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Experimental Design of Compact Heat Exchanger for Waste Heat Recovery of Diesel Engine Exhaust Gases for Grain Dryers

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***Abstract*— In diesel engine cycle, 35% of energy losses through the exhaust gases, the heat is an energy potential that can still be reused for various purposes. This research aims to design a heat exchanger, based of diesel engine exhaust gases integrated with rice milling unit for drying agricultural products. The exhaust gas is derived from 6D16 diesel engine of 120 kVA as a power generator for rice milling unit at South Sulawesi. Exhaust gas temperature reaches 357ºC with the mass flow rate of 636 kg/hour at ambient temperatures of 32ºC and 84% relative humidity. From the calculation, the energy of the exhaust gas is able to dry 2 tons of paddy in the drying air temperature of 53ºC and drying mass flow rate of 6,600 kg/hour for 8 hours drying time. Used is a compact heat exchanger with 0.3 m long, 0.3 m wide and 0.2 m high, using a plain- fin 2.0. Tests carried out using a flat bed drying 174 kg capacity of grain with 24.56% moisture content, using a drying air temperature of 53ºC and mass flow rate of 706 kg/hour. At the test, the diesel engine operates on medium speed and without milling process, can produce 128ºC exhaust gas temperature and mass flow rate of 403 kg/hour. Dried grain with a moisture content of 13.67% was obtained after the drying process for 5 hours 11 minutes.**

Keywords: Grain dryer, energy, cogeneration, exhaust gases, heat exchanger, waste heat.

I. INTRODUCTION

The utilization of exhaust waste heat is now well known and the forms the basis of many combined cooling and power installations. The exhaust gases from such installations represent a significant amount of thermal energy that traditionally has been used for combined heat and power applications [1]. An industrial sector uses more energy than any other end-use sectors and currently this sector is consuming about 37% of the world's total delivered energy. Energy is consumed in the industrial sector by a diverse group of industries including manufacturing, agriculture, mining, and construction and for a wide range of activities, such as processing and assembly, space conditioning, and lighting [2].

Rice milling industry is one of the most energy consuming industries. Such as capital, labor and materials, energy is one of the factors of production used to produce final products [3]. Rice milling unit at South Sulawesi, Indonesia using a diesel engine generator as a main power plant. In the diesel engine combustion cycle, the energy balance between the use of the heat of combustion of fuel, as 35% of the energy used as a work machine through the shaft work, 20% of the energy lost as the engine coolant, 10% lost by radiation and the remaining 35% is lost with flue gas at exhaust manifold [4]. Heat loss to the flue gas rate of 35% is a potential that can be used for various purposes such as for steam power plants, drying of foodstuffs and agricultural products, heating, or for other purposes. Quality waste heat from the flue gas are high temperature, and the greater potential value for heat recovery [5]. On this calculation, the use of hot air used for the drying process at integrated paddy rice milling unit. Exhaust gas from Diesel engine is the pollution that contaminates the environment like CO, HC, NOx, Sulfur compounds, Organic Acids, Ammonia, Aldehydes and solids [6].

Cogeneration technology is one solution to a more efficient use of energy as heat source for drying machines can take advantage of the heat wasted through engine exhaust gas of diesel engines power for rice milling unit. With the concept of cogeneration, energy efficiency in the overall energy system increases significantly. In some cases, could increase by more than 30% compared to the conventional systems. Heat loss with exhaust gas rate of 35% in diesel engine combustion cycle is a potential that can be used for various purposes such as for steam power plants, drying of foodstuffs and agricultural products, space heating, or for other purposes. Exhaust gas temperature for diesel engines can achieve 500 ºC with the magnitude of the mass flow rate within the capacity of the machine. This parameter is very potential to be exploited. Equipment used in this installation is the fan, heat exchanger and grain drying unit, which will be planned based on the specification of the exhaust gas

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from diesel engine power plants at a rice milling unit. The continuous research for an alternative power source due to the perceived scarcity of fuel fossils is its driving force. It had become even more popular as the cost of fossil fuel continues to rise [7].

