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Development of solar and gas hybrid energy bed dryer with implementing multivariable expert system controls

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Abstract. This study aims to develop a bed dryer prototype with optimum use of energy sources (solar and Liquified Petroleum Gas (LPG) hybrid). The material used in this study was fresh cocoa beans (Sulawesi 2 clones) purchased directly from Pattalassang Village, Tompobulu Subdistrict, Bantaeng Regency. The energy sources used were solar energy panels combined with an LPG burner. The tests conducted consisted of: a) control system test, b) drying test, and c) energy consumption test. In the drying test, the setting point was 60 ^{o}C and two methods of energy supply were (1) Solar and LPG hybrid energy, (2) LPG energy only. The test results show that the control system works well, and the flame of the burner can be set automatically at low, medium, and high along with the temperature in the drying chamber and the collector. The temperature of the dryer was very stable, and no overshoot, The settling time is quite short, which is only 5 minutes. Hybrid furnace operation was more efficient (gas usage was about 64.8% compared to non-hybrid). Hybrid furnace operation consumed only 0.116 kg/hour of gas while non-hybrid operation consumed LPG of about 0.179 kg/hour.

1. Introduction

The surplus of agricultural products at harvest times requires adequate postharvest handling so that the quality of the agricultural commodities can be maintained and protected from damage. Damage caused when the water content is still too high and then stored for a period long enough so that it can result in the emergence of fungus. Drying is one way to reduce the water content to the water content in a balanced state so that the quality of the agricultural product can be maintained. Drying can occur through liquid evaporation by applying heat to the wet feed material [1]. The drying process is carried out up to the water level in balance with the normal atmosphere of the atmosphere or at the water level where the decrease in the quality of fungi, the activity of enzymes and insects can be ignored [2]. The main purpose of drying is to reduce the seed moisture content from about 60 % to 6-7 % (SNI Biji Kakao 2323-2008) so it is safe during transportation and storage [3].

There are several methods used in analyzing water content, including distillation methods, drying methods and chemical methods [4].

$$Water\ Content\ (WB) = \frac{W_1 - W_2}{W_1} \times 100\% \text{........................}(1)$$

$$Water\ Content\ (WB) = \frac{W_1 - W_2}{W_2} \times 100\% \text{........................}(2)$$

In conventional processing which is still applied by large plantations is one-day drying and drying process using a dryer for 24 hours effectively [5]. The Cocoa beans produced by this drying will have good physical quality but have very low organoleptic quality [6]. Decrease levels begin as long as the water level moves through the diffusion process from the nib to the seed coat [7]. The Temperature and air rate are two key factors that influence drying, seed thickness is the third. These three main factors have been studied by Shelton [8]. In drying with the solar dryer Model Solar Building II engineered by the Coffee and Cocoa Research Center with a capacity of 5 tons of fresh cocoa beans [9]. Sime-Cadbury Drying System in principle is slow-drying in the beginning for three days with an ambient air blast, followed by mechanical engine drying at a maximum temperature of 60 ^{o}C for 12 hours effectively [10]. The processing time is closely related to the drying rate and the level of damage that can be controlled by drying [11].

The abundant source of sunlight as a natural resource can be utilized directly in the optimal and continuous drying process. However, under certain conditions, natural drying experiences obstacles if drying is done during the rainy season. Dryers are an artificial drying method to overcome these problems. Dryers in general still use energy derived from fossil energy in the form of fuel that is converted to heat energy; the use of this energy can certainly increase the cost of producing a commodity.

The potential of natural resources in the form of abundant sunlight and fossil energy that is still available even though in limited quantities, it is necessary to think about how to use these two energies wisely and adapt them to your needs. If the radiation energy hits the surface of a media, then some of the radiation energy will be reflected (reflection), some will be absorbed (absorption), and some will be transmitted (transmission) [12]

Availability of sunlight resources normally around 5-6 hours/day and even then, in the dry season conditions, in the rainy season, the intensity of sunlight will be much reduced or not available at all. Hybrid dryer is one of the solutions on how to combine the two energy in the form of solar energy and LPG and regulate its use alternately by the conditions of the availability of sunlight intensity.

