Evaluation of single stage centrifugal pump performance 103-P-509B after 26300 hours of use

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Abstract. Centrifugal pump is a type of pump used in low viscosity fluids. Therefore centrifugal pumps are widely used in the petroleum industry and power plants. At the Residual Fuel Catalytic Cracking (RFCC) there are 103-P-509A and 103-P-509B centrifugal pumps that function as cosolvent circulation media on the 103-V-503 vessel. To circulate cosolvent 103-P-509A and 103-P-509B pumps are arranged in parallel. While the operation of the 103-P-509A, pump impeller has become porous and destroyed. So it is necessary to know the actual performance of the 103-P-509B pump through analysis with analytical methods to process data and then compare it to the design performance. After calculating and comparing with the design performance, the differential head increases by 0.2 m, the decrease in NPSHa and NPSHr are 53.6 m and 0.62 m, and the pump efficiency decreases by 2%. Cosolvent circulation process does not experience interference, but the time needed to circulate cosolvent becomes longer. It can be concluded that the impeller pump 103-P-509B is in good condition.

Keywords: impeller, centrifugal pump, performance, RFCC

1. Introduction
Rotodynamic pumps or also called centrifugal pumps are probably among the most often applied machinery in industrial installation as well as in common life [1]. Centrifugal pumps have been increasingly utilized for various purposes, such as irrigation, water supply, steam power plants, oil refineries, air conditioning systems [2]. Therefore the petroleum industry and power plants use a lot of centrifugal pumps. When the pump operates, there will be friction between the fluid and the pipe caused by viscosity. Friction will convert some of the pressure energy of the fluid flow into heat and result in energy loss. A portion of that energy is lost due to the resistance to flow [3]. This resistance to flow is called head loss due to friction [3]. Friction between the pipe wall and the fluid tries to slow down the fluid unless to get an assistance from gravity or naturally occurring pressure, generally have to install pumps or compressors to counter the friction[3]. Newton’s second law determines Head Loss which is a basic equation in fluid mechanics and is simplified to
be a 3D flow momentum equation. When the flow state is frictionless, the 3D flow momentum equation will become Euler’s equation. Euler’s equation will be simplified to become Bernoulli’s equation with the condition that the fluid flows along a stable and incompressible flow current line. Through energy balance, headloss will be obtained. When the fluid flows in the impeller, the impeller rotation will form a speed triangle. The components of the velocity triangle are c, u, and w with in/out angles \( \alpha \) as seen in Figure 2. Angle \( \alpha \) is the angle formed between u and c. The energy transfer in the impeller is caused by the torsional moment acting on the shaft which is forwarded by the impeller causing the absolute velocity of the fluid c with its tangential component cu [4].

Refinery of The Residual Fuel Catalytic Cracking (RFCC) requires a pump to keep the processing process going. Refinery of the Residual Fuel Catalytic Cracking (RFCC) there is a centrifugal pump with tag number 103-P-509A and 103-P-509B which functions as a cosolvent circulation medium in the 103-V-503 vessel. To circulate the cosolvent pumps 103-P-509A and 103-P-509B are arranged in parallel. During the circulation process, the impeller of the 103-P-509A pump was porous and destroyed. Therefore the 103-P-509A pump cannot operate.

This study aims to determine the condition of the 103-P-509B pump impeller by calculating the performance of the 103-P-509B centrifugal pump, namely head, efficiency, Brake Horse Power (BHP), Hydraulic Power (HHP), and pump Net Positive Suction Head Available (NPSHa). Since the impeller is the part that increases energy to the liquid, the geometry has a big impact on the performance of the centrifugal pump. Since the impeller is an active part that adds energy to the fluid, its geometry plays a major role in the centrifugal pump performance [2]. Any change in the impeller geometry would have an impact on the impeller inlet or exit velocity triangles, which may result in significant performance change [2]. Therefore, calculating the performance can determine the impeller condition.

2. Material and methodology
This study used a single-stage centrifugal pump with the tag number 103-P-509B as the analysis medium. Single-stage centrifugal pump analysis uses an analytical methodology to process the data obtained. Based on the 103-P-509B pump datasheet, the 103-P509B centrifugal pump to be analyzed is shown in Figure 1 [5].

![Figure 1. Centrifugal Pump 103-P-509B](image)
The 3D flow momentum equation and Euler’s equation can be expressed in equations 1 and 2 below [6].

\[
\rho g + \frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} = \rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) \tag{1a}
\]

\[
\rho g + \frac{\partial \sigma_{xy}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} = \rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) \tag{1b}
\]

\[
\rho g + \frac{\partial \sigma_{xz}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} = \rho \left( \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) \tag{1c}
\]

\[\rho \frac{DV}{Dt} = \rho g - \nu p \tag{2}\]

For steady flow, Euler’s equation in rectangular coordinates can be expressed in equation 3 [6].

\[\frac{DV}{Dt} = u \frac{\partial V}{\partial x} + v \frac{\partial V}{\partial y} + w \frac{\partial V}{\partial z} = (\nabla \cdot V)V = -\frac{1}{\rho} \nu p - g \hat{k} \tag{3}\]

