Performance Prediction And Loss Estimation Of Centrifugal Pumps

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ABSTRACT

The centrifugal pumps are widely used in distribution system in various plants to overcome gravity and friction losses in pipes to move fluids with high efficiency. In order to improve the performance of the pump, hydraulic losses should be reduced. In the present study, an attempt is made to calculate the losses produce in centrifugal pump, which affect the hydraulic efficiency, with the use of theoretical models given by the various researchers. In the present study two loss models are studied which were previously published in the open literature and tried to find a convenient loss model for a reliable performance prediction of centrifugal pump. In this paper an attempt has also been made to give some information about the contribution of losses of different component of pump in total loss. A loss analysis has been presented to predict and improve the performance of centrifugal pump. Head vs flow characteristic curves obtained at design speed from the loss models are compared with the manufacturer's curves. Prediction of the shape of total head-flow curves are in good agreement with the manufacturer's data and from the study it is found that Gulich model is very convenient to predict the hydraulic losses.

Keywords: Centrifugal pumps, Performance, Hydraulic losses.

NOMENCLATURE

A	Area
A_R	Area Ratio
b	Width
C	Constant or Coefficient
c	Absolute velocity
C_d	Dissipation Coefficient
C_f	Coefficient of Friction
Csf	Coefficient of Skin Friction
CVD	Coefficient of diffuser
d	Diameter
D_h	Hydraulic Diameter
f	Friction Factor
g	Gravitational Acceleration
H	Head or Head Loss
L	Path Length
L_b	Length of Blade
N_b	Number of Blades
Q	Flow Rate
Re	Reynolds Number
R_h	Hydraulic Radius
u	Impeller Rotational Velocity
w	Relative Velocity
Subscript	
1	Inlet
1q	Inlet Throat
2	Outlet
3	Volute Inlet
a	Inlet
av	Average
b	Outlet
D	Discharge Nozzle
difn	Diffusion
F	Friction
FD	Friction and Diffusion

FM	Friction and Mixing
h	Hydraulic
im	Impeller
IN	Incidence
m	Mean
M	Mixing
q3	Volute Throat
SF	Skin Friction
th	Theoretical
vol	Volute
GREEK LETTERS	
ζ	Coefficient
$\in$	Roughness
ΔA	Wetted Area
φ	Flow Coefficient
τ	Blade Blockage
λ	Angle of twist

1 INTRODUCTION

Pumps are widely used throughout society for various purposes. Irrigation, water supply, steam power plants, oil refineries, air conditioning systems are some of the main applications. Centrifugal pumps are used in water distribution systems to overcome gravity and friction losses in pipes to move water. Low specific speed high speed centrifugal pumps are widely used in petrochemical and chemical industries to deliver low flow rate and high head liquids. But there exist many problems required to be solved, such as how to improve the efficiency of the pump. Various ways have been tried to reduce the mechanical and hydraulic loss in order to increase efficiency. In other words, both mechanical and hydraulic loss should be minimized. The hydraulic part is the main concern here.

Hydraulic losses consist of the losses in the different parts of the centrifugal pump, such as impeller, volute or diffuser. During the past several decades, various empirical loss correlation models have been persistently developed, some are well documented in the textbook by Tuzson [1] Gulich [2] and A. J. Stepanoff [3]. Tuzson [1] gives the correlation for the loss calculation with simple and fast procedure with minimum input requirements. Gulich [2] presents a loss model with various losses in various components of centrifugal pump. Thanapandi et al. [4] investigates dynamic behavior by experiment and compared with the prediction model and found that predicted results agree well with the experiment. Feng li [5] compared the results obtained from model with the experiment and modified loss coefficient in order to match the predicted results with experiment. Khin cho thin et al. [6] designed a centrifugal pump and performance analysis is predicted. Djebedjian [7] predicts performance of centrifugal pump when its impeller is equipped with splitter blades by theoretical model. He compared the results obtained from model with experiments and found that predicted results are in good agreement with the experiment. Nzumbe et al. [8] estimated the theoretical characteristic for centrifugal pump and compared with manufacturer's characteristic. They conclude that the theoretical characteristic lies between ideal and manufacturer's characteristic. Wen-guang li [9] examined various outlet blades and liquids with various viscosity, experimentally and by loss model. Thanapandi et al. [10] presented a performance prediction procedure for low specific submersible pump. Efficiency and head obtained by prediction procedure is compared with experimental results and they agree well with experimental results. H W Yooh et al. [11], they tested various loss models for centrifugal compressors and found optimum set of empirical loss models for a reliable performance prediction.

