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Thermal Performance Evaluation of a Small-Scale Drying Machine for Palm Oil Mill Sludge

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Abstract: Malaysia is one of the major contributors of palm oil production globally with large amount of palm oil production. This has significantly contributed to large amount of palm oil mill effluent that eventually affect the environment. A small-scale drying machine for palm oil mill is evaluated on its thermal performance to assess the suitability of the machine to produce organic fertilizer from the palm oil mill sludge. Evaluation was performed with computational fluid dynamics simulation and experiment on design configuration options of the drying machine. The effect of air flow to the thermal performance was also studied in conjunction with the design configurations of the drying machine. The results showed promising potential of a design configuration over another in term of thermal performance and functionality.

Keywords: Small-scale drying machine, thermal evaluation, palm oil sludge

1. Introduction

Malaysia and Indonesia contributed to about 85 - 90% production of palm oil globally [1]. The large amount of palm oil production also significantly contributes to the large amount of palm oil mill effluent produced that will eventually affect the environment. In current practice, more than 85% of palm oil mills manage their effluent with lagoons that require a large area of land for continuous operation [2]. Unfortunately, the by-product of the effluent treatment especially for palm oil mill sludge is biogas that contain about 60% of methane [3]. Methane is the second largest contributor to global warming after carbon dioxide but with higher effect as compared to carbon dioxide by more than 20 times for a span of over 100 years [4, 5]. Hence, there is a necessity for the control of methane emission starting with a small effort on the palm oil mill sludge treatment control.

Palm oil mill effluent (POME) is in the form of condensate water and normally is acidic with pH between 4.0 to 5.0 [6, 7]. Dried or semi dried sludge of palm oil mill wastewater have potential for reuse in various applications due to the high nutrient content of the sludge such as calcium, nitrogen, magnesium, and phosphorus [8, 9]. Anaerobically treated palm oil mill sludge with mixture of additional organic nutrients such as chicken manure is good for soil condition improvement [10]. Additionally, composting bacteria is also present in the palm oil mill sludge that indicates the high suitability for the application as organic fertilizer [11]. The idea of small-scale drying machine for palm oil mill sludge is to enable small and medium sized farmers or planters to benefit from the production of organic fertilizer from the palm oil mill sludge for own usage or as income generator. Additionally, the effort will allow the community to work towards environmental conservation efforts in reducing the usage of land for sludge treatment, as an example.

2. Machine Design

Available sludge drying machines are mostly designed to dry the sludge at maximum dryness to almost a powder for or in a form commonly called dewatered sludge cake [12]. As an example, combination of rotary drum dryer and heating

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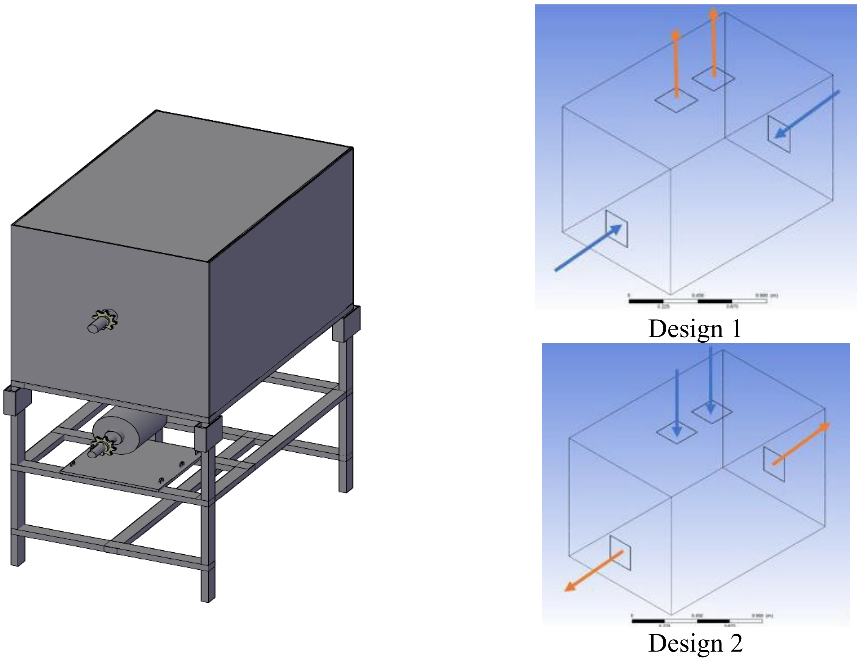
using waste steam from the palm oil mill process were utilized for the palm oil mill sludge drying mechanism [2]. In recent years, the use of microwave for was introduced in the effort to reduce the energy consumption in combination with flush drying [13]. Again, the aim for most available sludge drying machines is to maximize the dryness of the sludge and mainly for industrial applications. This study, on the other hand, will focus on the application level of small-scale production such as for small-scale farmers to self-produce their sludge-based fertilizers.