Based on the preceding, hybrid solar energy and LPG stack type food drying machine has been built, but the performance of the drying machine is not yet known when used for cocoa drying. Therefore, a series of tests are performed on the machine to obtain information.

2. Formulation of the problem

The use of solar thermal energy combined with natural gas (LPG) energy is possible to be developed considering these two energy sources are quite available and abundant, but sometimes the solar energy that we use for drying an agricultural commodity is not fully available at certain times or even not there is absolutely nothing. The formulation of the problem is as follows:

1. What is the method for developing a bed dryer and the making of an expert multivariable-based control system to maintain the temperature stability needed in the drying process?
2. How to arrange the rules of the Multivariable Expert System that can be applied to hybrid systems so that the use of solar energy is more optimum and the use of LPG is more efficient?
3. How is the performance of the dryer using a hybrid energy source and the quality of the cocoa produced?

3. Research methods

3.1. Descriptions of the drying machine

The drying machine consists of 1) two solar collector units, each measuring 184 x 93 x 12 cm, 2) a stack type drying chamber measuring 90 x 60 x 54 cm with a capacity of 40 kg cocoa beans, 3) Solar hybrid energy furnace with LPG, where furnace power with LPG energy is 400-6800 Watt and furnace power with solar energy is 0-2000 Watt, furnace efficiency is 83 %.

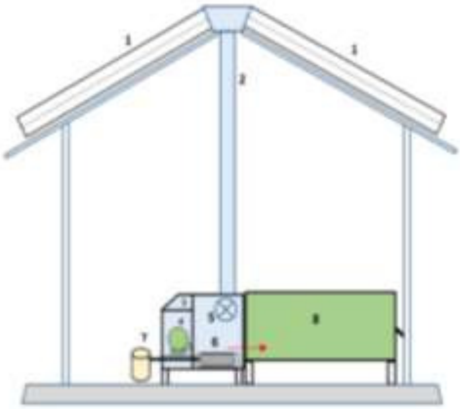

Figure 1. Solar energy hybrid dryer machine with LPG [13]. 1. Collector; 2. Air channel; 3. Control box; 4. Blower; 5. Air valve; 6. LPG burner; 7. LPG cylinder; 8. Drying chamber

Furnace operation is controlled by an expert control system so that the furnace can burn gas to be supplied to the drying chamber in a variety from 330 - 5,146 Joules/s depending on the temperature of the air in the drying chamber and collector.

3.2. *Test methods*
Test furnaces are grouped into 1) Test of solar collectors and furnaces, and 2) Drying test and energy consumption test. In the drying test, the engine is run in two ways, namely (1) the engine is run using solar hybrid energy and LPG, (2) the engine is run using only LPG energy, all scenarios use wet cocoa weighing 15 kg each, the temperature of the drying air (setting point), in accordance with SNI Cocoa that is SP = 60 ^{o}C, and stopped after reaching a 7 % water level (SNI Biji Kakao 2323-2008).

4. Results and discussion

4.1. *Solar collectors and furnaces*
When the furnace blower is turned on and the temperature of the air coming out of the collector is observed, the results can be seen in the following figure 2.

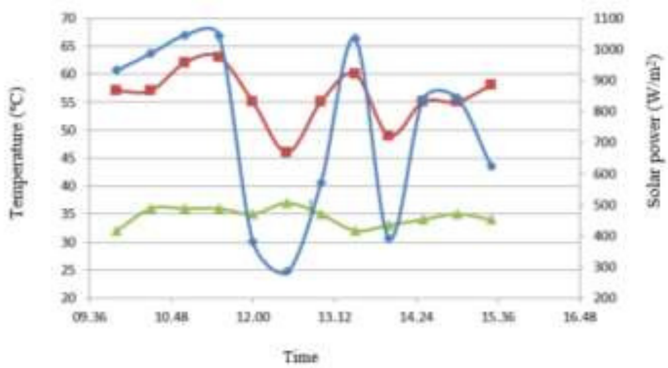

Figure 2. Solar irradiation and air temperature produced by the collector (Collector temperature, environment temperature, Solar power)

