HEAT AND MASS TRANSFER ANALYSIS IN A SPOUTED BED DRYER COUPLED WITH A CYCLONE FOR PEPPER DRYING

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Degree of Doctor of Philosophy

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Thesis submitted in partial fulfilment of the requirements for the degree Doctor of Philosophy in Chemical and Process Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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Abstract

This thesis outlines the analysis of heat and mass transfer process of drying of black pepper in a spouted bed coupled with a cyclone separator. Black pepper is a widely used spice and is well-known for its pungency and aroma. Experiments conducted with wetted black pepper reveals that conventional spouted bed has the higher drying rate, higher moisture diffusivity, lower drying time and lower activation energy compared to those of spouted beds equipped with porous draft tube and non-porous draft tube. Therefore, the conventional spouted bed was used to conduct the experiments to achieve the objectives of the study since it was identified as the optimum configuration of the spouted bed.

Spouting behaviour of raw black pepper was studied in the conventional spouted bed. The minimum spouting velocities of particular bed heights at ambient temperature were determined. Minimum spouting velocity of raw black pepper in the conventional spouted bed versus static bed height was correlated to a power form of function and the exponent of static bed height was 0.67. The effect of operational conditions; drying air temperature, air velocity and static bed height on drying kinetics of raw black pepper was analysed. The higher values of moisture removal rates were achieved when the dryer was operated with moderately high air temperatures, high air flow rates and shallow beds. Drying kinetic data of raw black pepper in the conventional spouted bed shows only falling rate periods. Effective moisture diffusivity values increased with increasing drying air temperature. The highest effective moisture diffusivity of 2.03×10^{-10} m^2/s was obtained at air temperature of 75 $^{\circ}$C. Activation energy for drying of raw black pepper in conventional spouted bed was 38.59 kJ/kmol. Specific energy consumption was calculated and the specific energy consumption values increased with increasing air velocity and decreased gradually with increasing the static bed height.

Drying kinetic data obtained from experiments were fitted to five thin layer drying models. Results show that the Logarithmic model gives the best fit. In addition, four models were developed for black pepper drying in the conventional spouted bed by correlating drying constants and coefficients of Logarithmic model to stagnant bed height at specified temperatures; 45 $^{\circ}$C, 55 $^{\circ}$C, 65 $^{\circ}$C, and 75 $^{\circ}$C. Developed models can be used to estimate the drying time of black pepper in the conventional spouted bed dryer for given moisture reduction in the ranges of 0.14-0.22 m stagnant bed heights and in 2.37 m/s air velocity at specified temperatures.

Essential oil was extracted using hydro distillation from black pepper dried at five different drying conditions. The analysis of components by Gas Chromatography Mass Spectrometry technique shows that the black pepper essential oil comprised mainly monoterpenes and sesquiterpenes. Analysis of variance was conducted and the results show that variation of sesquiterpenes concentration in black pepper essential oil was significant while variations of monoterpenes, oxygenated terpenes and caryophyllene concentration were non-significant in black pepper essential oil with drying air temperature. In addition, the variation of essential oil yield is statistically significant with drying air temperatures. 65 $^{\circ}$C drying air temperature provides consistent quality essential oil with high percentage of caryophyllene and higher oil yield.

Heat transfer coefficients for black pepper drying in the conventional spouted dryer were estimated for different drying conditions of unsteady state drying of black pepper dried from initial moisture content to final moisture content of 15% dry basis. Heat transfer coefficient varied from 35-68 W/m^2K for the conditions under the investigation. Dimensional analysis

was carried out and important dimensionless numbers were identified. A correlation was developed for heat transfer process as a function of dimensionless groups namely Reynolds number, Nusselt number, Gukhman number and static bed height to particle diameter with 0.791 of coefficient of determination. Heat transfer coefficients predicted from the developed correlation show a good agreement with the experimentally determined heat transfer coefficients.

Keywords: Black pepper, spouted bed, drying kinetics, heat and mass transfer, essential oil

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LIST OF ABBREVIATIONS

ANOVA - Analysis of Variance

ASTA - American spice trade association

CFD - computational fluid dynamics

CSA - Canadian spice association

CSB - conventional spouted bed

ESA - Europe spice association

GC-MS - Gas Chromatography Mass Spectrometry

MR – Moisture ratio

NCPHT & VA - National Committee on Post-Harvest Technology and Value Addition

R^2 - Coefficient of determination

RMSE - Root mean square error

SBNPDT - Spouted bed equipped with non-porous draft tube

SBPDT - Spouted bed equipped with porous draft tube

SEC - Specific energy consumption

SLCARP -"Sri Lanka Council for Agricultural Research Policy"

SSE - Sum of square error

VSD - variable speed drive