Study on Waste Heat Potential of Commercial Refrigerator Condenser

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Abstract: The waste heat from the commercial refrigerator came out from the heat released by the condenser. The released heat had the potential to be reused. The heat potential was suitable to be used for drying agricultural products that do not require too high temperatures or sensitive to high temperature such as materials containing volatile substances for example Curcuma rhizome. The amount of enthalpy and heat potential presented in the waste heat before doing modification is 94.29 $kJ.kg^{-1}$ and 1.336 $kJ.s^{-1}$. By doing a little modification on the condenser such as moved the condenser to the backside and added partitions, the enthalpy can be increased as much as 108.69 $kJ.kg^{-1}$ (increased up to 15.27%) as well as the heat potential as much as 1.723 $kJ.s^{-1}$ (increased up to 28.92%).

1 INTRODUCTION

There are several factors that influence the agricultural product processing activities as well as other processing industry. One of them that holds great impact is the availability of energy during those activities take place. That energy can be either thermal energy, electrical energy, chemical energy, mechanical energy, and others, which derived from various energy sources. Based on the source, the energy can be classified into two groups namely: fossil energy (diesel, petrol, kerosene or gas) and non-fossil energy (wind energy, water energy, biodiesel, biogas, bio-ethanol, etc). For the time being, fossil energy is still the main choice in the processing industry in Indonesia, although the latter not less than the first and has started to increase in utilization. Among the energy sources that have been mentioned earlier, there are other sources of energy that can still be exploited but tend to be ignored because they are considered no longer useful, which is the energy that derived from waste or by-product of the utilization of fossil and non-fossil energy when it is converted to another form of energy or when used for a process. Among the energy that comes from a by-product of a production process is wasted heat which is the unused output from a production process and usually discharged into the environment.

Utilization of waste heat into a source of energy that can be reused for another process has several positive impacts on the environment. First, the heat that usually discharged to the environment which is at a temperature above the ambient temperature, could be one of the factors that led to the increase of the environment temperature, can be reduced because the heat was used for other processes before discharged. Secondly, the aforementioned energy usage savings, which are certainly along with cost reductions for energy inputs. Thus, we can reduce the cost of production because some energy required comes from the waste that was previously about to be disposed of. Third, it has good environmental impacts, especially on the effects of fossil fuel exploration.

With the enormous benefits of reusing waste heat, it certainly has a new impact on future industry development. However, a more in-depth study of waste heat recovery is needed, such as: the quality of heat that can still be utilized, the type of activity that can exploit the heat potential possessed from waste heat, additional measures that must be done so that the waste heat can be utilized optimally, and how much benefit is gained by wasted heat recovery.

There are some activities that produce heat as a by-product, such as heat generated due to processing at the factory, heat emitted by vehicle radiators, and heat released by the condenser in the cooling system. The amount of waste heat from the factory is high

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because usually, the heat comes from the sterilization or the steaming process at very high temperatures while the waste heat of motor vehicles (such as cars or tractors) is classified as average. In addition to both types of heat, there is still a low waste heat from the condenser in the cooling system.

The heat from a cooling system derived from the cooling cycle as a heat discharged to the environment as a result of rising temperatures due to the compression process of the compressor. The cooling cycle includes: compressing refrigerant into the condenser by the compressor, discharging the heat from the condenser to the environment, throttling by the expansion valve, and absorbing the heat from the surrounding by the evaporator and then come back to the compressor, thus the cycle of the cooling system occurred. Based on the purpose, the cooling system could be divided into several types, such as air conditioner (AC) for cooling room and refrigerator for maintaining the freshness of food or drinks (for cold storage purpose). The refrigerator itself is divided into two types, namely domestic refrigerator and commercial refrigerator also known as showcase refrigerator.

The waste heat of an air conditioner and a domestic refrigerator has been studied before (Suntivarakon, et.al., 2009; Shinde, 2014; Rahmanto, 2011; and Momin, 2014), but not for a commercial refrigerator. Based on previous studies (Suntivarakon, et.al., 2009; Shinde, 2014; Rahmanto, 2011; and Momin, 2014), the potential of heat that can be utilized is quite satisfactory. Given that the objectives of a commercial refrigerator (showcase) are slightly different from domestic refrigerators, thereby resulting heat generation may have different potential values. Therefore, a more in-depth review of the potential for waste heat in the showcase refrigerator is required.