Co-relation among various hydraulics losses contains many geometrical variables which are difficult to calculate. Losses are calculated using the two models prescribed above, and corresponding head-flow curves are obtained. Their curves are compared for closeness with the manufacturer's head-flow curve.

2 LOSS MODELS:

The performance calculation of the centrifugal pump is based upon the loss co relations. There are many loss models available for prediction of the losses. In the present study mainly two models are used.

2.1 Tuzson [1]:

Tuzson takes the following internal losses into consideration for the calculating of hydraulic losses (a) Incidence loss, (b) frictional head loss, (c) Volute head loss, (d) Diffusion loss and (e) Diffuser loss.

2.1.1 Incidence loss:

It is calculated by assuming a leading-edge separation and a sudden expansion loss, when the separated flow is mixed. The inlet incidence loss calculated by:

$$H_{INim} = \left(\frac{u_1 - c_1 \tan \beta_1}{2g}\right)^2 \quad (1)$$

2.1.2 Frictional head loss:

It is the loss produced by the friction between the fluid and the surface of the pump component. The loss in the impeller is given as:

$$H_{SF,im} = \left\{ \frac{\begin{gathered}\text{csf}\,[(d2/d1)/(2\cos\beta_2)] \\ (1/R_{h12})(W2 + W1)^2\end{gathered}}{4g} \right\} \tag{2}$$

The loss in the volute passage is given as:

$$H_{SF,vol} = csf\left(\frac{\pi d_3}{\sqrt{\frac{A_3}{\pi}}}\right)\left(\frac{c_{q3}}{2g}\right) \tag{3}$$

Where *csf* is the coefficient of skin friction.

2.1.3 Volute head loss:

It is the result of the difference between the velocity leaving the impeller and the velocity at volute throat.
The volute head loss can be calculated by:

$$H_{IN,difr} = 0.8\frac{\left(c_3^2 - c_{Q3}^2\right)}{2g} \tag{4}$$

2.1.4 Diffusion loss:

Separation may appear in the impeller at some point then the diffusion loss needs to take into account. When the ratio of relative velocity at inlet and outlet exceeds a value of 1.4, portion of velocity head is lost, which is given by:

$$H_{difn} = \frac{0.25W_1^2}{2g} \tag{5}$$

2.1.5 Diffuser loss:

Diffuser head loss is given as:

$$H_{difr} = \text{CVD}\left(\frac{c_{Q3}^2}{2g}\right) \tag{6}$$

The value of CVD is adjustable.
The Co relation for the theoretical head given by Tuzson is,

$$H_{th} = \frac{u_2 c_{t2}}{g} = \frac{u_2^2 - u_2 w_{m2}\tan\beta_2}{g} \tag{7}$$

2.2 Gulich [2]:

Gulich proposed a model for calculating the losses in the (a) impeller, (b) volute and (c) diffuser. He has given the co-relations for the coefficient used in calculation of the losses.