In this study, the operating temperature for simulation of the drying chamber was set to 40ºC. The initial operating temperature was set for this study considering it is the optimum temperature for composting of the fertilizer from the palm oil mill sludge [14]. This temperature is also within the temperature range for needed bacteria to be active [15]. Higher temperature might affect the availability of required bacteria for the effective function of the palm oil mill sludge as fertilizer. Applying the Theory of Inventive Problem Solving (TRIZ) principles on the design selection, the chosen type of drying machine is the rotary drum dryer [16]. The concept of the rotary drum dryer is based on the concept of the clothes drying machine which mainly uses centrifugal force to separate water from the solid and using forced convection to aid the drying process. The conceptual design is shown in Figure 1. The machine presented in this paper was able to accommodate about 5 kg of slurry sludge.

Two configurations for the drying chamber will be presented in this paper: Design 1 and Design 2 as shown in Fig. 1. These configurations were evaluated on their thermal performance in terms of the ability of the drying chamber to reach operating temperature of 40°C in the shortest time with variation of air inlet velocity. In the drying chamber design configurations, Incoming air flow is indicated with blue incoming arrows while exhaust air flow is indicated with orange outgoing arrows. The drying chamber for Design 1 was designed with the inlet air entering from the lower sideway of the drying chamber and exiting the drying chamber through the top opening. Design 2 has inlet air entering from the top opening and exiting from the lower sideway opening. Both design configurations are fitted with heating elements at the inlet air opening based on the design configuration. The purpose of the heating elements was to provide the drying chamber with warm air for the desired operating temperature of 40°C.



(a) **(b)**

Fig. 1 - Small-scale drying machine design (a) conceptual design; (b) drying chamber design configurations

3. Thermal Performance Evaluation

Thermal performance evaluation of the small-scale palm oil mill sludge drying machine was performed by computational fluid dynamics simulation with commercially available software. Standard k-epsilon turbulence model was used through the simulation software to perform the simulation [17]. The purpose of simulation in this study was to assess the effect of air inlet velocity and drying chamber configuration to the temperature inside the drying chamber. Tetrahedron mesh was selected as the meshing scheme in this study. Mesh size was optimized at 0.03 m after grid independence test, skewness plot evaluation, and consideration on the available hardware performance for the simulation. All inlet velocity varied between 1 m/s to 3 m/s. Exit conditions was set at atmospheric pressure with no specific velocity value. The temperature was set at room temperature as initial condition and 40ºC was set as the simulation limit inside the drying chamber.

Thermal simulation was performed by varying drying chamber design configuration and inlet air velocity. Fan-heater set was used to introduce air flow and heat into the chamber at the air flow inlet of the chamber. Variation of inlet air velocity was evaluated for the temperature profile in the drying chamber with comparison between both drying chamber design configurations. The focus was on the required time to reach the operating temperature in the drying chamber.