The purpose of this paper was to get the heat potential value that was still held by the heat of the condenser and to propose the type of activity that was suitable based on the potential.

2 METHODOLOGY

The research was conducted on a one-door commercial refrigerator AGATE-300 model with R600a refrigerant type. The initial data on the refrigerator before and after modification were taken during 6 hours. Preliminary data required include refrigerant temperature leaving the condenser, temperature and RH of air around the condenser, the temperature in the cold region of the refrigerator, and the temperature and RH of the environment. The data will be used to calculate the potential value of waste heat, compression work, refrigeration effects and coefficient of performance before and after modification. Modification was made to the condenser to concentrate the condenser waste heat so that the heat can be utilized more centrally.

3 RESULTS AND DISCUSSIONS

The cooling process in the refrigeration machine occurs when heat from one region is absorbed by the refrigerant and releases the heat to another region. This refrigeration process runs with the help of refrigerant passing through the coil. This process begins with the flow of the refrigerant with the aid of a compressor from the evaporator (conducting heat absorption) to the condenser (releasing the heat) (Ashby, 2006). This process can be understood more clearly with the aid of pressure-enthalpy diagrams of the vapor refrigeration compression cycle (Figure 1) (Stoecker and Jones, 1987).

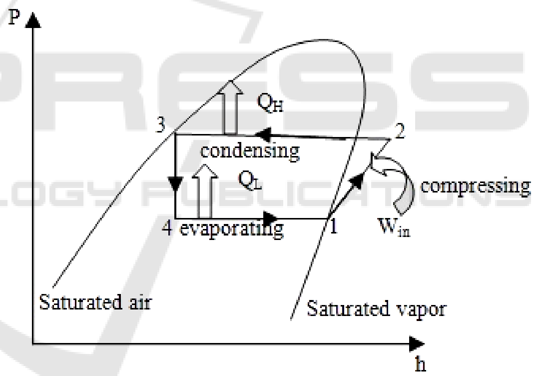

Figure 1: The standard vapor compression cycle in the pressure-enthalpy diagram.

There are some important parameters in refrigeration system that need to be known, such as, the refrigeration effect, the compression work, and the coefficient of performance (COP).

How much compression work during the ongoing refrigeration cycle is described as (Stoecker and Jones, 1987):

$$\dot{W}_c = \dot{m}(h_2 - h_1) \quad (1)$$

The effect of the refrigeration system is expressed in how much heat is released during the refrigeration cycle and described as (Stoecker and Jones, 1987):

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4) \quad (2)$$

The coefficient of performance (COP) signifies the achievement value of the vapor compression cycle is described as (Stoecker and Jones, 1987):

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \quad (3)$$

The waste heat from the condenser has the potential to be exploited. For example waste heat from an air conditioner used for drying clothes with COP between 2.66 to 3.45. Hot temperatures dispose of condensers vary between 41.9 to 42.6 ºC. Drying rate of 1.1 $kg.h^{-1}$ without an additional fan and 2.26 $kg.h^{-1}$ with an additional fan. The heat potential output of its air conditioner was 12,648 $BTU.h^{-1}$ or equivalent to 3.71 $kJ.s^{-1}$ (Suntivarakon, et.al., 2009) and for drying potato chips with COP of 2.64 to 3.26. Hot air temperature of 33.88 ºC to 44.05 ºC. The air conditioner cooling capacity was about 2.734 ± 0.023 $kJ.s^{-1}$ (Rahmanto, 2011). The waste heat of domestic refrigerator condenser can also be used to heat water up to 47 ºC (Shinde, 2014) to 52ºC (Momin, 2014).

Analysis of the heat potential of condenser output begins with the measurement of the temperature and humidity of the output air from the refrigerator condenser as well as the environmental air that described as (ASABE, 2006):

$$e^o(T) = 0.6010 \exp \frac{17.27\,T}{T+237.3} \quad (4)$$

$$Pv = e^o(Twet) - \gamma psy\,(T - Twet) \quad (5)$$

$$RH = 100 \times (Pv / e^o(T)) \quad (6)$$

In this case: $e^o(T)$ is saturated vapor pressure at air temperature (kPa), Pv is actual vapor pressure (kPa), $e^o(Twet)$ is saturated vapor pressure at wet bulb temperature (kPa), Twet is wet bulb temperature (ºC), T is dry bulb temperature (ºC), γpsy is the psychrometric constant (0.06738 at 1atm), and RH is relative humidity of air.

