# Experimental Investigation of a Solar Greenhouse Dryer Using Fiber Plastic Cover to Reduce the Moisture Content of Refuse Derived Fuel in an Indonesian Cement Industry

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***Abstract*— Refuse Derived Fuel (RDF) is a potential alternative energy made from municipal solid waste (MSW). RDF could partially substitute coal in industries that use combustion equipment, for example in cement manufacturing industries. The optimal moisture content for solid fuel is around 10-20%. However, RDF that supplied in one of Indonesian cement industries reached moisture content almost 30%. A solar dryer has been built and tested to reduce the moisture content of RDF. Its parts were a greenhouse type tunnel drying unit with fiber plastic cover and electrical axial fans. In this experiment, the effect of three fan modes on the thermal efficiency were also investigated. The modes were operating one fan, two fans, and without fan. The solar dryer had dimensions of 2 m x 1.5 m x 0.8 m (length x width x height). The mass of RDF was 20 kg. The efficiency was calculated using the measured experimental data, i.e. environment temperature, room temperature, air velocity, solar irradiation, and relative humidity. The result revealed that the lowest moisture content produced by the dryer reached to 14.75%. Furthermore, the thermal efficiency could increase up to about 17.07% by using two fans mode.**

***Index Terms*-- Moisture content, Refuse Derived Fuel (RDF), solar dryer.**

## I. Introduction

Refuse derived fuel (RDF) is one of products in waste processing machine located in Gresik city, East Java. RDF could be used as fuels since it has caloric value about 5178 kcal/kg [1]. It could substitute 5% coal for combustion process in cement plant. However, currently the substitution program does not work since the RDF moisture content reach 30%. This high value has a strong impact on the caloric value reduction. To solve this problem, a dryer need to be installed near to the waste processing machine.

Gresik has a large open space final disposal area exposed to direct sunlight, a solar energy would be potentially used in this dryer project. Based on various literature sources, enclosed structure heating system could dry the products quicker than open sun drying method. A. Fudholi et al. [2] observed the solar drying of the Malaysian red chili using kinetic curves. They obtained that to reduce the moisture content in red chili from 80% (wb) to 10% (wb), solar drying needed 33 h. Meanwhile, open sun drying took 65 h of processing. A. Fadhel et al. [3] studied the drying of red pepper by three drying process, namely, open-sun, under greenhouse and in a solar drier. The result shows that drying in the greenhouse has the shortest drying time among them.

A greenhouse is one kind of enclosed structure that essentially made of glass or plastic. A number of study mostly discuss about the application of greenhouse in crops drying. A. Kumar and G. N. Tiwari [4] used greenhouse to investigate study the effect of mass on convective mass transfer coefficient on onion flakes drying. A. Elkhadraoui et al. [5] observed the performance of solar greenhouse dryer to dry red pepper and sultana grape. M. M. Morad et al. [6] studied the thermal analysis of peppermint plants drying using a solar tunnel greenhouse. S. Janjai et al. [7] conducted experiment to dry peeled longan and banana using a PV-ventilated solar greenhouse dryer.

O. Prakash and A. Kumar [8] classified the heat transfer mode in a greenhouse into two types, specifically (i) passive mode and (ii) active mode. Passive mode refers to free convection principle where the circulation of air heated occurs naturally due to buoyancy effect. Meanwhile, active mode works with the support of mechanical or electric devices to force air enters the drying system. According to G. N. Tiwari et al. [9], drying under natural convection is slower than forced drying. Based on their experimental results, the drying of fish for natural condition has the minimum amount of moisture evaporated. Subsequently, V. Shrivastava and A. Kumar [10] compared the fenugreek drying under both natural and forced convection. They reported that forced convection system has higher convective heat transfer coefficient than natural convection drying.

In this present study, greenhouse type tunnel drying is used in an experimental investigation to estimate the temperature inside and outside the dryer, solar irradiation, drying rate, moisture content, and drying efficiency. Three different operations are performed in the experiment, namely (1) no fan, (2) with one fan, and (3) with two fans.

The remainder of this paper is organized as follow: the material and methodology is described in details in the section 2. The experiment result is explained in the section 3. At last, conclusion is discussed in the last section.

