch as non-dimensional ratios. The expression of both these parameters is provided below[17,36)]:

$$Q^* = \frac{Q_s}{Q_p} \tag{1}$$

$$P^* = \frac{P_d - P_s}{P_p - P_d} \tag{2}$$

The variables Q and P denoted the volume flow rate (L/min) and absolute pressure (Pa), respectively. Subscripts p, s, and d are used to indicate the primary, secondary, and discharge states, respectively (refer to Figure 1). Hence, the performance equation (η) for the jet pump can be formulated as follow**:**

Table 2*:* Experimental testing matrix

No. of Testing	Parameters	
	$L^*_x = \frac{x}{d_t}$	$L^*_t = \frac{l_t}{d_t}$
1	1	5
2	1	7
3	1	9
4	2	5
5	2	7
6	2	9
7	3	5
8	3	7
9	3	9

$$\eta = \frac{Q_s}{Q_p} \times \frac{P_d - P_s}{P_p - P_d} \tag{3}$$

In the case of loss coefficients, the analysis focuses on K_{td}, which dominates energy dissipation in the jet pump when the ratio of volumetric changes. The K_{td} value is evaluated using an iterative solver solution in an MS Excel sheet. The value of the loss coefficient is accepted when the error value between numerical and experimental value achieves the minimum error criteria. The formulation for performance evaluation has been relegated[37)].

In order to obtain the relation between projection and throat aspect ratios on performance statistically, the non-linear multiple relation regression is applied. Nonlinear multiple regressions are used to derive an empirical approximation of each variable. The details of nonlinear multiple regression in logarithmic and linear space can be found in Tsykin[38)]. In this case, a nonlinear equation form for performance and throat diffuser loss coefficient was developed by using four variables as predictors and a determined parameter as predictors. Thus, the equation in the linear space is written as:

$$\eta = a(L^*_x)^b (L^*_t)^c (Q^*)^d (P^*)^e \tag{4}$$

$$K_{td} = a(L^*_x)^b (L^*_t)^c (Q^*)^d (P^*)^e \tag{5}$$

3. Results

3.1. Loss coefficient determination

Since the water jet pump was designed by assuming a constant *K* and full jet loss occurred during the suction process. The actual loss coefficient, especially K_{td}, was required to be determined and evaluated through trial-and-error numerical calculation. It was useful to know the effect changing of both ratios on the loss coefficient and to improve jet pump performance. Using Cunningham's method, it was assessed that the lowest K_{td} was estimated at about 0.21, corresponding to η_{op} = 24.52%. This value was close to K_{td} of the water jet pump design.

Figure 2. illustrates that as L_x* and L_t* increase, there is a

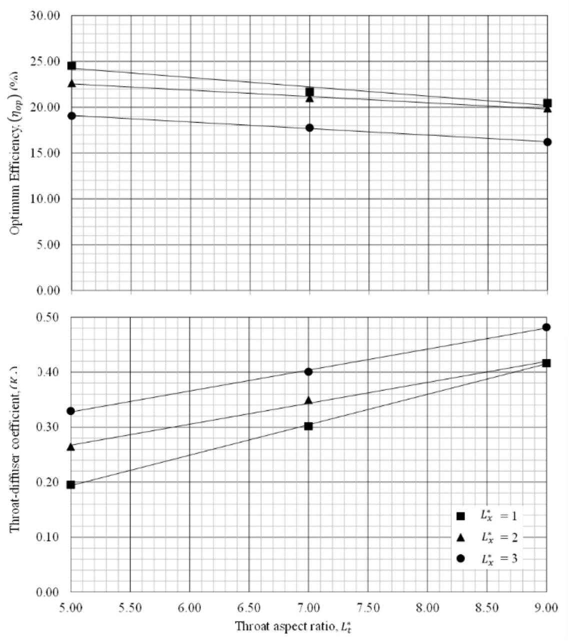

Fig. 2: Optimum performance (η_{op}) and throat diffuser loss coefficient (K_{td})

corresponding decrease in optimum efficiency and an increase in the throat diffuser loss coefficient. This trend is consistent with the established principle that higher loss coefficients lead to reduced pump efficiency. The value of K_{td} indicated that the energy dissipation occurred either in the throat or in the diffuser. Increasing two times L_x^* leads to a growth in K_{td} by about 30%. Similarly, the raising of L_t^* triggers the loss coefficient to climb up to about 25%.

