Dedicated to my son

“Arjyaraj”

DECLARATION

I do hereby declare that the thesis, entitled "**Prospect of Intervention of Solar Thermal Energy in Tea Leaf Withering: A Modeling and Experimental Study**", is the record of work done by me under the supervision of Dr. Partha P. Dutta, Professor, Department of Mechanical Engineering, Tezpur University, Tezpur. The contents of the thesis represent my original work that have not been previously submitted for any other degree or diploma in any other University or Institute.

This thesis is being submitted to Tezpur University for the degree of Doctor of Philosophy in Mechanical Engineering.

Date: 09.07.2024

Place: Tezpur University, Tezpur

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CERTIFICATE

This is to certify that the thesis entitled "**Prospect of Intervention of Solar Thermal Energy in Tea Leaf Withering: A Modeling and Experimental Study**", submitted to the School of Engineering, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy in Mechanical Engineering is a record of research work carried out by Ms. Anindita Sharma (MEP16102) under my supervision and guidance. All help received by her from various sources have been duly acknowledged. No part of this thesis has been submitted elsewhere for award of any other degree or diploma.

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Anindita Sharma

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NOMENCLATURE

A_E	Edge area (m^2)
A_S	Area of the collector plate (m^2)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
C_p	Heat capacity of air (=1.005 kJ/kg K)
CTC	Crush-Tear-Curl
CV	Calorific value (kJ/kg)
C_w	Cost of fresh tea leaves against 1 kg of withered leaves ($)
C_{ft}	Cost of fresh tea leaves per kg ($)
C_{ws}	Cost of withering 1 kg of tea leaves in the trough ($)
C_s	Cost of solar withering ($)
C_c	Capital cost of the chamber ($)
C_{ann}	Annualized cost of the trough ($)
C_{acc}	Annualized capital cost ($)
C_{mc}	Maintenance cost ($)
C_{rfc}	Running fuel cost ($)
C_{ec}	Running electrical cost ($)
C_{elc}	Electricity cost per unit ($)
C_{pw}	Cost of withered tea in the market ($)
D_e	Effective diffusivity (m^2/s)
D_0	Diffusivity constant
D_r	Drying rate (g water/g solid-h)
E_a	Activation energy (kJ/mol)
E_b	Power consumption of the blower (W)
E_P	Energy payback time
E_m	Embodied energy (kWh)
$E_{a,out}$	annual energy output of the system (kWh/year)
$E_{d,out}$	Daily thermal output (kWh)
ECC	Carbon credit earned ($)
E_t	Total energy supplied in the EC (MJ)
E_T	Total energy input to the withering chamber (kWh)

$\dot{Ex}_i$, $\dot{Ex}_o$	Exergy at inlet and outlet of SAH (kJ)
$\dot{Ex}_{ic}$, $\dot{Ex}_{oc}$	Exergy at inlet and outlet of withering chamber (kJ)
$\dot{Ex}_{des}$	Rate of exergy destruction (kW)
$\dot{Ex}_L$	Exergy loss (kJ)
EC	Environmental chamber
Exp	Experimental
GAE	Gallic acid equivalent
HD	Hygrometric difference (°C)
h_{fg}	Latent heat of evaporation (kJ/kg)
H	Relative humidity (%)
h_1	Total heat transfer coefficients from collector plate to cover (W/m^2 K)
h_2	Total heat transfer coefficients from cover to ambient (W/m^2 K)
h_b	Heat loss coefficient from the bottom (W/m^2 K)
h_i, h_o	Enthalpy at inlet and outlet (kJ/kg)
h_w	Wind heat transfer coefficient (W/m^2K)
$\dot{I}$	Rate of irreversibility (kW)
I_S	Solar radiation (W/m^2)
i	Inflation rate (%)
IP	Improvement potential (J)
K	Thermal conductivity of air (W/m-K)
K_{in}	Conductivity of insulation (= 0.03 W/m-K for dry wood)
k	Drying rate constant (s^{-1})
k_1, k_2, A, B, N	Drying model constants
L	Spacing between plate and cover (m)
L_{in}	length of insulation (m)
L_y	Lifetime of the drying system
L_D	Domestic appliance losses
L_T	Transmission losses
m_i, m_o	Mass flow rate of air at inlet and outlet (kg/s)
$\dot{m}_{air}$	Mass flow rate of air (kg/s)

$M_{(0)}$	Initial moisture content (% w.b.)
$M_{(t)}$	Moisture content at a given time *t* (% w.b.)
$M_{(e)}$	Equilibrium moisture content (% w.b.)
$M_{L(t)}$	Moisture loss of the leaves at any instant *t*
m_i, m_f	Initial and final masses of the tea leaves (g)
m_{ft}	Mass of fresh tea leaves per batch (kg)
m_{wt}	Withered tea leaves per batch (kg)
MR	Moisture ratio
MR_{ei}	Experimental *MR*
MR_{pi}	Predicted *MR*
MS_r	Residual mean square error
MS_t	Total sum square error
M_w	Mass of water removed (kg)
N_s	Number of sunshine days in a year
Nu	Nusselt number
n	Lifespan of the chamber
P	Payback period of the solar thermal based tea withering trough
P_i, P_o	Pressure inlet and outlet
Pre	Predicted
QCE	Quercetin equivalent
Q_u	Useful heat gain (W)
Q_h	Rate of exergy received by the solar air heater from solar radiation (W)
RH	Relative humidity (%)
R	Ideal gas constant (= 8.314 J/K-mol)
R^2	Coefficient of determination
R^2_{ad}	Adjusted R^2
RMSE	Root mean square error
R_d	Savings per day ($)
R_n	Annual savings in the n^{th} year ($)
R_1	Savings in the first year of operation ($)
SE	Specific energy consumption (MJ/kg)
SI	Sustainability index

SV	Salvage value
S_r	Residual sum square
S_t	Total sum square
s_i, s_o	Entropy at inlet and outlet (kJ/K)
t_0	Half thickness of leaf (m)
t_h	Annual running hours of the blower
t_s	Number of available solar withering trough operating days
t_d	Withering time required per batch (days)
t	Withering time duration (h)
T	Temperature (°C)
T_e	Ambient temperature (°C)
T_i, T_o	Inlet and outlet temperature (°C)
T_p, T_g	Mean temperatures of plate and glass cover (°C)
T_{sky}	Sky temperature (°C)
T_s	Sun temperature (K)
TFC	Total flavonoid content (mg QCE/g)
TPC	Total phenolic content (mg GAE/g)
U_T, U_B, U_E	Top, bottom and edge losses (W/m^2 K)
U_{over}	Overall heat loss coefficient (W/m^2 K)
v_w	Wind velocity (= 1 m/s)
V	Annual salvage value (Rs)
WER	Waste energy ratio
x	Rate of interest on the investment (%)
X	Fraction of energy taken from air heater
η_{SAH}	Thermal efficiency of the air heater
η_{over}	Overall efficiency of the withering trough
ψ_{SAH}	Exergy efficiency of the SAH
ψ_C	Exergy efficiency of the withering chamber
Δ	Difference
α	Absorptivity (=0.85)
τ	Transmissivity (=0.95)
ε_p	Emissivity of plate (= 0.9)

ε_g	Emissivity of glass (=0.88)
σ	Stefan-Boltzmann constant (= 5.67×10^{-8} W/m^2 K^4)