Study Improving Performance of Centrifugal Compressor In Paiton Coal Fired Power Plant Unit 1 And 2

Yuriadi Kusuma, Dadang S Permana
Department of Mechanical Engineering, Faculty of Engineering, Universitas Mercu Buana, 11650 Jakarta, Indonesia
kusuma.yuriadi@gmail.com

Abstract. The compressed air system becomes part of a very important utility system in a Plant, including the Steam Power Plant. In PLN’S coal fired power plant, Paiton units 1 and 2, there are four Centrifugal air compressor types, which produce compressed air as much as 5.652 cfm and with electric power capacity of 1200 kW. Electricity consumption to operate centrifugal compressor is 7.104.117 kWh per year. This study aims to measure the performance of Centrifugal Compressors operating in Paiton’s coal fired power plant units 1 and 2. Performance Compressor is expressed by Specific Power Consumption (SPC) in kW/100 cfm. For this purpose, we measure the compressed air flow rate generated by each compressor and the power consumed by each compressor. The result is as follows: Air Compressor SAC 2B : 15.1 kW/100 cfm, Air Compressor SAC 1B : 15.31 kW/100 cfm, Air Compressor SAC 1A : 16.3 kW/100 cfm and air Compressor SAC 2C : 18.19 kW/100 cfm. From the measurement result, air compressor SAC 2B has the best performance that is 15.1 kW / 100 cfm. In this study we analyze efforts to improve the performance of other compressors to at least match the performance of the SAC 2B air compressor. By increasing the Specific Power Consumption from others Compressor, it will get energy saving up to 284,165 kWh per year.

1. Introduction
This future market requires flexible systems that can react to rapid variations in energy demand and supply. Moreover, because renewable sources like solar energy have their peak power production during the day, it is expected that coal-fired power plants will be in full operation during the night and part load operation during the day. Until a economical efficient way of storing huge amounts of energy is developed, coal-fired power plants will keep playing a central role during the transition to renewable energy [1].

The coal-fired power plant in the road project is designed for rapid changes in power supply. This ramping up and down of the power plant has a direct effect on the amount of CO2 captured in the capture unit, which could range between 40-100 % of the nominal mass-flow[2]. Paiton PLN power plant is located in Paiton, Probolinggo, east java, Indonesia. The Paiton power plant is a coal-fired power plant (PLTU) with an installed capacity of 800 MW consisting of two units (2 x 400). Both units were commissioned in 1993 and operated by the Java Bali Plant (PJB). Each year the Paiton power plant generates electricity at an average of 5606.18 GW transmitted through an extra 500kV high-voltage network connecting the Java power system. Paiton PJB units 1 and 2 have two Compressor houses located each in units 1 and 2. Lay out of the compressed air system in each Compressor house is schematically described as follows;
Figure 1. Lay Out Compressor House

The P and ID Layout of the Compressor house are shown in the following figure.

Figure 2. P & ID of Compressed Air System

Three Ingersoll-Rand Centrifugal Compactor Centacts operate alternately supplying compressed air. In practice, only one compressor that operates alternately, because one compressor is considered sufficient in Plant needs. The system is equipped with two Receiver tanks placed outside the Compressor House. Air from Receiver tanks flows into two pipelines each for the need of "water service" and "water instrument". Air for Instrument Air needs to be passed to the air treatment unit consisting of Refrigerated Dryer and Filter. In each Compressor House, there are two Refrigerated Dryers, although daily operations only one Dryer.

Compressor house equipped with a good ventilation system, consisting of ducting to remove hot air, as well as Fan exhaust. However, the exhaust heat from the electric motor Fan driving the compressor is not delivered to the Ducting. The temperature of the exhaust air from the motor cooling fan is measured between 50 - 51 °C. Fresh air flows into the compressor through a large door that is always wide open and through a gap in the wall. The outside air can go inside because of the negative pressure generated by the Exhaust Fan placed on the roof of the compressor room.

