Compressed Air Quality, A Case Study In Paiton Coal Fired Power Plant Unit 1 And 2

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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. Compressed air generation is not only sufficient in quantity (flow rate) but also meets the required air quality standards. compressed air at Steam Power Plant is used for; service air, Instrument air, and for fly Ash. This study aims to measure some important parameters related to air quality, followed by potential disturbance analysis, equipment breakdown or reduction of energy consumption from existing compressed air conditions. These measurements include counting the number of dust particles, moisture content, relative humidity, and also compressed air pressure. From the measurements, the compressed air pressure generated by the compressor is about 8.4 barg and decreased to 7.7 barg at the furthest point, so the pressure drop is 0.63 barg, this number satisfies the needs in the end user. The measurement of the number of particles contained in compressed air, for particle of 0.3 micron reaches 170,752 particles, while for the particle size 0.5 micron reaches 45,245 particles. Measurements of particles conducted at several points of measurement. For some point measurements the number of dust particle exceeds the standard set by ISO 8573.1-2010 and also NACE Code, so it needs to be improved on the air treatment process. To see the amount of moisture content in compressed air, it is done by measuring pressure dew point temperature (PDP). Measurements were made at several points with results ranging from -28.4 to 30.9 °C. The recommendation of improving compressed air quality in steam power plant, Paiton unit 1 and 2 has the potential to extend the life of instrumentation equipment, improve the reliability of equipment, and reduce the amount of energy consumption up to 502,579 kWh per year.

1. Introduction

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;
Three Centers Ingersoll-Rand Centrifugal Compactor Contacts in turn operate pressurized air. In practice, only one compressor operates alternately, because one compressor is considered sufficient for the Plant. 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 and 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.

The capacity of an air-conditioning unit must be able to remove the maximum cooling load, which is the full load condition of an air-conditioning unit. The centrifugal chiller is mostly used for large buildings and usually works all year round[1,2].

2. Problems
In the Paiton Power Plant the pressurized air quality is considered to be one of the causes of the low life time of the instrument equipment and solenoid valve using pressurized air.

3. Basic Theory
An air compressor is a device that converts power (using an electric motor, diesel or gasoline engine etc...) in to potential energy stored in pressurized air. By one of several methods, an air compressor forces more and more air into a storage tank, increasing the pressure. When tank pressure reaches its upper limit the air compressor shuts off. The compressed air in the tank is held until used [3].

Each day people are exposed to millions of bioaerosols, including whole microorganisms, which can have both beneficial and detrimental effects[4]. Environmental air contains a lot of water vapor, dust particles, microorganisms, and others. In air compression should be taken into account the oil content that comes with the air flow. But on Centrifugal Compressor, oil content is not a problem, because this compressor pertained to free oil compressor. Thus the biggest issue of contaminants on the Centrifugal compressor is the moisture content and dust particles. The quality of compressed air is regulated by the standards, among which the most widely referred is ISO 8573.1.

Recent advances in high-throughput sequencing have generated a rush to characterize the microbiome of various environments, including indoor and outdoor air[5-8]. The built environment is of particular interest because humans spend over 90 % of their time indoors[9].

The function of air compression system is to produce dry air, oil free, and dust particles. The remaining oil and dust particles can be removed by a complex filter media. However, water vapor should be reduced by the medium Dryers (refrigeration dryers, membrane dryers, adsorption dryers and others) that ideally work independently of the load. Air can bind more moisture if the temperature is higher and the volume is larger. In
contrast, air has poor capacity when air is compressed. A compressor compresses atmospheric air into a small part of the volume. At one point the compression process will reach the limit of the air's ability to bind water vapor.

The air will become saturated and some of the air will turn into water droplets or condensate. With the added effort of reducing the temperature will even increase the amount of water droplets that come out in the exit air. The amount of air coming out of the compressed air under pressure conditions can become even greater. For example, a 30 kW compressor removes about 20 liters of water into the compressed air system under a Humidity condition of 60% and an ambient temperature of 20 °C. On larger compressors, the numbers will be much higher.

Generally compressed air piping lines are made of steel or steel without zinc lining. Therefore the corrosion rate will increase quite high from the relative humidity 50%. Water vapor will cause corrosion in the case of pipes made of non-zinc coated steel. Rust will release gradually and carry over to the point of use. This will cause problems such as compressed nozzles, defective control elements and disturbed production. Impact Poor air quality can be seen in Figure 2.

