Calculation of Cogeneration Technology System in Waste Heat Recovery of Diesel Engine Exhaust Gases for Grain Dryers

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***Abstract*—The purpose of this paper is to calculate a cogeneration system for utilization diesel engine exhaust gas temperature at the power plant of rice milling unit for paddy drying process. The method used is to measure the temperature and mass flow rate of the exhaust gas of a diesel engine as the initial data for calculating heat exchanger design. Results of measurements at 120 kVA diesel engine exhaust gas temperature at 357 °C and the mass flow rate 636 kg/h at 82% relative humidity. From the calculation results have been using cross flow compact heat exchangers, with plate-fin surfaces plain fins 2.0 for air section and 2.0 for exhaust gas, dimensional shape width 0.3 m, high 0.2 m and 0.3 m long, produces drying temperature 53 ° C, can drying 2 (two) tons of paddy grain for 8 hours drying time, use the power of 0.95 kW electric motor fan. This study shows that the exhaust gas of a diesel engine can be applied to the dryer with a cogeneration system.**

Keywords: Grain dryer, energy, cogeneration, sustainable, 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 exhaust 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]. Exhaust gas has a high enough temperature is still potential to be applied for various purposes such as generating steam for power generation, drying, heating, or for any other use. If this waste heat can be recovered in addition to reducing the environmental pollution can also save fossil fuel consumption.

In order to utilize the heat wasted, it needs a merger between the heat exchanger within an integrated system called cogeneration. With the application of cogeneration technology in the industrial sector, particularly in the rice milling unit for grain drying needs, produces drying facilities are inexpensive and effects of weather, there was a saving use of fossil energy sources such as oil and coal, which is directly active role in the decline emissions of greenhouse gases to reduce global warming. One form of waste heat utilization of exhaust gas with the diesel engine cogeneration technology is for drying agricultural commodities such as corn, chocolate, rice and etc. The main problem of the farmers during the rainy season is the process of harvesting and grain drying. High initial moisture content and unfavorable weather are often become a very difficult obstacle to overcome. Farmers are forced to bear the risk by selling their crops of grain harvested in wet or dry rice grain quality is considered low, consequently receiving a lower selling price. Therefore, farmers should know how to post good harvest handling, among others is through drying technology.

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 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].

A. Heat Exchanger

Heat exchanger is a unit of equipment used to change the temperature of the fluid or fluid phase in heat exchange with another fluid. Heat exchangers operate for two different types of fluid temperature with different flow and heat exchange through the fields of heat transfer. This displacement field is in the form of intersected walls of the pipe or fins. Heat which can be moved in between the fluid the magnitude depending on the speed of fluid, direction flow, the physical fluid properties, the condition of surface and the area of heat transfer, and the different temperatures between both fluids [8]. Examples of heat exchangers are shown in Figure 1.

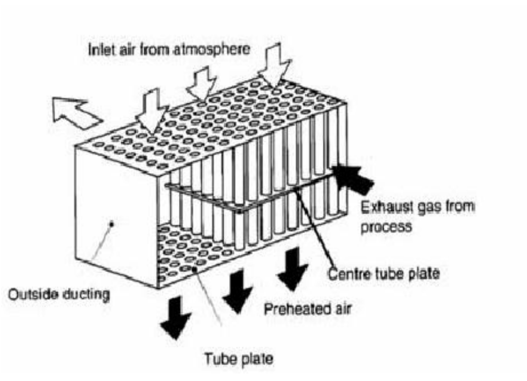

Figure 1. Types of heat exchangers [8]

Heat exchanger which is compact and efficient way to absorb the flue gas must be adjusted to the conditions in which the heat exchanger will be installed. In the planning of grain drying with a cogeneration system to be installed in door so the size of heat exchanger adapted to the characteristics of the air dryer is required.

B. Flat Bed Dryer

Drying is processes of spending moisture content of the material until it reaches a certain speed so that material damage can be reduce. Drying can be done by the use of sun drying or by artificial means. Artificial drying in addition to counter the effects of weather is also intended to improve the quality of agricultural products. There are two kinds of drying process are natural drying that uses heat from the sun is directly above the floor drying and artificial drying using a dryer. A large scale farmer still drying on the drying floor with direct sunlight, such natural drying has several drawbacks, among others, depending on the weather, difficult to control, in need of extensive drying, easily contaminated, disturbed by animals and take a length time.