## II. Material and Methodology

### *A. Material*

Samples of Refused Derived Fuel (RDF) were obtained from final disposal area in Gresik city. 20 kg of RDF were used in each experiment. To maintain the same condition for each experiment (30% moisture content), RDF was sprayed with 500 ml water

### *B. Solar Drying*

A solar dryer of 2 m x 1.5 m x 0.8 m (length x width x height) was constructed at final disposal site in Gresik. It was basically consisted of a drying tunnel unit with fiber plastic cover, two electrical axial fans driven by electric motor of 21 W, a black painted aluminum plate as a collector with dimension 1,8 m x 1 m (length x width) and an iron sheet as a dryer base. A front door of 1 m long and 0.3 m wide was installed to accommodate the material to be dried. A schematic diagram of the solar dryer is shown in Figure 1.

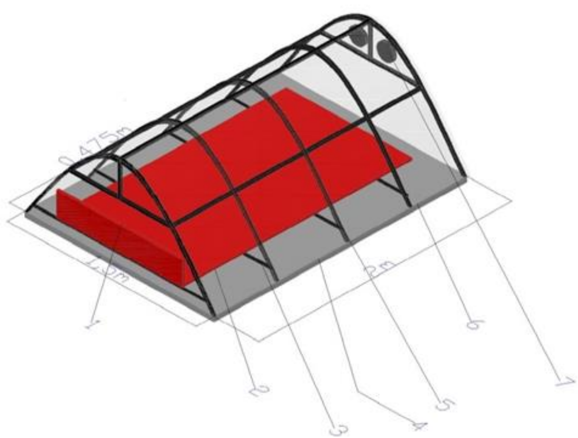

Figure 1. Solar tunnel drier: 1. door; 2. collector; 3. collector support; 4. wall; 5. dryer frame; 6. solar dryer base; 7. axial fans.

### *C. Experimental Procedure*

Experiment were conducted between 09.00 and 15.00 using 20 kg of RDF. The variation used in this study were operating one fan, two fans, and without fan. Figure 1 depicts the photograph of a solar dryer from outside view. Subsequently, figure 2 shows the fan with switch on/off function and ventilation position on solar dryer. At without fan mode, the small plat (sign with red circle) was slid up to provide air flow. Meanwhile, for one or two fans mode, on/off switch was simply used.

Figure 1. Pictorial view of greenhouse dryer (outside).

Figure 2. Experimental setup for greenhouse drying under no fan mode (passive mode).

### *D. Estimation of Solar Dryer Performances*

Drying rate was calculated by differentiation of material weight with respect to time. The equation is shown as follow:

$$\frac{dW}{dt} = \frac{w_t - w_{t+1,5}}{t} x100\% \qquad (1)$$

Where

$\frac{dW}{dt}$ : Drying rate (%/ hour)

$w_t$ : Material weight at time *t* (kg)

$w_{t+1}$ : Material weight at time *t+1* (kg)
t : Drying time (hour)

### E. Estimation of Moisture Content

Refused Derived Fuel (RDF) moisture content was estimated on dry basis. Dry matter value of the RDF was determined by oven-drying method. The moisture content at different operation mode was calculated according to the following equation.

$$M_{db} = \frac{W_0 - W_d}{W_d} \quad (2)$$

Where
$w_0$ : initial weight of the product (%/ hour)
$w_d$ : weight of the dry matter (kg)

### F. Solar Dryer Performance Efficiency

Solar dryer performance efficiency can be determined as the ratio of energy required for moisture evaporation to the heat supplied to the dryer. The numerator consists of latent heat and RDF heat gain. Meanwhile, denominator is composed of total solar radiation through the cover, heat received by fluid (air), and energy consumed by the exhaust fan.

$$\eta_d = \left(\frac{m_l.L_h + m_{0,RDF}.C_{p,RDF}.(T_2 - T_1)}{R.A_d + \frac{\dot{m}_{air}}{v}.(T_R - T_\infty).C_{p,air}.3600t + P_f}\right).100 \quad (3)$$

Where
$A_d$ : drying surface area ($m^2$)
$C_{p,RDF}$ : RDF specific heat (kJ/kg°C)
$C_{p,air}$ : air specific heat (kJ/kg°C)
$m_{0,RDF}$ : RDF initial mass (kg)
$\dot{m}_{air}$ : air mass flow rate (kg/s)
$R$ : solar radiation ($W/m^2$)
$P_f$ : electricity power (W)
$T_1$ : RDF temperature before drying (°C)
$T_2$ : RDF temperature after drying (°C)
$T_R$ : greenhouse temperature (°C)
$T_\infty$ : environment temperature (°C)
$v$ : air specific volume ($m^3$/kg)

## III. RESULT AND DISCUSSION

### Chamber and Environment Temperature

The drying room and environment temperature are factors that affect the drying process. Experiments were carried out to observe RDF drying process by utilizing sunlight as the main energy and also fans as air circulation system. To find out how much the drying room and environment temperature, thermocouples were placed inside and outside solar dryer. Figure 3 shows the temperature distribution of drying room and environment start from 09.00 AM to 15.00 PM. Based on inspection, 1 fan mode has the highest average drying room temperature.