3.1 Design Configurations Effect on Thermal Performance of the Drying Chamber

Fig. 2 shows the temperature profile for the drying chamber of Design 1 and Design 2 with several inlet air temperatures. The simulation was stopped at 120 seconds as the temperature inside the drying chamber is at a constant value of 40°C for about 30 seconds before reaching simulation time of 120 seconds. Hence, further simulation is expected to give no change in the temperature value due to the maximum temperature setting in the simulation is at 40°C.

Drying chamber configuration of Design 2 shows similar trends of temperature profile in the drying chamber with the variation of inlet air velocity as shown in Fig. 2. The results, however, shows a slower approaching to the operating temperature for the lower values of inlet air velocity. Interestingly, with inlet velocity of 1.5 m/s, the drying chamber temperature almost not reaching the operating temperature at 120 seconds.

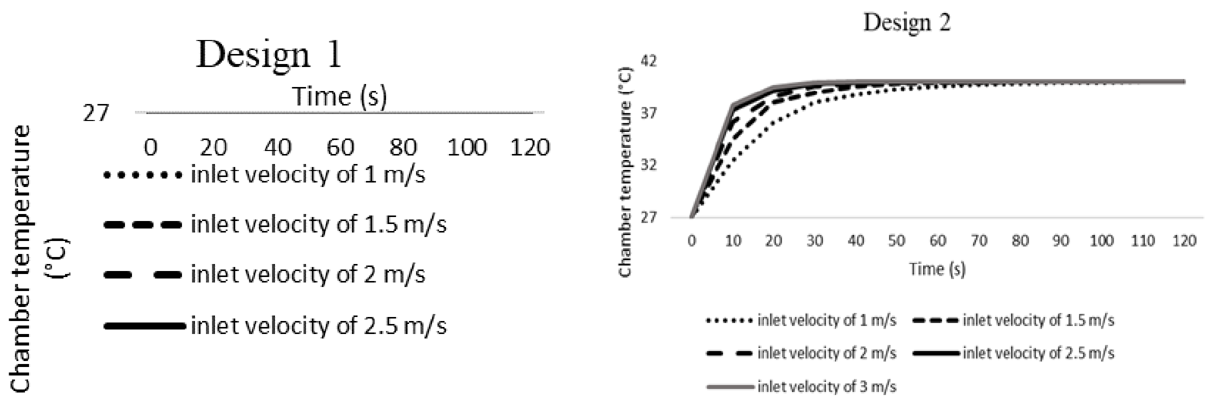


Fig. 2 - Simulated temperature profile inside the drying chamber

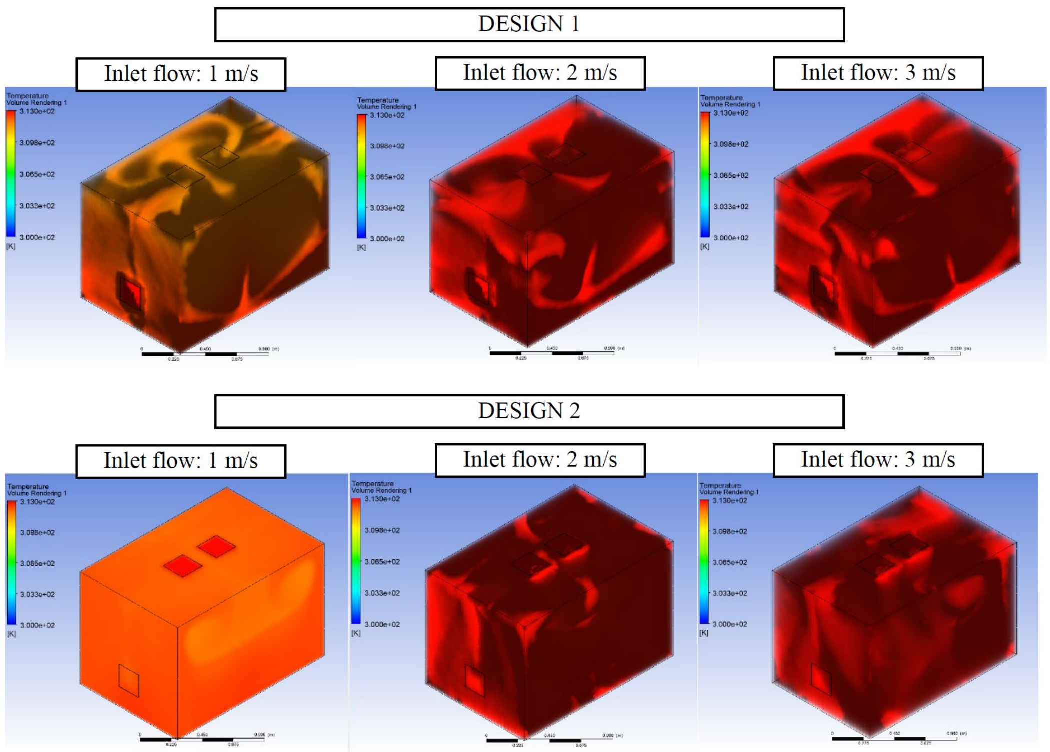


Fig. 3 - Temperature distribution inside the drying chamber at simulation time of 60 seconds

This difference can be well explained by the projected hot air movement behaviour at low speed based on occurrence of natural convection that assist the distribution of temperature in the chamber. The natural convection itself works better in Design 1 as the air movement is designed to enter from the lower side of the chamber and exit at the higher side of the chamber that is in consistent with the principles of natural convection. On the other hand, Design 2 has opposed the natural convection law by forcing the hot air to enter from the higher position and exit at a lower position. The simulated temperature profile in the drying chamber for Design 2 is shown in Fig. 2. Fig.3 shows the temperature distribution for both Design 1 and Design 2 at 60 seconds of simulation time. Design 1 having a better performance in terms of temperature distribution at lower air velocity. This indicates that the time to reach the desired temperature of 40°C would be shorter for Design 1. Hence, giving the benefit of lower energy requirement for the operation.