2. Problems
In the Paiton power plant units 1 and 2, six air compressors are installed, each composed of 4 2826 cfm compressors with the same brand and type, and 2 pieces of air compressor with a capacity of 1557 cfm of the
same type and brand. However, the energy consumption of compressors of the same type is different, indicating that the performance of each compressor is different even though the type, brand and size are the same [2]. Therefore, it is necessary to measure each air compressor and then calculated the energy saving potential that can be obtained if the performance compressor can be upgraded to the best level owned by one of the machines in Paiton units 1 and 2.

3. Basic Theory
A compressor is a fluid handling mechanical device capable of efficiently transferring energy to the fluid medium so that it can be delivered in large quantities at elevated pressure conditions. Compressors have numerous applications ranging from aircraft and process industries to household appliances such as refrigerators and air conditioners [4].

The modern practise to determine the impeller meridional blade angle distributions is to calculate the compressible inviscid flow through the impeller passage, to determine the blade loading along the blade, and then to modify the meridional blade angle distribution to produce more favourable blade loading[5-6].

The flow in a centrifugal compressor is very complicated, with strong three-dimensional features. The subject of designing impellers is widely covered in the literature[7-12].

The achievement of the air compressor in general can be expressed by Specific Power consumption (SPC) ie how much power is required to produce 100 cfm of compressed air, thus SPC is expressed in kW / 100cfm. It is therefore necessary to measure the consumption of electrical energy and the rate of air flow generated by each air compressor as well as the cooling water temperature and environmental air temperature.

Performance of Centrifugal Compressor depends on several parameters such as:

a. Water Inlet Temperature
b. Inlet Air Pressure
c. Relative Humidity of Air
d. Temperature of cooling water
e. Cooling water flow rate

Usually the manufacturer of air compressor engine (Ingersoll-Rand) provides a performance curve of each centrifugal compressor, which can be used as a reference benchmark between actual operating conditions and current conditions at commissioning test (when the curve is made). Since the performance curve is not available, the performance compressors in Paiton units 1 and 2 will be compared between actual and rating and are also compared between them respectively.

4. Measurement Methods
To calculate the performance of each compressor needs to be measured electrical energy consumption of compressor machine using power meter and measurement of air rate produced by each compressor using pitot tube flow meter.

Since both of these measuring devices are not installed in the compressor machine, a portable measuring device is used, and specially for measuring the air flow rate of the compressor, it is necessary to prepare the insertion point in the pipeline first. Making insertion point is done by drilling on pipe and welding to install valve.

Further, the compression of air pressure measurements are made using pressure gauge mounted on the pipe by piercing the pipe.
5. Measurement Results
Based on the result of measurement on all compressors, the performance are shown in Figures 4, 5, 6 and 7 in graphs and resumes shown in table 1, 2, 3 and 4.

**Compressor SAC 1A**

![Figure 4. Compressor Performance of SAC 1A](image)

| PERFORMANCE KOMPRESSOR SAC 1A | DESIGN | ACTUAL |
|-------------------------------|--------|--------|
| Air Capacity                  | cfm    | 2826   |
| Barometric Pressure           | Psia   | 13.94  |
| Relative Humidity             | %      | 78     |
| Inlet Air Temperature         | °F     | 82.4   |
| Discharge Pressure            | Psig   | 120.4  |
| Cooling Water Inlet Temperature | °F | 104     |
| Specific Power Consumption    | kW/100cfm | 16.3   |

**Compressor SAC 1B**

![Figure 5. Compressor Performance SAC 1B](image)

| PERFORMANCE KOMPRESSOR SAC 1B | DESIGN | ACTUAL |
|-------------------------------|--------|--------|
| Air Capacity                  | cfm    | 2826   |
| Barometric Pressure           | Psia   | 13.94  |
| Relative Humidity             | %      | 78     |
| Inlet Air Temperature         | °F     | 82.4   |
| Discharge Pressure            | Psig   | 120.4  |
| Cooling Water Inlet Temperature | °F | 104     |
| Specific Power Consumption    | kW/100cfm | 15.31  |