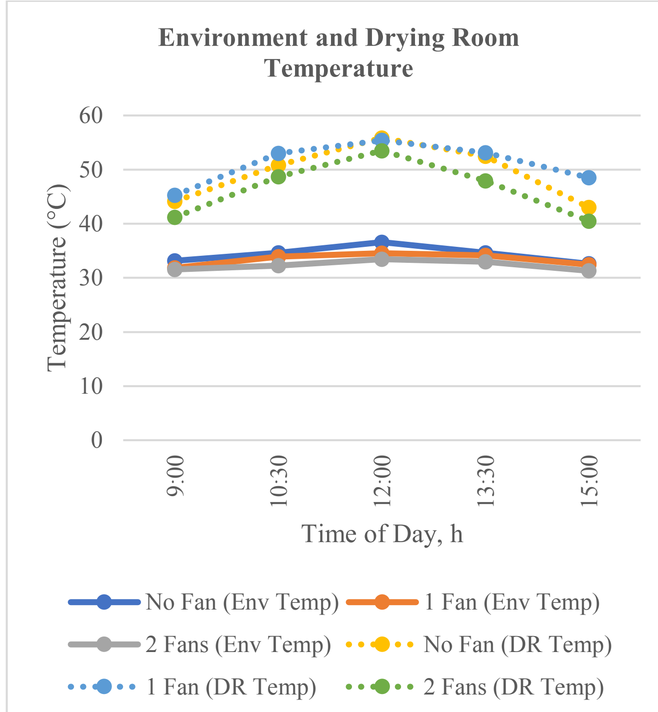


Figure 3. Outside and Inside Drying Room Temperature.

### Solar Irradiation

To measure the solar irradiation, a 5 in 1 multimeter device was used. The feature in this tool are thermometer, hygrometer, sound meter, and lux meter. To obtain the solar irradiation value, the output of lux meter should be converted to W/m2unit (683 lux= 1 W/m2). Based on figure 4, all modes have the highest solar irradiation at 12.00.

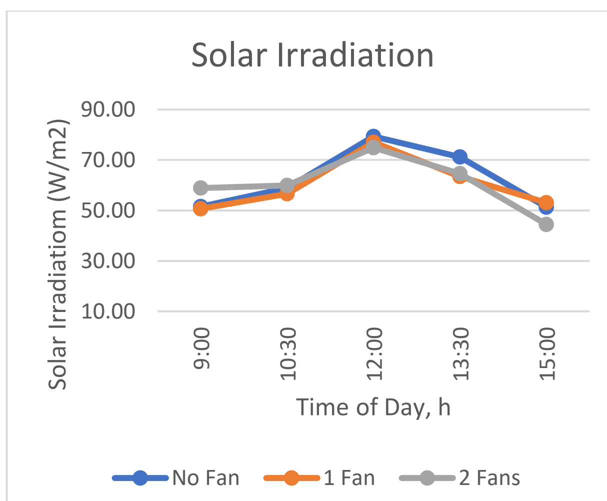


Figure 4. Outside and Inside Drying Room Temperature.

### Drying Rate

The drying rate is a process of decreasing the moisture content of a product in a certain time. The material that has been evaporated during the drying process will change in terms of water content so it will affect the weight of the material. As depicted in Figure 5, experiment with 1 fan has the highest drying rate compared to others. It is about 0.73 kg/ jam. Meanwhile, in the experiment using 2 blowers, the average is around 0.69 kg / hour. For no fan mode, the average drying rate was about 0.67 kg / hr. This finding is reasonable since 2 fans mode could provide more air flow inside the greenhouse.

