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Research article

Engineering

SIMULATION OF RECIRCULATION TYPE DRYER USING PNEUMATIC CONVEYORS

循環式乾燥機氣力輸送模擬

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Abstract

Recirculating rice dryers are suitable for a large amount of loading capacity. It generally comprises two parts, the tempering section, a drying section, and the grains are dried intermittently until the final moisture content of the grains can be achieved. Wet grains are initially dried for about 11 minutes within the drying section of the dryer. The grains then are conveyed to the tempering section, stored for about 40 to 50 minutes. At every passes, about less than 2% (wb). The moisture content can be removed from the grains. The number of passes required to accomplish a drying process in a recirculation dryer depends on the initial moisture content and the amount of rough rice to be dried. The drying and tempering duration can be adjusted through a mechanical valve. The purpose of this study was to examine the performance of recirculating dryers equipped with pneumatic conveyors instead of bucket elevators to reduce electricity cost and heated using a proper blend between kerosene and jatropha oil. Several experimental runs were conducted under a constant drying temperature of 60℃ and were controlled by adjusting the fuel consumption rate. The experimental results showed that the drying efficiency was in the range of 22.2% to 31.1%, the specific energy consumption was between 3,475-4,785 MJ/kg H2O evaporated, fuel consumption at 0.95 to 1.15 liters/hr, and the drying rate was 0.9% per day. Using 465 kg of rough rice, the entire drying operation required 10 hours of drying time with 74.3% of head yield. The mathematical model used in this study also had indicated close agreement with experimental data.

Keywords: Recirculating Dryer, Pneumatic Conveyor, Drying Performance, Tempering Period, Bio-Kerosene Blend

摘要 循环式大米烘干机适用于大量装载量。它一般包括调温段、干燥段两部分，对谷物进行间歇

干燥，直至达到谷物的最终含水量。湿谷物最初在干燥机的干燥部分干燥约 11 分钟。然后将谷物运送到调温部分，储存约 40 至 50 分钟。每次通过时，大约小于 2% (白)。水分可以从谷物中去除。在循环干燥机中完成干燥过程所需的通过次数取决于初始水分含量和要干燥的糙米量。干燥和回火持续时间可以通过机械阀进行调节。本研究的目的是检查配备气动输送机而不是斗式提升机的循环干燥机的性能，以降低电力成本，并使用煤油和麻风树油之间的适当混合物进行加热。在 60±0C 的恒定干燥温度下进行了几次实验运行，并通过调节燃料消耗率进行控制。实验结果表明，干燥效率在 22.2%~31.1%之间，比能耗在 3475~4785 兆焦耳/公斤水蒸发之间，燃料消耗在 0.95~1.15 升/小时之间，干燥速率为 0.9 % 每天。使用 465 公斤糙米，整个干燥操作需要 10 小时的干燥时间，头部产量为 74.3%。本研究中使用的数学模型也表明与实验数据非常吻合。

关键词: 循环干燥机、气力输送机、干燥性能、回火周期、生物煤油混合物

I. Introduction

Rice is one of the important food crops in Indonesia because the fruit or rice seeds known as rice are the staple foodstuffs of Indonesian people. The pattern of rice consumption is slowly but steadily increasing in line with the increase in income, education, and easy access to information. The increase in domestic demand for rice has reached 1.6% per year [1]. The production of unhauled rice in 2019 is predicted to reach 54.6 million tons of harvested dry unhauled rice, equivalent to 37.6 million tons of rice [2].

A critical aspect in the development of a rice agribusiness system is post-harvest handling. This is related to the problem of yield loss that occurs in harvest activities post-harvest, both in the form of weight loss (quantitative) and in the form of quality degradation and physical damage (qualitative), which is relatively high [3]. The yield loss in the drying process in the sun in Indonesia was between 2.3% and 2.6%, which means that in 2008 there were 1.47 million tons of unhauled rice lost due to drying or the equivalent of IDR 3.53 trillion [4].