2.2.1 Hydraulic losses in impeller:

The coefficient for losses in the impeller is given as:

$$\zeta_{im} = \zeta_{im,fm} + \zeta_{im,s} \tag{8}$$

He considers the impeller losses include the friction, mixing losses and shock losses.
The friction loss coefficient is given as:

$$\zeta_{im,fm} = 4C_d\frac{L_b}{D_h}\left(\frac{W_{av}}{u_2}\right)^2 \tag{9}$$

The shock loss in the impeller is given as:

$$\zeta_{in,s} = 0.3\left(\frac{W_{1m} - W_{1q}}{u_2}\right)^2 \tag{10}$$

2.2.2 Hydraulic losses in the volute:

The coefficient for the volute loss is given as:

$$\zeta_{vol} = \zeta_{vol,f} + \zeta_{vol,d} + \zeta_{vol,s} \tag{11}$$

The volute loss coefficient consists of the coefficient for the losses by friction, shock, and discharge nozzle.
Coefficient for friction loss is given as:

$$\zeta_{vol,f} = \frac{1}{Qu_2^2}\sum\left(c_f + 0.0015\right)c^3\Delta A \tag{12}$$

Coefficient for losses in discharge nozzle is given as:

$$\zeta_{vol,d} = \frac{c_X^2}{u_2^2}\left(1 - c_p - \frac{1}{A_R^2}\right) \tag{13}$$

Coefficient for shock loss is given as:

$$\zeta_{vol,s} = \varphi_{2,La}^2\left(\tau_2 - \frac{b_2}{b_3}\right)^2 \qquad (14)$$

3 RESULTS AND DISCUSSION

The proposed methods are used to estimate the performance of a centrifugal pump. The comparison of predicted head by both methods and the head provided by the manufacturer is presented in this section. The calculations were done using Matlab programming, which includes main dimensions, empirical loss models and performance prediction. The hydraulic losses obtained from the selected models are subtracted from the ideal head calculated from Euler's head equation to obtain the actual head. The recorded data obtain from the loss model will be helpful in identifying the effective model and estimating empirical quantities for a pump of a given specific speed.

Four centrifugal pumps are taken with various specific speeds such as specific speeds 19.83 rpm, 28.91 rpm, 38.47 rpm and 53.43 rpm for the study of losses. The specification and the dimensions of the centrifugal pump used in the analysis are given in Table 1.

Table 1 Specification and Dimensions of the Centrifugal Pump

	Ns 19.83	Ns 28.91	Ns 38.47	Ns 53.43
Rotational Speed	2900 rpm	2900 rpm	2900 rpm	2900 rpm
Suction diameter	100 mm	100 mm	100 mm	100 mm
Discharge diameter	63.5 mm	100 mm	100 mm	63.5 mm
Impeller				
Inlet diameter	119.7 mm	82.5 mm	93.2 mm	109 mm
Outlet diameter	260 mm	168 mm	158.2 mm	140.8 mm
Inlet vane angle	8.2	22	19	19
Outlet vane angle	26	35	23	23
Inlet passage width	59 mm	44 mm	45 mm	65 mm
Outlet passage width	14 mm	15.5 mm	21.2 mm	26.5 mm
Vane number	5	6	6	6
Volute				
Throat diameter	50 mm	70 mm	70 mm	85 mm
Radius at tongue (from impeller center)	150 mm	90 mm	75 mm	75 mm

The results obtained by solving the models are compared with each other and with the performance given by the manufacturer. Compared head and flow characteristics various pump with various specific speed are given in the Figure 1 to Figure 4.