For the industries which is need of energy in different forms such as electricity and steam, (most widely used form of heat energy), the cogeneration is the right solution due to its viability on technical, economical as well as environmental angle. The benefits of cogeneration systems are to produce hot air that can be used for drying agricultural commodities such as grain. Schematic utilization of the diesel engine power plant at rice milling unit installation can produce an integrated production process of drying and milling processes continuously without being interrupted by the weather as shown in Figure 1. The high temperature of exhaust gas is a potential that can be used for various purposes, but connot be used directly because of the chemical elements that were dangerous. Utilization of waste gas as an energy source can be done using a tool called a heat exchanger where the tool is, the temperature of the exhaust gas can be transferred to another fluid, either gas or water without contamination by chemicals it contains. The merger of a diesel engine power plant with heat exchanger is a unity which is called cogeneration. With this cogeneration system, heat emitted by diesel engine exhaust gas can be utilized for various purposes such as heating and drying of food materials and agricultural commodities.

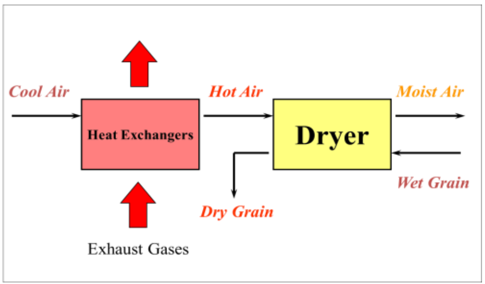

Figure 1. Scheme utilization of waste heat of diesel engine exhausts gas for drying with the cogeneration technology

The benefits that can be applied to the drying of grain are a unit of rice milling machines. Exhaust gas waste heat power generation diesel engines for rice milling can be used to dry the grain before grinding, thus obtained a production process of simultaneous, efficient and environmentally friendly. Based on the above can be modeled framework as Figure 2.

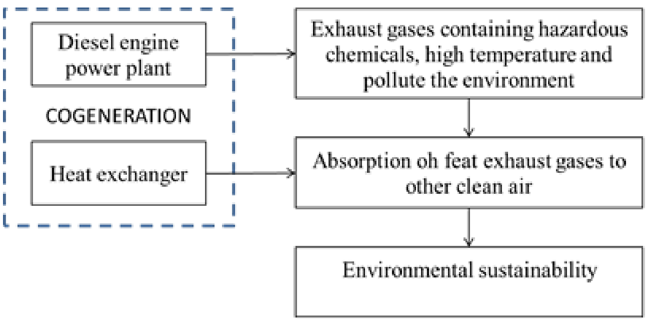

Figure 2. Framework of cogeneration system

II. MATERIALS AND METHOD

The research was conducted at the Bola Ase Milling Unit, Sidenreng Rappang, South Sulawesi, Indonesia, to measure the temperature and exhaust gas mass flow rate of diesel engine power plant a rice milling machine. The data was used as a reference for calculating the characteristics of the heat exchanger. The results obtained from the design of heat exchanger and the temperature of the air mass flow rate was used to calculate the appropriate grain drying capacity. 6D16 120 kVA diesel engine in the power plant of a rice milling unit was used. At the experiment, the diesel engine operates on medium speed without milling process, obtained the exhaust gas temperature of 128 °C, exhaust gas flow rate of 403 kg/h with the ambient air temperature of 32 °C and 84 % relative humidity.

A. Compact Heat Exchanger Construction and Fabrication

Heat exchanger dimension are length 0.3 m, width of 0.3 m and a height of 0.2 m, using a fin made of aluminum sheet with a thickness of 0.8 mm. Fin fabrication is done manually to produce shapes and dimensions in accordance with the plain plate-fin surface 2.0 [8].