To overcome losses in the drying process and to deal with climate change due to global warming. The success rate of drying in December-April in the Jatiluhur area is only 17%, therefore to increase the drying success, a mechanical dryer is needed [5].

Commercial mechanical drying uses hot air from fuel combustion by utilizing a heat exchanger, generally using a fixed batch dryer type (box dryer, inclined bed dryer flatbed), continuous flow, and recirculating batch. The use of the fixed batch type has the advantages of being simple, cheap, and easy. Still, it has the disadvantage of the water content gradient between the bottom and the top, which can reach 3-4% [6]. When using high-temperature drying air, over-drying may occur at the bottom.

Previous research made a circulation dryer for soybean seeds. The tool has a capacity of 2 tons using kerosene as a heat source and a conveyor bucket to circulate the material, with a motor power of 746 watts [7]. The test results show kerosene consumption of 5.12 lt/hour with a drying efficiency of 28.43% and a decrease in moisture content of 0.96% per hour, and the damage rate of broken seeds is 1.13%, which the duration of the drying process is 5 hours.

Another study produced a recirculation-type grain dryer using solar energy, with the addition of wood charcoal fuel, the electrical energy used for the 0.18 kW vibrating motor, and 0.25 kW blowers [8]. This tool is used to dry grain weighing 24 kg with an initial moisture content of 23% BW to 15.8%, requires 12 kg of wood charcoal and 7 hours of drying time, drying efficiency of 1.93%.

The drying time and tempering time ratio are between 1/1 to 1/9, and the drying rate is less than 1.5% per hour [9]. Paddy is the primary raw material for food, so the quality of rice is important. The physical quality index is shown by the amount of head rice yield (HRY), namely the number of whole grains and large broken grains, which have a size of 6/10 parts of the average length grain [2]. It is minimizing the reduction in HRY during drying is a major interest in the rice industry.

For the type of recirculation, which is also known as intermittent drying, there are generally two parts, namely the tempering part and the drying part. [6]. Figure 1 explains that the material circulates through these parts so that the drying and tempering processes occur alternately, generally using a bucket conveyor to recirculate the dried material.

Grain moves during drying at a constant rate, so the grain to be dried and the grain that has been dried is maintained at a rate consistent with the drying capacity.

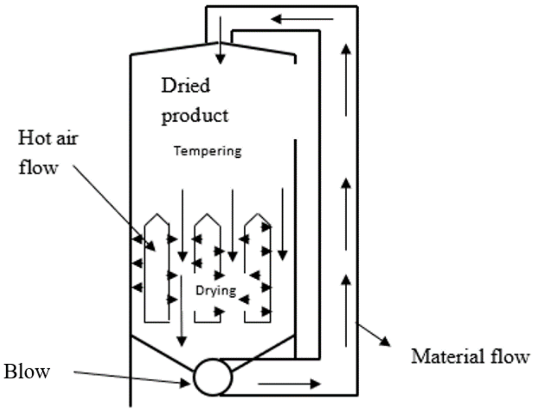

Figure 1. Recirculation drying system

The recirculation process is also intended to prevent over-drying, like in other drying processes [10]. After the drying process, the material is raised again to the tempering room to equalize its moisture content and down to the drying section, circulating until the water content is reached as desired.

The drying system can use high-temperature drying air, increasing the drying rate and speeding up the drying process without compromising quality. Recirculation dryers do not require a large area, can be placed in a warehouse, and allow automatic operation.

II. Materials and Methods

A. Material

The research material used in this research is Ciherang variety paddy, tested for its thermophysical properties described in Table 1.