The temperature profile for simulation with inlet air velocity of 3 m/s is further evaluated is shown in Fig.4. At any value of inlet velocity, the simulated temperature profile in the drying chamber does not show significant difference between Design 1 and Design 2. A slight improvement can be observed at the time between 10 s to about 25 s during the phase when the chamber temperature almost reached the desired 40°C temperature. Design 1 shows a minor advantage of reaching higher temperature in about 10 seconds earlier as compared to Design 2 but with only about 1°C advantage. On overall, at 3 m/s of air inlet velocity, the thermal performance on both design configurations were almost identical. Extending the comparison between both design configurations across various inlet air velocities, Design 1 has a better configuration in achieving the desired temperature faster as compared to Design 2. The comparison is based on the time required to reach the operating temperature of 40ºC as shown in Fig. 5. At 3 m/s of inlet air velocity, there is a difference of about 10 s in term of time to reach the desired chamber temperature. Interestingly, Design 1 is capable of consistently reducing time to reach the desired chamber temperature starting with the lower side of the air inlet velocity. At the velocities of between 1 m/s to 1.5 m/s, Design 2 is still showing a constant time requirement while Design 1 can achieve the reduction of time with the increase of air inlet velocity. Similar justification applies to this scenario as in the earlier results of this section in relation to the natural convection.

As the simulation results is in favour to Design 1 as the better configuration among the two options, the configuration is used for experimental setup to evaluate the effect of temperature variation to the moisture removal of the sludge.

