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Finite Element Model for Heat and Mass Transfer in a Paste Convective Dryer under the Effect of Paste Local Heating.

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ABSTRACT

The Drying Process of pastes is the heart of the Food Industry, and its Design represents a state of Art that defines the size and power demand of Food facilities. The subject papers demonstrate a Finite Element Model that gives a good estimation of the required heat and Quantum of Mass extracted from the paste by convective air drying. The Model also introduces the method and analysis of bottom heating of dryer metallic belts by Jet Nozzles. The Results study the ambient temperature and relative humidity and the velocity of the air on the rates of heat and mass transfer

Introduction

The phrase "drying" often refers to the process of taking something dry. Drying is frequently required in a variety of industrial processes, particularly in the Food and paste process industries to remove moisture from a wet Paste and reach the final product, The Hot Air Drying, in which materials are subjected to a blast of hot air. Drying is typically achieved via thermal procedures, which entail the application of heat, most frequently through convection from an air current. Convective drying of solid materials involves two simultaneous processes: the transfer of moisture from the solid and the transfer of energy from the local environment to the dryer. It is possible to think of this unit operation as a simultaneous heat and mass transfer operation.

The Length of the Dryer and the quantum of Heat are two of the Main Factors that affect the design. In the following Study, an Engineering Equation Solver Model will be established, and this Model will Clearly Identify the Main Parameters that affect the Performance and Length of the Dryer and could be a Tool that Helps designers to conduct a numerical estimation for the heat dryer.

Methodology and Mathematical Model

The approach is to establish a finite element module that represents the dryer and heat and mass transfer process the model calculates the quantum of mass and heat transfer and the outlet temperature level & and dryness at the outlet this is studied against the change of inlet velocity of air and the temperature of air.

The Model has a new addition which is a unique modification for this model that is a change of the paste temperature due to the bottom heating of the metallic dryer belt.

The Model brief is as follows: -

δQ

δm_v

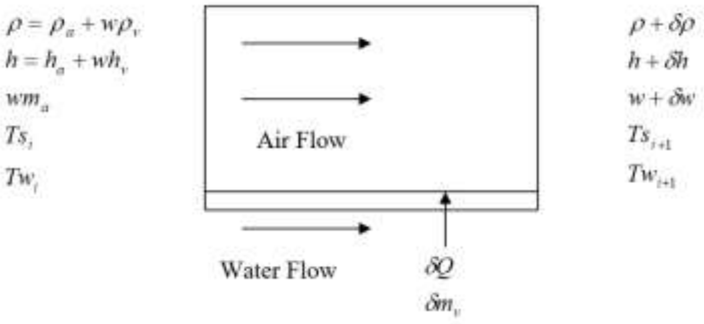


Fig-1

The Governing Equations for The Finite Element

As Wet Sheet Drying contains Cellulose water mixture of Water Content about three times the cellulose the Following procedure is followed

Heat Transfer Between the Air and The Water:

Equation Set 1

$$dQ = Ud(\Delta T)dA$$

$$Q = U\Delta T_{lm}dA$$

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln(\frac{\Delta T_2}{\Delta T_1})}$$

$$\Delta T_1 = Tw_i - Ta_i$$

$$\Delta T_2 = Tw_{i+1} - Ta_{i+1}$$

$$\frac{1}{U} = \frac{1}{hw} + \frac{1}{ha}$$

$$Q = MwaterCp_w(Tw_i - Tw_{i+1})$$

$$Q = MairCp_a(Ta_{i+1} - Ta_i)$$

$$Tw_i = Const(40 - 50^0 C)$$

Heat and Mass Transfer Between Wet Sheet and Air:

Equation Set 2

$$\delta m = \delta Ahm.(\rho_{vs} - \rho_{va})$$

$$\delta Q = dA.ha.(Ts - Ta)$$

$$\delta w = \frac{\delta m}{Mair}$$

$$\delta h = \frac{(\delta Q + \delta m.Latentheat)}{Mair}$$

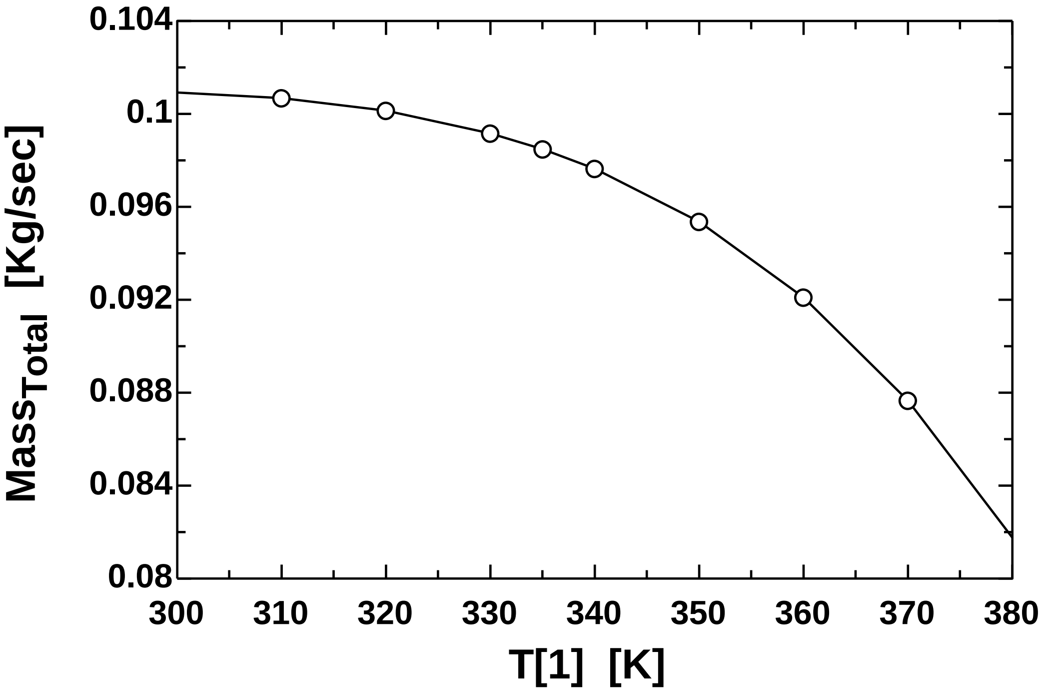
$$w_{i+1} = w_i + \delta w$$

$$h_{i+1} = h_i + \delta h$$

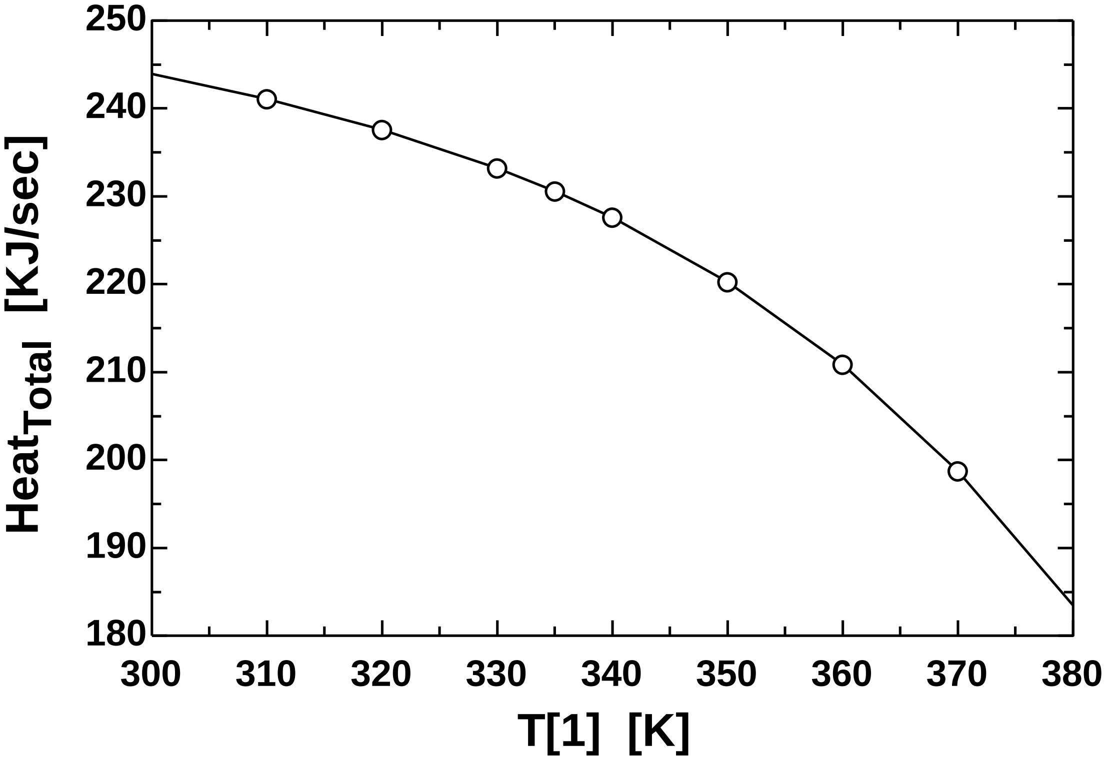
Results

The Results Include the following discussions

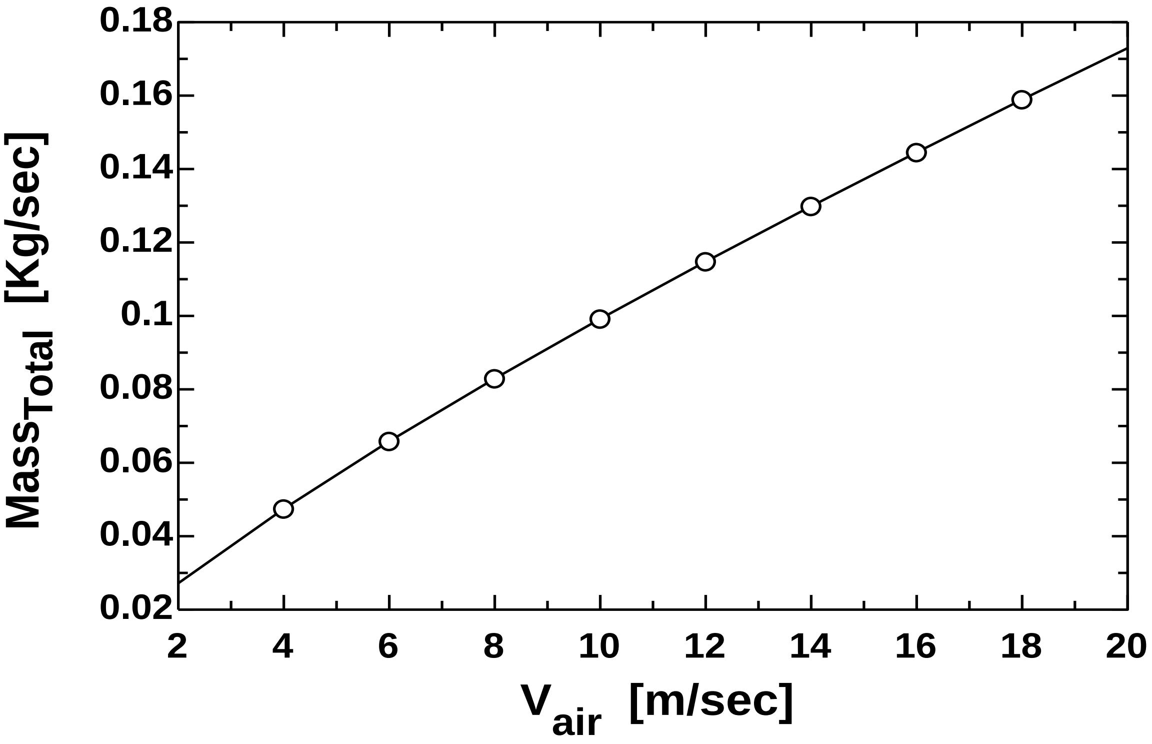
