Performance correction chart of centrifugal oil pump for handling viscous liquids

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Abstract. The viscosity of oil has a pronounced impact on the operating conditions of the pump. Pumps that are tested with water but are used to transport viscous fluids must have their head, flow, and efficiency values corrected to approximate their performance with the viscous fluid. In this article the hydraulic characteristics of centrifugal oil pumps with different specific speeds for pumping viscous fluids are studied experimentally. The relationship of correction factor with performance characteristics, rotational speed and oil viscosity is investigated. According to the affinity law by KSB, the performance correction chart of flow rate, head and efficiency is plotted. The typical calculated examples show that the calculated results by the diagram methods are consistent with the experiments.

1. Introduction
The performance of centrifugal pumps is affected when handling viscous liquids. When a fluid of high viscosity -such as heavy oil- is pumped by a centrifugal pump the performance is impaired in comparison to service with water due to increased losses. The performance is decreased comparing with water due to the increased losses. The higher the viscosity of the fluid compared to water, the greater is the losses of delivery capacity and head for a given power input [1, 2]. Usually the performance reduction is estimated by means of correction factors for flow, head and efficiency by which the data measured with water are multiplied in order to get the performance when operating with highly viscous fluids.

The performance of the centrifugal oil pump is generally calculated by conversion method with that of pumping water. The performance correction charts of USSR’s and America Hydraulic Institute Standards for centrifugal, rotary & reciprocating pumps (AHIS) [3] and the viscosity diagram of KSB’s [4] are commonly used. When determining viscosity correction factors, different researchers or research institutions consider different influences, which results in different definitions of criterion number. GCT, National petroleum machinery institute of USSR expressed affinity law with $Q_{wup} \times 10^3 / (\pi D_2)$ . While AHIS expressed it with $Q^{1/2} H^{1/2} / \nu$ and KSB expressed it with $Q_{wup} \times n / (60 \cdot \nu \cdot (gH_{wup})^{0.5})$ . Consulting the affinity law proposed by KSB, the flow, head and efficiency conversion diagram of five types of centrifugal oil pump, whose specific speeds are 40, 50, 82, 90 and 130, are plotted.

2. Correction factor of centrifugal oil pump for pumping viscous fluids
2.1. The test pump and the test fluid
A single-stage, single-entry volute centrifugal pump with axial suction and radial discharge was used in the experiment test. The test fluids are the mixing fluids of 120BS base oil and diesel with characteristic of Newtonian fluid. Its compressibility is very small under test pressure, which can be ignored. Its work pressure is high enough to avoid vaporization. We change the viscosity of test fluids by using different ratio of 120BS base oil and diesel.

2.2. Calculation method of correction factor
The flow-head curve and flow-efficiency curve of centrifugal oil pump for pumping viscous fluids are generally corrected based on the two curves for pumping water. The flow, head and efficiency correction factor are defined as follows:

\[
f_Q = \frac{Q}{Q_w}, \quad f_H = \frac{H}{H_w}, \quad f_\eta = \frac{\eta}{\eta_w}\]

(1)

Where \(Q\), \(Q_w\), mean the flows of the highest efficiency point for pumping viscous fluids and water; \(H\), \(H_w\), mean the heads of the highest efficiency point for pumping viscous fluids and water; \(\eta\), \(\eta_w\) mean the highest efficiency for pumping viscous fluids and water; \(f_Q\), \(f_H\) and \(f_\eta\), mean flow, head and efficiency correction factor.

2.3. Correction factor of centrifugal oil pump for pumping viscous fluids
Taking flow correction factor for example, the relationship of correction factor of centrifugal oil pump for pumping viscous fluids with performance characteristics and operating condition are studied.

2.3.1 Relationship between flow correction factor and rotational speed. The flow correction factors changes for pumping fluids of 36mm\(^2\)/s, 86 mm\(^2\)/s, 105 mm\(^2\)/s, 152 mm\(^2\)/s, 210 mm\(^2\)/s, 290 mm\(^2\)/s with the rotational speed are shown in figure 1. The abscissa means rotational speed and the ordinate means flow correction factor.

The conclusions below can be drawn from figure 1.

1) The flow correction factor is related with rotational speed. In a certain viscosity, it declines with the rise of the rotational speed. In a low viscosity, its change is not obvious with the change of rotational speed. For the fluid of 105mm\(^2\)/s, it is 0.96 at the rotational speed of 1800r/min, 0.95 at 2400r/min and 0.93 at 2900r/min. In a high viscosity, its change is more obvious with the change of rotational speed. For the fluid of 210mm\(^2\)/s, it is 0.88 at the rotational speed of 1800r/min, 0.84 at 2400r/min and 0.72 at 2900r/min.

2) The flow correction factor is related with the viscosity of the fluid transported. At the same rotational speed, the higher the viscosity is, the smaller the flow correction factor is. And the lower the viscosity is, the larger the flow correction factor is.

3) The flow correction factor is always less than 1.0.