Table 1.
Grain thermophysical properties

Character	Score	Unit
Density (ρ)	580-600	kg/m^3
Specific heat capacity (Cp)	1.75-1.97	kJ/kg.K
Initial moisture content (Mo)	22.3-23.5	% (bb)

The equilibrium moisture content of Me and drying constant k is calculated based on equations 5 and 6 [11], while the material's latent heat of water evaporation is Δhfg/Δhfgw = 1.298. The equipment used is a designed recirculation dryer, digital scale, anemometer, temperature sensor, temperature and RH (SHT11) sensor, 8051 mercury thermometer microcontrollers, measuring cup, stopwatch, digital moisture meter, winnowing machine, and paddy husker.

B. Experimental Setup

The experiment was carried out using a recirculation dryer (Figure 2). The dryer consisted of a heat exchanger with a blower power of 0.25 HP; a pneumatic conveyor system with a motor power of 0.5 HP; a drying and tempering room building; and a pressure cooker with an electric pump equipped with a set of data sets. The measurement points are also determined, and the drying air temperature is maintained at 600°C by adjusting the fuel line valve opening.

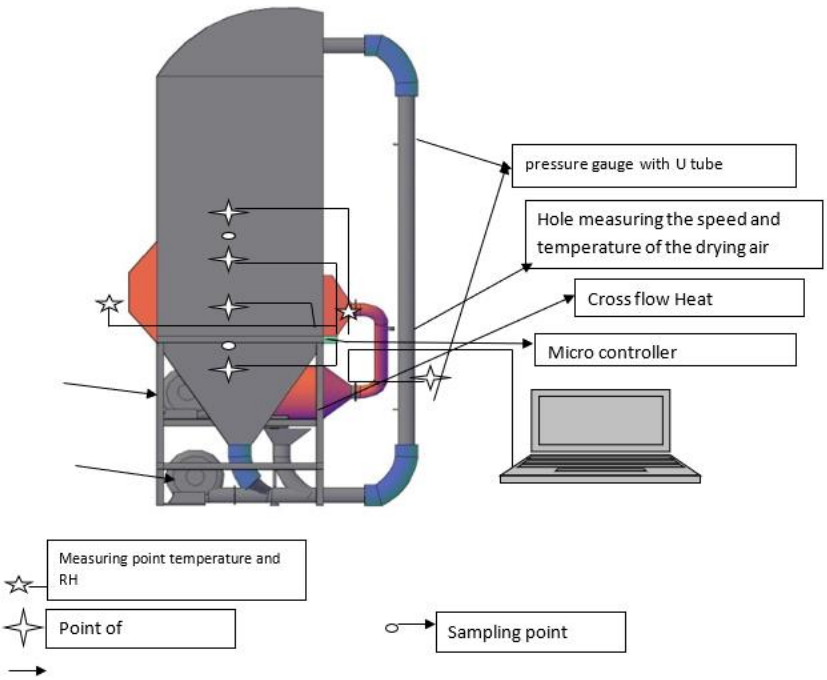

Figure 2. Recirculation dryer

The experimental procedure is as follows: freshly harvested unhauled rice is cleaned of the remaining straw and other impurities by using a winnowing machine, then weighed as much as 450 kg of harvested dry grain put into the recirculation dryer, the stove is turned on, after three minutes then the blow air dryer is turned on so that the drying air rate is 0.16 m^3/sec. When the drying air temperature has stabilized at 600°C, the blower of the pneumatic conveyor system is turned on, and then the grain flow valve is opened at a specific size to obtain a grain flow rate of 6 kg/sec. Sampling is done every hour, from the top of the drying room and at the bottom of the drying room, then the water content is tested using the oven method or a digital moisture meter.

C. Numerical Study

The drying process ends when the sample's moisture content from the top of the drying chamber and the bottom equals 14% ± 0.5% wet basis. Based on the volume element (dx dy) per unit length in each direction of the location in the material movement shown in Figure 3.