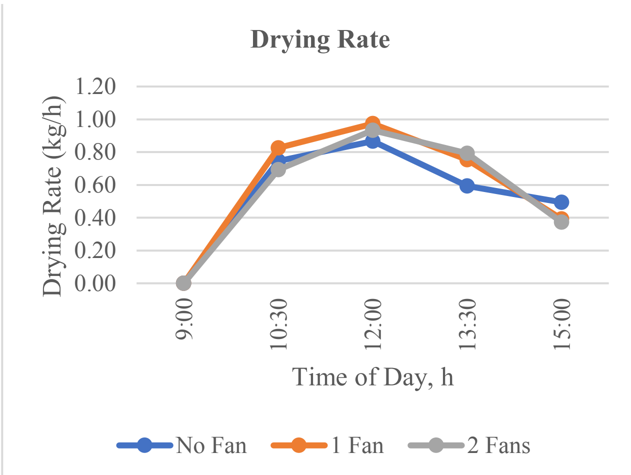


Figure 5. Drying Rate for Each Modes.

*Moisture Content*

As aforementioned, RDF had the same initial condition for each variation, i.e. the moisture content was 30%. After drying for six hours (09.00-15.00), the RDF moisture content was measured by oven-drying method at 100°C. Figure below shows the final moisture content of RDF.

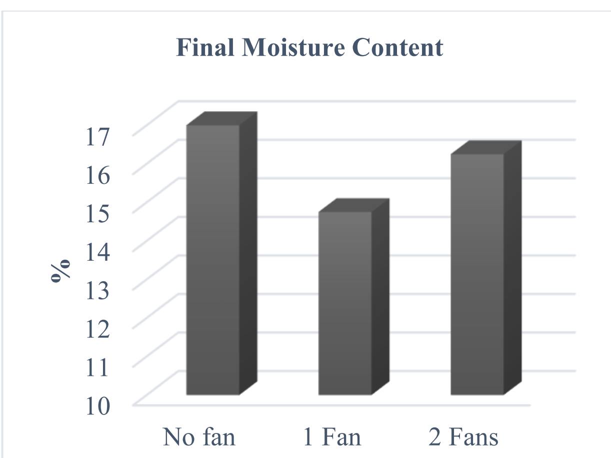


Figure 6. Final Moisture Content of RDF for Each Modes.

From inspection, the experimental results show that drying RDF inside the greenhouse without operating fan could decrease the moisture content to 17%. Meanwhile, the final moisture content for the dryer with one fan and two fans are 14.75% and 16.25 % respectively. Thus, the final moisture content of dried RDF is sufficient to meet the requirements of cement manufacturing industries. Moreover, using the fans would much lower the moisture content than that of no fan. This finding is reasonable since fans circulate the air inside the greenhouse.

*Efficiency*

As seen in Figure 7, it is observed that drying inside the greenhouse by operating two fans has the highest energy efficiency. The efficiency is about 17,07%. Subsequently, it is followed by one fan mode, i.e. 16.3%. No fan mode has 15.87% energy efficiency. The result reveals that as the drying process takes place, water vapor from the evaporation of the product will be quickly removed with the help of 2 fans.

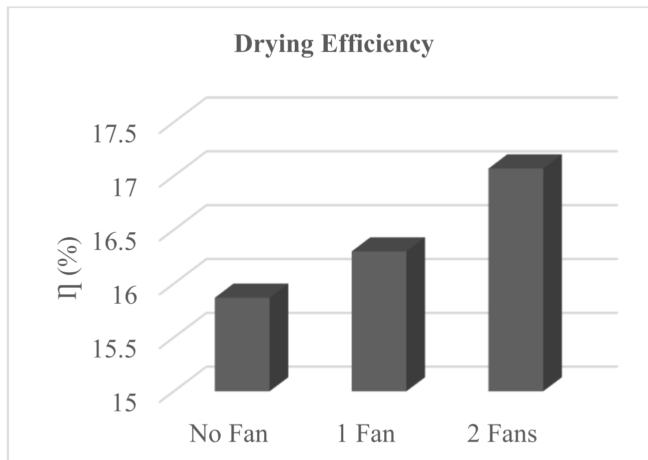


Figure 7. Drying Efficiency for Each Modes.

## IV. CONCLUSIONS

Solar drying of Refuse Derived Fuel (RDF) was observed in this experiment using greenhouse system. According to the results, it is concluded that drying RDF with one fan produced the lowest moisture content (14.75%). Meanwhile, for drying efficiency, two fan mode generated the highest value (17%). It is recommended to replace black plate with wire range in order to prevent wetness on plate.

## ACKNOWLEDGMENT

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