Performance evaluation of 2-C-470 compressor of gas recycle process at PT. Lotte Chemical Titan Nusantara

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Abstract. Recycle compressor used at PT. Lotte Chemical Titan Nusantara utilizes a four-stage piston compressor type. The compressor increases the gas pressure from the S-425 degasser at 0.3 bar to the R-400 reactor with a pressure of 22 bars. Evaluation of a compressor performance encompasses assessment over a number of aspects such as the capacity and volumetric efficiency of each stage, mechanical efficiency, compressor power, and cost saving. Performance analysis on the C-470 compressor implied a decrease in a performance marked by a decrease in mechanical efficiency from the design at 96.43% to the actual condition at 79.72%, along with the decrease in volumetric efficiency from the initial design to the actual efficiency for each stage. The differences occurred due to the changes in pressure and temperature of the input and output fluid at each stage. However, the compressor still appropriates to save the cost up to 99.7% with actual efficiency of 79.72%.

1. Introduction

Compressor is a mechanical component that plays a role in increasing pressure of a fluid (compressible fluid) by volume reduction. Rising pressure provides energy to the fluid allowing it to flow from one place to another continuously [1]. Compressors usually work by sucking in atmospheric air. If a compressor works at a pressure higher than the atmospheric pressure, the compressor is called a booster, and if the compressor works under the atmospheric pressure, it is called a vacuum pump. Based on the working principle, the compressors have two different types, i.e. positive displacement compressor and dynamic compressor (turbo). The positive displacement one is subdivided into reciprocating and rotary, meanwhile the dynamic one (turbo) consists of centrifugal and axial as well as ejector [2].

The function of a compressor is to increase the pressure of a gas. Gas pressure can be increased by reducing the volume. When volume is reduced, pressure rises. As the compression process occurs, the air acquires higher pressure than the surrounding air pressure (1 atm) [1]. In everyday life, we often utilize compressed air both directly and indirectly. For instance, compressed air is used to fill tires for cars or motorbikes, clean dirty engine parts in workshops, among other benefits, often found every day. In the industry, the use of compressors is very important, both to produced readily compressed air or as a unit of machinery. Compressors are widely designed as pneumatic engines, while some are also designed as parts of bigger machinery as turbines, cooling machines, and others.

In the polymerization process that occurred in a fluidized bed reactor at PT. Lotte Chemical Titan is carried out with a continuous process system. This means that every time new reactants are introduced, the product undergoes continuous extraction through four powder withdrawals (D-420 A/B/C/D). Based on data from the DCS of the Production Department at PT. Lotte Chemical Titan Nusantara, the
composition of powder that came out of the reactor was 40% polymer and 60% hydrocarbon gas. This product would then enter the primary degasser (S-425). In the primary degasser (S-425), the polymer powder and hydrocarbon gas undergo separation. Hydrocarbon gas would later be recycled into the reactor (R-400) by the gas recycle compressor (C-470) after separation of fines in the gas recycle filter (F-426) and oligomers in the compressor system, as shown in Figure 1.

Figure 1. Process Flow Diagram of a Hydrocarbon Gas Recycle System

The compressor utilized was a reciprocating compressor with four stages. Reciprocating or piston compressors have the advantages of having a large capacity and ability to compress gas to very high pressure, though several stages are needed to achieve this [3]. The recycle compressor used serves to increase the pressure from 0.3 bar to 22 bar at the temperature of 110°C so that the recycled gas can be returned back to the reactor. The use of recycle compressors is intended to maximize the use of reactants to implement efficiency in terms of engineering and economic values, minimizing reactants wastes and increasing company profits.

The purpose of this observation is to determine the performance of the C-470 compressor over its capacity and volumetric efficiency of each stage, compressor power, mechanical efficiency, and cost saving merit.