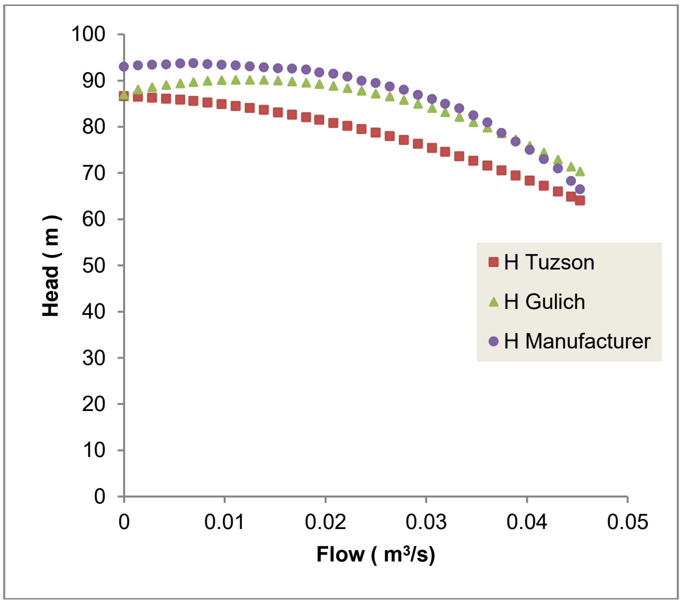

Figure 1 H-Q characteristic of pump with specific speed 19.83

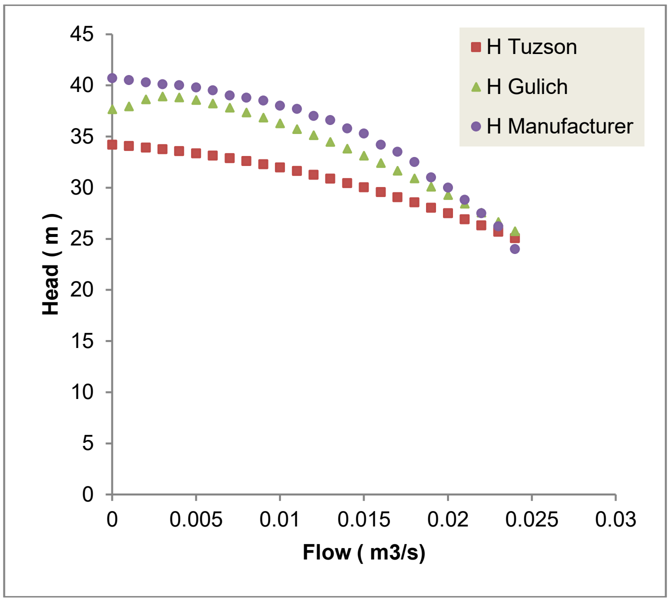

Figure 2 H-Q characteristic of pump with specific speed 28.91

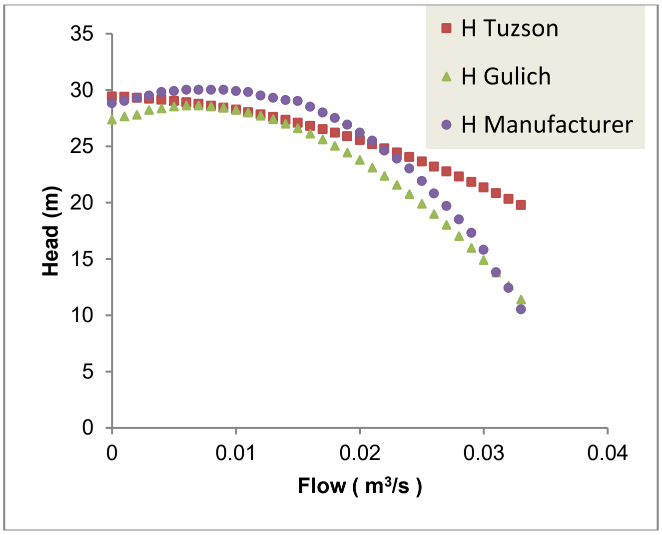

Figure 3 H-Q characteristic of pump with specific speed 38.47

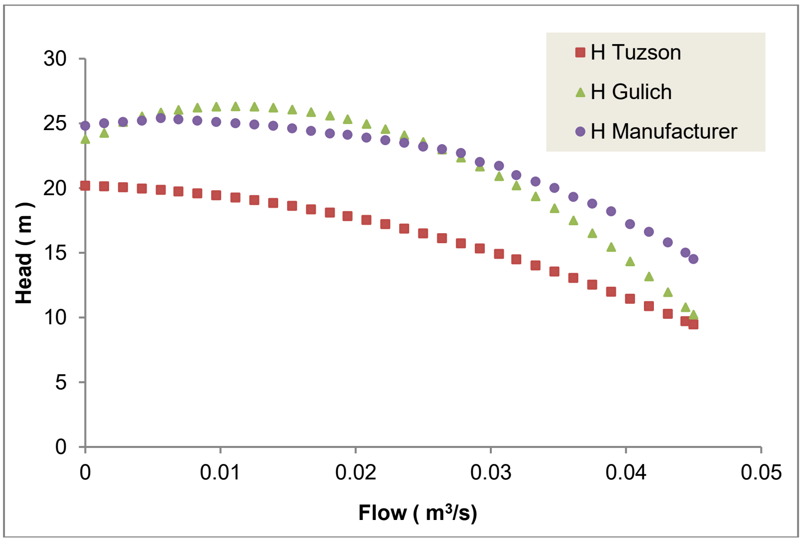

Figure 4 H-Q characteristic of pump with specific speed 53.48

Figure 1, 2, 3 and 4 shows the results obtained from the two loss models suggested by Tuzson [1] and Gulich [2] for the various specific speed pumps. From the Figure it is clear that the loss model suggested by Gulich [2] predicts losses with good accuracy. Head obtained by Gulich [2] model agrees well with the manufacturer's head. The Tuzson model also predicts quite good results, but it has been seen that in a 53.43 rpm specific speed pump it predicts more losses than the losses given by the pump manufacturer. It means the Gulich [2] model is more convenient and accurate than the Tuzson model in theoretically prediction of the hydraulic losses for the entire range of specific speed pumps taken for this study. But the Tuzson [1] model is easy and fast to predict the losses because it requires minimum geometrical parameters. Moreover, the Gulich [2] model may be accurate due to it requiring more geometrical parameters and it is quite difficult to calculate the losses.

Table 2 Loss analysis of the centrifugal pump at BEP.

Pumps (Specific Speed, rpm)	**Model**	**Losses in Impeller (% of total loss)**	**Losses in Volute (% of total loss)**
19.83	Tuzson	27.17	69.83
	Gulich	11.90	86.47
28.91	Tuzson	20.95	66.27
	Gulich	17.19	75.66
38.47	Tuzson	25.82	67.43
	Gulich	10.31	84.22
58.48	Tuzson	32.25	50.69