The fabrication process starts with cutting sheets of 0.8 mm aluminum plate and then molded to produce the final form of an array of fins with the cross flow. Fin arrangement is then covered by a cover made of steel plate, as shown in Figure 3. Heat exchanger made such that no fluid leakage between the two sides of the gases, in order to produce clean hot air, free of smoke, dust and particles to avoid contamination of the flue gas with dried food.

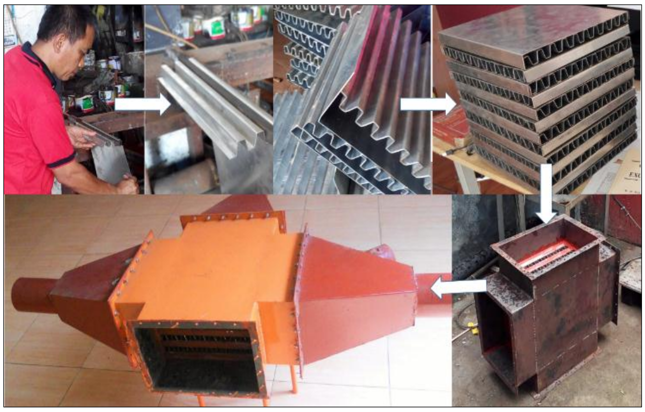

Figure 3. Fabrication and construction of compact heat exchanger

B. Flat Bed Construction

Dimensions of flat bed dryer made in accordance with the calculation of dryer capacity of 174 kg of wet rice grain or the equivalent volume of 0.3 m^3, acquired dimensions of length bath tub width of 1.2 m and 0.83 m. The shape and dimensions of the dryer tub shown in Figure 7.

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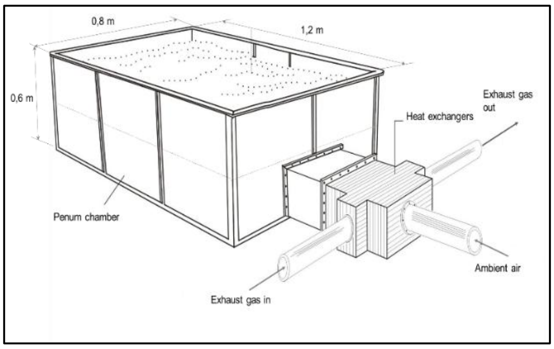

Figure 7. The shape and dimensions of flat bed dryer

III. RESULTS AND DISCUSSION

A. *Heat Exchanger Test*

Installation of compact heat exchanger test consists of diesel engines, heat exchanger and blower as shown in Figure 4. Additional equipments are a thermocouple, a pitot tube and manometer as an instrument measuring for temperature and mass flow rate of air and exhaust gases.

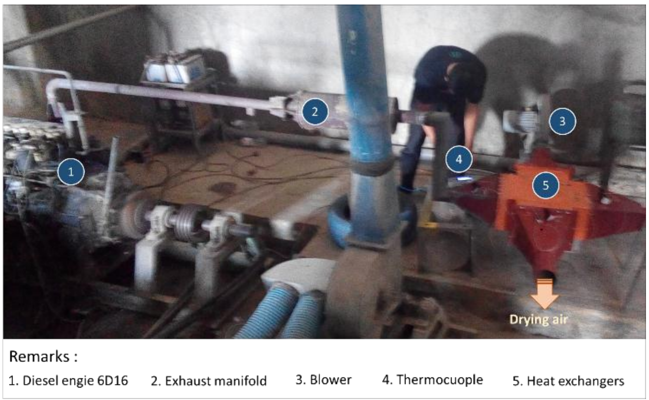

Figure 4. Experimental equipment of compact heat exchanger

When the testing of a heat exchanger, 6D16 diesel engine operating on medium speed and without the milling process. From the measurement results obtained by the amount of the maximum temperature of the exhaust gas in a stsady state at 128°C with the mass flow rate of 403 kg/hour.

The testing conducted to obtain information about the characteristics of heat exchanger deviations between the test results and predicted by theoretical calculations.