Utilizing the experimental results from nine configurations, the proven correlation to predict the performance and throat diffuser loss coefficient of a water jet pump was engendered by involving both geometrical parameters, Q^* and P^* as shown in Figure 3. Using the regression method, the correlation can be written as:

$$\eta = 100.2134\left(\frac{x}{d_t}\right)^{0.00036}\left(\frac{l_t}{d_t}\right)^{0.00051}\left(\frac{Q_s}{Q_p}\right)^{1.00186}\left(\frac{P_d-P_s}{P_p-P_d}\right)^{1.00209} \qquad (6)$$

The correlation was a nonlinear relation and had a coefficient of determination higher than 0.90. It was able to predict jet pump performance with less than ± 5% margin error. However, this correlation was not only valid for the nozzle throat area ratio (A_{on-t}^*) in this case but also for other diffuser throat area ratios (A_{d-t}^*). Since there is no present correlation study, the consistency error of correlation is required to be validated with literature data. Figure 4. shows a comparison of efficiency predictions from the regression correlation against experimental

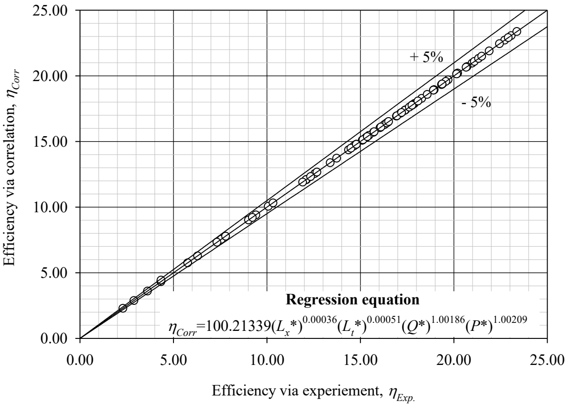

Fig. 3: Comparison of regression equations for performance with present experimental data

results for four different geometric configurations. The correlation aligns closely with the experimental data, with most points within ±5% error in Figure 4(a), 4(c), and 4(d), and within ±10% in Figure 4(b). A slight tendency to overestimate efficiency is noted, with deviations in A_{on-t}^* below 0.1. These discrepancies likely arise from variations in operating conditions such as flow rate and pressure, as well as differences in geometric parameter (L_x^* and L_t^*) highlighted in each subplot. Measurement uncertainties due to instrument calibration and accuracy may also contribute. Additionally, the model was developed using a limited range of dimensionless parameters, which restricts its predictive accuracy outside these bounds.

Similar to the performance correlation, K_{td} correlation was presented by involving the same ratios. Figure 5. shows K_{td} correlation of nine configurations of jet pumps. It was able to assess and evaluate K_{td} with a margin error of ± 10%. In another form, the correlation can be written as:

$$K_{td} = 0.04935\left(\frac{x}{d_t}\right)^{0.27721}\left(\frac{l_t}{d_t}\right)^{0.9091}\left(\frac{Q_s}{Q_p}\right)^{-0.00616}\left(\frac{P_d-P_s}{P_p-P_d}\right)^{-0.01321} \qquad (7)$$

Since there are limited studies that provide a correlation between the throat diffuser loss coefficient. The present correlation is only valid for the following dimension ranges: $1 \le L_x^* \le 3$ and $5 \le L_t^* \le 9$. These limitations imply that extrapolating the correlation beyond these ranges may result in inaccurate predictions due to unaccounted geometric and flow effects. Therefore, engineers should ensure design parameters fall within these validated ranges for reliable applications. For future work, extending the dimension ranges through additional experimental and computational studies is recommended to enhance the correlation's applicability and provide more comprehensive design guidance.