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When starting using the hybrid dryer furnace, the position of the air valve is fully opened (opening 90 degrees), then the blower is turned on and the temperature of the air coming out of the collector is observed, the results can be seen in figure 2. It can be seen in the picture that the solar radiation received by the collector can raise the air temperature the collector, which is between 10:30 and 11:30, the temperature of the collector rises around 62 – 63 ^{o}C, then between 11:30 and 12:30. The temperature of the collector has decreased dramatically to 42^{o}C; this is proportional to the measured solar power also decreased from 1044 W/m^2 to 283 W/m^2; This shows that the temperature of the collector is very dependent on the light received, this event is caused by cloud, the position of the sun is suddenly covered by clouds so that the source of solar energy received is drastically reduced. In such conditions, the role of the expert control system is needed to regulate the use of other alternative energy sources in the form of gas so that the predicted energy needed can be fulfilled quickly. At 12:30, the received source of solar energy rose from 1035 with an increase in temperature from 46 to 60 ^{o}C.

4.2. Furnaces test
The furnace test is performed to determine whether the installed power is sufficient based on the results of calculations can increase the temperature in the drying chamber in a short time and be able to pass the limit of the setting point (SP = 60 ºC) either by using solar and gas (hybrid) or LPG energy alone (nonhybrid). From the results of trials on hybrids obtained at 4 minutes (240 seconds) while non-hybrids at 11 minutes (400 seconds). As seen in figure 3 below, it appears that the maximum installed power (6500 W) in the furnace can increase the temperature from 31 to 65 ºC is fast enough. The rate of increase in temperature for hybrids is 8.5 ºC/min while the hybrid no. is 3.09 ºC/min. That shows that the furnace gain for drying machines is quite large or the gas power installed in the furnace can support the food drying process with good performance. In non-hybrid drying, there was a slight delay; it was suspected that the cocoa beans used during the drying process still contained water when compared to non-hybrids.

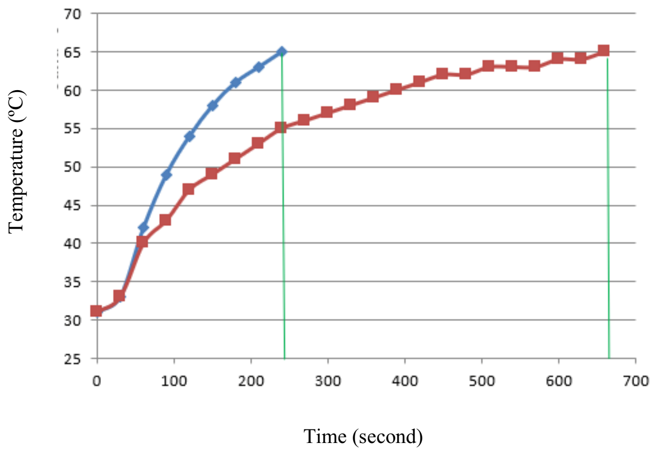

Figure 3. Temperature gain of the drying air produced by the furnace (hybrid; non-hybrid)

4.3. Dryer air temperature
From the observations of the transient response and steady-state of the drying air temperature for one more hour in the cocoa drying process, it can be seen in figure 4 that the settling time temperature in scenarios 1 and 2 is the same, namely 60 minutes. In this condition, there is no overshoot. In figure 4, it can also be seen that the steady-state response to hybrid energy and LPG energy is generally very good, namely, the temperature of the drying air is quite stable. That shows that the temperature of the drying air when the furnace uses only LPG energy is generally the same when the furnace uses solar hybrid energy with LPG. However, if you look at LPG energy sources, where the temperature of the drying air can reach a setting point of 60 ^{o}C and the rest only reaches 58-59 ºC the temperature is unstable. That shows the

solar energy received from the collector is insufficient because the intensity of sunlight decreases. To cover the energy shortage combined with LPG energy.