The first test is to operated of heat exchanger to be started when 6D16 diesel engine began operating in constant speed and load until it reaches the maximum flue gas temperature and stable. Air mass flow rate adjusted to the maximum valve opening in the air inlet of the blower of 1,117 kg/h, the ambient temperature is 32,23°C.

When testing begins early flue gas temperature recorded at 70°C until it reaches a maximum at 128°C for 12 minutes. In these conditions obtained by the drying air temperature variations out of heat exchanger in the range between 37,75°C to 48,50°C. Data from those measurements are then compared with the predictions of the discharge air temperature variation of heat exchanger is based on the calculation in the same conditions, the results are as shown in Figure 5.

Based on the test data, obtained a description of the deviation between the temperature of the experiment results and temperature predictions. Temperature forecast average 18.7% higher above the average temperature of the experiment and 15.7% when the exhaust gas temperature and discharge air temperature of heat exchanger has reached a steady state.

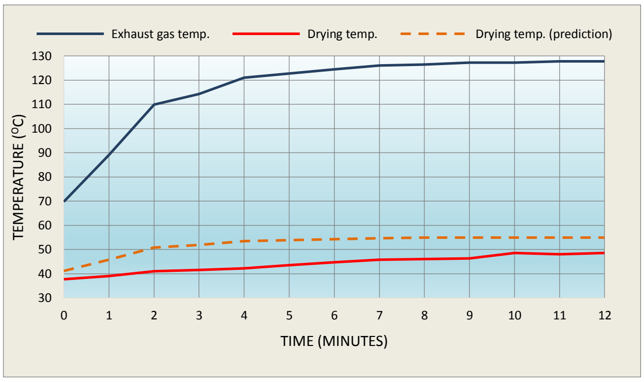

Figure 5. Relationship between exhaust gas temperature, drying temperature from heat exchanger actual and prediction.

The next test is a variation of the mass flow rate of air drying when the maximum of exhaust gas temperature is reached and stable at a temperature of 128°C. Variations in the mass flow rate of air is obtained by adjusting the valve gate of blower inlet. The measurement results showed dryer temperature rise is inversely proportional to the increase of the mass flow rate of air. For variations in the level 5 intake air mass flow rate, drying air temperature is 48,56°C air mass flow rate of 1117 kg/h and the highest is 55,25°C the air mass flow rate of 500 kg/hr. drying air temperature is 53°C for drying test obtained in air mass flow rate 706 kg/h. The measurement results for the dryer temperature variations in the air mass flow rate shown in the graph in Figure 6.

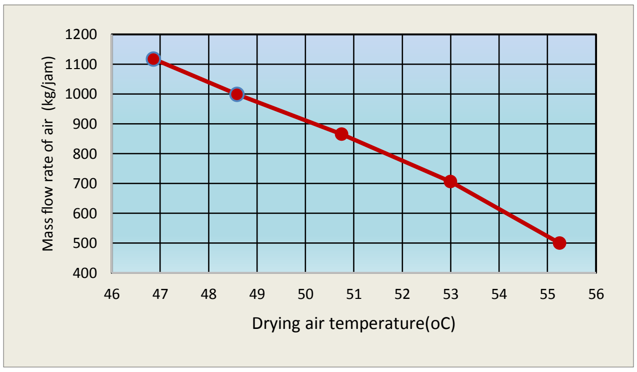

Figure 6. Drying air temperature from heat exchanger with a variation of the mass flow rate of air in the exhaust gas mass flow rate of 403 kg/h and temperature of 128°C

B. *Grain Drying Test*

Grain drying experiment installation consists of several main components include a flat bed dryer equipped with a blower dryer, LPG burner and some devices such as moisture tester, thermocouple and timer as shown in Figure 8.

