DESIGN AND PERFORMANCE EVALUATION OF AN INTEGRATED SOLAR DRYER FOR FISH AND MARINE PRODUCTS THROUGH COMPUTATIONAL FLUID DYNAMICS SIMULATION

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I hereby declare that the material in this thesis is my own except for quotations, equations, summaries, and references, which have been duly acknowledged.

12 April 2023

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ABSTRACT

There are several drawbacks remain to be resolved for the application of solar dryer in fish drying, such include low solar intensity, uniformity of heat distribution, and inadequate air circulation. In this present study, a mixed mode type solar dryer namely, Integrated Solar Dryer (INSOLER) was presented and the performance under pseudo natural convection was studied through Computational Fluid Dynamics (CFD) simulation under inlet mass flow rate of 0.012 kg/s and solar irradiance of 438.58 W/m^2. In this solar dryer, enhancement was proposed on the design of solar heat collector, air distribution system, and chimney, which governs the temperature, uniformity, and air circulation, respectively, to address the limitation mentioned. The main purpose of this research is to address the gaps in the design of these components and identify the improvements in term of heat transfer and fluid flow characteristics. The first objective of this work aimed to determine the performance of baffle-type solar heat collector (B-SHC) with different baffle arrangement, namely longitudinal SHC (L-SHC) and transversal SHC (T-SHC). It was found that L-SHC offers higher outlet temperature, collector efficiency, and thermo-hydraulic performance factor (THPF) of 59.43 °C, 46.2% and 2.1, respectively, indicating flow resistant presence in the air passage of longitudinal arrangement does not outweigh the enhancement of heat transfer in the collector. To ensure uniform heat distribution across the drying house, air distribution system with different perforation direction – upward and downward, was proposed. The latter configuration was proposed to address potential faulty operation caused by moisture accumulation and to ensure maximum heat transfer enhancement in the solar dryer. As expected, this perforation demonstrated more uniform temperature profile with p-value greater than 0.01 across different tray level and exhibits superior performance with heat transfer enhancement factor of 1.09. Followed by, three different chimney placement – exterior chimney, interior chimney, and interior chimney with perforation, were evaluated in term of the temperature distribution and the velocity profile attained across the drying house. Interior chimney was proposed to prevent continuous outflow of air which ultimately promotes heat accumulation in the dryer. Interior

chimney with perforation demonstrated highest temperature with a value of 67 °C and the velocity profile obtained implied extended air residence time in the solar dryer due to the presence of greater air resistance. Lastly, INSOLER developed with the combination of these improvements offers drying temperature range suitable for the drying of fish (maximum temperature = 66 °C), uniform temperature profile across different tray level (p-value>0.01), and air circulation that promote heat accumulation in the drying area, which compensated the limitations of solar dryer mentioned earlier. For optimization purpose, the performance of INSOLER under different mass flow rate and solar irradiance was also studied. It was revealed that there is a difficulty in compromising between attaining allowable temperature range and better uniformity. With these findings obtained, this research could serve as a baseline study for the implementation of solar heat collector, air distribution, and chimney design covered in this work as a continuous effort for solar dryer enhancement to achieve sustainable development in food processing industry.

ABSTRAK

REKA BENTUK DAN PENILAIAN PRESTASI PENGERING SOLAR UNTUK PRODUK-PRODUK IKAN DAN LAUTAN MELALUIS SIMULASI COMPUTATIONAL FLUID DYNAMICS

Terdapat beberapa kelemahan yang masih perlu diatasi bagi menggunakan sistem pengering suria untuk pengeringan bahan makanan seperti tenaga haba yang tidak mencukupi, pengagihan haba yang tidak homogen, dan peredaran udara yang kurang memuaskan. Dalam kajian ini, pengering suria jenis 'mixed-mode' dinamakan Integrated Solar Dryer (INSOLER) telah direka bentuk dan seterusnya diuji di bawah pseudo natural convection (aliran jisim 0.012 kg/s, solar sinaran 438.58W/m^2) menggunakan simulasi Computational Fluid Dynamics (CFD). Oleh itu, kajian ini memberi fokus kepada manambah baik kecekapan sistem pengering suria dari segi rekaan pengumpul suria (SHC), sistem peredaran haba dan cerobong. Dalam kajian ini, SHC jenis baffle direka dengan konfigurasi aliran yang berbeza – longitudinal SHC (L-SHC) dan transversal SHC (T-SHC), telah dicadangkan. Prestasi terma SHC telah diramalkan dari segi ciri-ciri pemindahan haba dan aliran udara dalam pengumpul tersebut melalui simulasi CFD. Didapati bahawa L-SHC mempunyai suhu, kecekapan pengumpul dan thermo-hydraulic performance factor (THPF) yang lebih tinggi, iaitu 59.43°C, 46.20% dan 2.1. Ini menunjukkan kalis aliran dalam pengumpul tidak melebihi peningkatan pemindahan haba yang tercapai. Bagi memastikan penyebaran haba yang seragam, sistem pengedaran udara yang berlubang (perforation) telah dicadangkan. Komponen ini telah menunjukkan profil suhu yang seragam dan menunjukkan p-value lebih daripada 0.01 dan faktor peningkatan pemindahan haba sebanyak 1.09. Cerobong dengan reka bentuk yang berbeza – cerobong external, cerobong interior, dan cerobong interior berlubang, telah dinalai dari segi profil suhu dan profil aliran udara merentasi sistem ini. Didapati bahawa cerobong interior berlubang menunjukkan suhu tertinggi (67 °C) dan mempamerkan faedah tambahan bawah keadaan with-load. Akhir sekali, INSOLER dibangunkan dengan gabungan penambahbaikan ini menawarkan julat suhu pengeringan yang sesuai untuk pengeringan ikan (suhu maksimum = 66°C), profil suhu seragam (p-value>0.01), dan peredaran udara yang menggalakkan pengumpulan haba di kawasan pengeringan. Untuk tujuan pengoptimuman, prestasi INSOLER di bawah kadar aliran