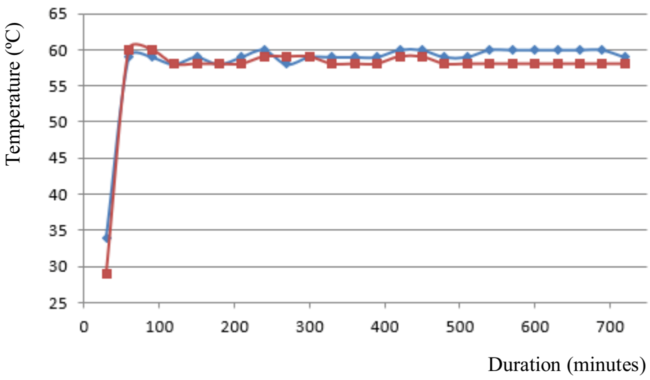

Figure 4. Temperature of drying air at various furnace energy sources (solar and gas hybrid energy; PG)

In figure 4. it can also be seen that the steady-state response of methods 1 and 2 is generally following the criteria [14]. ie the drying air temperature is quite stable and only a few times a steady-state error of 1 ºC occurs. That shows that the temperature of the drying air when the furnace uses only LPG energy is generally the same when the furnace uses solar hybrid energy with LPG. That is caused by an intelligent control system that can control the rate of combustion of LPG equally well. However, at way 3, where the temperature of the drying air does not reach the set point of 60 ºC and the temperature is unstable. That shows that the solar energy that comes from the collector can not support good engine performance; solar energy is only good to use if dihybrid with LPG energy.

4.4. Cocoa water content

In the drying test used 15 kg of fresh cocoa beans with an initial moisture content of 52.79 % wet basis, the drying energy used comes from Solar-Gas LPG (hybrid) and LPG only (non-Hybrid), the drying process is carried out until the water content reaches 7 % Drying air temperature uses a setting point of 60ºC. From the test, results can be seen in figure 5 obtain the following results:

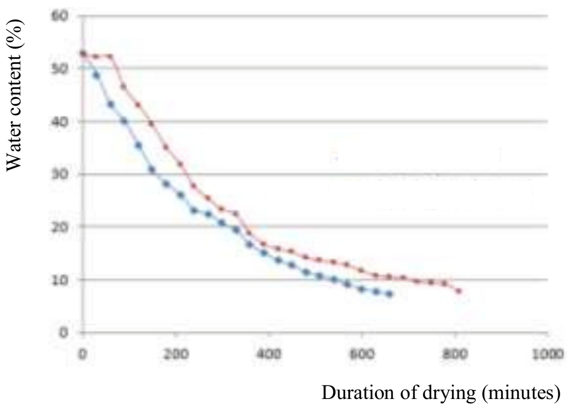

Figure 5. Decreased levels of water moisture content of cocoa in various energy sources (hybrid drying; Non=hybrid drying)

In figure 5 above, it can be seen that the length of the drying process to reach a water content of about 7 % varies between hybrid and non-hybrid. In the graph above the hybrid, drying time reaches 660 minutes (11 hours) while using only LPG energy (non-hybrid) takes 810 minutes (13.5 hours); this illustrates that the use of both energy in the hybrid system is better and more efficient if compared to non-hybrid.

4.5. Energy consumption

The measurement of the LPG consumption rate is done when the dryer dries 15 kg of cocoa from 52.79 % to 7 % moisture content, wet basis. The results of observations of operations using solar with LPG (hybrid) can be seen in Figure 4.9. It appears that the rate of combustion of the gas gradually decreases along with the predicted energy needed starting from 6500 Watt down to 2000 Watt. That relates to the intensity of sunlight received by the collector so that the heat supplied is sourced from the heat of the collector which is then distributed to the drying chamber. Gas energy that is burned looks irregular due to unstable temperature conditions. That shows that the intelligent control system functions very well predicting the energy needed in the drying chamber and the energy produced by the collector and then burning the gas properly.