- Fig-2 The Effect Of Changing The Inlet air Temperature on Evaporated Mass of Water from The Cellulose Water Mixture The Effect Of Changing The Inlet air Temperature on Evaporated Mass of Water from The Cellulose Water Mixture Air Velocity 10 m/sec Cellulose Surface Temp 365 K Initial Relative Humidity 0.1



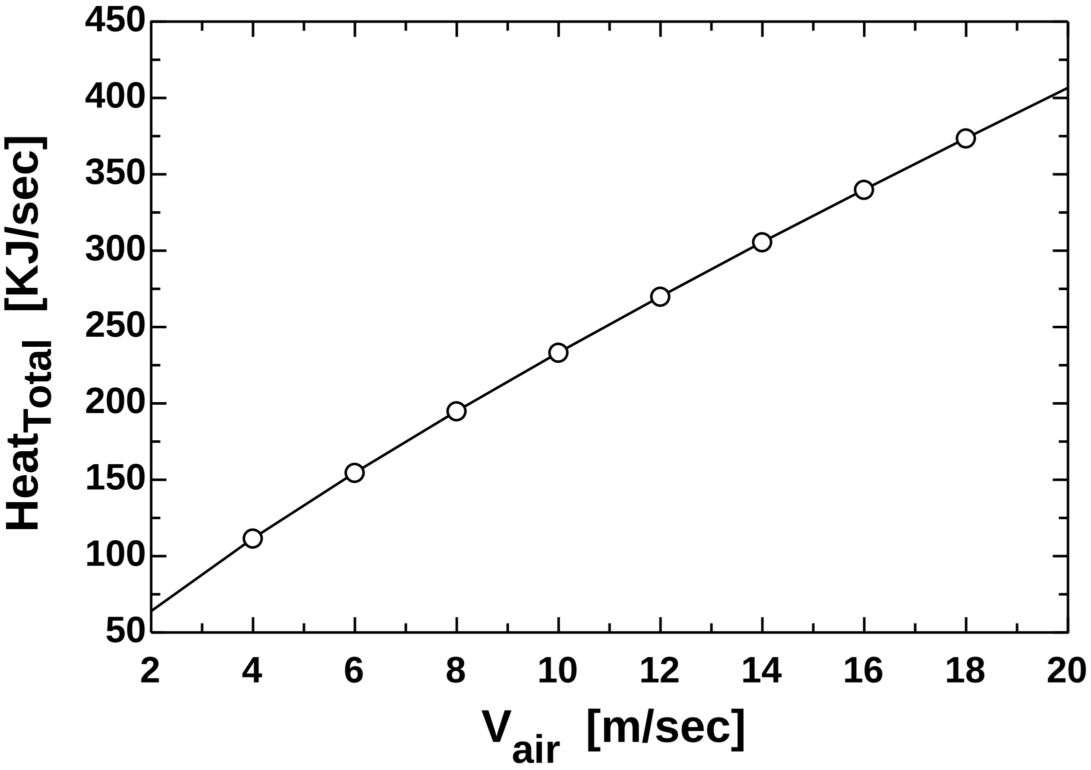
- Fig-3 The Effect of changing the Inlet Air Temperature on the Required Heat rate Velocity 10 m/sec Cellulose Surface Temp 365 K Initial Relative Humidity 0.1