2. Research Methodology

Data collection methods consists of two articles of collections, namely primary data and secondary data. The primary data were obtained by collecting data in the field through the Department of Maintenance and Engineering and the DCS (Display Control System) of PT. Lotte Chemical Titan Nusantara obtained on Tuesday, July 23, 2019 to calculate the capacity and volumetric efficiency of each stage, compressor power, mechanical efficiency, and cost saving on the compressor. The primary data comprise of the temperature of hydrocarbon gas entering the compressor, the temperature of the hydrocarbon gas exiting the compressor, hydrocarbon gas pressure entering the compressor, hydrocarbon gas pressure exiting the compressor, flow rate and type of hydrocarbons entering the compressor, maximum power of the compressor, cylinder, piston, and motor conditions of the compressor.

Meanwhile, secondary data were obtained indirectly from sources such as literatures, books, lecture materials, and other references that can support the primary data. Algorithms applied on the compressor encompass the determination of the capacity and gas power at each stage of the compressor, and the determination of the compressor power. Several approaches are used to process the sets of data obtained.

2.1. Capacity determination of each stage

1. Determination of total MCp of each stage
   a. The following data are used
      Ts : Inlet temperature
Td : Outlet temperature  

b. Equation [4] :  

\[ M \cdot C_p = n \cdot R \cdot \left( \int_{T_s}^{T_d} A + BT + CT^2 + DT^{-2} \right) \]  

(1)

2. Determination of \( k \) value  

a. Data on the total \( C_p \) are used  

b. Equation [5] :  

\[ k = \frac{C_p \text{ mix}}{C_p \text{ mix} - 1,99} \]  

(2)

3. Determination of volumetric efficiency of each stage  

a. Data required :  

\( C_n \) : Clearance volume  
\( P_s \) : Inlet pressure  
\( P_d \) : Outlet pressure  
\( k \) : Previously obtained constant  

b. Equations [5] :  

\[ r_n = \frac{P_d}{P_s} \]  

(3)  

\[ V E_n = 0,96 - C_n \left( \frac{1}{r_n^{\frac{k}{n}} - 1} \right) \]  

(4)

4. Determination of capacity  

a. Data required :  

\( D_n \) : Cylinder diameter  
\( d_s \) : Piston rod diameter  
\( S \) : Stroke  
\( N \) : Rotation speed  
\( V E_n \) : Volumetric efficiency of each stage  

b. Equations [5] :  

\[ Q_n = \frac{\pi \cdot (2D_n^2 - d_s^2) \cdot S \cdot N \cdot V E_n}{4} \]  

(5)

2.2. Determination of gas power of each stage  

1. Determination of \( n \) value  

a. The following data are used  

\( T_s \) : Inlet temperature  
\( T_d \) : Outlet temperature  
\( P_s \) : Inlet pressure  
\( P_d \) : Outlet pressure  

b. Equation [5] :  

\[ \frac{n - 1}{n} = \frac{\ln(Td \times Ts^{-1})}{\ln(Pd \times Ps^{-1})} \]  

(6)

2. Gas power determination  

a. Data required :  

\( P_{sn} \) : Inlet pressure of each stage
Pdₙ : Outlet pressure of each stage  
Qₙ : Capacity of each stage

b. Equation [5] :

\[
GHPₙ = \frac{n(n - 1)^{-1} \times 144 \times Pₛₙ \times Qₙ \left( (Pdₙ \times Pₛₙ)^{-1} \right)^{-\frac{n-1}{n}} - 1}{33000}
\]  (7)

2.3. Determination of compressor power

1. Driving power determination
   a. The following data are used :
      I : Current
      V : Voltage
   b. Equation [5] :

\[
DHPₙ = \frac{I \times V \times \cos \phi \times 3^{\frac{1}{2}}}{1000} \times \eta_{me}
\]  (8)

2. Mechanical efficiency determination
   a. Data required :
      GHPₜotal : Total gas power
      DHP : Driving power
   b. Equation [5] :

\[
\eta_{me} = \frac{GHP \ total}{DHP \ \eta_{trans}}
\]  (9)

3. Compressor power determination
   a. Data required :
      GHPₜotal : Total gas power
      ηme : Mechanical efficiency
   b. Equation [5] :

\[
CHP \ Total = \frac{GHP \ total}{\eta_{me}}
\]  (10)