Drying is an important step in the process of post-harvest rice. Basically with the drying of materials will be durable and facilitate further processing. In addition to drying can reduce the volume of material so that it can more easily be transported by low cost. Dryer machine using heated air then flows into the material to be dried by using a fan. The advantage of drying machine is not dependent of weather, drying capacity can be selected as appropriate, does not require a large place and the drying conditions can be controlled. Dryer machine are generally composed of a fan, burner and container or batch for drying. Compared with the traditional sun drying method, drying with the dryer was found to be a viable option with many benefits, such as a protected drying environment, improved dried product quality and increased throughput. The drier is suitable for rural farm applications where grid electricity and fossil fuel are either nonexistent or extremely expensive for the average farmer [9].

Flat bed dryers are most inexpensive and simple. Its main component consists of the dryer tub plate made of a rectangular box with a various size, fan and burner located on the outside of a dryer. Useful savings in energy may be achieved by switching off the fan when the ambient air is damper than a preset level. However the simplicity and safety of continuous fan operation may often be preferable. The value of the lost potential weight caused by over drying can far exceed fan energy costs. Fan control is most useful for the final conditioning of the grain [10].

The quality of dried paddy is judged by several criteria; the paddy is not contaminated with black ashes from the furnace, the paddy final moisture content is uniform at the desired level for storage, for seed grain, the germination is high and for commercial grain, the dried grain crack is minimized [11]. A flat bed dryer with a kerosene fuel burner is illustrated in Figure 2. Sources of heat generated by the heating unit (burner or heater) that uses fuel oil, or electric heating elements in the grain flat bed dryer unit was replaced by a heat exchanger which utilizes waste heat from exhaust gases diesel engine of power plants such as rice milling machine unit shown in Figure 3.

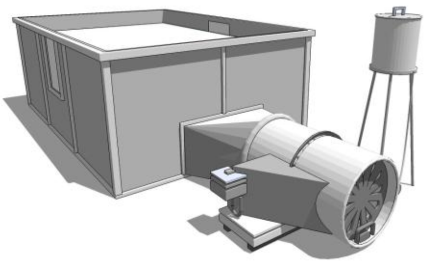

Figure 2. Flat bed dryer with kerosene fuel burner

Heat exchanger is hoped will useless fuels for electromotor and burner, but using the waste heat from diesel engine exhaust gas power plants of rice milling unit. Thus the cost will be more economical and more effective in work processes.

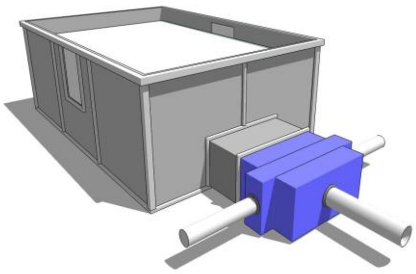

Figure 3. Flat bed dryer with a cogeneration system.

C. Cogeneration

Cogeneration is defined as the sequential generation of two different forms of useful energy (typically mechanical energy and thermal energy) from a single fuel source. Cogeneration concept offers significant increase in efficiency of energy system. In some cases, it can save over 30% of the primary energy compared to a conventional energy system [12]. There are various types of cogeneration system available commercially. The equipment used to support the cogeneration system is the heat exchanger. This system can be applied to industrial facilities or commercial buildings that require electricity and heat. Electricity is used to mechanical equipment and lighting, while the heat in the form of steam or hot air, which is used for power generation in steam, heating and drying of foodstuffs and agricultural commodities, etc. The cogeneration plants considered include steam-turbine system, gas-turbine system, diesel-engine system, and geothermal system. Here, the cogeneration operation refers to the simultaneous generation of electrical power and heating for buildings (especially for space heating and hot water) [13].

Cogeneration technology is expected the drying and grinding grain in a single integrated system by utilizing a highly efficient fuel and human resources. A simple picture of the efficiency comparison between the conventional energy systems with cogeneration system is shown in Figure 4. The conventional system energy efficiency is 58% while a cogeneration system recorded an efficiency of 85% using the same fuel source of electricity and heating needs.

