NON-DIMENSIONAL ANALYSIS OF MASS TRANSFER IN A SPOUTED BED DRYER FOR BLACK PEPPER DRYING

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Degree of Master of Science in Sustainable Process Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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Name of the supervisor: Prof (Mrs.) B.M.W.P.K Amarasinghe

Signature of the co-supervisor: ……………… Date: ………………………

Name of the co-supervisor: Dr. (Mrs.) G.K. Jayathunga

ABSTRACT

Black pepper is an agricultural crop that is extensively used as a spice and as an additive in numerous other applications. Postharvest drying of pepper is an important step to enhance the pepper quality and shelf life. Among many types of dryers spouted bed dryer is suitable for wide range of agricultural products. Knowledge on mass transfer analysis in the drying process is vital for improvements in the drying process and for dryer design. In this study, non-dimensional analysis of the mass transfer process of black pepper drying, in a spouted bed dryer was performed. Experimental results of a research conducted on black pepper drying using a conventional spouted bed dryer along with a cyclone separator was used for the analysis. The drying experiments were conducted to study the effect of operating variables; inlet air temperature, bed height and air velocity.

Non- dimensional analysis of mass transfer coefficient was employed using the Buckingham *pi* theorem and the data generated in a series of black pepper drying experiments in a spouted bed dryer were used to develop the model equation. The model consists of dimensionless parameters; Sherwood (Sh) number, Reynolds (Re) number, Schmidt (Sc) number and bed height to particle diameter (H/d_p). R software (Version 4.1.2) was employed for the determination of the coefficients of the model using the non-linear regression method and for statistical analysis. The model shows mass transfer coefficient is a function of the inlet air temperature, air velocity, dynamic viscosity of air, moisture diffusivity, bed height and air density.

The mass transfer coefficient values predicted from the developed correlation varied between 0.012 m/s and 0.032 m/s. The model predicted results were validated against experimentally determined values of mass transfer coefficients. The experimentally estimated mass transfer coefficients varied between 0.012 and 0.031 m/s and were in good agreement with model predicted values. Further, mass diffusivity values of the drying process varied between 2.87 x 10^{-5} – 3.6 x 10^{-5} m^2/s.

The results show that an increase in inlet air temperature reduces the mass transfer coefficient and the Sh number. However, increase in air velocity increases the mass transfer coefficient, which is in agreement with available relations for other similar products. Furthermore, mass transfer coefficient values decreased while increasing static bed height. This is an acceptable trend because of lower turbulence created by the higher static bed and the spouting of more particles in the higher bed rather than lower static bed heights.

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LIST OF ABBREVIATIONS

CFD	-	Computational Fluid Dynamics
CSB	-	Conventional Spouted Bed
GMI	-	Global Market Insight
MC	-	Moisture Content
MR	-	Moisture Ratio
R^2	-	Coefficient of determination
RSE	-	Residual Standard Error

NOMENCLATURE

L_s	Mass of dried solid (kg)
A	Exposed surface area for drying (m^2)
T	Time (s)
N_A	Mass flux or moisture removal rate per unit surface area of the material available for mass transfer of the bed (kg/m^2s)
C_s	Saturation moisture content (kg moisture /m^3 of dry air)
C	Moisture content of air stream (kg moisture /m^3 of dry air)
K	Mass transfer coefficient (m/s)
Y_s	Saturation moisture content (kg moisture /kg of dry air)
Y_{in}	Moisture content of gas stream in inlet air flow (kg moisture/kg of dry air)
Y	Moisture content of air stream (kg moisture /kg of dry air)
ρ_g	Dry air density (kg of dry air/ m^3 of dry air)
ρ_s	Solid density (kg/m^3)
a	Interface surface area per unit mass of bed (m^2/kg) *
V	Volume of the bed (m^3)
ε	Voidage
X	Moisture content of solid (kg moisture/kg of dry solid)
X_t	Moisture content of solid in dry basis at time t (kg moisture/kg of dry solid)
$X_{t+\Delta t}$	Moisture content of solid in dry basis at time t+ Δt (kg moisture/kg of dry solid)
G	Dry air flow rate (kg/s)
Sh	Sherwood number
Sc	Schmidt number
Re	Reynolds number
ρ	Density of medium at drying temperature (kg/m^3)
U	Superficial velocity (m/s)
d_p	Diameter of black pepper particle (m)
μ	Dynamic viscosity (kg/m.s)
P*	Standard pressure (N/m^2)
R	Gas constant (287.05 J/kg.K)

D	Diffusivity (m^2/s)
D^*	Diffusivity (cm^2/s)
M_a	Molecular weight of air
M_b	Molecular weight of moisture
P	Pressure (bar)
σ_{ab}	Collision diameter (Lennard-Jones parameter, angstrom)
Ω	Diffusion collision integral (dimensionless)