TEKNOLOGI BERBASIS SUMBER ENERGI TERBARUKAN UNTUK PERTANIAN

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8 CFD ANALYSIS OF AIR FLOW PROFILE WITHIN A GHE SOLAR DRYER

Dyah Wulandani, Edy Hartulistiyoso, Ahmad Indra S., Kamaruddin Abdullah

ABSTRACT

In our previous study several experimental runs were conducted using a laboratory scale Green House Effect (GHE) Solar Dyer to test CFD software for the purpose of improving the performance of field size solar dryer. Three modes of component re-arrangements of air inlet, heat exchanger, fans and outlet were selected using cloves as the drying load of a field size solar dryer. Using the Fluent version 6.1. soft ware it was capable to determine the optimum re-arrangements of the field size solar dryer components so that better distribution air flow, RH and temperature distribution within the chamber could be created.

Key words: CFD, greenhouse effect solar dryer, cloves, biomass stove, operating parameters, field test.

I. INTRODUCTION

Greenhouse effect (GHE) solar dryer was found to be more economical in comparison to the conventional solar dryer using separated solar heat collector as hot air generator. Laboratory as well as several field tests had indicated techno-economic potentiality of the GHE solar dryer design to dry various agromarine products in Indonesia as well in other developing countries (Kamaruddin, 1993; CREATA-IPB, 2000). Some of the installed GHE solar dryer have been integrated to form a Small Processing Unit (SPU), a kind of small factory in the village, which could produce semifinished or finished products ready to be sold in the market. In this way, beside quality improvement, the products processed could be stored for longer period of time and hence reduces post harvest losses. Formerly it has been a common practice by the farmer and even by the estate plantation owner, to dry their export quality only by means of direct sun drying. This method of post harvest handling, although looks easy and only needs a low cost, the final products quality can not be controlled and are susceptible to contamination by dirt, foreign materials including pebbles. Food products such as rough rice, corn or fish are also susceptible to loss by rodents, birds and other animals. As the interest on solar drying, it begin to take place now in

Indonesia as an indicated by an increase in request of the Ministry of Energy and Mineral Resources, local government of West Nusatenggara, the private sectors and the NGOs that optimization and improvement of the current design was felt necessary. New designs with an easy operation and users friendliness are being developed after receiving feed backs from the customers. One of the important aspect of improvement was on how to obtain even distribution of drying air flow, RH and temperature distribution within the drying chamber as a prerequisite condition to obtain even quality of the dried product. This paper aims to improve the operating condition of a field size GHE solar dryer by applying CFD techniques using three different modes of major component re-arrangement and positioning.

II. THE EXPERIMENT

The tested field size Green House Effect (GHE) solar dryer used in this study is as shown schematically in Fig 1. The dryer was comprised of transparent wall, 3.6 m x 3.6 m floor area and height of 2.7 m. The floor was made of black painted concrete pavement where steel frames for the polycarbonate wall were anchored. In the middle section of the drying chamber two trolleys, each containing 7 trays loaded with cloves to be dried. The dryer was also equipped with biomass stove to supply hot air to the drying chamber by means of an heat exchanger. A Savonius wind mill equipped with fan blades was installed to accelerate the exhaust of moisture from the chamber. On the axis of the Savonius wind mill a cam was provided to enhance drying process due to the shaking action of the cam on the trolleys. At critical location within and out side the dryer CA thermocouples were placed and measured by means of Chino Recorder with smallest readings of ±1 °C. The air flow rate was measured using the Kanomax with the smallest readings of 0.01 m/s. Solar irradiation was measured using Eko-Eppley pyranometer. Three test runs were conducted between October 2002 through March 2003. With the loading of 39 kg (68.4% wb) in experimental Run 1 and 80 kg each in Run 2, and Run 3 (72.0% wb and 72.8% wb, respectively) the drying time required to reach the final moisture of 12% wb was 51 hrs, 61 hrs and 41 hrs, respectively. In test Run 3, where the average solar irradiation was at 310 W/m^2, the resulting drying air temperature was 48.4 °C, RH of 46.5 %, the total specific energy for drying was 16 MJ/kg of water evaporated with the contribution of electricity was only 0.8 MJ/kg of water evaporated or mearely 5% of the total.

III. CFD ANALYSIS

In this study solver Fluent 5.3 and 6.1 software were used to solve the simultaneous, momentum and energy transfer. The grid was constructed using

Gambit as pre-processor compatible with the solver. The *Pre-rocessor* comprises of input of flow properties to the CFD using the interface into format easy to be solved by the *solver* (Versteeg, dan Malalasekera, 1995). The preparation works was initiated by defining the areal geometry suitable for domain computation, the grid /mesh arrangement on cell or control volume (shown in Fig.1), selection of the phenomena, specification of transport properties, and the definition of the initial and boundary conditions of each cells. The governing equations of the air flow within the drying chamber were established for the continuity, momentum, and energy in three dimensional Cartesian coordinates (Bird. *et. al.* 1960).