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Tests using a drying Ciherang wet rice with initial moisture content of 24.53% on average. The drying process was conducted in rice mills Bola Ase, District Watang Pulu, Sidenreng Rappang, Indonesia on February 14, 2016 starting at 08:05. Ambient temperature during the test is 32,23°C and relative humidity 84%

Figure 8. Installation of test equipment grain drying

During the drying process lasts stirring rice at intervals time of 1 hour so that the moisture content of grain distributed evenly. Drying parameters observed every interval 30-minute in the form of outside air temperature, drying air temperature, temperature and moisture content of grain in 3 layers on grain thickness of 0.3 m. The test results showed that grain moisture content reaches an average of 13.67% after drying for 5 hours 11 minutes.

Grain drying rate is 2.09%/hour according to the required maximum drying rate is 2%/hour for consumption purposes [9]. A decrease of grain moisture content shown in Figure 9. Temperature measurement is performed at three layers of grain each on the top, middle and bottom of grain.

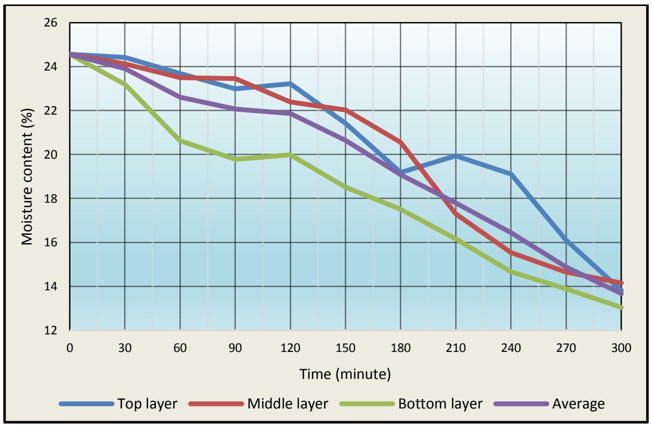

Figure 9. The decline in grain moisture content of the drying time

From the test results obtained by the average temperature of the air dryer when drying takes is 53°C and average grain temperature is 38°C to all layers of the grain, as it exits the grain surface average temperature of air coming down on the amount 36,46°C. Distribution of temperature profile at each layer of grain is shown in Figure 10.

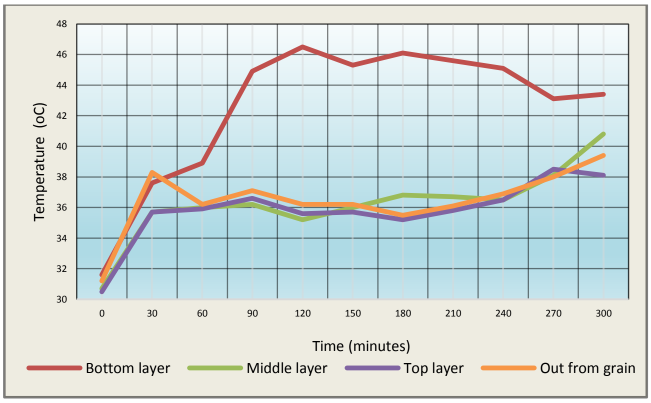

Figure 10. Distribution of temperature at each layer of grain during in the drying air temperature of 53°C

Loss of free moisture (kg.H_2O / kg.dry solid) for each layer of grain during the drying process is shown in Figure 11.

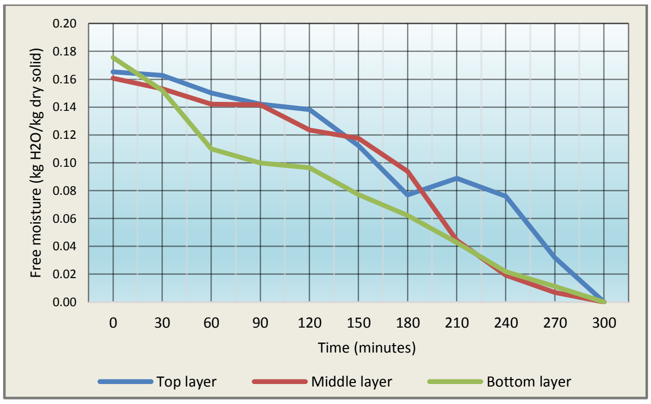

Figure 11. Loss of free moisture with time for a solid

Profile grain drying rate of the initial moisture content of 24.56% to 13.67% and the grain temperature characteristics shown in Figure 12.