Table 1. Design and Actual Data of the C-470 Compressor

| Stage | 1   | 2   | 3   | 4   | 1   | 2   | 3   | 4   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|
| Ps    | 0.3 | 2   | 5   | 10  | 1.2 | 2.48| 5.58| 10.77|
| Pd    | 2   | 5   | 10  | 22  | 2.6 | 5.34| 11  | 22.18|
| Ts    | 31  | 35  | 33  | 34  | 35  | 35  | 35  | 35  |
| Td    | 118 | 94  | 96  | 110 | 115 | 115 | 115 | 110 |

(Source : Display Control System of the Production Department and the Engineering & Maintenance Department PT. Lotte Chemical Titan Nusantara)

Table 2. C-470 Compressor Performance Analysis Calculation Results

| Stage | Actual | Design (BP License) |
|-------|--------|---------------------|
|       |        |                     |
3. Result and Discussion

3.1. Comparison of compressor capacity for each stage

The product extracted through the powder withdrawal process (D-420 A/B/C/D) contained 40% polyethylene and 60% hydrocarbon gas. Hence, the recycling of hydrocarbon gas back into the R-400 was necessary to be carried out in order to increase the efficiency of the production process. The recycling process was initiated with the separation of powder and hydrocarbon gas in the S-425 primary degasser. The gas would then undergo compression from pressure of 0.3 bar to 22 bar through a C-470 compressor. In the recycle process, the capacity of the recycled gas would determine the efficiency of the production process. Compressor C-470 that consists of four stages has varying capacity for each of its stage thus affecting how it efficiently recycle gas into the reactor. The results of the capacity calculations of each stage cylinder from the initial design data and actual data in the field is deliberated in later discussion.

Table 2 presents the capacities of the stages in the C-470 compressor based on its initial design data and actual data. From the calculation results, the capacities of the design data are greater than the actual data obtained. This occurrence is due to differences in operating conditions (temperature, pressure, and gas composition) in the collection of the actual data and design data. Pressure can affect the compression ratio of a compressor. The compression ratio is the ratio between the absolute output pressure (Pd) and the absolute input pressure (Ps). The compression ratio can be used as an indicator of the compressor’s performance [6]. Table 1 shows the output pressure (Pd) and input pressure (Ps) based on its initial design and actual data. From the calculation results, the compression ratio of the actual data is higher than the design data obtained. The higher compression ratio will produce smaller volumetric efficiency as in equation (4). Therefore, the actual data capacities are lower than the design data obtained as in equation (5).

However, in both the design data and the actual data, there are decreases in the capacities of each stage cylinder. This is a subsequent result of the phenomenon of condensation of the gas that comes out of each stage. The outlet temperature of each stage is always higher than the inlet temperature. In actual conditions, the temperature of the incoming gas fluid at stage 1 is not the same as the temperature of the incoming fluid at stage 2 and so on [7]. The temperature that comes out of each stage will be decreased through the implementation of an intercooler (E-470 A/B/C/D) at each end of the cylinder. In this cooling process, condensation of gas fluid occurs, resulting in a decrease in capacity.

3.2. Compressor volumetric efficiency analysis for each stage

After the field and plant design data, observations were conducted to determine the operating conditions of the C-470 compressor, calculations were made to determine the actual and design volumetric efficiency as presented in Table 2.

From the data, it can be seen that, for all stages, the volumetric efficiencies of the design are greater than the actual volumetric efficiencies. The design data assume that the compressor works in ideal conditions where there is no condensed gas. In contrast, the phenomena observed in the field exhibit gas condensation processes that acquire smaller gas volumes and thus resulting in the differences in the
values obtained. According to Brown [5], volumetric efficiency is directly proportional to the inlet gas volume as expressed in the following equation:

$$Q_1 = Ev 	imes Pd$$  \hspace{1cm} (11)

Descriptions:
- **Q1** = Inlet gas volume
- **Ev** = Volumetric efficiency
- **Pd** = Piston displacement

The condensation phenomenon causes the volume for gas in the actual compressor stage to be lower than the supposed ideal space, meaning that the volume of gas undergo compression and becomes smaller in actual conditions.