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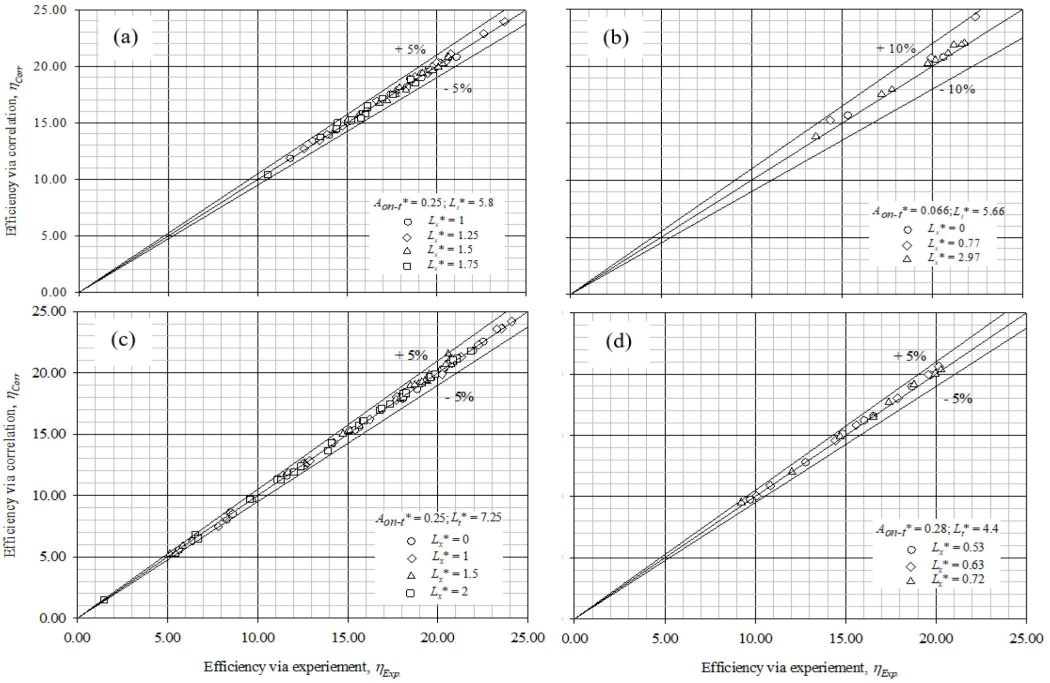

Fig. 4: Comparison of regression equations of efficiency to literature data: (a) Hammoud [5)], (b) Sanger [21)], (c) El-Sawaf, et al [23)], and (d) Gugulothu & Manchikatla[39)]

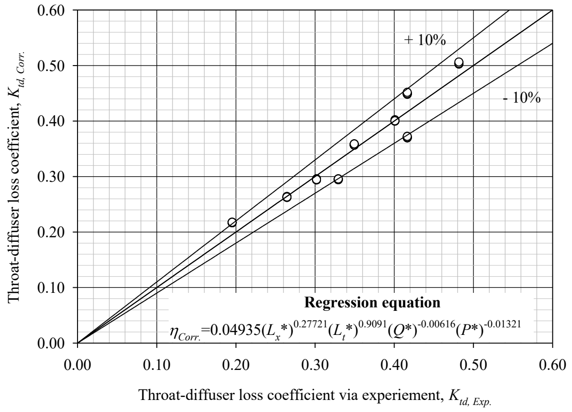

Fig. 5: Comparison of regression equations for throat diffuser loss coefficient with present experimental data

4. Conclusion

This study experimentally investigated the influence of L_x^* and L_t^* on the hydraulic performance and loss characteristics of a water jet pump. A total of nine geometric configurations were tested, covering three variations of each parameter. The experimental results revealed that the highest pump efficiency reached 23.37%, and the corresponding throat-diffuser loss coefficient was 0.195. These values closely matched the outcomes predicted by the numerical design, which were 24.52% efficiency and 0.2 for K_{td}, thereby validating the experimental setup and confirming the reliability of the observed trends.

Subsequently, regression analysis was performed using the dataset from the nine test cases to develop two new empirical correlations that quantify the relationship between jet pump performance parameters η_{op} and K_{td} and the geometric ratios L_x^*, L_t^*. The proposed correlations demonstrated strong predictive capability, with deviations of less than ±5% for efficiency and ±10% for K_{td} when compared against experimental results.

These findings provide a practical tool for preliminary design and optimization of jet pumps by enabling more accurate prediction of performance metrics based solely on geometric parameters. Future work should include both a CFD based sensitivity analysis to refine the correlations under wider operating conditions, and a formal uncertainty analysis to strengthen the experimental validation.

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Nomenclature

d	diameter
l	length
x	distance between nozzle tip and throat entry
Q	volume flow rate
Q^*	ratio of volumetric
A^*	area ratio
L^*	aspect ratio
K	head loss coefficient
P	absolute pressure
P^*	ratio of pressure
a, b, c, d, and e	predictors
Greek symbols	
α	converging section angle
β	diverging/diffuser angle
η	performance
θ^*	section angle ratio
Subscripts	
on	outlet nozzle
s	suction
t	throat
d	diverging/diffuser
c	converging section
de	diffuser extended
p	primary fluid at lower pressure levels
s	secondary fluid at lower pressure levels
d	dicharge fluid at lower pressure levels
op	optimum
on-t	nozzle throat
cd	converging-diverging
x	projection
s-on	suction chamber
d-t	diffuser to throat
td	throat diffuser

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