Study and Analysis of an Industrial Compressor Facing Overheat Problem

by Ekadewi Handoyo

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Ekadewi A. Handoyo[1, a)], Fery Marianto[1], and Joshua H. Tandio[2]

[1]*Mechanical Engineering Dept., Petra Christian University, Indonesia*
[2]*Department of Agricultural and Biological Engineering, Mississippi State University, USA*
[a)] Corresponding author: ekadewi@petra.ac.id

Abstract. A compressor in a rice manufacturer, PT. X, got overheated especially on hot days. The overheat makes the compressor shut off and stops the production line. From the observation and data collected in PT. X, it was found that the overheat problem in the compressor was caused by (1) the dust on the surface of the aftercooler and the fluid cooler, and (2) the high temperature of the intake air to the compressor. The management comprehends the suggestion to clean the coolers' surface, close the door to the compressor room, and install an intake duct to bring in cooler air input to the compressor. Carrying out the suggestion, the overheat problem is overcome and there is saving in operational cost. The savings could be more than 4000 kWh/year for eight hours of work each day. By lowering the inlet air temperature as much as 4C° for the compressor, the CO_2 emission could be reduced around 4000 kg/year. A heat exchanger could replace the after cooler and the fluid cooler for recovering the waste heat of the compressor. The heat to be recovered from the compressor is approximately 40 kW. The waste heat recovery framework will produce 13 liter/min water at 70°C.

Keywords: overheat in compressor, CO_2 emission, intake air, waste heat recovery

Conference topics: Energy conversion: Heat and Mass Transfer

INTRODUCTION

Energy is an important issue in daily lives and industries. The conventional source of energy has been gradually replaced with renewable energy that is always available for us to use. The renewable energy which comes from solar, wind, tidal or wave is more environment friendly and produces less harmful gas emissions. It is just that renewable energy cannot be controlled and depends on nature. When such renewable energy sources are connected to an electrical grid directly, they can cause serious safety problems for the grid. Thus, a compressed air energy system is used as an energy storage (1), (2), (3), (4), (5).

Besides being used as an energy storage, compressed air is used a lot in industries, too. A compressor is used to produce pressurized air in some industries, such as automotive, pharmaceutical, railroad, food, and beverage, agricultural, woodworking, textiles, and manufacturing industries. For general manufacturing industries, air compressors are used for clamping, tool powering, stamping, cleaning, actuators, and controls. For textile industries, industrial air compressors are used for agitating liquids, conveying, and clamping, automated equipment, weaving by loom jet, actuators and controls, spinning and creating textures. For food industries, the compressor helps in dehydration, bottling, actuators and controls, spraying coatings, conveying, cleaning and vacuum packing. In Surabaya – Indonesia, there is a rice manufacturer in Surabaya – Indonesia, called PT. X, that uses a rotary screw compressor to drive some important equipment, such as to remove the unwanted materials or small stones from the rice, to polish the rice, and to measure the amount of rice in a scale.

An air compressor is an equipment that consumes a lot of energy in an industry. In general, a compressed air system consumes around 10% of industrial electricity energy (6) (7) (8). Some studies stated that about 80 – 93% of the electrical energy during air compression is converted into thermal energy (9) (10). The energy that the compressor consumes is used to increase the air pressure. Unfortunately, the increasing air pressure is accompanied with increasing air temperature. There are two important things regarding this fact. First, the heat in the air needs to be removed to maintain a proper temperature for the compressor to operate. Thus, there is an opportunity to use this waste heat (7) (8) (9). Second, if the temperature is too high, it will shut off and even fail the compressor. Thus, an overheat compressor is important to be analyzed (11) (12) (13).

According to some compressor manufacturers, the temperature in the discharge line should not be more than 225°F or equal to 107°C. The possible causes of air compressor overheating are (1) a low suction pressure that makes a high compression ratio, (2) excess discharge pressure, (3) inadequate cooler space, (4) inadequate room for compressor to properly vent, (5) ambient temperature, (6) the machine is old, (7) level and condition of oil, (8) frequent use for a long time (13) (14).

This paper will discuss the overheating disaster that happened on the compressor in PT. X especially on hot days. The compressor shut off, and the production line was stopped until the discharge temperature cooled down below 107°C. Since the discharge temperature is quite high, there is possibility to employ a waste heat recovery in the compressor.