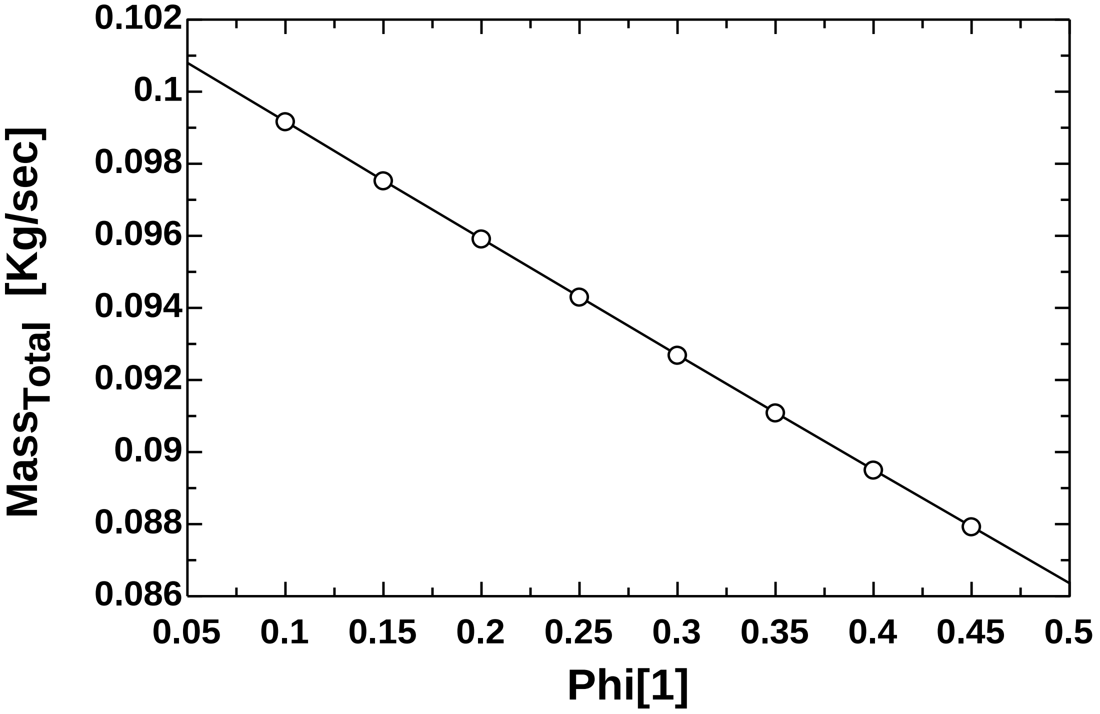
- Fig-4 The Effect Of changing The Inlet air Velocity on the Evaporated Mass of water from The Cellulose Water Mixture Air inlet temperature 330K Cellulose Surface Temp 365 K Initial Relative Humidity 0.1

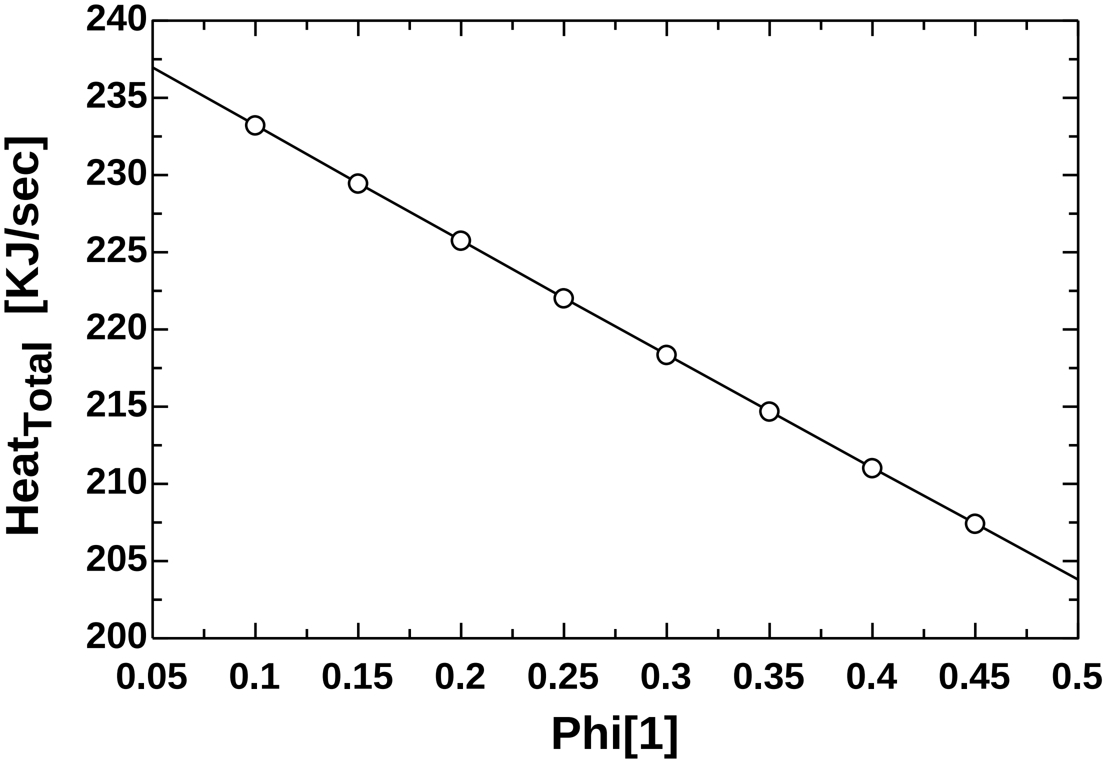


- Fig 5 The Effect of Changing the Inlet Air Velocity on the required Heat rate with Air Inlet temperature of 330 K, cellulose surface Temperature of 365 Initial relative humidity of 0.1