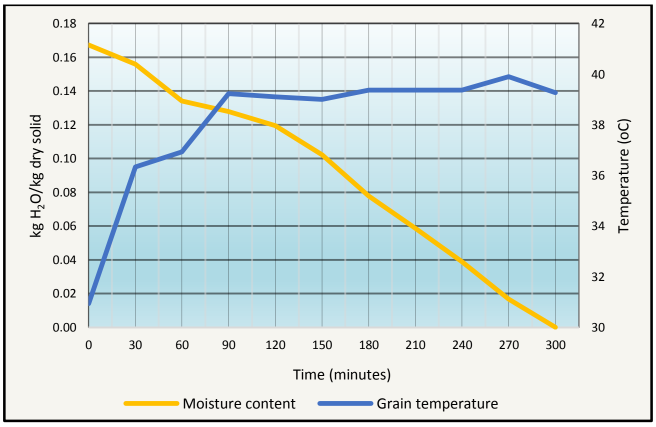

Figure 12. Drying rate and grain temperature of grain with drying time

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From the same data, obtained grain drying rate curve (kg.H_2O/kg dry solid/hr) against the drying time, as shown in Figure 13

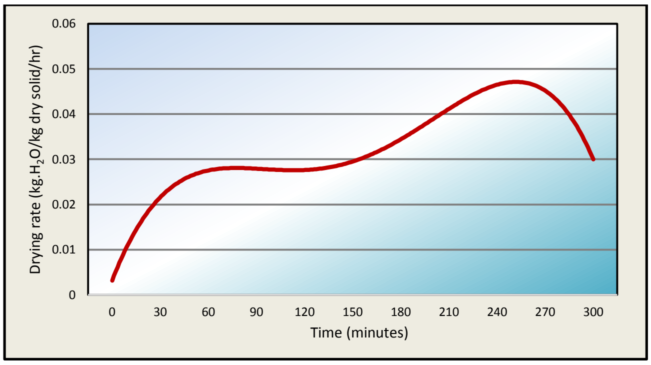

Figure 13. Drying rate curve

Duration of drying occurs difference between testing and predictions that are technically influenced by several things, among others, is the difference in the estimated discharge air temperature dryer tub and several other factors. Differences in the duration of drying between the test results and the predictions and calculations based on the results of the test data shown in Figure 13

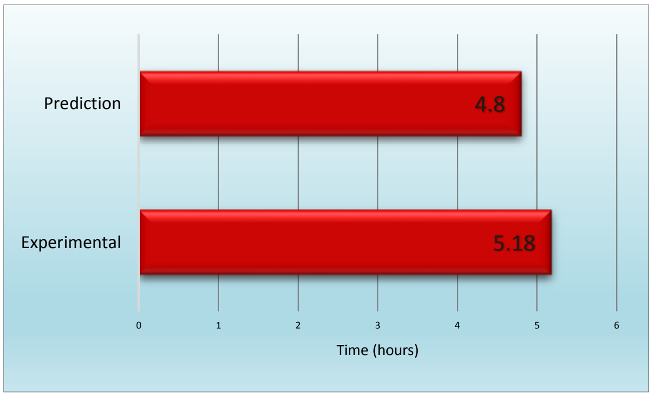

Figure 13. Duration of drying based on predictions and experimental

C. Analysis of Energy

Based on data from the results of several previous test, obtained some magnitude characteristic as a drying system which is shown in Table 1.