Legend:

1. Primary air inlet
2. Heat Exchanger
3. Lower fan
4. Trays
5. Top fans
6. Outlet

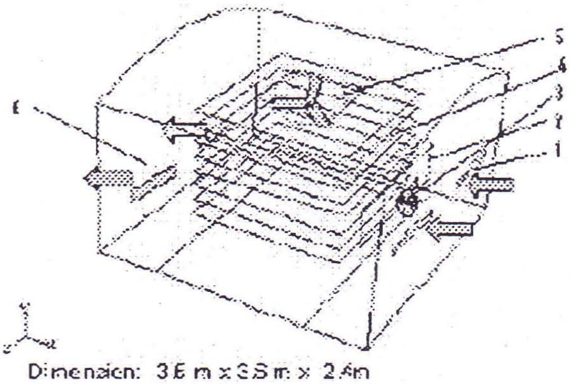

Fig. 1 Schematic diagram of tested field size GHE solar dryer

3.1. Basic Assumptions

In order to conduct CFD analysis of the air flow within the drying chamber it was necessary to impose the following assumptions: a). Air density was considered constant during the drying process (incompressible), b). Constant Prandt number of the air , c). The air moves under steady state condition , at Re= 75.5 d). The ambient air temperature was considered constant at 36 °C., and e). Air velocity created by all the fans was constant.

3.2. The Initial Condition

CFD analysis was conducted with the I.C. that the initial velocity of the air at all coordinate x,y and z was at 0 m/s, the wall temperature was equal to the ambient temperature, and the atmospheric pressure was at 101.325 kPa. The distribution of RH was computed using different software using the basic mass balance within the drying chamber.

3.3. The Boundary Conditions

The boundary condition imposed for the purpose of the current analysis is summparized in Table 1. Solar irradiation heat flux was considered contant and represented by a constant value of 500 W/m^2. The heat flux from the heat exchanger was also considred to have a constant value of 653.1 W/m^2.

Table 1. The boundary condition set up for CFD analysis of the tested fixed size GHE solar dryer

Parameter	Quantity	Parameter	Quantity
Inlet air velocity (m/s)	0.24	Transparent walls • Thickness (mm) • Heat flux (W/m^2) • Wall temperature (°C) • Film heat transfer coeff. (W/m^2 °C) • Emissivity	 8 12.5 36 1 0.95
Outlet opening	1	The tray (8 trays) • Surface permeability (m^2) • Thickness (m) • Porous jump coefficient (1/m)	 1.596×10^{5} 0.01 5203.1
Bottom fan • Pressure drop (kPa) • Minimum air velocity (m/s) • Maximum air velocity (m/s)	 1458 1 2	Heat exchanger • Loss coefficient • Convective heat transfer coefficient (W/m^2 °C) • Temperature °C • Thermal Flux W/m^2	 1855 35 64 653.1
Central fan on the top of the trolleys. • Pressure drop (kPa) • Minimum air velocity (m/s) • Maximum air velocity (m/s)	 875 0.05 0.2	Solar irradiation • Loss coefficient • Convective heat transfer coefficient (W/m^2 °C) • Wall Temperature °C • Irradiation Flux (W/m^2)	 40 32 64 500
Middle fan above the Heat exchanger • Pressure drop (kPa) • Minimum air velocity (m/s) • Maximum air velocity (m/s)	 1458 1 2		

IV. CFD ANALYSIS FOR COMPONENT ARRANGEMENT

Referring to Fig 1. three modes of component arrangement were selected to obtain the best position of inlet, out let, heat exchangers and fans. In the first mode, two inlets each having 0.1 m x 1m were located 1 m above the floor, two outlets each with 0.2 m x 0.8 m were located at 1.6 m above the floor of the opposite wall, 1 m x 1.2 m heat exchanger was installed 0.2 m in front of the inlet. A 100 W bottom fan was located 0.2 m in front of the heat exchanger. Two 40 W air mixing fans, were placed on the center of the chamber and located 2 m above the floor. In mode 2, keeping other arrangement at the same size and position, the bottom and central fans were replaced, respectively, with one 120 W at the bottom and another at the top location of the chamber. In mode 3, the same size of inlet and outlet was used except the the location of the inlet was placed at 1.4 m above the floor while the out let at 0.8 m above the floor. Three fans were installed one 100 W at 0.2 m in front of the heat exchanger now raised to 0.4 m above the floor, a 40 W center fan was installed above the top tray.