METHODS

There are two things to be discussed, i.e., overheating in the compressor and analysis of employing waste heat recovery. To overcome the overheat problem, there is a checklist to follow. The checklists are (1) setting of the suction and the discharge pressure in the compressor, (2) the air temperature in the compressor room, (3) the vent out of compressor, (4) how old the compressor is, (5) level and condition of oil, and (6) the production schedule. To find the source of the overheat problem, some data were collected from March to June 2021 in the factory. The data are the specification of the compressor, the pressure setting in compressor panel, the electric current of the compressor using Amperemeter, the air temperature and humidity at inlet and outlet of compressor using thermo hygrometer, and the maintenance schedule of the compressor. The data will be analyzed to obtain suggestions for the factory to overcome the overheat problem.

Since the compressor is facing overheat problems, the outlet air temperature must be quite high. The electrical energy input is used to compress the air in the screw barrel in the compressor. This compression process increases the internal energy of the air which is indicated with the temperature raise. Energy is an important part of most aspects of daily life. Energy can be viewed as the ability to cause changes. The quality of life, and even its sustenance, depends on the availability of energy. Energy exists in numerous forms such as thermal, mechanical, electric, chemical, and nuclear. The conservation of energy or sometimes called energy balance is related to the first law of thermodynamics.

The air compression process that could be assumed to be a steady-flow process needs energy as follows: energy input – heat reclamation = enthalpy change of the air flow or shown in Eq (1).

$$\dot{W}_{in} - \dot{Q}_R = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{in} \qquad (1)$$

During the compression process in a compressor, the internal energy of the air is increasing due to the energy given by the electric motor. Thus, the enthalpy of the outgoing air at discharge is higher than the incoming fresh air. The energy efficiency of the compression process usually is defined as the ratio of the change in enthalpy of the air to the electrical energy as shown in Eq (2). Q_R in Eq (2) is the heat reclamation (15). If there is no heat reclamation, then $Q_R = 0$. The compressed air can be treated as an ideal gas. The three-phase electrical energy is calculated with Eq (3). This energy efficiency is sometimes called the first law efficiency (6).

$$\eta = \frac{\dot{m}_{out} h_{out} - \dot{m}_{in} h_{in} + Q_R}{\dot{W}_{elec}} = \frac{\dot{m} C_p (T_{out} - T_{in}) + Q_R}{\dot{W}_{elec}} \qquad (2)$$

$$\dot{W}_{elec} = I.V.pf.\sqrt{3} \qquad (3)$$

The electric current that the compressor drew was measured during the existing condition. Then, after the investigation to find the reason for the overheating in the compressor, the electric current was measured again. This paper will discuss the overheating problem, analyze the energy input to the compressor when it is overheated and not, and propose a scheme to employ waste heat recovery. The waste heat could be installed to replace the air aftercooler and fluid cooler. The waste heat recovery should not affect the compression process but could save energy consumption.

RESULT AND DISCUSSION

The Overheat Analysis

To analyze the overheat problem in PT. X, it is necessary to know the compressed air system (CAS) in there as shown in Fig 1. The specification of the compressor is in Table 1. The compressor is in a separate room from the vessel or the dryer. The air intake is drawn from the air in the room. While the hot air that cools the oil in the fluid cooler is flowing out of the room in an exhaust duct. The thermal energy carried by this hot air could be used in a waste heat recovery system.

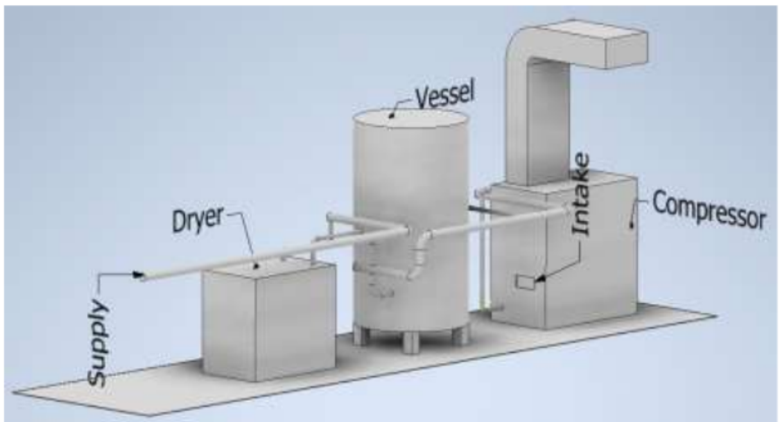

FIGURE 1. The compressed air system in PT. X

TABLE 1. The specification of compressor used

	Kaeser Rotary Screw Compressor
Model	CSD 125
Year manufacture	2011
Rated Power	75 kW
RPM	2978 /min
Flowrate	12.02 m^3/min
Max. pressure	8.5 barg
Ambient temperature	3°C - 45°C