![Figure 2. Impact of Poor Air Quality](image)

In practice, different types of Dryers are used to control problems due to the high moisture content. The compressor used the pressure dew point parameter to indicate the dryness level of the compressed air. Pressure Dew Point is the temperature where the water vapor contained by air will condense into water liquids (saturated with 100% relative humidity). The lower the pressure dew point, the lower the amount of water vapor in the compressed air. Refrigeration dryers have a dew point value of about +2°Ctd.

The existing air dryer is not suitable. For example, the traditional air dryer has many defects due to the pure machine structure, such as the inaccurate control of pressure, the exceeded waiting time for the regeneration control of molecular sieve, eventually, leading to the untimely failure of the air dryer[10-13].

There are several types of Air Dryers, the most famous are refrigeration dryers and adsorption dryers. Refrigeration Dryers cool compressed air up to 2 to 5 °C. Excess amount of water vapor will be condensed and discarded. In this case pressure dew point also ranges from 2 to 5 °C, while adsorption dryers have greater capability with pressure dew point can reach between -40 to -70 °C.

The air quality needed depends on the application of compressed air usage itself. As example, table 1 and table 2 below can be used as reference, the kind of compression air quality needed.
Table 1. Relationship between Air Quality and Application of its Usage

| APPLICATION                          | APLICATION COMPRESSED AIR QUALITY CLASSES ACCORDING TO DIN ISO 8573-1 |
|--------------------------------------|------------------------------------------------------------------------|
|                                      | PARTICLE | RESIDUAL FLOW |
|                                      | CLASS    | µm           | CLASS | DEW POINT            |
| Respiration Air                      | 1        | 0.1          | 1−3   | -70/-20 °C           |
| Spray Gun                            | 1        | 0.1          | 2     | -40 °C               |
| Medical Technology                   | 1        | 0.1          | 3−4   | -20/+3°C             |
| Measurement & control                | 1        | 0.1          | 4     | +3 °C                |
| Transportation food & beverages      | 2        | 1            | 3     | +3 °C                |
| General Factory Air                  | 3        | 5            | 4     | +3 °C                |

Table 2. ISO 8573-1-2010

| Solid Particles/Dust | Humidity and Liquid Water | Oil |
|----------------------|---------------------------|-----|
| Particles per m³, by size | Pressure Dewpoint | Total Concentration (Liquid, Aerosol and Vapor) |
| 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron | 0.1 to 0.5 Micron |
| Class | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 | 0.1 to 0.5 |
| 0     | As Specified | As Specified | As Specified | As Specified | As Specified | As Specified | As Specified | As Specified |
| 1     | ≤ 20,000    | ≤ 400       | ≤ 10       | 1           | ≤ -70       | ≤ -94       | 1           | ≤ 0.03       | ≤ 0.008       |
| 2     | ≤ 400,000   | ≤ 6,000     | ≤ 100      | 2           | ≤ -40       | ≤ -40       | 2           | ≤ 0.1        | ≤ 0.08        |
| 3     | Not specified | Not specified | ≤ 1,000    | 3           | ≤ -20       | ≤ -4        | 3           | ≤ 1.0        | ≤ 0.8         |
| 4     | Not specified | Not specified | ≤ 10,000   | 4           | ≤ -3        | ≤ -38       | 4           | ≤ 5.0        | ≤ 4           |
| 5     | Not specified | Not specified | ≤ 100,000  | 5           | ≤ -7        | ≤ -45       | X           | > 5.0        | > 4           |
| 6     | Particle Concentration (mg/m³) | ≤ -10 | ≤ -50 |
| 7     | 0 to 5      | Liquid Water Concentration (g/m³) | 7 | ≤ 0.5 |
| x     | >10         | 8 | 0.5 to 5 |
| 9     | 5 to 10     | X | >10 |

4. Measurement Methods

To prove the hypothesis at the beginning, that the pressurized air quality becomes the main factor of the low life time of instrumentation equipment and solenoid valve, it is necessary to measure the quality of compressed air. There are three air quality parameters that must be obtained from this measurement namely: pressure dew point temperature (Pdp), the number of particles in the air and the relative humidity, and the amount of lubricating oil in pressurized air. However, in this case because Paiton uses Centrifugal Compressor free oil, the measurement of oil content in the air is not done.

