Study on Batch Drying

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Objective :

- To understand the importance of a rate of drying curve in determining the drying time of a solid substance.
- To understand the difference between free moisture and bound moisture.
- To identify the factors that affect drying time.

Theory:

Drying is an important unit operation in Chemical Engineering. During a drying operation, a solvent that is not chemically bonded to a solid is removed by blowing a hot gas over or through the solid. Examples of its use are the drying of washed and centrifuged sugar crystalline solids as the final stage to get the finished product for packing or the drying of a natural product such as wood. The fundamental nature of the drying process is the removal of volatile substances (mainly moisture) from the mixture to yield a solid product. In general, drying is accomplished by thermal techniques and thus involves the application of heat, most commonly by convection from the current of air. Throughout the convective drying of solid materials, two processes occur simultaneously namely, transfer of energy from the local environment in the dryer and transfer of moisture from within the solid. Therefore, this unit operation may be considered as simultaneous heat and mass transfer operation.Drying is a diffusional process in which the transfer of moisture to the surrounding medium takes place by the evaporation of surface moisture, as soon as some of the surface moisture vaporizes, more moisture is transported from the interior of the solid to its surface.

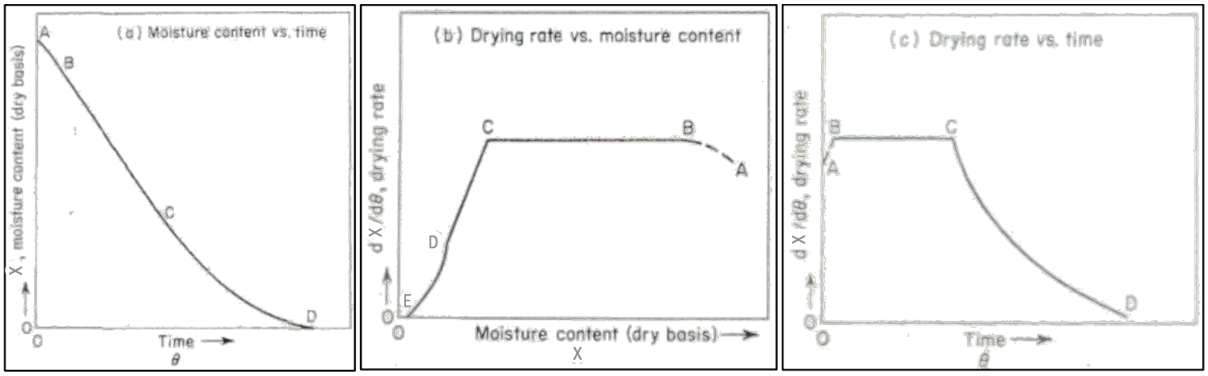
Applications of Drying:

- Preservation of drug products
- Improve handling, characteristics
- Reduction in transportation cost
- Purification of crystalline product
- Prevention of corrosion

$$\text{Moisture content, } X = \frac{\text{kg of moisture present in solid}}{\text{kg of dry solid}}$$

$$\text{Drying Rate, } N_c = -\frac{S}{A}\frac{dX}{d\theta}$$

S is weight of dry solid
A is drying surface area
θ is time



Regimes of the Drying Process as labelled in the curve:

- A-B: This section of the curve represents a warming up period, when the hot air used for drying is heating the surface of the wet solid.
- B-C: This region is known as the constant rate period. In this region, the surface of the solid is saturated with water and the rate at which water evaporates is controlled by the rate of heat transfer to the surface of the solid. Drying proceeds by diffusion of water from the solid surface, across a stagnant air film and into the surroundings. The rate of mass transfer of water from the solid matches the rate of heat transferred from the surroundings. The process is the same as evaporation from a pool of liquid. The constant rate period ends at point C, which is known as the critical moisture content (CMC).
- C-D: This region is known as the falling rate period. It starts at the critical moisture content and is split into two zones. The first zone is called the unsaturated surface drying zone and as its name implies it is like the constant rate period but not all the surface is saturated. As drying proceeds, the surface of the solid becomes completely unsaturated. The movement of moisture from within the solid to the surface then controls the rate of drying. This can be a very slow process.