### 3.3. Compressor power and mechanical efficiency comparison of design and actual data

The use of the C-470 compressor is very valuable in restoring the hydrocarbon gas from the degassing process into the reactor. This recycled gas will increase the efficiency of polyethylene production. However, continued use results in a decrease in the performance of the compressor. Therefore, a four-stage reciprocating compressor must always be checked and evaluated for its performance in restoring useful gas back into the reactor. In addition, the evaluation and maintenance of compressors are important because no backup compressors are available should certain problems arise. The results of the calculations of mechanical efficiency and compressor power of the design data and the actual data are presented in Table 2.

As seen on Table 2, the mechanical efficiency of the C-470 compressor has a value of 79.72% in the actual data and 96.43% in initial design data implying that the mechanical efficiency in actual conditions is smaller compared to design conditions. Furthermore, the C-470 compressor obtained a power value of 219.1847 kW based on the actual data and 290 kW for the initial design data. The differences occur because in actual conditions the compressor works continuously for a long time and thus wearing out the cylinder wall. This will cause additional leeway between the piston and cylinder and cause gas leakage, reduced compression pressure and consequent reduction in energy [8]. According to Smith [4], a compressor is still suitable for use when its efficiency still remains in the 70-80% range. Thus, the efficiency calculation result of the actual data of the C-470 compressor at a value of 79.72% suggests that the compressor is still suitable for use under the actual conditions.

### 3.4. Cost saving calculation of the recycle system

Cost saving calculation is necessary to be done to find out whether the C-470 compressor is still economically fit for use or not. With a power of 219 kW and an ethylene gas return capacity to the reactor of 8190 kg/hour, the following cost saving calculation is obtained:

a. By continuously running the compressor for 6 days cost of operation needed is calculated as follows:
   - Power used
     $$= 219 \text{ kWh}$$
   - Price of PLN (State Electricity Company) special services per kWh
     $$= Rp. 1.063,80/\text{kWh}$$
   - C-470 total operation cost
     $$= \text{219 kWh} \times \text{Rp. 1.063,80/ kWh} \times 24 \text{ h x 6 days}$$
     $$= \text{Rp. 33.547.996,80 / 6 days}$$
   - The compressor is able to return 8190 kg/h of ethylene into the reactor

b. Implications of not using C-470 compressor over 6 days:
   - Ethylene of 8190 kg/h will be burned in flares
   - Ethylene burned
     $$= 8190 \text{ kg/h x 24 h x 6 d}$$
\[ 7 \]

\[ = 1.179.360 \text{ kg} / 6 \text{ days} \]

- Price of ethylene
  \[ = \text{USD 1000/ton} \]
- Total cost of ethylene burned
  \[ = 1.179,36 \text{ ton} / 6 \text{ days} \times \text{USD 1000/ton} \]
  \[ = \text{USD 1.179.360} / 6 \text{ days} \]
- Total cost of ethylene burned in Rp (Rupiah)
  \[ = \text{USD 1.179.360} / 6 \text{ days} \times \text{Rp. 14.000,00/USD} \]
  \[ = \text{Rp. 16.511.040.000,00} / 6 \text{ days} \]

c. Saving of using C-470 compressor over 6 days:

- Cost saving:
  \[ = \text{cost of burned ethylene} – \text{electricity cost used by the C-470 compressor} \]
  \[ = \text{Rp. 16.511.040.000,00} / 6 \text{ days} – \text{Rp. 33.547.996,80} / 6 \text{ days} \]
  \[ = \text{Rp. 16.477.492.003} / 6 \text{ days} \]

Thus, the cost saving obtained by using a C-470 compressor is 99.79%.

4. Conclusions

From the analysis conducted, the following conclusions are obtained: the capacities of the C-470 compressor at all four stages of the design data are greater than the actual data; the volumetric design efficiencies of the C-470 compressor at all four stages are greater than the actual volumetric efficiency; the C-470 compressor power of the actual conditions amounts to 219.1847 kW and 290 kW under design conditions; the mechanical efficiency of the compressor in terms of actual data is 79.72% while for the design data is 96.34%, and the cost saving obtained as a result of utilizing the C-470 compressor compared to not using a C-470 compressor is 99.79%.

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