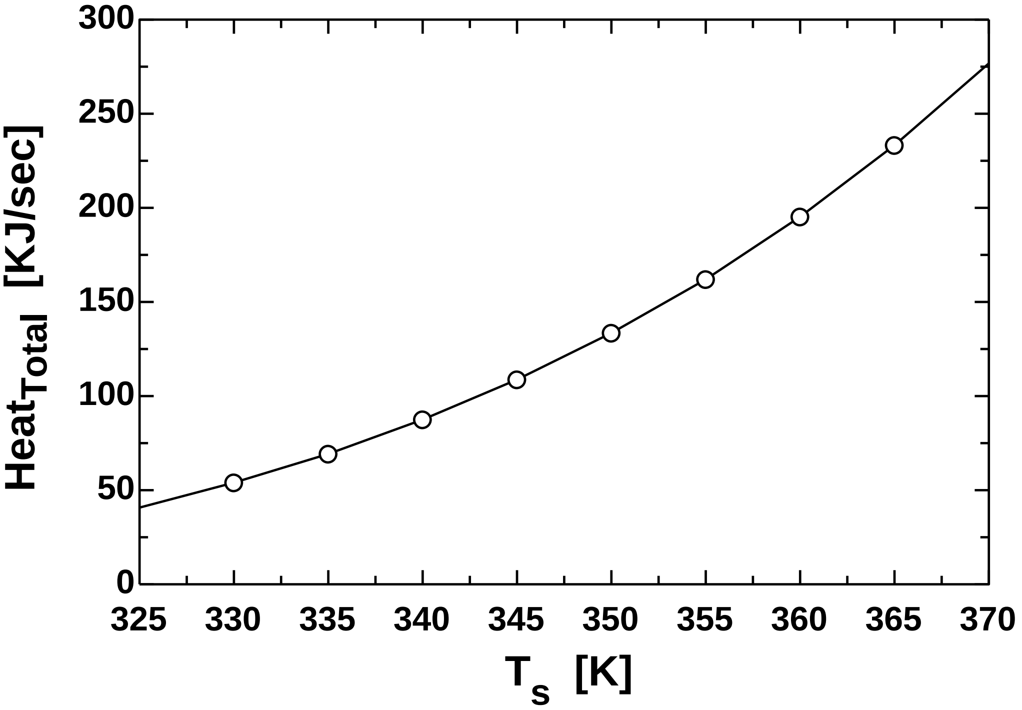


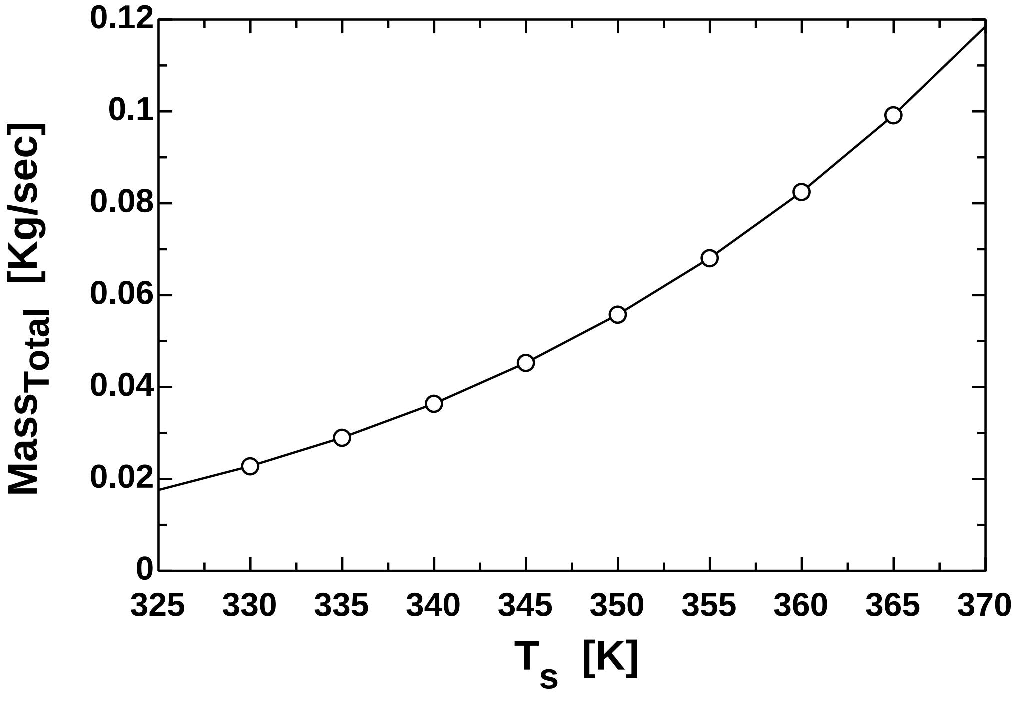
- Fi 6&7 The Effect of Changing the Inlet Air RH on final RH Air the Mass Evaporated Required Heat Rate inlet temperature 330K Cellulose Surface Temp 365 K Initial Velocity 10 m/sec