Equipment used in this measurement is the Portable Dew Point model 500 CS and Particle Counter CS Instrument equipped with data logger to record the measurement results.

5. Measurement Results

Measurement of dew point pressure is done at some point of compressed air usage. The results are shown in the following table.

From the measurement results, the dew point numbers ranged from -28.4 to 30.9 oC. With Realitf humidity ranges from 0.85 to 99.95%. The 100% figure means the air is saturated and the moisture will condense.
Table 3. Dew Point Measurement Results

| No | LOCATION                              | Dew Point | Pressure | Temperature | Relative Humidity |
|----|---------------------------------------|-----------|----------|-------------|------------------|
| 1  | After Dryer and Receiver Tank Instrument | 9.3 °C gd | 7.83 bar | 27.7 °C     | 31.75 %RH       |
| 2  | Area Turbin UNIT 2                    | 27.6 °C gd| 8.00 bar | 38.4 °C     | 21.94 %RH       |
| 3  | Line WTP After Dryer                  | 24.5 °C gd| 4.87 bar | 33.7 °C     | 58.60 %RH       |
| 4  | Area Turbin UNIT 1                    | 8.5 °C gd | 7.89 bar | 34.5 °C     | 20.32 %RH       |
| 5  | Supply Shot Boiler UNIT 2             | 20.2 °C gd| 7.94 bar | 33.1 °C     | 80.24 %RH       |
| 6  | Before Dryer SAC2                    | 29.0 °C gd| 7.97 bar | 29.0 °C     | 99.95 %RH       |
| 7  | Supply Shot Boiler UNIT 1             | 13.2 °C gd| 7.82 bar | 35.5 °C     | 26.29 %RH       |
| 8  | Area Fly Ash                         | 6.7 °C gd | 7.42 bar | 32.0 °C     | 20.68 %RH       |
| 9  | Supply Shot Boiler UNIT 2             | 25.0 °C gd| 7.95 bar | 33.2 °C     | 79.61 %RH       |
| 10 | Chemis Analysis UNIT 2               | -29.4 °C gd| 8.00 bar | 36.8 °C     | 0.85 %RH       |
| 11 | Line WTP                             | 27.7 °C gd| 7.50 bar | 27.7 °C     | 93.95 %RH       |
| 12 | After Dryer and Receiver Tank Inst. SAC 2 | 7.4 °C gd | 7.97 bar | 29.6 °C     | 24.68 %RH       |
| 13 | After Dryer and Receiver Tank Inst. SAC 1 | 9.2 °C gd | 7.83 bar | 27.7 °C     | 31.44 %RH       |
| 14 | D2 Analysis UNIT 1                   | -1.2 °C gd| 4.25 bar | 34.9 °C     | 9.88 %RH       |
| 15 | D2 Analysis UNIT 2                   | 8.1 °C gd | 7.61 bar | 32.5 °C     | 22.16 %RH       |
| 16 | Before D2 Analysis UNIT 2            | 24.0 °C gd| 7.13 bar | 35.1 °C     | 58.9 %RH       |
| 17 | Line WTP                             | 27.6 °C gd| 7.50 bar | 27.6 °C     | 99.93 %RH       |
| 18 | Before Dryer SAC 1                   | 30.9 °C gd| 8.02 bar | 30.9 °C     | 99.94 %RH       |
| 19 | Area Fly Ash UNIT 1                  | 24.8 °C gd| 7.80 bar | 32.4 °C     | 64.16 %RH       |

Measurement of the number of particles in the air using a Portable particle counter, carried out at several important points includes:

- Measurement after Centrifugal Compressor
- Measurements in PAPs
- Measurements in O2 analysis lines
- Measurements on fly ash lines

The results are displayed on the following charts:

**a. Measurements on Centrifugal Compressor SAC 1:**

The number of particles of 0.3 microns reaches the highest level at 18,000, while for particles of 0.5 microns reaches 12,500

![Figure 3. Results of Measurements of Air Particles in SAC1](image-url)
b. Measurements on the side after Centrifugal Compressor SAC 2
The number of particles of 0.3 microns reached the highest level at 97.458 while for particles of 0.5 microns reached 37,712.