jisim dan sinaran suria yang berbeza turut dikaji. Telah diramalkan bahawa terdapat kesukaran untuk berkompromi antara mencapai suhu yang dibenarkan untuk pengeringan ikan dan keseragaman yang lebih baik. Dengan penemuan ini yang diperolehi, penyelidikan ini boleh menjadi kajian asas untuk pelaksanaan pengumpul haba suria, pengagihan udara dan reka bentuk cerobong yang dikaji dalam kerja ini sebagai usaha untuk peningkatan pengering suria untuk mencapai pembangunan dalam industri pemprosesan makanan. Kesimpulannya, kesukaran untuk berkompromi antara mencapai julat suhu yang dibenarkan dan keseragaman yang lebih baik boleh diatasi dengan mengawal selia kadar aliran jisim di salur masuk pengering suria mengikut variasi sinaran suria sepanjang hari.

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A_c	-	Solar heat collector	m^2
$A_{ch,in}$	-	Cross-sectional area at chimney inlet	m^2
$A_{ch,out}$	-	Cross-sectional area at chimney outlet	m^2
A_{ch}	-	Cross-sectional area of chimney	m^2
A_{fl}	-	Surface area of drying house floor	m^2
A_p	-	Cross-sectional of pipe	m^2
A_r	-	Ratio of cross-sectional area of outlet over inlet	-
C_o	-	Discharge coefficient	-
Cp_d	-	Specific heat capacity of air @ T_d	kJ/kg ºC
Cp_p	-	Specific heat capacity of product	kJ/kg ºC
Cp_w	-	Specific heat capacity of water	kJ/kg ºC
D_{hole}	-	Perforation diameter	mm
D_{pipe}	-	Pipe diameter	m
f_o	-	Friction factor without perforated air distributor	-
f_s	-	Friction factor of smooth heat collector	-
H_a	-	Ambient relative humidity	%
h_f	-	Final enthalpy of drying	kJ/kg dry air
h_{fg}	-	Latent heat capacity @ T_d	kJ/kg K
H_{house}	-	Drying house height	m
h_i	-	Initial enthalpy of drying	kJ/kg dry air
k_t	-	Non-uniform coefficient	-
L_{house}	-	Drying house length	m
L_p	-	Pipe length	m
$m_{a,ch}$	-	Mass flow rate of air required at each chimney	m^3/s
$m_{a,pipe}$	-	Air flow rate in each inlet	kg/s
m_a	-	Mass flow of drying air required	kg/h
m_a	-	Total quantity of air required	kg/s
m_a	-	Mass flow rate of air required to remove moisture	m^3/s

M_p	-	Loading capacity per batch	kg
M_r	-	Moisture to be removed	kg
MC_f	-	Final moisture content	%
MC_i	-	Initial moisture content	%
n_c	-	Number of chimney	-
n_p	-	Number of air inlet	-
Nu_o	-	Nusselt number without perforated air distributor	-
Nu_s	-	Nusselt number of smooth heat collector	-
$Q_{loss,o}$	-	Heat loss through drying house outlet	W
$Q_{loss,SHC}$	-	Heat loss in solar heat collector	W
Q_r	-	Energy gained in drying house	W
Q_u	-	Energy gained in solar heat collector	W
T_a	-	Ambient air temperature	ºC
T_d	-	Drying temperature	ºC
T_{fl}	-	Temperature of floor surface	K
T_{rm}	-	Temperature of air in drying house	K
$\bar{t}$	-	Arithmetic average of temperature measured in each point.	K
t_s	-	Sunshine hour	hours
V_{ch}	-	Velocity produced in chimney	m/s
V_{in}	-	Wind speed	m/s
V_{pipe}	-	Air velocity in each pipe	m/s
W_f	-	Humidity ratio of humid air	kg water/kg of dry air
W_{house}	-	Drying house width	m
W_i	-	Humidity ratio of pure heated air	kg water/kg of dry air
η_c	-	Collector efficiency	%
$\rho_{air,c}$	-	Density of air in chimney	kg/m^3
ρ_d	-	Density of air @ T_d	Kg/m^3
ρ_d	-	Density of air @ T_d	kg/m^3