Some data got from the observation i.e. (1) the discharge pressure was set to 6.5 barg and the suction was atmospheric pressure, (2) the usage of compressed air is in Table 2 and all equipment run well, (3) the compressor is built in 2011 and less than 20 years old, (4) the vent out of compressor is running well, (5) the compressor is well maintained shown in Table 3.

TABEL 2. The equipment and the working air pressure required

No	**Equipment**	**Number**	**Air pressure (barg)**
1.	Huller	1	5
2.	Polisher	6	4
3.	Color Sorter	3	4
4.	Scale	4	4

TABLE 3. The compressor maintenance schedule

Part	Time use (hour)	Limit (hour)
Oil Filter	2052	3000
Oil Change	3042	6000
Air Filter	1527	2000
Valve Inspection	9042	12000
Bearing lube	1563	2000
Motor bearings	21042	24000
Fan bearing	21042	24000
Electrical equipment	8019	9000

From the data in Table 2 and Fig. 1, the suction and discharge pressure of the compressor are in normal operation and less than the maximum working pressure (8.5 barg). The hot air can vent out of the compressor well. According to compressor manufacture or compressor maintenance service, the compressor life is around 20 years (13) (14). Thus, the compressor in PT. X could be considered running well. Table 3 shows that the oil condition and other parts are maintained well. The management complies with the maintenance schedule given by the compressor manufacturer. The production schedule is intermittent, and they have a break time. The production could be 24 hours a day when they have more demand. The above observation did not contribute to the overheat of the compressor.

The problem observed was the air temperature in the room as shown in Table 4. The inlet air is taken from the room which is quite hot and contains a lot of dust. Since the room is quite hot, the workers open the door to cool the room. Opening the door brought the dust from outside to the room. The air in the room is taken to the compressor as the working fluid and to cool the after cooler and fluid cooler. The dust will cover the surface of the cooler and make the oil leave the cooler at a higher temperature than usual. Table 4 shows average data for several day observations.

TABLE 4. Data of air intake and electric current of the compressor

Time	Intake air temperature (°C)	Humidity (%)	Discharge air temperature (°C)	Electric current (Amp)
08.00	32.1	58.3	90.3	120.5
10.00	34.6	53.5	98.0	123.6
12.00	37.2	48.5	103.5	124.5
14.00	37.2	43.3	104.5	124.9
16.00	35.8	46.8	101.3	123.8

Table 4 shows that the intake air temperature is highest at noon, i.e., 12.00 – 14.00 pm. The higher the intake air temperature, the higher the discharge air temperature and the higher the electric current consumed by the compressor. The humidity does not affect the temperature or electric current. When the discharge temperature is higher than 107°C, the compressor will shut off and the production will stop. From Table 4, it is found that the overheat is coming from the high intake air temperature.

Another source of overheating is because the dust that comes to the room covers the surface of the cooler. The surface of the fluid cooler is shown in Fig 2 (a) when the surface is dirty with dust and (b) when it is a little bit cleaner. The surface cannot be completely clean because no dust collector was installed in the factory.

(a) dirty with dust (b) a little bit clean

FIGURE 2. The surface of fluid cooler in the compressor

To overcome this high intake air temperature, an intake duct is proposed. In the compressor room, there are some supply air grills to cool the room. This supply air is coming from outside and much cooler than the air in the room. After getting the approval from the management, the intake duct is built as shown in Fig 3. Closing the door in the compressor room and using the intake duct to obtain cooler air from outside for the compressor, the electric current is reduced as shown in Table 5. Thus, the overheat problem is solved and the electrical consumption is reduced.