Importance of the rate-of-drying curve:

- If the initial and final moisture contents for the solid are both greater than the critical moisture content, then drying will be a fast operation whose speed can be controlled by external factors such as air flow rate and air temperature.
- If the initial moisture content is greater than the CMC but the final moisture content is less than the CMC, then drying could be an extremely slow process and the rate will depend heavily on the nature of the solid and cannot be altered by external variables such as air flow and temperature.

Experimental Setup

The set-up consists of drying chamber, blower, air-heater, wet-bulb and dry bulb thermometers, digital weighing balance and other accessories.

Experimental Procedure:

1. Take empty weight of a petridish.
2. Take some (say 50 gm)bone drysand in this petridish.
3. Add water(say 15 cc)to this sandas specified by instructor.
4. Switch on the blower and the air heater. Maintain a temperature of 45ºC in the drying chamber. The digital thermometer display indicates the chamber temperature.
5. At 45ºC, put the wet sand in the drying chamber and take the loss in weight at every two minutes interval till the weight is constant. Measure the air velocity and ambient air wet and dry bulb temperatures.

Experimental Data and Calculation

- Weight of empty Petri dish = 30.71 g, Weight of dry sand = 50 g
- Amount of water = 10 ml
- Initial weight of wet sand = 90.02 g
- Temperature = 450C
- Air flow rate = 7 m/s
- Diameter of the Petri dish = 7 cm
- Sample Calculation: For time (θ) = 3min

At time $t = 0$ min, wt. of wet sand (with Petri dish (g)) = 90.02g

$t = 3$ min, wt. of wet sand (with Petri dish (g)) = 89.73g

$$\text{Moisture content } (x) = \frac{89.73 - (50 + 30.71)}{50} = 0.1804$$

$$\text{Moisture Content Rate} = \left(\frac{0.1804 - 0.1862}{30\ \text{min} - 0\ \text{min}}\right) = -0.0019333$$

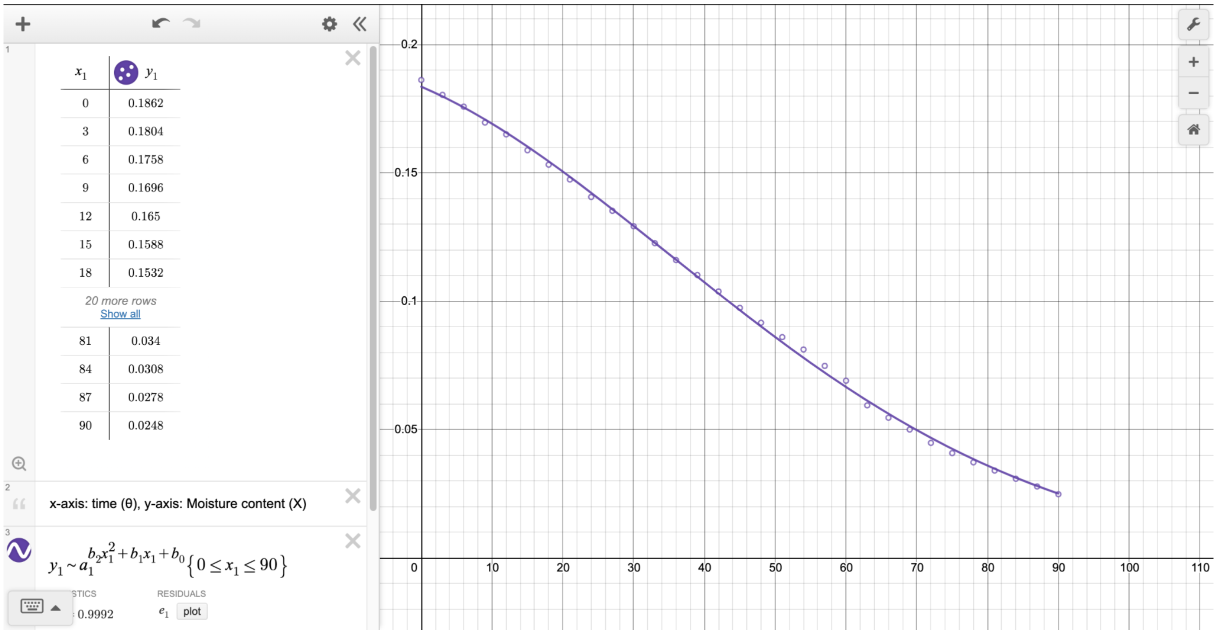
$$\text{Drying Rate} = \left(\frac{-50g}{\frac{\pi}{4}\ (7\ cm^2)}\right)(-0.0019333) = 0.002512\ g/cm^2\text{-min}$$