If the flow is along a streamline with steady and incompressible flows, then the equation is simplified to equation 4

\[\frac{dp}{\rho} + \frac{1}{2} d(V^2) + gdz = 0 \tag{4}\]

If equation 4 is integrated with constant density, it will produce the Bernoulli equation shown in equation 5.

\[
\frac{p}{\rho} + \frac{V^2}{2} + gz = c \tag{5}
\]

The loss of energy caused by friction in the fluid when moving causes energy differences at two points. Through energy equilibrium, the head loss obtained is shown in Equation 6.

\[
\left( \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 \right) - \left( \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 \right) = H_l \tag{6}
\]

Figure 2 shows inlet and outlet velocity triangles in the present pump impeller [4]. At inlet condition, the fluid moving with an absolute velocity \(v_1\) enters the pump impeller through a cylindrical surface of radius \(r_1\) and angle \(\beta_1\), as shown in Figure 2 [4]. At outlet condition, the fluid leaves the pump impeller through a cylindrical surface of radius \(r_2\), with absolute velocity \(v_2\) inclined to the tangent at the angle \(\beta_2\), as also shown in Figure 2 [4].

![Figure 2. Velocity diagram for impeller model [4]](image-url)
By comparing the condition of the pump design and the actual condition of the pump, it is possible to determine the feasibility of the pump operate. Table 1 is a design specification of the 103-P-509B centrifugal pump [5]. The pump installation system is a system consisting of a pump unit, a piping system, and a control panel. The 103-P-509B centrifugal pump installation system based on the 103-P-509B pump data sheet can be seen in Figure 3 [5].

Table 1. Specifications of the 103-P-509B centrifugal pump design [5].

| Data           | Value | Units    |
|----------------|-------|----------|
| Total Head     | 21.3  | meter    |
| NPSHa          | 233   | meter    |
| NPSHr          | 1.37  | meter    |
| BHP            | 3.56  | hour power |
| Efficiency     | 44    | %        |
| Suction Pressure | 24.38 | Kgf cm²  |

Figure 3. 103-P509B centrifugal pump installation [5].

By using equation 7 will get the density of the flowing fluid, while Equations 8 and 9 can determine the flow velocity and reynold number. Flow will generally be laminar for Re ≤ 2300 and turbulent for larger values [6].

\[ \rho_{\text{cairan}} = S G x \rho_{\text{air}} \]  (7)

\[ V = \frac{Q}{A} \]  (8)

\[ \text{Re} = \frac{\rho V D}{\mu} \]  (9)

Loss of energy due to piping installations causes the flowing fluid to occur headloss. Equation 10 [5]. Show that pressure drop is a function of diameter, pipe length, pipe roughness, fluid velocity, density, and viscosity.

\[ \Delta p = \Delta p(D, L, e, V, \rho, \mu) \]  (10)
Table 2. Installation of 103-P-509B centrifugal pump piping

| Data          | Dimension | Length/quantity |
|---------------|-----------|-----------------|
| Pipe          | Ø 3”      | 0.5 m           |
|               | Ø 4”      | 4.1 m           |
| Elbow 90°     | 4”        | 3               |
| Tee           | 4”        | 1               |
| Gate Valve    | 4”        | 2               |
| Reducer       | 4” x 3”  | 1               |
| Strainer      | 4”        | 1               |

Table 2 is pipeline installation data on the 103-P-509B centrifugal pump. The relative roughness of the pipe is used to obtain the friction factor. Then the relative roughness can use equation 11. Furthermore, to obtain major and minor head losses using equations 12 and 13 [9].

\[
\varepsilon = \frac{e}{D} \tag{11}
\]

\[
h_{L,\text{major}} = f \frac{LV^2}{D.2g} \tag{12}
\]

\[
h_{L,\text{minor}} = n.K_i \frac{V^2}{2g} \tag{13}
\]

The addition of major and minor headloss in equations 12 and 13 will produce the total head loss as shown in equation 14 [9].

\[
h_{L,\text{total}} = h_{L,\text{major}} + h_{L,\text{minor}} \tag{14}
\]

**Figure 4.** Performance curve of 103-P-509B centrifugal pump [5]

The 103-P-509B pump performance curve serves to get the efficiency and pump head by reviewing the pump capacity. The 103-P-509B pump performance curve can be seen in Figure 4.
a pump capacity of 18.36 m³ hour⁻¹ gets a head of 21.5 m and an efficiency of 42%. The NPSHr is obtained using Figure 5 provided by the vendor on the 103-P-509B pump datasheet [5]. A capacity of 18.36 m³ hour⁻¹ gets an NPSHr of 0.75 m.