![Figure 4. Results of air particle measurements in SAC 2](image)

c. Measurements in the WTP Path
The number of particles measuring 0.3 microns reaches the highest at 81,552 while for 0.5 micron particles it reaches 28,384.

![Figure 5. Results of measurements of air particles in WTP Line](image)

d. Measurement on the side of O2 Analysis Unit 1
The number of particles measuring 0.3 microns reaches the highest at 16,066 while for the 0.5 micron particles it reaches 11,663.

![Figure 6. Air Particle Measurement Results in O2 Analysis Line](image)
e. Measurements in the fly Ash Line of Unit 1

The number of particles of 0.3 microns reaches the highest level at 170,752 while for 0.5 micron particles reaches 45,245.

![Figure 7. Results of fly ash line of unit 1](image)

6. Analysis

Water Content Analysis

The content of water vapor in pressurized air is directly proportional to the Pressure Dew Point Temperature, as shown in the following table 4:

| Dewpoint | $g/m^3$  |
|----------|----------|
| +10      | 588.20   |
| +9       | 417.93   |
| +8       | 290.01   |
| +7       | 196.21   |
| +6       | 129.02   |
| +5       | 82.25    |
| +4       | 50.67    |
| +3       | 30.07    |
| +2       | 17.14    |
| +1       | 9.35     |
| +        | 8.34     |

| Dewpoint | $g/m^3$  |
|----------|----------|
| +        | 7.24     |
| +        | 6.35     |
| +        | 5.57     |
| +        | 4.86     |
| -10      | 2.15     |
| -20      | 0.8      |
| -30      | 0.3      |
| -40      | 0.11     |
| -50      | 0.03     |
| -60      | 0.01     |
| -70      | 0.003    |

The result of measurement of pressure dewpoint compared to the standard shown in table 5 as follows:
Table 5. Dew Point measurement results compared to standard.

| LOCATION | AKTUAL | STANDARD ISO 8573-1 |
|----------|--------|---------------------|
|          | DEW POINT °Ctd | Water Vapour g/m3 | DEW POINT °Ctd | Water Vapour g/m3 | KELAS |
| After Dryer and Receiever Tank Inst. SAC 1 | 9.3 | 417.93 | 3 | 30.7 | 4 |
| Area Turbin UNIT 2 | 27.6 | > 588.20 | 3 | 30.7 | 4 |
| Line WTP After Dryer | 24.5 | > 588.20 | 3 | 30.7 | 4 |
| Area Turbin UNIT 1 | 8.5 | 290.01 | 3 | 30.7 | 4 |
| Supply Shoot Boiler UNIT 2 | 29.2 | > 588.20 | 3 | 30.7 | 4 |
| Before Dryer SAC2 | 29 | > 588.20 | 3 | 30.7 | 4 |
| Supply Shoot Boiler UNIT 1 | 13.2 | > 588.20 | 3 | 30.7 | 4 |
| Area Fly Ash | 6.7 | 129.02 | 3 | 30.7 | 4 |
| Supply Shoot Boiler UNIT 2 | 29 | > 588.20 | 3 | 30.7 | 4 |
| Chems Analisis UNIT 2 | -28.4 | 0.8 | -20 | 0.8 | 3 |
| Line WTP | 27.7 | > 588.20 | 3 | 30.7 | 4 |
| After Dryer and Receiever Tank Inst. SAC 2 | 7.3 | 196.21 | 3 | 30.7 | 4 |
| After Dryer and Receiever Tank Inst. SAC 1 | 9.2 | 417.93 | 3 | 30.7 | 4 |
| O2 Analisis UNIT 1 | -1.2 | 7.24 | -20 | 0.8 | 3 |
| O2 Analisis UNIT 2 | 8.1 | 290.01 | -20 | 0.8 | 3 |
| Before O2 Analisis UNIT 2 | 24 | > 588.20 | 3 | 30.7 | 4 |
| Line WTP | 27.6 | > 588.20 | 3 | 30.7 | 4 |
| Before Dryer SAC 1 | 30.9 | > 588.20 | 7 | 196 | 5 |
| Area Fly Ash UNIT 1 | 24.8 | > 588.20 | 3 | 30.7 | 4 |

Based on the measurements in Paiton Units 1 and 2. The dew points vary from -28.4 to 30.9 °C, the relative humidity ranges from 0.85 to 99.95%. The 100% figure means the air is saturated and the moisture will condense. This condition is quite bad and is still far from the standard required for compressed air usage especially for use in the water instrument sector. Since the water instrument requires grade 3 air quality from the water content side, it means the dew point should be less than -20 °C with a water content of no more than 0.8 g/m³.