$$= 0.00042\ kg/m^2s$$

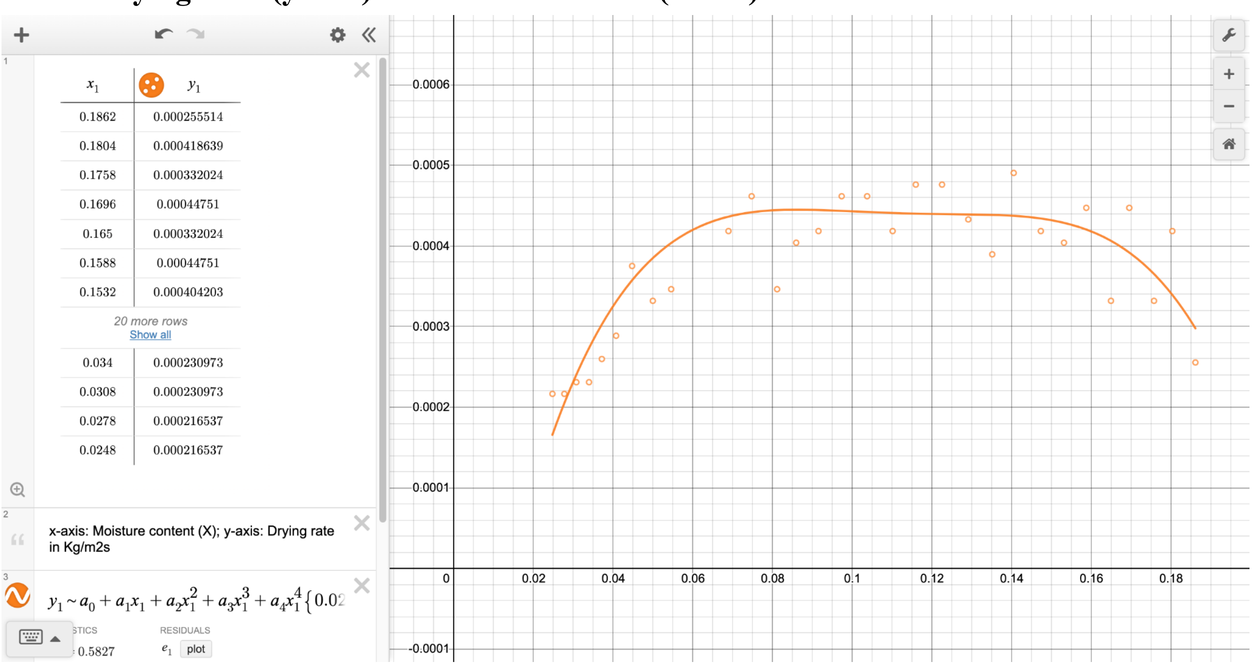
Time θ,(min)	**Weight of wet sand with Petri dish (gram)**	**X,moisture content**	**Moisture content ate, dX/d θ(1/min)**	**drying rate (kg/m2.s)**
0	90.02	0.1862		
3	89.73	0.1804	-0.001933333333	0.0004184753641
6	89.5	0.1758	-0.001533333333	0.0003318942543
9	89.19	0.1696	-0.002066666667	0.000447335734
12	88.96	0.165	-0.001533333333	0.0003318942543
15	88.65	0.1588	-0.002066666667	0.000447335734
18	88.37	0.1532	-0.001866666667	0.0004040451791
21	88.08	0.1474	-0.001933333333	0.0004184753641
24	87.74	0.1406	-0.002266666667	0.0004906262889
27	87.47	0.1352	-0.0018	0.0003896149942
30	87.17	0.1292	-0.002	0.0004329055491
33	86.84	0.1226	-0.0022	0.000476196104
36	86.51	0.116	-0.0022	0.000476196104
39	86.22	0.1102	-0.001933333333	0.0004184753641
42	85.9	0.1038	-0.002133333333	0.000461765919
45	85.58	0.0974	-0.002133333333	0.000461765919
48	85.29	0.0916	-0.001933333333	0.0004184753641
51	85.01	0.086	-0.001866666667	0.0004040451791
54	84.77	0.0812	-0.0016	0.0003463244392
57	84.45	0.0748	-0.002133333333	0.000461765919
60	84.16	0.069	-0.001933333333	0.0004184753641
63	83.68	0.0594	-0.0032	0.0006926488785
66	83.44	0.0546	-0.0016	0.0003463244392
69	83.21	0.05	-0.001533333333	0.0003318942543
72	82.95	0.0448	-0.001733333333	0.0003751848092
75	82.75	0.0408	-0.001333333333	0.0002886036994
78	82.57	0.0372	-0.0012	0.0002597433294
81	82.41	0.034	-0.001066666667	0.0002308829595
84	82.25	0.0308	-0.001066666667	0.0002308829595
87	82.1	0.0278	-0.001	0.0002164527745
90	81.95	0.0248	-0.001	0.0002164527745