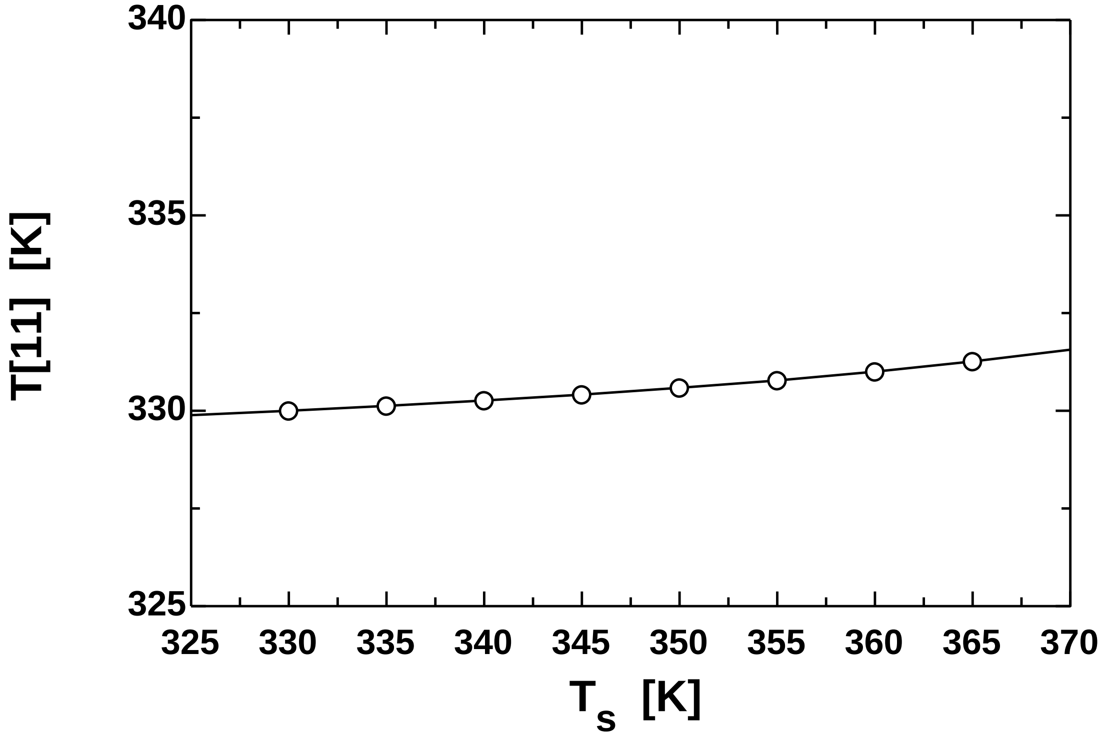


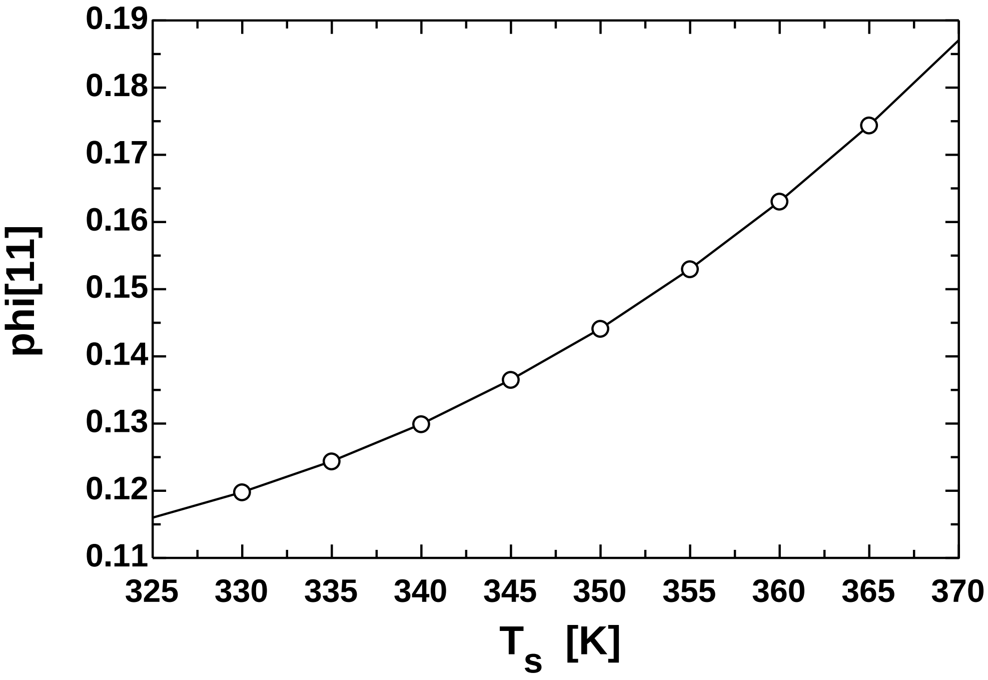
- Fig 8&9 The Effect of Changing the Cellulose Surface Temp. on the Required Heat Rate, Mass Evaporated, at inlet temperature 330K Initial RH 0.1 Initial Velocity 10 m/se