The solution of this problem is to improve the water treatment system on the user side, some efforts can be done:

a. Install the Water Separator on the user side
b. Install Electronic Zero loss Drain, to dispose of water.
c. Change filter coalescing elements periodically
d. Evaluate the existing Dryer system.

Based on the Dryer measurement results on the WTP, the dew point indicates a 24.5 °C number which should be between 3 - 7 °C, so it should be considered to replace the two Dryers, as it no longer shows the expected performance, and is physically unfeasible.

e. Replace and or repair an existing Desiccant Dryer.

The results of measurements after the Desiccant Dryer showed results varying from -28.7 °C to over 20 °C, it is known that some Desiccant Dryers are not functioning properly, as Desiccant Dryers should produce air with dew point pressure ranging between -40 to -73 °C.

Air Particle Analysis
From the particle measurement results can be summarized in the following table.

Table 6. Summary Measurements of Air Particles

| No | Location          | Maximal Number of Particle | Actual       | Standard ISO       |
|----|-------------------|----------------------------|--------------|--------------------|
|    |                   |                            | 0.3 mikron   | 0.5 mikron         |
| 1  | SAC 1             | 18.000                     | 12.500       | 20.000             | 400               |
| 2  | SAC 2             | 97.458                     | 37.612       | 20.000             | 400               |
| 3  | WTP Line          | 81.552                     | 28.384       | 20.000             | 400               |
| 4  | O2 Analysis Line Unit 1 | 9.421                    | 7.136        | 20.000             | 400               |
| 5  | O2 Analysis Line Unit 2 | 16.066                    | 11.663       | 20.000             | 400               |
| 6  | Fly Ash Line Unit 1 | 170.752                    | 45.245       | 20.000             | 400               |
| 7  | Fly Ash Line Unit 2 | 92.529                     | 6.790        | 20.000             | 400               |
The particle content of the SAC 2 measurements shows a considerable number of 97,458 well above the standard 1st air standard requirements of ISO standards. However, on O2 line on units 1 and 2 have met the criteria, because the particle content measuring 0.3 microns is less than 20,000. While in the WTP path, the number of particles both measuring 0.3 microns and 0.5 microns far above the standard ISO for air class 1 is much greater than 20,000 for 3 micron size.

So far, it seems necessary to evaluate the filter system both in terms of frequency replacement and technology. It is suggested that the filter rating is set based on the air conditions standard i.e. inlet air temperature of not more than 21 ° C. The Standard life time is 6000 hours or a year while the active carbon element is 1000 hours. If the default condition is exceeded then the element's age will be shorter.

Based on the analysis of water vapor and the number of particles, some improvement recommendations may be proposed as follows:

- Due to the lack of Dryer capacity in the Compressor house, as only one compressor operates, it is advisory to run both refrigerated dryers. Operation of two Dryers will ensure the decrease of Dew Point pressure value, air quality will be better because the amount of water present in the compressed air is reduced. To calculate the cost-benefit, it is necessary to calculate the losses due to damage to end-users (solenoid valve and instrument) due to high water content.
- Investigation of some Desiccant Dryers in point of use, as the result of dew point measurement at this point shows poor results.
- Further investigation of the filter system and its elements is required associated with replacement schedule and technology used. It is recommended to install Coalescing filter before end-users especially for applications on instrumentation.
- Periodic monitoring of compressed air quality is required. If possible mounted measuring tools that monitor the dew point and particle counter.

7. Conclusion

Based on the results of compressed air quality measurements at several points in the usage line, the results obtained that most air quality parameters such as pressure dew point temperature associated with the amount of water vapor in the air and the number of particles in the pressurized air has not met the desired standard by ISO 8573.1-2010.

This issue impacts the lifetime of instrumentation equipment and solenoid valve. Since both types of equipment will be exposed to high pressure water and dust in unacceptable quantities, then it will lead to accelerated damage and it will result in declining lifetime of pressurized air user equipment.

From these findings, it can be done several precautions such as repairing the filter system, dryer system and installing some new equipment such as desiccant dryers, coalescing filters and water separator.

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