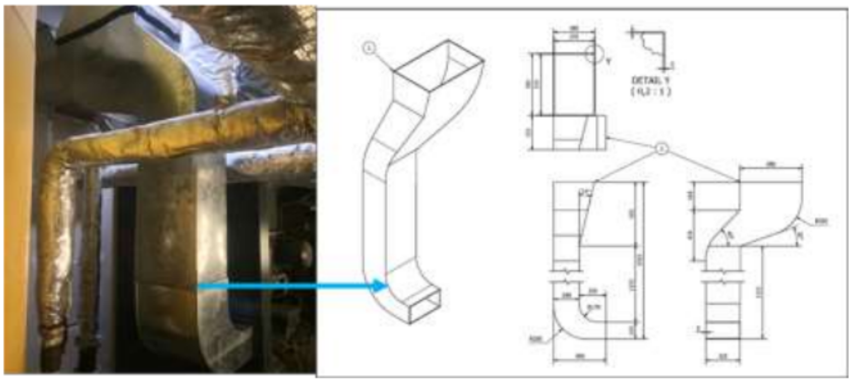

FIGURE 3. The intake duct built during observation

TABEL 5. Data of air intake and electric current of the compressor after installing intake duct and cleaning the aftercoler and fluid cooler

Date	Time	Intake air temperature (°C)	Discharge air temperature (°C)	Electric current (Amp)	Humidity (%)
11/06/2021	08.00	29.7	91	120.2	54
	10.00	32.0	94	121.0	50
	12.00	32.4	95	121.5	47
	14.00	33.0	96	121.5	41
	16.00	32.7	95	121.0	43

The impact of installing an intake duct or lowering the inlet air temperature has already been shown in Table 5. For understanding better, Fig 4 shows the comparison of the first law efficiency and the electrical consumption of the compressor before and after installing the intake duct. The first law efficiency and the electrical consumption were calculated using Eq (2) and Eq (3), respectively. The energy lost for cooling is calculated using Eq (1). The energy lost is the Q_R, the difference between the electrical energy input and the energy used to increase the energy of air flow as it is compressed. Figure 5 shows the effect of the inlet air temperature to the electrical input energy and the energy lost for cooling. Some energy lost to the oil in the screw barrel and some to the air in the after cooler. Since the discharge air temperature is lower when the inlet air is taken from the intake duct, the heat loss to the oil and cooling air is also decreasing.