- Fig 10&11 The Effect of Changing the Cellulose Surface Temp. on outlet air Temp, and final RH Air inlet temperature 330K Initial RH 0.1 Initial Velocity 10 m/se





Conclusion

The Analysis Indicates that the Increase of inlet ambient air temperature includes an increase in Heat and mass transfer and the Increase in Inlet relative humidity decreases mainly the mass transfer and level of drying. The increase in the air velocity is associated with increased mass transfer but the cost of power is a factor also. The Increase in the paste temperature through steam jets below the dryer will have a significant effect on the mass transfer with chances of better drying through compact dryers which decreases the factory size in a remarkable way. Finally, The effect of paste temperature on the outlet relative humidity is remarkable as the air capacity to carry & dry more water had increased .

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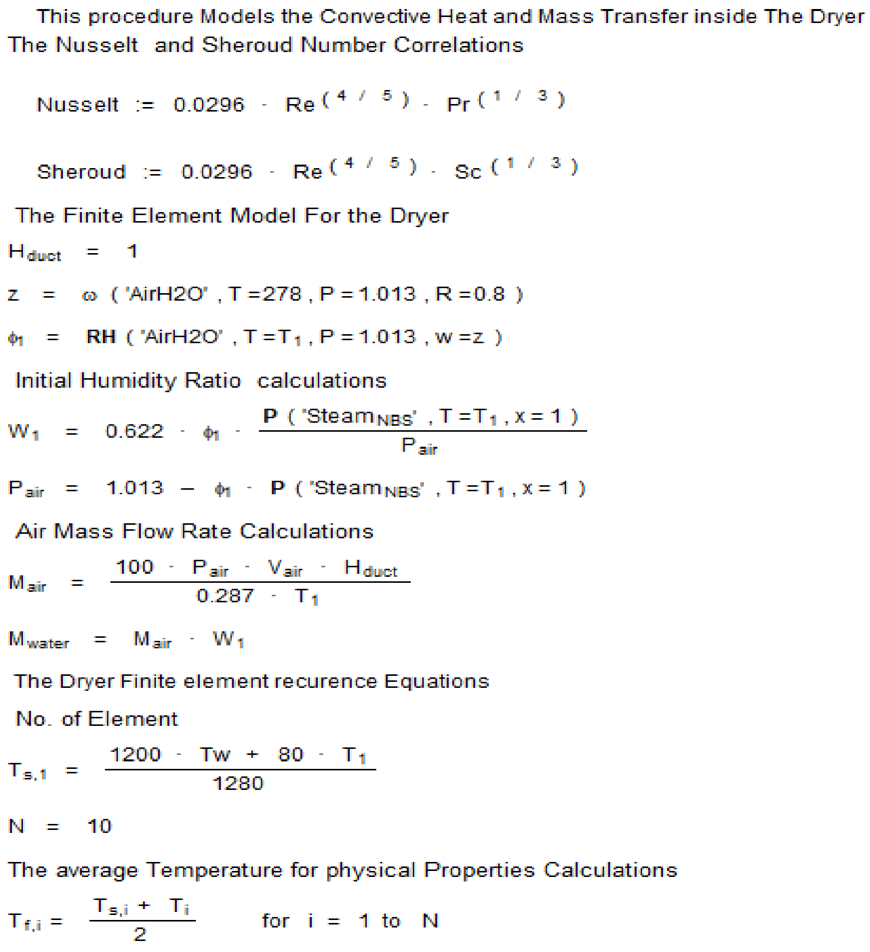
APPENDIX 1 The EES Formatted Equations are as follows



This procedure Models the Convective Heat and Mass Transfer inside The Dryer

The Nusselt and Sheroud Number Correlations

$$Nusselt := 0.0296 \cdot Re^{(4/5)} \cdot Pr^{(1/3)}$$

$$Sheroud := 0.0296 \cdot Re^{(4/5)} \cdot Sc^{(1/3)}$$

The Finite Element Model For the Dryer

$$H_{duct} = 1$$

$$z = \omega\ (\text{'AirH2O'}, T=278, P=1.013, R=0.8)$$

$$\phi_1 = \mathbf{RH}\ (\text{'AirH2O'}, T=T_1, P=1.013, w=z)$$

Initial Humidity Ratio calculations

$$W_1 = 0.622 \cdot \phi_1 \cdot \frac{\mathbf{P}\ (\text{'Steam}_{NBS}\text{'}, T=T_1, x=1)}{P_{air}}$$

$$P_{air} = 1.013 - \phi_1 \cdot \mathbf{P}\ (\text{'Steam}_{NBS}\text{'}, T=T_1, x=1)$$