Plots & Calculations

Plot of Moisture content (y-axis) vs time (x-axis):



Plot of Drying Rate (y-axis) vs Moisture content (x-axis):



Discussion

- Moisture content vs time plot fits perfectly for the theoretical expectation. Drying Rate plot's data set is much dispersed. Interpolation gives a curve close to the theoretical expectation with a slight deviation from the linear behavior. Final phase from D to E requires further operation of the experiment.
- A better data set with less deviation will have a horizontal line for BC-regime and linear profile for CD-regime. If few particles are relatively lighter, then they may affect the actual weight of the sand that we measure to be as remained time-to-time.
- Drying time depends on,
  - Temperature
  - Humidity
  - Nature of solid
  - Flow rate of drying gas.
  - Saturation conditions (Temperatures and Pressure)
- From the Drying rate plot, we can understand that during the constant rate drying period, the moisture evaporated per unit time per unit area of drying surface remains constant and in falling rate drying period (after critical moisture content point), the amount of moisture evaporated per unit time per unit area of drying surface continuously decreases.
- If we want to infer the results from this experiment and extrapolate them at large scale, then we need to ensure, the sand particles follow similar configurations those which prevail at full scale plants, importantly, Exposed-to-Non-exposed area ration, particle geometry and transfer coefficients.
- As during the constant rate period, rate of heat transfer to saturated solid surface is matched by rate of mass transfer, we can equate the rates to moisture content rate to find the heat and mass transfer coefficients (assuming we know the surface temperature of air stream and partial pressure of water in air).

Results and Conclusion:

- Critical moisture content is 0.05.
- Terms for designing drying system:
  - Bound Moisture: Moisture content of a substance which exerts as equilibrium vapor pressure less than of the pure liquid at the same temperature.
  - Unbound Moisture: Moisture content of the solid which externs an equilibrium vapor pressure equal to that of pure liquid at the given temperature.
  - Free Moisture: The moisture content of solid in excess of the equilibrium moisture content. During drying, only free moisture can be evaporated. Free moisture content of a solid depends upon the vapor concentration in the gas.
- Drying Rate curve helps us to estimate the time and rate of drying operation pre- matured to the experiment, as it distinguishes the regimes of convection and diffusion.