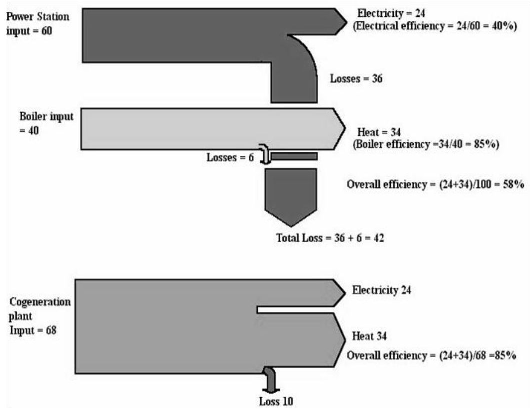

Figure 4. Comparison of the efficiency of the conventional (top) and cogeneration system (bottom) [14].

The most prevalent example of cogeneration is the generation of electric power and heat. The heat may be used for generating steam, hot water, or for cooling through absorption chillers. In a broad sense, the system, that produces useful energy in several forms by utilizing the energy in the fuel such that overall efficiency of the system is very high, can be classified as Cogeneration System. A plant requires 24 units of electrical energy and 34 units of steam for its processes. If the electricity requirement is to be met from a centralized power plant (grid power) and steam from a fuel fired steam boiler, the total fuel input needed is 100 units. Refer figure 4 (top). If the same end use of 24 units of electricity and 34 units of heat, by opting for the cogeneration route , as in Figure 4 (bottom), fuel input requirement would be only 68 units compared to 100 units with conventional generation (Anon, 2006).

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 5. 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.

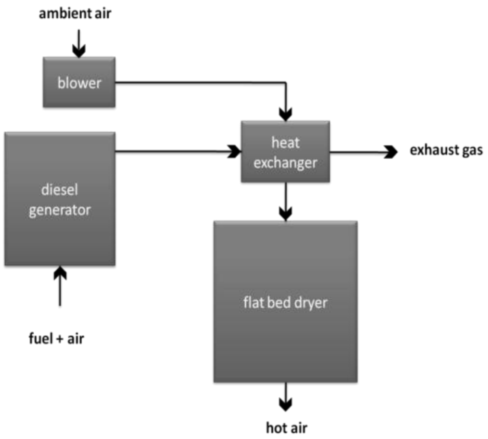

Figure 5. Scheme utilization of waste heat of diesel engine exhausts gas for drying with the cogeneration technology

A mathematical expression for the determination of this increase is given. In the system tested, cogeneration contributed from 30 to 70% of the total energy supplied to the air, under good and poor weather conditions, respectively [15]. 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 6.

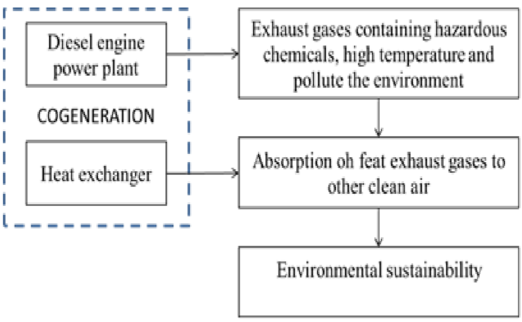

Figure 6. Framework of cogeneration system

II. MATERIALS AND METHOD

The research was conducted at the Haikal Rice 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. A Mitsubishi 6D16 120 kVA diesel engine in the power plant of a rice milling unit was used. Data was collected using a digital thermocouple capacity of 0-500 °C to measure the exhaust gas temperature, digital thermo-anemometer for measuring the exhaust gas mass flow rate and psychrometer for measuring relative humidity, respectively at an exhaust gas temperature of 357 °C, exhaust gas flow rate of 635.72 kg/h with the ambient air temperature of 27 °C and 82 % relative humidity.

III. RESULTS AND DISCUSSION

The present contribution shows certain practical aspects of selection and design of heat exchangers for industrial applications where polluted flue gas represents one process fluid. One of the key factors in designing heat exchangers for these applications is the primary selection of a suitable type [16]. Heat exchanger designs based on data measured in the field, and then selected specify the materials to be used. Material from the both heat transfer surface is selected from Aluminum because this material has a good value of thermal conductivity relativity and easy to find in the market. As an initial estimate, to determine the properties of air and exhaust gas, assuming the effectiveness of heat exchanger by 86 %, dimensions of heat exchanger are width 0.3 m, high 0.20 m and length 0.30 m. So the estimated temperature of the air out 53 °C and 72 °C for exhaust gas exit. From the results of calculations for some of the air mass flow rate and various combinations of exhaust gases temperature and ideal for use as a heat source for drying grain is as follows, (a) drying temperature: 35 °C, (b) mass flow rate of air: 6,601 kg/h, heat exchanger effectiveness ε: 80%, and (c) surface type of 2.0 for air section and 2.0 for exhaust gas and air section [17], as shown in Figure 7. Results of drying temperature calculation for some of the air mass flow rate and drying capacity vs various combinations of exhaust gases temperature for 8 hours drying time as shown in table 1.