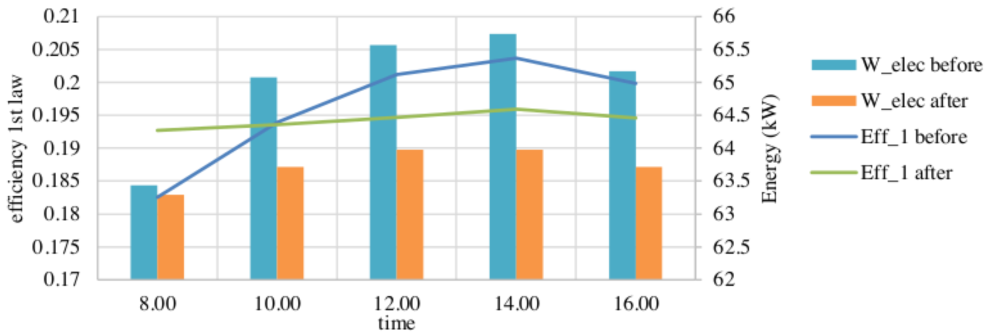

FIGURE 4. The first law efficiency and energy usage of the compressor

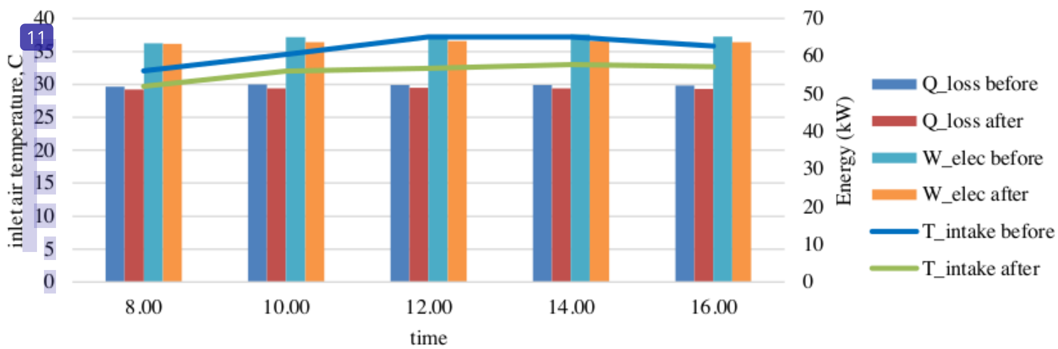

FIGURE 5. The effect of inlet air temperature to the energy in the compressor

The first law or sometimes called the energy efficiency is lowered after the air inlet temperature is reduced with installing the intake duct, because the electrical consumption is less to produce the same amount of compressed air. The production is still the same, but the input energy is lower. Figure 5 shows that the loss energy is also reduced with lowering the air inlet temperature. The savings because of the reducing electrical consumption per year can be seen in Table 6. The calculation was based on only eight hours of work each day. The savings could be more than 4000 kWh/year. Consuming less electrical energy means reducing the CO_2 emission. Just lowering the inlet air temperature as much as 4C°, the CO_2 emission could be reduced by around 4000 kg/year. This calculation was based on data that there is 0.87 kg CO_2/kWh electric used (16).

TABEL 6. The saving of electrical energy and the reducing of CO_2 emission after lowering inlet air temperature

time	saved energy (kWh/yr)	reduced CO2 emission, kg/year
08.00	422.8	370.8
10.00	3997.5	3505.8
12.00	4651.0	4078.9
14.00	5150.6	4517.1
16.00	4266.6	3741.8

The after cooler and the oil cooler could be replaced with a heat exchanger to catch the heat released by the compressed air at the discharge and the heat released by the oil. In the heat exchanger, compressed air and oil could transfer their heat to the water or the air. Water has higher density, specific heat, and thermal conductivity compared to the air. Air is cleaner and less corrosive than water. Whatever the fluid media, a waste heat recovery could save more energy and reduce CO_2 emission. One of the compressor manufacturers explains that the recoverable heat energy could be 96% (17). Opoku et al reported that the hot water with temperatures between 42 and 70°C could be achieved with the cross-flow air to water heat exchanger (9). Assume that 80% of the lost heat is recovered in the heat exchanger. When the water gets heated, its temperature will increase from 25 to 70°C. The possible water flow rates are shown in Fig 6.

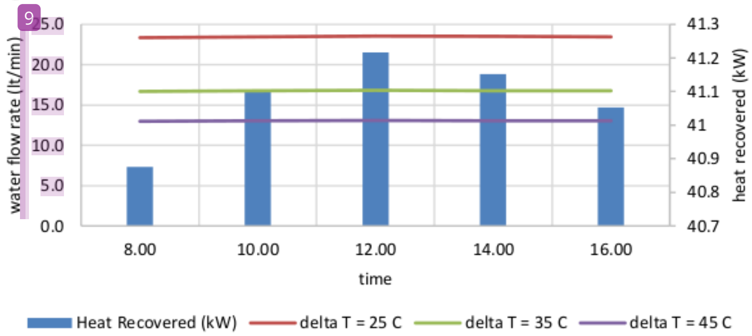

FIGURE 6. The heat recovered and the water flow rate in the waste heat recovery heat exchanger

Employing waste heat recovery could save approximately 40 kW energy to produce hot water at 70°C. If the inlet water is at 25°C, the water flow rate would be 13 liter/min. When the temperature increase is planned to be 35°C and 25°C, the water flow rate will be 16.8 liter/min and 23.5 liter/min, respectively. There is an opportunity to use a heat exchanger to recover the waste heat from the electrical energy input of a compressor.

CONCLUSION

From the observation and data collected in PT. X, it was found that the overheat problem in the compressor was caused by (1) the dust on the surface of the aftercooler and the fluid cooler, and (2) the high temperature of the intake air to the compressor. The management comprehends the suggestion to clean the coolers' surface, close the door to the compressor room, and install an intake duct to bring in cooler air input to the compressor. Carrying out the suggestion, the overheat problem is overcome and there is saving in operational cost. The savings could be more than 4000 kWh/year for eight hours of work each day. By lowering the inlet air temperature as much as 4C° for the compressor, the CO_2 emission could be reduced around 4000 kg/year.

A heat exchanger could replace the after cooler and the fluid cooler for recovering the waste heat of the compressor. The heat to be recovered from the compressor is approximately 40 kW. The waste heat recovery framework will produce 13 liter/min water at 70°C.

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