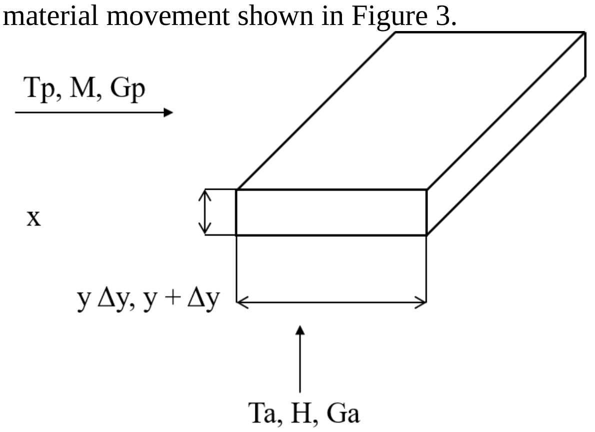

Figure 3. Volume elements for the cross-flow drying process

There are four variables, namely Ta, Tp, H, and M, so four equations are needed to solve them: three partial differential equations and one equation for the thin layer used in this simulation model study [12].

D. Drying Rate Equation

∂M /∂t = using the thin layer drying equation, the basic equation for the change in water content of materials from the initial moisture content M0 to the final moisture content M for the thin layer drying model [13]:

$$\frac{M-M_e}{M_o-M_e} = e^{-kt} \quad (1)$$

$$\frac{dM}{dt} = -k(M - M_e) \quad (2)$$

Me = 17.7700 exp (-0.0516.ΔT)/100 (3)

k = exp (6., 8274 - 4431.98/T) min-1 (4)

In this research, a drying simulation for the recirculation type dryer is carried out, shown diagrammatically in Figure 1. From the equation above, four things are unknown: the moisture content (M), drying absolute air humidity (H), the drying air temperature (Ta), and the temperature of the material (Tp). To solve the above equations, the finite difference technique is used [14], for the cross-flow recirculation dryer equation where the following equations are obtained:

$$\text{Ta (i + 1, j) = Ta (i, j) + }\Delta\text{x (i, j)}\frac{dT_a}{dx} \quad (5)$$

$$\text{Tp (i, j + 1) = Tap (i, j) + }\Delta\text{y (i, j)}\frac{dT_p}{dx} \quad (6)$$

$$\text{H (i + 1, j) = H (I, j) + }\Delta\text{x (i, j)}\frac{dH}{dx} \quad (7)$$

$$\frac{dT_a}{dx} = \frac{-\left\{h_{cv}+G_aC_{pw}\left(\frac{dH}{dx}\right)\right\}(T_a-T_p)}{G_a(C_{pa}+C_{pw}H)} \quad (8)$$

$$\frac{dT_p}{dy} = -\frac{h_{cv}(T_a-T_p)-(G_a\left(h_{fg}+(C_{pw}-C_{pl})\right)T_p(dH/dx)}{G_p(C_{pp}+C_{pl}M)} \quad (9)$$

$$\frac{dH}{dx} = -\frac{G_p}{G_a}\frac{dM}{dy} \quad (10)$$

$$\frac{dM}{dy} = \frac{dM}{dt}x\frac{dt}{dy} \quad (11)$$

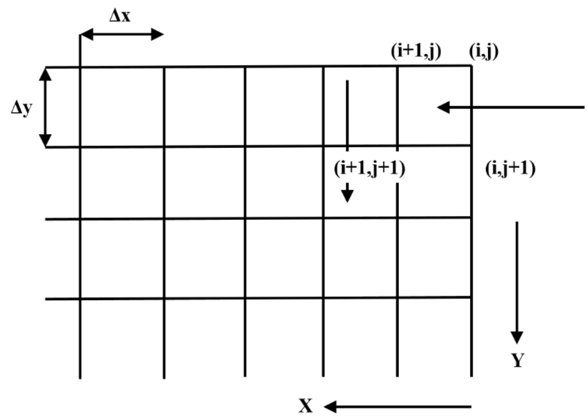

Figure 4. Grid finite difference

So that:

$$\text{Tan + 1 = Tan + }\Delta\text{x}\frac{dT_a}{dx} \quad (12)$$

$$\text{Tpn + 1 = Tpn + }\Delta\text{y}\frac{dT_p}{dy} \quad (13)$$

$$\text{Hn + 1 = Hn + }\Delta\text{x}\frac{dH}{dx} \quad (14)$$

The parameters used in the simulation as input are the initial moisture content (M0), the initial grain temperature (Tp0), the drying air temperature (Ta), the drying air rate, the absolute humidity of the air (H) as measured directly by field experiments, relative humidity. Drying air (RH), as well as several parameters related to the properties of air and grain, used, namely:

Specific heat of grain Cpp = 1850 (J/kg.K)

The hcv convection heat transfer coefficient is based on the equation [15]:

hcv = 3.9178 (737.33 Ga) 0.49 for Ga < 0.678 km/m^2.s

hcv = 2.0611 (737.33 Ga) 0.59 for Ga > 0.678 km/m^2.s

Specific heat of water Cpw = 4187 (J/kgK)

Specific heat of water vapor Cpv = 1850 (J/kgK)

Specific heat of air Cpa = 1008 (J/kgK)

The latent heat of hfg evaporation is obtained from the equation Δhfg/Δhfgw = 1.298 [12].

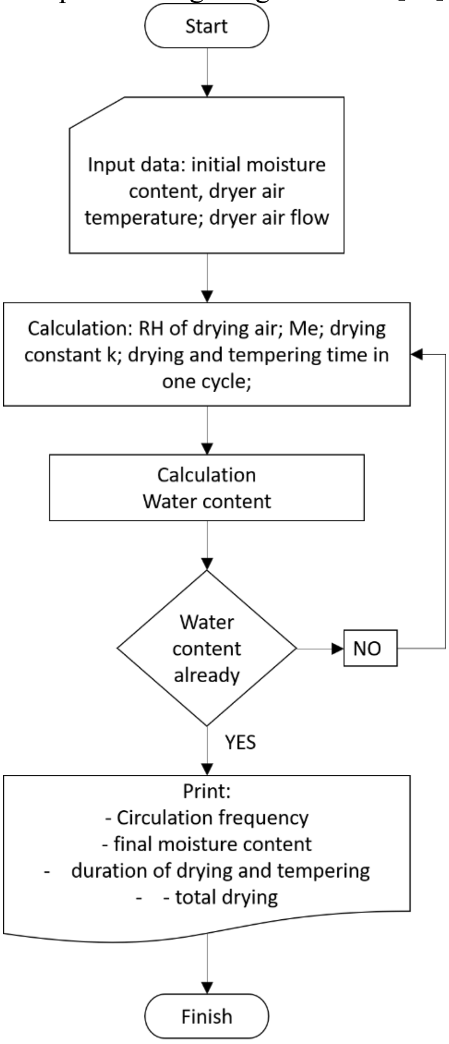

Figure 5. Flow chart of the recirculation type dryer

The k, Tp, and Ta values are assumed to be constant at the beginning of the drying process in a recirculating dryer. After drying, there is tempering, where the temperature of the material gradually returns to its initial temperature. After all, there is no heating during the tempering process. There is no mass transfer on the surface of the material, the calculation for the tempering process is like the calculation of the drying process, but it is assumed that the value of k is equal to 0.

III. Results and Discussion

A. Drying Curve between Simulation and Experiment

From the recirculation drying model, the moisture content of the material can be calculated using parameter values (Me, k, Ta, and RH), assuming the dryer is a thin layer drying, cross-flow dryer airflow for grain drying. Figure 6 shows the water content reduction curve during the drying process based on simulation and measurement results. With the dried material 450 kg, the initial moisture content is 23.5% (bb). The simulation shows that the drying time is 11.8 minutes, and tempering is 50 minutes per cycle. There are nine cycles to reach the final moisture content of 12.9% (bb) so that the total drying time is 557 minutes, meanwhile based on the experiment, the total drying time is 600 minutes, and moisture content final 13.3% (bb).