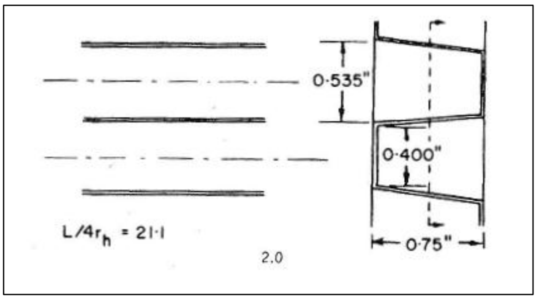

Figure 7. Plate-fin surfaces, plain fins 2.0 [17]

Table 1. Results of drying temperature calculation for some of the air mass flow rate and drying capacity vs various combinations of exhaust gases temperature for 8 hours drying time.

Pressure drop on the air section is necessary to be taken into account in order to know the power needed to drive the fan. Pressure drop on the air section occurs in a batch dryer for 0.5 m high layer of grain is 8.9 kg/m2 [18]. The calculation of pressure drop at the heat exchanger from equation (2-26) [17] was, with a total pressure drop for air section of 47.18 kg/ m^2. Based on the total pressure drop in the air section, need 1.02 HP power of electromotor fan was obtained. Assuming that the fan efficiency was 80%, the fan electromotor power required was 1.28 HP or 0.95 kW. The power of electromotor fan was taken from the diesel engine generator power plant.

Table 1. Results of calculation for some of the air mass flow rate and various combinations of exhaust gases temperature

No	Exhaust gas temperature (°C)	Drying Capacity (tone)/Mass flow rate of air (kg/h)					
		1,0	1,2	1,4	1,6	1,8	2,0
		3.300	3.960	4.620	5.280	5.940	6.601
1	170	48.92					
2	180	50.49					
3	190	51.75					
4	200	53.61	49.22				
5	210	55.30	50.65				
6	220	56.78	52.29				
7	230	58.10	53.60	50.00			
8	240	59.70	54.60	51.18			
9	250	61.33	55.97	52.69	49.76		
10	260	63.62	57.34	53.70	50.72		
11	270		58.73	54.89	51.55	49.16	
12	280		60.11	56.10	52.61	50.01	
13	290		61.52	57.31	53.67	50.80	
14	300			58.52	54.74	51.75	
15	310			59.74	55.81	52.70	50.20
16	320			60.06	56.88	53.66	51.07
17	330				57.96	54.63	51.94
18	340				59.48	55.59	52.81
19	350					56.80	53.67
20	357						54.30

Grain drying appliance can be made in various shapes and sizes. One of grain dryers are widely used is the flat bed dryers. These dryers use a burner with fan electromotor 4 kW powers, as shown in Figure 2. With cogeneration systems, a grain dryer are no longer using a burner, but uses a heat exchanger utilizing the exhaust gas of diesel engine power plant rice milling systems simultaneously, as shown in Figure 3. Dimensions adapted to grain dryers on the market 4 m length, 2 m width and 1 m high. The box consists of two parts, each 0.5 m to the bottom of the hot air flow, and 0.5 m for the top spot of dried grain. The volume of 1 ton grain approximately 1.667 m^3, if thin layer of grain height 0.42 m, batch drying capacity obtained at 2 ton. For example, we want to drying of grain with moisture content 20% wet basis to 14% wet basis for exhaust gases temperature 340 °C at ambient temperatures 27 °C, obtainable drying temperatures 52.81 °C, and need the mass flow rate of air 6,601 kg/h. Assuming the humidity of the air dryer is 0.01 kg H20/kg dry air, for 2 tons grain capacity, require 8 hours drying time, as shown at table 1.

IV. CONCLUSION

The exhaust gas of 120 kVA diesel engines at 357 °C 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 636 kg/h. The drying temperature is 54.3 °C with an electromotor fan power output of 0.95 kW. The drying capacity was 2 tons for 8 hours drying time.

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