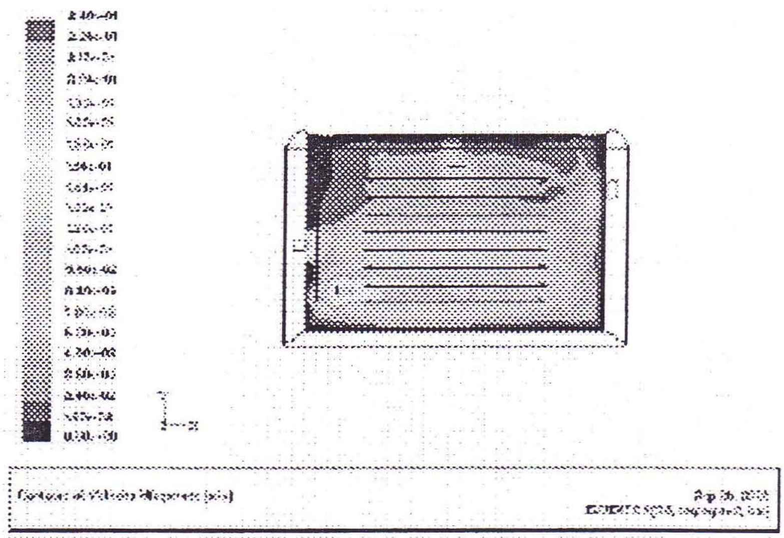

Figure 2. Temperature distribution for the mode 1 component arrangement

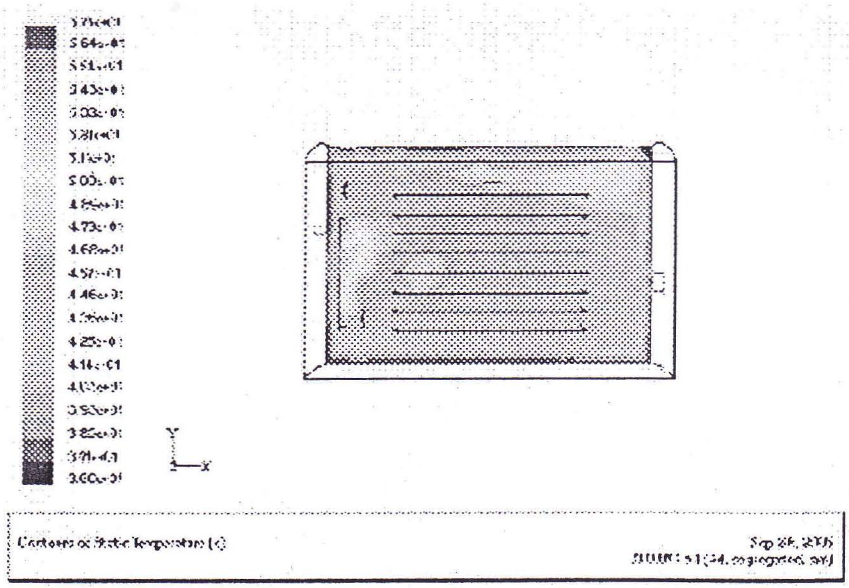

Figure 3. Typical temperature profiles when the GHE dryer was operated using mode 3.

Another 100 W fan was placed 1.8 m above the heat exchanger coincided with the height of the top tray. Figs. 2 and 3 compare the two modes of operation 1 and 3 in terms of temperature profiles within the GHE solar dryer. The result of temperature distribution on each tray of the three modes of operation can also be seen in Table 2. Simulation results using the three modes had indicated that mode 3 had proved to provide the best operating condition where the average tray temperature was 45.4 °C ± 1.6 °C, air velocity of 0.05 m/s ± 0.03 m/s, and RH of 45.6 % ± 3.7 %. During the night only the bottom fan should be used to maintain chamber temperature of 43.2 °C ± 2.2 °C, air velocity of 0.17 m/s ± 0.02 m/s and RH of 31.7% ± 2.2 %. Fig. 2 and 3 show the typical results of temperature profile when operated with modes 1 and 3 using CFD analysis.

Table 2. Comparison in terms of Standard Deviations of temperature distribution among the three modes of operation

Mode / Tray	1	2	3	4	5	6	7	8	Average of all trays
I	0.5	1.3	2.2	2.5	2.3	1.5	1.8	2.2	2.2
II	0.6	1.0	0.9	1.3	1.7	2.4	1.9	1.8	1.9
III	0.6	1.6	1.3	1.2	1.5	1.9	1.8	2.15	1.64

V. CONCLUSIONS

1. Test results of experimental GHE solar dryer indicated that the optimum operating temperature for clove drying was 48 °C but the bigger value of deviations in temperature profiles occurred along the vertical axis rather toward horizontal direction as indicated by the value of their respective standard deviations namely 2.4 °C on the vertical axis and 0.95 °C on the horizontal direction. This amount of temperature deviations had resulted in 3.78 % wb difference in final moisture content of the cloves.
2. The average drying efficiency of the system was 19 % obtained from the three experimental runs and the average specific energy was 16 MJ/kg of water evaporated
3. The average grade of the final products fell into the category of grade I and II.
4. In order to improve the operating condition of the dryer it was recommended to select mode 3 of the component arrangement.

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