	Gulich	18.68	68.96

Table 2 shows the losses in percentage of total loss calculated from two loss models given by Tuzson and Gulich at best efficiency point. From both of these models it is possible to predict contribution losses in different components. The model suggested by Tuzson [1] predicts the different types of losses and the model suggested by Gulich [2] predicts the losses occur in different components of the centrifugal pump. It has been seen from the present study that according to Tuzson model losses in impeller are about 20 to 30 % of the total loss for all the pump whereas according to the Gulich model losses in impeller is about 10 to 20 % of the total loss. The Tuzson model predicts that the losses in volute are about 50 to 70 % of the total loss and the Gulich model predicts that losses in volute are about 70 to 85 % of the total loss. From this analysis it is clear that the losses in volute are more than the losses in impeller [10]. This shows that volute has an important role in the performance of the pump. From this analysis it is clear that care should be taken in designing the volute and the incidence angle of the volute throat to reduce the hydraulic losses.

4 CONCLUSIONS

In this study four centrifugal pumps with various specific speeds have been analyzed for the performance, the following conclusions are derived from the results obtained from two loss models.

- The Gulich model is more accurate than the Tuzson model in prediction of the losses in centrifugal pump.
- The Tuzson model is fast and easy to predict the losses.
- Both models predict that the volute has significant effect on the performance of the centrifugal pump.

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