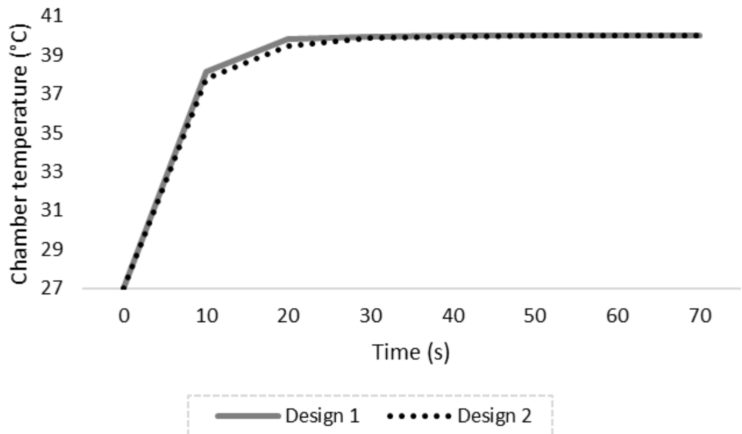


Fig. 4 - Simulated temperature profile inside the drying chamber with inlet air velocity of 3 m/s

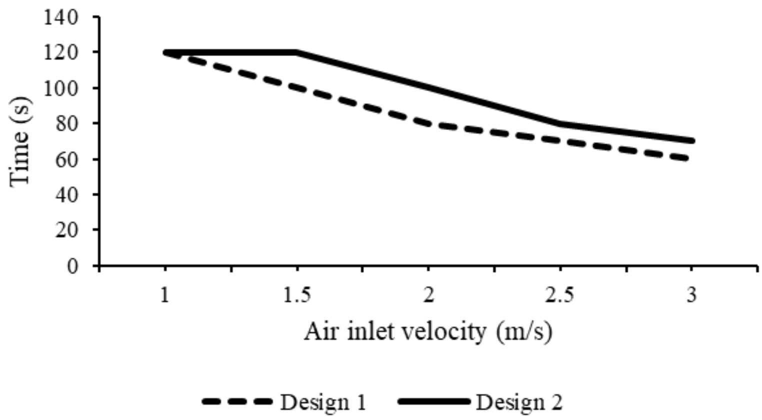


Fig. 5 - The influence of inlet air velocity to time taken for the chamber to reach 40°C of operating temperature

3.2 Drying Machine Experimental Test

The experiment was conducted on a reduced scale machine at 1:5 with the drying chamber configuration of Design 1. The experiment was conducted with 1 kg of wet palm oil mill sludge to observe the effect of low temperature to the reduction of sludge moisture content. Other drying parameters such as rotation speed of the drum and air flow into the chamber were kept constant throughout the experiment. Moisture content reduction was evaluated by the weight difference of the sludge before and after the drying process; $m_w = m_{initial} - m_{final}$, where m_w is mass of water, $m_{initial}$ is mass of sludge before drying experiment, and m_{final} is the mass of sludge after the drying experiment. Fig. 6 shows the experimental setup for this study. By principle, the increase of temperature from room temperature would affect the amount of moisture content reduction due to increase of evaporation potential even at low temperature increase from the ambient temperature [18]. The experiment is to evaluate the reduction of moisture because of drying time and temperature. Three temperatures were set for the inlet air heaters at 30°C, 35°C and 40°C for evaluation of the temperature effect to the moisture reduction.