**Compressor SAC 2B**

![Figure 6. Performance of Compressor SAC 2B](image)

| PERFORMANCE KOMPRESSOR SAC 2B | DESIGN | ACTUAL |
|-------------------------------|--------|--------|
| Air Capacity                  | cfm    | 2826   |
| Barometric Pressure           | Psia   | 13.94  |
| Relative Humidity             | %      | 78     |
| Inlet Air Temperature         | °F     | 82.4   |
| Discharge Pressure            | Psig   | 120.4  |
| Cooling Water Inlet Temperature | °F | 104     |
| Specific Power Consumption    | kW/100cfm | 15.1   |

**Compressor SAC 2C**
Based on the survey results shown in the graph and table above can be concluded that the performance compressor varied, if sorted by ranking as follows:

1. Compressor SAC 2B: 15.1 kW / 100 cfm
2. Compressor SAC 1B: 15.31 kW / 100 cfm
3. Compressor SAC 1A: 16.3 kW / 100 cfm
4. Compressor SAC 2C: 18.19 kW / 100 cfm

Measurement on Air Compressor Cooler
The results of measurements at the air-cooling temperature of the air compressor are as follows:

**SAC 1B**
- $T_{in} = 90 \, ^\circ F = 32.2 \, ^\circ C$
- $T_{out} = 100 \, ^\circ F = 37.8 \, ^\circ C$
- $P_{water\, in} = 76 \, Psig$
- $P_{water\, out} = 70 \, Psig$

**SAC 2B**
- $T_{in} = 84 \, ^\circ F = 28.8 \, ^\circ C$
- $T_{out} = 104 \, ^\circ F = 40 \, ^\circ C$
- $P_{water\, in} = 76 \, Psig$
- $P_{water\, out} = 72 \, Psig$

**Table 4. Resume of Compressor Performance SAC 2C**

| PERFORMACE KOMPRESSOR SAC 2C | DESIGN | ACTUAL |
|-------------------------------|--------|--------|
| Air Capacity                  | cfm    | 1557   | 1599   |
| Barometric Pressure           | Psia   | 13.94  | 14.64  |
| Relative Humidity             | %      | 78     | 82     |
| Inlet Air Temperature         | °F     | 82.4   | 89.6   |
| Discharge Pressure            | Psig   | 120.4  | 120    |
| Cooling Water Inlet Temperature | °F | 120.4  | 120    |
| Specific Power Consumption    | kW/100cfm | 18.19  |
Based on the measurement result can be concluded the things as follows;
SAC 1B
Delta T on the cooling water side = 10 ° F or 5.6 ° C
Delta P on the cooling water side = 6 kg / cm2

SAC 2B
Delta T on the cooling water side = 20 ° F or 11.2 ° C
Delta P on the cooling water side = 4 kg / cm2

Terms of manufacturer Ingersoll Rand, for water Cooler; temperature rise 25 ° F, thus generally the two Coolers are not yet in the desired condition. Seen Cooler on SAC 2B is better than Cooler in SAC 1B, because its delta T is higher which means to throw more heat with lower pressure drop. There is a possibility that the water pipeline in SCA 1B is dirty, It is advisable to check the condition of cooling water pipes in SAC 1B.

Analysis
It appears that for compressor type CV2, Specific power consumption number is owned by Compressor SAC 2B with the number 15.1 kW / 100 cfm. So the SAC 2B compressor can be used as a reference for improvement. Some things that can be done to improve performance compressor is;

1. Maintain compressor room temperature is low, by repairing ventilation system, install ducting to remove hot air from electric motors, and install insulation on hot air ducting.

2. Clean the filter water inlet regularly, and check with more frequencies around the compressor room due to the dust potential from fly ash Coal, especially the inlet side of the air in the outside facing the coal conveyor.