Air Mass Flow Rate Calculations

$$M_{air} = \frac{100 \cdot P_{air} \cdot V_{air} \cdot H_{duct}}{0.287 \cdot T_1}$$

$$M_{water} = M_{air} \cdot W_1$$

The Dryer Finite element recurence Equations

No. of Element

$$T_{s,1} = \frac{1200 \cdot Tw + 80 \cdot T_1}{1280}$$

$$N = 10$$

The average Temperature for physical Properties Calculations

$$T_{f,i} = \frac{T_{s,i} + T_i}{2} \quad \text{for } i = 1 \text{ to } N$$

The Local Density , Vescosity, Prandtl, Diffusivity & Schmidit , Reynolds ,Nusselt and Sheroud Numbers

$$Row_i = \rho(\text{'Water'}, T=T_i, x=1) \cdot \phi_i \quad \text{for } i = 1 \text{ to } N$$

$$\nu_i = \frac{\mathbf{Visc}(\text{'AirH2O'}, T=T_{f,i}\ P=1.013, w=W_i)}{\rho(\text{'AirH2O'}, T=T_{f,i}\ P=1.013, w=W_i)} \quad \text{for } i = 1 \text{ to } N$$

$$Pr_i = \mathbf{Cp}(\text{'AirH2O'}, T=T_{f,i}\ P=1.013, w=W_i) \cdot 1000 \cdot \frac{\mathbf{Visc}(\text{'AirH2O'}, T=T_{f,i}\ P=1.013, w=W_i)}{\mathbf{k}(\text{'AirH2O'}, T=T_{f,i}\ P=1.013, w=W_i)} \quad \text{for } i = 1 \text{ to } N$$

$$D_{ab,i} = 0.000026 \cdot \left[\frac{T_{f,i}}{298}\right]^{1.5} \quad \text{for } i = 1 \text{ to } N$$

$$Sc_i = \frac{\nu_i}{D_{ab,i}} \quad \text{for } i = 1 \text{ to } N$$

$$X_{L,i} = i - 0.5 \quad \text{for } i = 1 \text{ to } N$$

$$Re_i = V_{air} \cdot \frac{X_{L,i}}{\nu_i} \quad \text{for } i = 1 \text{ to } N$$

Call **Nuslt** (Re_i, Pr_i : $Nusselt_i$) for $i = 1$ to N

Call **Shrud** (Re_i, Sc_i : $Sheroud_i$) for $i = 1$ to N

Local Heat and Mass Transfer

$$h_{m,i} = Sheroud_i \cdot \frac{D_{ab,i}}{X_{L,i}} \quad \text{for } i = 1 \text{ to } N$$

$$h_i = Nusselt_i \cdot \frac{\mathbf{k}(\text{'Air'}, T=T_{f,i})}{1000 \cdot X_{L,i}} \quad \text{for } i = 1 \text{ to } N$$

Local Sensible Heat, Latent Heat Due to Evaporation and Total Heat

$$Q_{s,i} = h_i \cdot (T_{s,i} - T_i) \quad \text{for } i = 1 \text{ to } N$$

$$Q_{evap,i} = M_i \cdot (\mathbf{h}(\text{'Water'}, T=T_{s,i}, x=1) - \mathbf{h}(\text{'Water'}, T=T_{s,i}, x=0)) \quad \text{for } i = 1 \text{ to } N$$

$$Heat_i = Q_{s,i} + Q_{evap,i} \quad \text{for } i = 1 \text{ to } N$$

Local Mass Transfer and Humidity Ratio

$$M_i = h_{m,i} \cdot (\rho(\text{'Water'}, T=T_{s,i}, x=1) - Row_i) \quad \text{for } i = 1 \text{ to } N$$

$$W_{i+1} = W_i + \frac{M_i}{M_{air}} \quad \text{for } i = 1 \text{ to } N$$

Local Air Enthalpy and Vapor Enthalpy

Local Air Enthalpy and Vapor Enthalpy

$$h_{air,i} = 2501 \cdot W_i + (1.005 + 1.88 \cdot W_i) \cdot (T_i - 273) \quad \text{for } i = 1 \text{ to } N$$

$$h_{v,i} = \frac{M_i}{M_{air}} \cdot (2501 + 1.88 \cdot (T_{s,i} - 273)) \quad \text{for } i = 1 \text{ to } N$$

NEXT STEP TOTAL ENTHALPY, TEMPERATURE AND RELATIVE HUMIDITY

$$E_{i+1} = h_{v,i} + h_{air,i} + \frac{Q_{s,i}}{M_{air}} \quad \text{for } i = 1 \text{ to } N$$

$$T_{i+1} = \frac{E_{i+1} - 2501 \cdot W_{i+1}}{1.005 + 1.88 \cdot W_{i+1}} + 273 \quad \text{for } i = 1 \text{ to } N$$

$$\phi_{i+1} = \frac{1.0133 \cdot W_{i+1}}{(0.622 + W_{i+1}) \cdot \mathbf{P}(\text{'Steam}_{NBS}\text{'}, T=T_{i+1}, x=1)} \quad \text{for } i = 1 \text{ to } N$$

$$T_{s,i+1} = \frac{1200 \cdot Tw + 80 \cdot T_{i+1}}{1280} \quad \text{for } i = 1 \text{ to } N$$

Summation for the Liberated MASS and the Total USED HEAD (SENSIBL and LATENT)

$$Heat_{Total} = \sum_{i=1}^{N} (Heat_i)$$

$$Mass_{Total} = 3600 \cdot \sum_{i=1}^{N} (M_i)$$