Figure 6, with the amount of material dried at 410 kg, the initial content of the material is 22.3% (bb). The simulation takes a drying time of 11.8 minutes and a tempering time of 40 minutes for each cycle. To reach a final moisture content of 13.4% (bb), it required eight cycles, so the total drying time was 463 minutes, while based on experiments, the total drying time required to reach the final moisture content of 13.8% was 540 minutes.

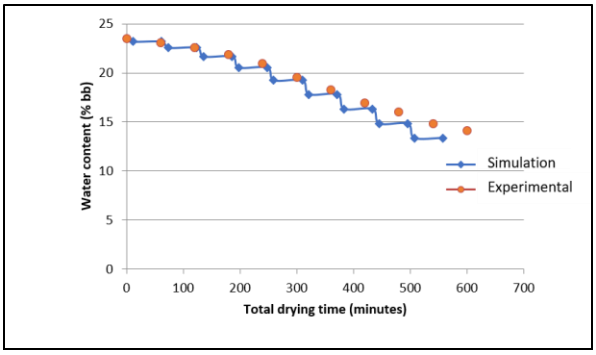

Figure 6. The curve of the reduction in moisture content between the experiment and the simulation with a drying time of 11.8 min and tempering of 50 min

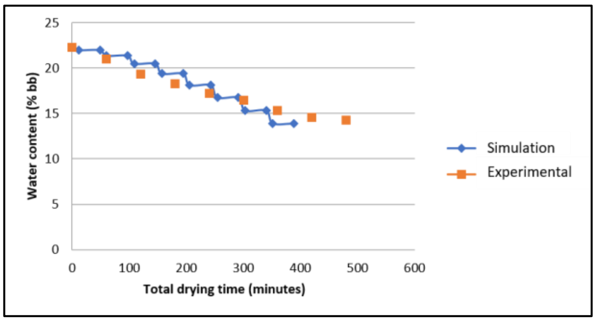

Figure 7. The curve of the reduction in moisture content between the experiment and the simulation with a drying time of 11.8 min and tempering 40 min

The curve of the experimental results does not reflect the tempering process because, in the experiment, the drying process occurs continuously in circulation, and measurements are made every hour at the point before and after drying only.

The simulation results using the thin-layer drying model are close to the experimental results for decreasing moisture content and the time required for drying. The difference is that the total drying time in the experiment is 1.08 to 1.2 times longer than the total simulation time and the moisture content. The final drying results based on the simulation are lower than the experimental results. It is due to the assumption in the simulation that the temperature and RH of the drying air are constant at all times. Experimentally, the condition of the drying air changes due to changes in temperature and RH of ambient air and fluctuations in material flow fuel. Besides that, the difference in measurement time also causes the total drying time to differ.

B. Effect of Tempering Time on Head Rice

The effect of tempering time on grain quality is indicated by the value of head rice, as shown in table 2. It appears that although there is a small difference, the longer the tempering time, the greater the value of head rice. It shows the need for tempering time so that the moisture content of the material between the center of the material and the surface is evenly distributed and reduces the presence of heat stress (thermal stress) continuously, which can cause cracks [11].

Table 2.
Rice head against tempering time

Duration of Tempering	**40 minutes**	**50 minutes**
Rice head (against skin broken rice)	72.69%	74.3%

C. Temperature Distribution of Intake and Outlet Air

The drying air temperature entering the drying room is relatively constant at an average of 59.52°C and RH 17.33%, while the average enthalpy is 135.71 (kJ/kg of dry air). In comparison, the average temperature of the exit air is 42.29°C, an average RH of 53.57%, and the average enthalpy of 135.58 (kJ/kg of dry air). Thus, the enthalpy of drying air in and out of drying air is almost the same. It shows that the drying process occurs with constant enthalpy. Based on Figure 8 above, it can be seen that the temperature of the air coming out of the dryer is increasing. This indicates that the water content of the material is decreasing so that the energy required to evaporate water in the material is getting smaller.