3. Perform the routine cleaning of the cooling water pipe. This is evidenced from the results of pressure measurements on Cooling water system, the pressure drop of cooling water on SAC 2B compressor only 4 Psig. Compared to the pressure drop on the Compressor SAC 1B of 6 Psig. The pressure drop is associated with the resistance to the piping caused by one of them by the dirt on the pipe surface. The effectiveness of the Air Cooler can also be seen from the delta Temperature that is the difference temperature outlet and temperature inlet of the cooling Water.

4. Ensure the Preventive Maintenance program runs well in accordance with the SOP of the vendor. It is also important of doing predictive maintenance activities such as the level of vibration checking, oil analysis and the temperature checking of the electric motor as a compressor drive.

5. Keep the coolant flow rate in the standard specified by the vendor can be seen in table 5, that is;

| Table 5 Cooling Water Rate |
|---------------------------|
| STAGES                   | GPM |
| First Stage              | 36  |
| Second Stage             | 41  |
| After Cooler             | 43  |
| Oil Cooler               | 50  |
| Total Cooler             | 170 |

Based on the simulation we can compare the annual operating cost between SAC 2B compressor with Compressor SAC 1A, then the difference of energy cost is Rp. 292.408.704, as shown in the following figure 8;
Figure 8. Simulation of Operating Cost Compressor

Conclusion
The measurement results show that the air compressor has different performance levels. The SAC 2B compressor has the highest performance of 15.1 kW / 100 cfm, while the SAC 2C Compressor has the worst performance of 18.19 kW / 100 cfm. If several improvement steps are taken to raise the compressor's performance to the level of SAC 2B compressor, energy saving will be obtained. For example, if the SAC 1A compressor is upgraded from 16.3 to 15.1 kW / 100 cfm, saving energy of Rp. 292.408.704.

Reference:
[1] H. Chalmers, M. Leach, M. Lucquiaud, and J. Gibbins, “Valuing flexible operation of power plants with CO2 capture,” in Energy Procedia, vol. 1, pp. 4289–4296, 2009.
[2] M.H.L. Ogink, “Analyses and dynamic modelling of the compressor section in a PCC-process for coal-fired power plants with offshore storage”, Master of Science Thesis For the degree of Master of Science in Mechanical Engineering at Delft University of Technology, June 2015.
[3] Hazel Ariantara, The Solution for Optimal Power Flow (OPF) Method Using Differential Evolution Algorithm, ISSN 2550-0554 JITEE, Vol. 1, No. 1, March 2017.
[4] Meherwan P. Boyce Dr. “Principles Of Operation And Performance Estimation Of Centrifugal Compressors” Proceedings Of The Twenty-Second Turbomachinery Symposium, 1993.
[5] M. Zangeneh, M. Schleer, F. Pløger et al., “Investigation of an inversely designed centrifugal compressor stage—part I: design and numerical verification,” Journal of Turbomachinery, vol. 126, no. 1, pp. 73–81, 2004.
[6] Pekka Röyttä, Aki Grönman, Ahti Jaatinen, Teemu Turunen-Saaresti, and Jari Backman, “Effects of Different Blade Angle Distributions on Centrifugal Compressor Performance” International Journal of Rotating Machinery Volume 2009 (2009), Article ID 537802, 9 pages http://dx.doi.org/10.1155/2009/537802
[7] O. E. Balje, Turbomachines: A Guide to Design, Selection and Theory, John Wiley & Sons, New York, NY, USA, 1981.
[8] P. M. Came and C. J. Robinson, “Centrifugal compressor design,” Journal of Mechanical Engineering Science, vol. 213, no. 2, pp. 139–155, 1998. View at Google Scholar
[9] S. L. Dixon, Fluid Mechanics, Thermodynamics of Turbomachinery, Pergamon Press, Oxford, UK, 3rd edition, 1989.
[10] D. Japikse, Centrifugal Compressor Design and Performance, Concepts ETI, Wilder, Vt, USA, 1996.
[11] H. I. H. Saravanamuttoo, G. F. C. Rogers, and H. Cohen, Gas Turbine Theory, Prentice-Hall, Upper Saddle River, NJ, USA, 5th edition, 2001.