Air specific humidity is described as (Cengel and Boles, 2002):

$$\omega = 0.622 \times \frac{P_v}{P - Pv} \quad (7)$$

In this case: ω is specific humidity ($kg.kg^{-1}$), and P is the atmospheric air pressure (kPa).

The enthalpy of air before and after passing through the condenser is described as (Cengel and Boles, 2002):

$$h = 1.005\,T + \omega(2501.3 + 1.82\,T) \quad (8)$$

In this case: 1.005 is specific heat of dry air at 1 atm ($kJ.kg^{-1}$), 2501.3 is air coefficient, and 1.82 is specific heat of air ($kj.kg^{-1}K^{-1}$).

The specific volume of air passing through the condenser is described as (Singh and Dennis, 2009):

$$Vs = (0.082\,T + 22.4)\,X\,(1/29 + \omega/18) \quad (9)$$

In this case: Vs is the specific volume of air ($m^3.kg^{-1}$).

Airflow rate pass through the condenser is described as (Cengel and Boles, 2002):

$$V = v \times A \quad (10)$$

In this case: V is air flow rate ($m^3.s^{-1}$), v = air velocity ($m.s^{-1}$), and A is surface area (m^2).

The potential heat of the condenser is described as (Cengel and Boles, 2002):

$$Q = \frac{V}{V_s}(h_2 - h_1) \quad (11)$$

In this case: Q is heat ($kJ.s^{-1}$), h_2 is the enthalpy of air after passing through the condenser ($kJ.kg^{-1}$), and h_1 is the enthalpy of air before passing through the condenser ($kJ.kg^{-1}$).

3.1 Waste Heat Potential of Commercial Refrigerator Condenser

Based on observation, the following data (Table 1) were obtained:

Table 1: Initial observation data (before modification).

Parameters	quantity
T ambient db	28.78 ºC
T ambient wb	26.96 ºC
T air from condenser db	33.39 ºC
T air from condenser wb	29.25 ºC
RH of air from condenser	73.57 %
Velocity of air leaving condener	5 $m.s^{-1}$

From the potential value obtained from observation and calculation, it is advisable to utilize the heat potential for the drying process of curcuma chips. Given that, to dry the curcuma requires a temperature between 40ºC – 60 ºC (Sapei, et al, 2017). This is due to the presence of essential oils in those rhizomes that would be lost if dried at high temperatures.

Based on Table 1 and by using Equation 8 and 11, the enthalpy and the waste heat potential from commercial refrigerator condenser could be calculated and obtained respectively 94.29 $kJ.kg^{-1}$ and 1.336 $kJ.s^{-1}$. This amount of energy can be used for draying agricultural product such as curcuma rhizomes. If all of the energy used for draying in 6 hours then the amount of curcuma chips that can be dried as much as 13.2 kg, with the assumption that all of energy used for drying or there are no energy loss during drying process (efficiency is 100%), 90% of initial water content, and 7% of desired water content.

The waste heat potential can be raised if a modification is made to the condenser. In addition, this modification can also increase the number of activities that can use the waste heat. Furthermore, this needs to be done because in the default condition the direction of the waste heat (air leaving the condenser) leads to the front of the refrigerator, making it quite difficult to exploit the heat potential. In addition, the heat tends to spread in all directions.

The modification done by moving the condenser position to the back of refrigerator and adding some partitions outside the condenser. Adding partitions could reduce the air velocity leaving the condenser but it also increased the air contact time with the condenser surfaces. Here are the data obtained after modifications (Table 2)

Table 2: Observation data after modification.