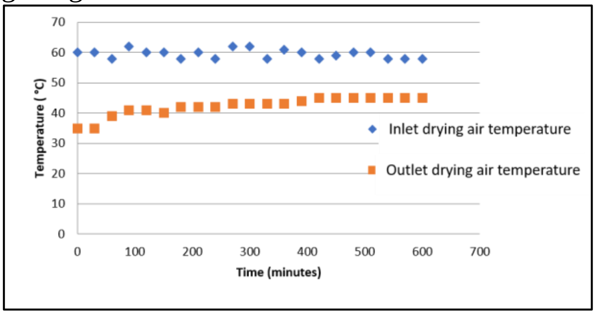

Figure 8. Drying air temperature distribution

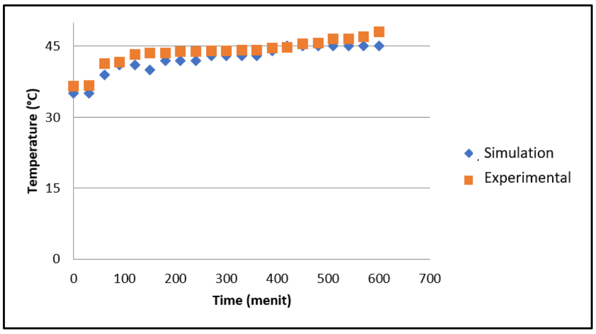

Figure 9. Temperature distribution of dryer exhaust air, in simulation and experiment

Figure 9 shows the comparison of the temperature distribution of the drying air outlet based on simulations and experiments. It appears that the simulation results are not much different from the measurement results in the experiment, so the simulation can be used to predict the value of the dryer exit temperature very well.

Table 3.
General tool performance

Parameter	**Unit**	**Experiment I**	**Experiment II**	**Experiment III**
The initial grain mass	kg	450	410	410

Initial water content	% bb	23.5	22.3	22.8
Final Water Content	% bb	13.95	14.15	14.20
Environmental Air Temp	^{0}C	31	31	31
RH air environment	%	80	80	80
The air temp of the dryer is average	^{0}C	59.5	59.5	60
RH Air Dryer	%	19	20	18
Dryer air rate	m^3/s	0.16	0.16	0.16
Air dryer blower power	Watt	125	125	125
The dryer air out temp was average	^{0}C	43	42	43
Carrier Air Rate	m^3/s	0.23	0.23	0.23
Carrier air blower power	Watt	370	370	370
Total drying time	Hour	10	9	9
Fuel consumption	Liter/hour	0.95	1.15	1.20
Drying efficiency	%	31.1	22.2	22.6
RICE HEAD (against skin broken rice)	%	74, .3	72.69	72
Specific Energy Consumption	Mj/kg H2O	3,475	4,786	4,131

IV. CONCLUSION

This study uses computer simulations that are made to predict the time and result of drying, with an accuracy of between 85-93%. The recirculating dryer is designed for a capacity of 500 kg/operation, with a drying air temperature of 60°C, the renewable energy fuel used in this tool is bio-kerosene. With a total drying time of 9-10 hours, it is much faster than direct sun drying, which takes 2-3 days. The drying air temperature of 600°C was able to increase head rice to 72 -74.3% compared to using a temperature of 112–1160°C, with HRY; 65-68%. Specific energy consumption between 3,475 MJ/kg H2O steam to 4.786 MJ/kg H2O steam, much smaller than the tool made by P. Srinivasa Rao, Satish Bal, TK Goswami [16], which has a value of 8.5 to 10, 7 MJ/kg H2O vapor and drying efficiency between 22.22-31.10%. Electric energy consumption is 0.90 watts/kg of the product while using a bucket elevator 1.35 watts/kg.

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