Table 1 Data result from experimental

No	Item	Unit	
1	Mass of grain	403	kg/hr
2	Mass flow rate of air	706	kg/hr
3	Ambient air	32.23	°C
4	Drying air	53	°C
5	Air temperature out from dryer	36.46	°C
6	Exhaust gas temperature to heat exchangers	128	°C
7	Exhaust gas temperature from heat exchangers	93	°C

In a diesel engine combustion energy balance, 35% of fuel energy released in the form of heat energy being wasted exhaust gases. This energy can be used for grain drying process with a system of energy transformation as illustrated in Figure 1.

Based on the calculation, it can be seen the amount of system efficiency, as a reference to determine the level of overall system performance. The calculation of the efficiency of the system is done by first calculating the amount of energy and efficiency at every sub-systems as follows:

Energy of drying:

Require heat for drying air

$q._{da} = \dot{m}._{ud} \text{ x } Cp\ (T_2 - T_1)$
$Cp._{da} = 1{,}0062\ kJ/kg^oC$

$q._{da} = 706\ kg/hr \text{ x } 1{,}0062\ kJ/kg^oC \text{ x } 20{,}8^oC \text{ x } 5{,}18\ hr$
$= 76.539\ Kj$

Require heat for drying grain:

Sensible heat of grain;
$q._{grain} = m._{gbh} \text{ x } Cp\ (T_2 - T_1)$
$Cp._{grain} = 1{,}942\ kJ/kg^oC$
$q._{grain} = 174\ kg \text{ x } 1{,}942\ kJ/kg^oC \text{ x } 16{,}54^oC = 5.589\ kJ$

Latent heat of vaporization;

$q._v = m._{ua} \text{ x } H_{fg}$

Where;

$m._v$ = mass of vapor, 22 kg
H_{fg} = latent heat of vapor at 53°C = 2.375,5 kJ/kg

$q._{ua} = 22\ kg \text{ x } 2.375{,}5\ kJ/kg = 52.261\ Kj$

Total heat of grain drying = 5.589 kJ + 52.261kJ = 57.850 kJ

Based on the above calculation, we obtained drying efficiency:

$\eta_{drying} = (57.850\ kJ / 76.539\ kJ) \text{ x } 100\ \% = 75{,}6\%$

Energy of Exhaust gas:

Heat released by the exhaust gas:
$q._{eg} = \dot{m}._{eg} \text{ x } Cp\ (T_2 - T_1)$
$Cp._{eg} = 1{,}0122\ kJ/kg \text{ x } 1{,}018 \text{ x } 1{,}048$
$Cp._{eg} = 1{,}0799\ kJ/kg$
was obtained;
$q._{eg} = 403\ kg/jam \text{ x } 1{,}0799\ kJ/kg^oC \text{ x } 35^oC \text{ x } 5{,}18\ jam$
$= 78.902\ kJ$

Based on the amount of heat released by the exhaust gas and received by a heat exchanger, we obtained:

$\eta_{heat\ exchangers} = (76.539\ kJ / 78.902\ kJ) \text{ x } 100\ \% = 97\%$

From the calculation of the energy and efficiency of the above sub-system, system efficiency is obtained:

$\eta_{system} = \eta_{drying} \text{ x } \eta_{heat\ exchangers}$

$= 75{,}6\% \text{ x } 97\% = 73{,}32\%$

System efficiency of 73.32% indicates that the use of exhaust gas energy to grain drying applications using compact heat exchanger 0.18 m3sized, feasible and efficient with energy loss rate of 26.68%.

IV. CONCLUSION

The exhaust gas of 120 kVA diesel engines at 128 °C at medium speed and without load, has a potential to be used as a heat source in a cogeneration system for grain drying. The cogeneration systems for grain drying produced the heat exchanger dimensions of 0.3 m x 0.3 m x 0.2 m, with heat exchanger plate-fin surfaces plain fins 2.0 for air section and 2.0 for exhaust gas section and a mass flow rate of exhaust gas of 403 kg/h. The drying temperature is 53 °C with an electromotor fan power output of 0.5 kW. The drying capacity was 174 kg for 5 hours drying time.

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