Parameters	quantity
T ambient db	28.78 ºC
T ambient wb	26.96 ºC
T air from condenser db	42.12 ºC
T air from condenser wb	32.09 ºC
RH of air from condenser	50.28 %
Velocity of air leaving condenser	1.6 $m.s^{-1}$

After modification the enthalpy and the waste heat potential respectively 108.69 $kJ.kg^{-1}$ and 1.723 $kJ.s^{-1}$. The enthalpy can be increased as much as 15.27% and the the waste heat potential can be increased as much as 28.92%.

With this amount of energy, then 16.7 kg of curcuma chips will be able to be dried, with assumptions that all of energy used for drying or there are no energy loss during drying process (efficiency is 100%), 90% of curcuma water content, and 7% of desired water content.

Although this modification could improve the quality of heat that can be utilized, this also changed the value of COP, compressor work and refrigeration effect.

3.2 Work of Compressor, Refrigeration Effect, and COP

The work of a compressor from a refrigeration can be calculated using Equation1 and using properties of refrigerant R600a (ASHRAE, 2009). From the calculation, the work of compressor before and after modification obtained as follows (see Figure 2):

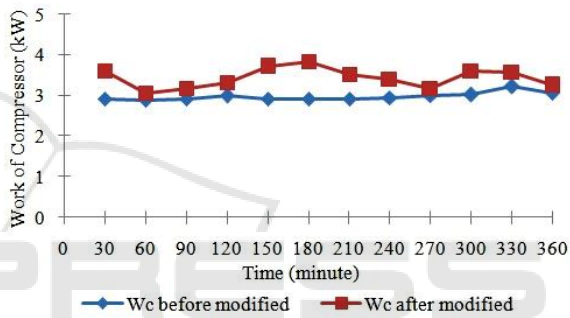

Figure 2: The work of compressor.

The refrigeration effect of a commercial refrigerator can be calculated using Equation 2. Here is the refrigeration effect before and after modification (see Figure 3).

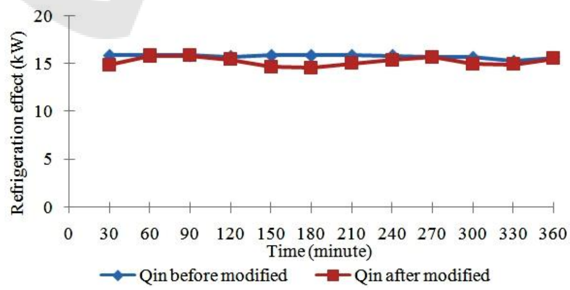

Figure 3: The refrigeration effect.

The COP of a commercial refrigerator can be calculated using Equation 3. Here is the COP before and after modification (see Figure 4).

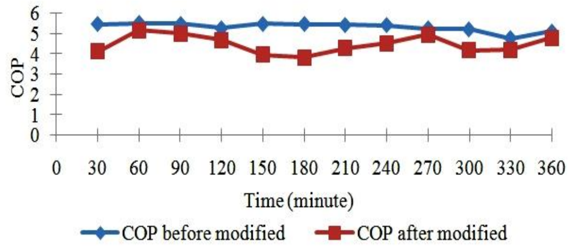

Figure 4: The coefficient of performance (COP).

The COP after modification (Figure 4) was lower than before modification. This happened because the work of compressor (Figure 2) has been increased after modification although the refrigeration effect (Figure 3) was almost constant. Nevertheless, the average of COP was still relatively high, which was above 4. The increase in the work of compressor could occur due to modification made to the condenser position and the partitions added on the outside of the condenser which resulted in a reduced air velocity passing through the condenser. Thus made the compressor work more even though the refrigeration effect was almost constant. This illustrates the considerable influence on the performance of irreversible heat transfer between the refrigerant on the cold and warm region.

4 CONCLUSIONS

From the observation, it can be concluded that the waste heat of a commercial refrigerator had potential to be utilized for another process such as for drying process. The potential heat also can be improved by doing some modification in to the system. The enthalpy and the potential heat presented in the waste heat before doing modification respectively was 94.29 kJ.kg^{-1} and 1.336 kJ.s^{-1}. Modifications done to the condenser such as moved the condenser to the backside of refrigeration and added partitions on the outside of condenser. By doing modifications, the enthalpy could be increased as much as 108.69 kJ.kg^{-1} (increased up to 15.27%) as well as the potential heat as much as 1.723 kJ.s^{-1} (increased up to 28.92%).

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