![Figure 1](image1.png)

**Figure 1.** Relationship curves between flows correction factor and rotational speed.

![Figure 2](image2.png)

**Figure 2.** Relationship curves between flows correction factor and fluid viscosity.
2.3.2 Relationship between flow correction factor and fluid viscosity. The relationship curves between flow correction factor and fluid viscosity at different rotational speeds of 1500 r/min, 1800 r/min, 2100 r/min, 2400 r/min, 2700 r/min and 2900 r/min are shown in figure 2. The abscissa means fluid viscosity and the ordinate means flow correction factor. They are all expressed in logarithmic coordinates.

The conclusions below can be drawn from figure 2.

(1) The flow correction factor is related with fluid viscosity. It declines with the increase of fluid viscosity. It changes slowly when the viscosity is less than 150 mm$^2$/s and declines quickly when the viscosity is more than 150 mm$^2$/s.

(2) The flow correction factor is related with rotational speed. It is larger at a higher rotational speed and smaller at a lower speed.

(3) The decline of the flow correction factor with the increase of fluid viscosity is not drab down trend. It increases at the beginning and then appears steep drop tendency.

2.3.3 Relationship between flow correction factor and flow. The relationship curves between flow correction factor and flow at the highest efficiency point in different viscosities are shown in figure 3. The abscissa means the flow of the highest efficiency point at different speeds and the ordinate means flow correction factor.

It can be seen from figure 3 that in a low viscosity, flow has a small effect on flow correction factor and it has a larger effect on that factor in a high viscosity. In the same flow, viscosity has a large effect on flow correction factor. The higher the viscosity is, the smaller the flow correction factor is. In the same viscosity, the flow correction factor increases with the decrease of the flow.

2.3.4 Relationship between flow correction factor and head. The relationship curve between flow correction factor and head at the highest efficiency point in different viscosities is shown in figure 4. The abscissa means the head of the highest efficiency point at different speeds and the ordinate means flow correction factor.

It can be seen from figure 4 that the flow correction factor keeps stable with the change of the head of the highest efficiency point in a low viscosity and it declines with the increase of the head in a high viscosity.

2.3.5 Flow correction factor change with Reynolds number. The relationship curve of flow correction factor change with Reynolds number at different rotational speeds is shown in figure 5. The abscissa means Reynolds in logarithmic coordinates and the ordinate means flow correction factor. The definition of Reynolds number is shown as follows:

$$Re = \frac{Q_{\text{inlet}} \cdot n}{60 \cdot \nu \cdot (g \cdot H_{\text{inlet}})}$$
Where $Q_{W_{Bep}}$ means the flow and $H_{W_{Bep}}$ means the head of the highest efficiency point for pumping water. $n$ is the rotational speed. $\nu$ is the fluid viscosity. $g=9.81\text{m/s}^2$

The conclusions below can be drawn from figure 5.

(1) The flow correction factor is related with Reynolds number. It is far less than 1.0 when $Re$ is less than $2.0 \times 10^6$. It needs to be corrected. And it becomes larger when $Re$ is large.

(2) The rotational speed has some effects on flow correction factor with the same Reynolds number. The flow correction factor is small when the rotational speed is high and it’s large when the speed is low.

![Figure 5. Relationship curve of flow correction factor and Reynolds number.](image)

3. Performance correction chart

3.1 Drawing method of performance correction chart

The performance correction chart is drawn based on a large number of experimental data got from the experiments of the centrifugal oil pumps, the specific speeds of which are 40, 50, 82, 90 and 130, on condition that the range of speed is from 1000r/min to 3000r/min and the range of viscosity is from 1mm$^2$/s to 290mm$^2$/s.

The drawing method of the performance correction chart of centrifugal oil pump is as follows.

The conversion factors can be expressed as the functions of Reynolds number.

$$f_Q = f_Q(Re), \quad f_H = f_H(Re), \quad f_\eta = f_\eta(Re)$$

Reynolds number is the function of flow, head, viscosity and speed.

$$Re = \frac{Q_{W_{Bep}} \cdot n}{60 \cdot \nu \cdot (g \cdot H_{W_{Bep}})^{\frac{1}{3}}}$$

It can be written as:

$$Re = \frac{Q_{W_{Bep}}}{H_{W_{Bep}}^{\frac{1}{3}}} \cdot \frac{1}{\nu} \cdot \frac{n}{60 \cdot g^{\frac{1}{3}}}$$

According to the chart algorithm design theory, an intermediary variable $A$ is introduced. It is defined as:

$$A = \frac{Q_{W_{Bep}}}{H_{W_{Bep}}^{\frac{1}{3}}} \cdot \frac{1}{\nu}$$

So Reynolds number becomes the function of the two variables, $A$ and $n$.

$$Re = A \cdot \frac{n}{60 \cdot g^{\frac{1}{3}}}$$
While the intermediary variable A is still the function of flow, head and viscosity. In order to facilitate the drawing, an intermediary variable B is introduced. Set

\[ B = \frac{Q_{\text{wbep}}}{H_{\text{wbep}}} \]