**Table 3. Actual Data of Pumps 103-P-509**

| Description          | Value | Units    |
|----------------------|-------|----------|
| Capacity (Q)         | 18.36 | m³/hr    |
| Suction Pressure (Ps)| 21    | Kgf cm²  |
| Discharge Pressure (Pd)| 26  | Kgf cm²  |
| Vapppore Pressure (Pv)| 0.0703| Kgf cm² |
| Head Statis (hs)     | 0.6   | Meter    |
| Specific Gravity (SG)| 1.17  |          |

The calculation data uses the actual pump 103-P-509B data as shown in Table 3. Net Positive Suction Head available (NPSHa) is a measure of the suction head available in the pump system. In order for the pump not to be cavitated, NPSHa must be greater than NPSHr [7]. It is using equation 15, NPSHa will be obtained.

\[
NPSHa = \frac{Ps - Pv}{\gamma} + hs - hl
\]  

(15)

Hydraulic power is the power required to flow a certain amount of liquid, also called Hydraulic Horse Power (HHP). Shaft Power (BHP) is the power supplied by the motor to the pump through the pump shaft [8]. It is used Equations 16 and 17 to obtain HHP and BHP.

\[
HHP = \frac{QHp}{75}
\]  

(16)

\[
BHP = \frac{HHP}{\eta p}
\]  

(17)

3. Result and discussion

3.1 Result

The actual performance of the 103-P-509B pump can be obtained by the analytical method as shown in Table 4. Headloss is divided into two, namely major and minor headloss. Equations 12 and 13 are used to obtain major and minor head losses. Equation 14 is the total head loss of 0.081 m which is obtained from the sum of major and minor head losses.
Table 4. The Calculation Results

| Information                        | Value | Units  |
|------------------------------------|-------|--------|
| Capacity (Q)                       | 18.36 | m³ hour⁻¹ |
| Headloss (hl)                      | 0.081 | meter  |
| Differential Head (H)              | 21.5  | meter  |
| Net Positive Suction Head Available (NPSHa) | 179.4 | meter  |
| Net Positive Suction Head Requirement (NPSHr) | 0.75  | meter  |
| Brake Horse Power (BHP)            | 4.07  | horse power |
| Hydraulic Horse Power (HHP)        | 1.71  | horse power |
| Pump Efficiency (ηp)               | 42    | %      |

Figure 4 is used to obtain the values of the head differential and efficiency. The value of the head differential was 21.5 m and the value of the efficiency was 42%. This is obtained by reviewing the actual pump capacity value of 18.36 m³ hour⁻¹. The brake horse power (BHP) and hydraulic horse power (HHP) are obtained by equation 16 and equation 17. Brake horse power (BHP) is 4.07 HP and hydraulic horse power (HHP) is 1.71 HP.

Equation 15 is used to obtain an NPSHa of 179.4 m. By reviewing the pump capacity in Figure 5, the NPSHr value is 0.75 m, because when operating the NPSHa value is greater than NPSHr, there is no cavitation on the pump.

3.2 Discussion

The actual performance will be compared with the pump design performance to determine the state of the 103-P-509B centrifugal pump. Table 5 is a comparison of the design performance with the actual pump performance. After comparing the design performance with the pump’s actual performance, it was found that the actual NPSHa value decreased by 53.6 m which was caused by the pressure drop in the pump suction section (Ps). The reduced pump capacity causes a decrease in the cavitation coefficient so that the NPSHr in the actual state has decreased by 0.62 m.

Table 5. Comparison of design and actual performance

| Data         | Design | Actual  |
|--------------|--------|---------|
| Differential Head | 21.3 m | 21.5 m  |
| NPSHa        | 233 m  | 179.4 m |
| NPSHr        | 1.37 m | 0.75 m  |
| BHP          | 3.56 HP| 4.07 HP |
| Efficiency   | 44%    | 42%     |

The differential head (H) has increased by 0.2 m and the pump efficiency has decreased by 2%. This is due to the characteristics of the 103-P-509B pump, if the capacity decreases, it causes an increase in the differential head (H) and a decrease in efficiency. This decrease in efficiency causes an increase in BHP in the actual situation of 0.51 KW. Figure 6 is a graph comparing the BHP design and actual design with a distortion of 14.13% at each point.
Since the 103-P-509B pump operates, maintenance has never been carried out because the pump is still operating in good condition. However, the pump performance has begun to decline, which is shown in a decrease in the differential head, NPSHa, efficiency, and an increase in BHP when compared to pump design performance. The reason is that the strainer is dirty which causes a decrease in suction pressure (Ps) and pump capacity. If the strainer is not cleaned, the dirt filtered by the strainer will accumulate and in extreme conditions will cause cavitation in the pump.

The 103-P-509A and 103-P-509B pumps arranged in parallel do not interfere with the cosolvent circulation process. This is because the parallel arrangement of the pump aims to increase flow capacity, so the circulation process continues if one of the pumps is not operating. However, the time needed is longer because the capacity is less.

4. Conclusion
After obtaining the calculation results in Table 3 and making comparisons between the design performance and the actual performance in Table 4, an increase in the differential head is 0.2 m, the NPSHa, and NSPHr management is 53.6 m and 0.62 m respectively, and a decrease pump efficiency by 2%. So it can be concluded that the condition of the 103-P-509-B centrifugal pump impeller is still in good condition.

5. References
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