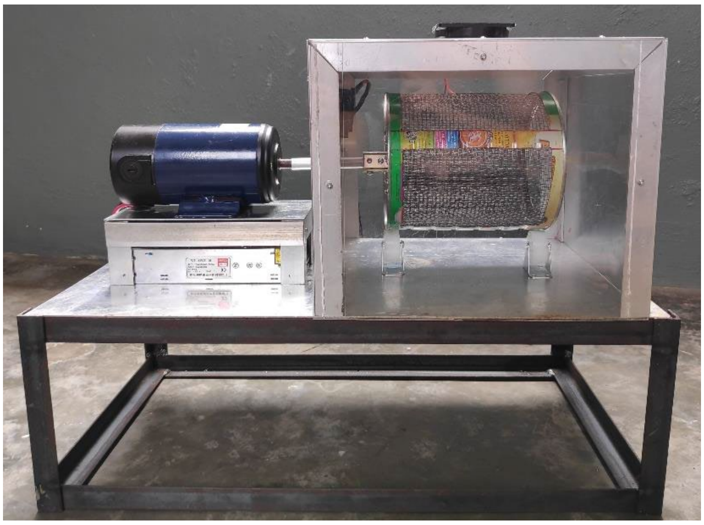


Fig. 6 - Experimental setup for sludge drying

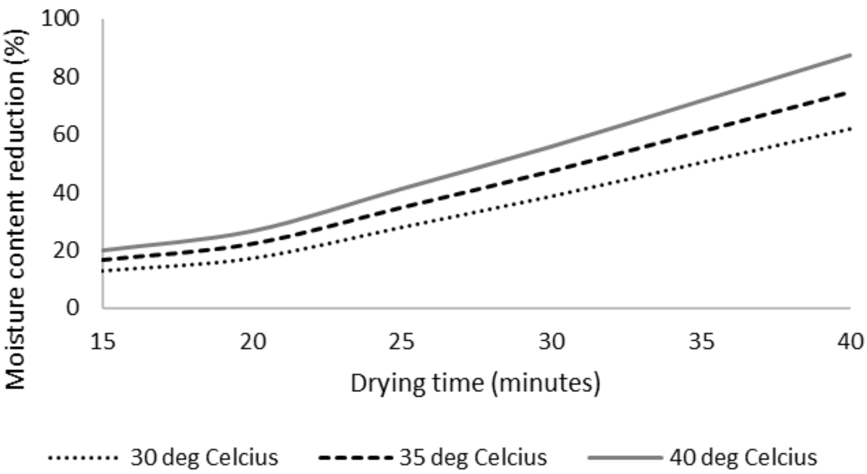


Fig. 7 - Moisture content reduction for temperature variations between 30°C to 40°C

Fig. 7 shows the moisture content reduction for experiments conducted with varying temperatures between 30°C to 40°C. Moisture content reduction shown in Figure 6 is the percentage of moisture content reduced from the initial moisture content. For this experiment, the initial moisture content was at 39%. Moisture content reduction did not show significant difference with the variation of temperature at the shorter drying duration of less than about 25 minutes. The effect of temperature was significant towards the 35 to 40 minutes of drying duration with the increase of capability for moisture removal up to 25% in difference. At 40°C, the dryer was able to remove about 85% of the moisture content as compared to the initial moisture content, which resulted to only 6% of moisture content reduced from 39% at the beginning of the experiment. While, for drying process with 30°C of temperature inside the drying chamber, the removal capability was about 60% of the initial moisture content.

This result also indicates that the increase in temperature can also allow the drying duration to be shortened to achieve the same required moisture content at lower operating temperature. For example, to achieve the same moisture removal at 40 minutes for 30°C operating temperature, the dryer can be operated at 40°C for about 30 – 32 minutes, that is a saving of about 10 minutes of machine operation. With continuous drying activity, the time saving for drying can be translated into more production time for more output. Desired final moisture content varies based on the intended applications of the dried sludge and the initial moisture content of the raw palm oil mill sludge. Therefore, based on results, the drying machine in this study should be able to perform drying for palm oil mill sludge to achieve various outcomes in term of moisture content with the variation of temperature in the drying chamber.

4. Conclusions and Recommendations

Design 1 of the small-scale drying machine has a thermal performance advantage over Design 2 in terms of the shorter time required to achieve operating temperature in the drying chamber. Further improvement can be made to Design 1 for enhancement of automatic temperature regulation that was unsuccessful in this experiment. Another aspect of limitation in this study was that the effect of rotational motion and sludge drying were not included in the simulation.

As a recommendation for future works, consideration for higher drying temperature is possible but should be followed by the analysis of sludge nutrient content after drying process to evaluate the effect of the temperature on the composition and quality of the sludge. This is to determine the suitability of the sludge for re-use as organic fertilizer. The nutrient and microbial contents of the sludge could be affected by both temperature and moisture content of the dried sludge [19, 20].

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