Thus

\[ A = B \cdot \frac{1}{\nu} \]

So that A becomes the function of B and \( \nu \). And B becomes the function of Q and H. Re can be divided as follows:

\[ B = \frac{Q_{\text{wbep}}}{H_{\text{wbep}}^{0.5}} \quad A = B \cdot \frac{1}{\nu} \]

\[ \text{Re} = A \cdot \frac{n}{60 \cdot g^{0.5}} \]

The drawing procedures are shown as follows:

1. Draw the diagram of

\[ B = \frac{Q_{\text{wbep}}}{H_{\text{wbep}}^{0.5}} \]

Make the flow Q be the abscissa and B be the ordinate. And draw the diagram with different heads. The B values corresponding to the heads are drawn.

2. Draw the diagram of

\[ A = B \cdot \frac{1}{\nu} \]

B is written as B=\( A \nu \).

Make A be the abscissa and B be the ordinate. Draw the diagram in different viscosities.

3. Draw the diagram of

\[ \text{Re} = A \cdot \frac{n}{60 \cdot g^{0.5}} \]

Make A be the abscissa and Re be the ordinate. Draw the diagram in different rotational speeds.

4. Draw the diagram of correction factors and Re.

Transform the abscissa Re to the ordinate. And draw the correction factors in the diagram by the formula of them and Reynolds. During drawing, the coordinates of flow, head, viscosity and rotational speed should be logarithmic coordinates and all the coordinates of correction factors should be the linear coordinates.

3.2 Performance correction chart and its usage

3.2.1 Performance correction chart. Figure 6 is the performance correction charts of centrifugal oil pumps whose specific speeds are 40, 50, 82, 90 and 130. It can be used to determine the performance of centrifugal pump handling viscous liquid when its performance on water is known.

3.2.2 Usage of performance correction chart. (1)Set Q=\( Q_0 \) in the abscissa based on the flow at the highest efficiency point. Draw a vertical line from the point to intersect the oblique line of H=\( H_0 \).

(2)Draw a horizontal line from the intersection point \( H=H_0 \) to intersect the fluid viscous \( \nu_0 \).

(3)Draw a vertical line from the intersection point \( \nu_0 \) to intersect the rotational speed curve in diagram above at the point of \( n_0 \).

(4)Draw an auxiliary parallel line at the intersection point \( n_0 \) to intersect the coordinate at Re_0.

(5)Draw a vertical line up from the intersection point Re_0 to intersect the correction factor curves of different specific speeds.
(6) The flow correction factor $f_{Q0}$, head correction factor $f_{H0}$ and efficiency correction factor $f_{\eta0}$ can be got by drawing parallel lines of abscissa from the intersection points.

(7) The performance for pumping vicious fluid can be calculated by formula (1).

![Figure 6. Performance correction chart.](image)

### 3.3 Application example of performance correction chart

When the centrifugal oil pump for pumping water, the performance parameter is $n_s=82$, $n=2900 \text{ r/min}$, $Q_{WBep}=16.16 \text{l/s}$, $H_{WBep}=43.94 \text{m}$, $\eta=0.645$. Calculate the performance curve for pumping fluid of 150mm$^2$/s at the same rotational speed.

We use figure 6 to get the correction factors by the performance characteristics known. The correction factors obtained are shown as: $f_Q=0.88$, $f_H=1.02$, $f_\eta=0.71$.

The parameters in the highest efficiency work condition for pumping viscous fluids can be calculated as: $Q_\nu=f_Q \times Q_{WBep}=14.22 \text{ l/s}$, $H_\nu=f_H \times H_{WBep}=44.82 \text{ m}$, $\eta_\nu=f_\eta \times \eta_{WBep}=0.46$

Then set $Q_1=0.6 \times Q_{WBep}$, $Q_2=0.8 \times Q_{WBep}$, $Q_3=1.2 \times Q_{WBep}$.

According to the conversion flow, head and efficiency, the performance curves of centrifugal oil pump for pumping viscous fluid can be plotted. It is shown as figure 7. The measured data are also
plotted in the same diagram when the fluid of 150mm²/s is pumped. It can be seen from the comparison, the conversion result is generally consistent with the measured result.

![Characteristics conversion curves of centrifugal pump.](image)

**Figure 7.** Characteristics conversion curves of centrifugal pump.

4. **Conclusions**

The correction factor of centrifugal oil pump for pumping viscous fluids is related with transport medium viscosity. In a certain rotational speed, the higher the viscosity is, the smaller the flow correction factor is. It is less than 1.0.

The correction factor of centrifugal oil pump for pumping viscous fluids is related with the rotational speed of the pump. In a certain viscosity, the flow correction factor declines with the rise of the rotational speed. Especially in a high viscosity, the trend is more apparent.

The correction factors of centrifugal oil pumps with different specific speeds are different. The results calculated by the performance correction chart are almost consistent with the experimental results.

**References**

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