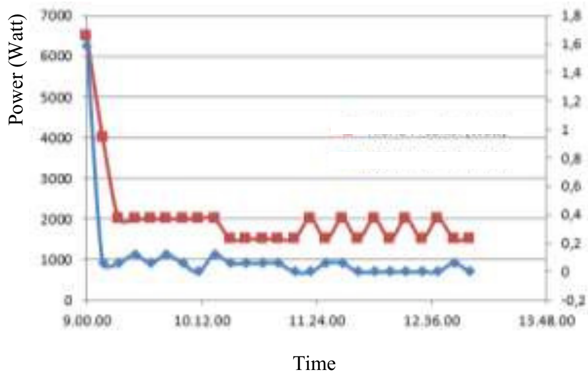

Figure 6. Current LPG Energy Consumption Rate implementing a hybrid system [burnt LPG (J/s); Hybrid prediction (Watt)]

From the results of LPG weight measurements before and after 11 hours of drying, it is known that the weight of the gas is reduced by 1.17 kg or the rate of combustion of LPG by 0.106 kg/hour. When comparing the use of gas with LPG only (non-hybrid) to hybrid, using hybrid can save 64.8 %.

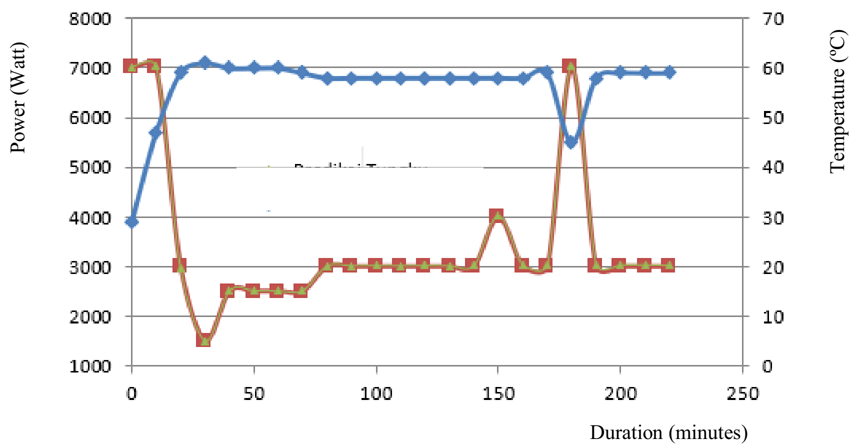

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Figure 7. Current LPG Energy Consumption Rate is implementing a hybrid system (Energy prediction (Watt); furnace prediction; temperature)

Based on the measurement of LPG weight before and after drying for 13.5 hours of cocoa in drying using only gas, it is known that the weight of the gas is reduced after weighing 2.15 kg or the burning rate of 0.159 kg/hour.

In the non-hybrid furnace, the energy prediction in the drying chamber and the furnace prediction are needed. From the measurement of the weight of LPG consumed and the calculation of the energy produced by the furnace during the cocoa drying process, it can be seen that the thermal efficiency of the furnace can reach 85.92 %. In this case, the furnace is included as a middle-class stove and meets operating standards. The furnace has exceeded conventional furnace (η = 55-72 %) and has approached the modern furnace whose efficiency is around η = 90-97 %. The efficiency of the gas furnace can be increased again by adding a secondary heat exchanger and induced draft fan so that it can extract most of the heat that comes out in the chimney. At the connection, a pipe channel can be added as an insulator (glass wool) to reduce the release of heat energy.

5. Conclusions and suggestions

5.1. Conclusion

1. The performance of the drying machine when operated in hybrid and non-hybrid (LPG only) from the aspect of temperature has met the criteria, namely no overshoot, short settling time, stable temperature, and very small steady-state error.
2. The performance of the drying machine when operated in hybrid and non-hybrid (LPG only) from the aspect of Cocoa moisture content is the same. But in terms of energy consumption, hybrid systems are more economical, up to 64.8 %.
3. The cost of operating a drying machine by applying a solar energy hybrid system with LPG is cheaper than implementing a non-hybrid system (LPG energy).

5.2. Suggestions

If the dried material is high in water and requires an operating temperature greater than 50^{o}C, the drying machine should be operated in hybrid mode. The application of non-hybrid mode is chosen if the dried material is low in the water, requires an operating temperature of less than 50^{o}C, and sufficient solar energy is available.

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