DRYING OF GRANULAR SOLID IN A ROTARY DRIER

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Objective

- To determine the solids hold-up in the drier
- To determine the extent of drying achieved for a wet solid for different drier inclinations
- To estimate the air and heat requirements and compare the results with theoretical calculations.

Theory

A moisture balance gives:

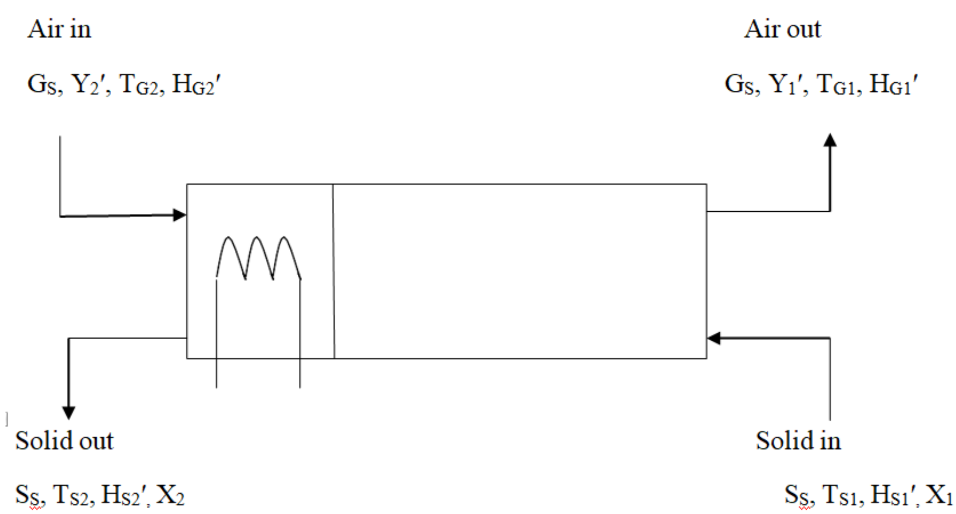
$$S_S X_1 + G_S Y_2' = S_S X_2 + G_S Y_1'$$

$$\text{Or, } G_S (Y_1' - Y_2') = S_S (X_1 - X_2) \qquad \text{.... (1)}$$

Since the heat input by the heater is not known, the enthalpy balance equations are

expressed as Enthalpy input = $G_S H_{G2}' + Q_{HEATER} + S_S H_{S1}'$

Enthalpy output = $G_S H_{G1}' + S_S H_{S2}'$ + Heat loss from drier



The value of heat input by the heater is calculated on the assumption of insignificant heat loss from the surface of the drier.

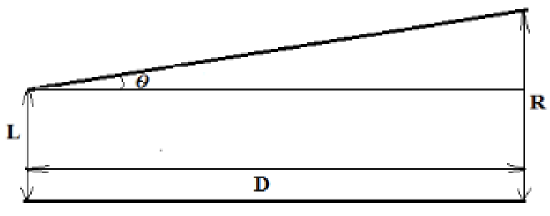
$$Q_{HEATER} = G_S (H_{G1}' - H_{G2}') + S_S (H_{S2}' - H_{S1}') \qquad \text{.... (2)}$$

Experimental setup:

Procedure

- Prepare a sample of sand (about 5 kg) containing the specified (say 4%)moisture(wet basis)
- Atmospheric air-heater at the ambient temperatureandhumidity will be heated by air-heater to about 900C.
- Put on the blower and when the heatertemp is 900C,feed one kilogram of wet sand into hopper at a constant rate.
- Note the temp of wet solid before feedingand the exit air temperature leaving the drier.The rate of product leaving the drierand the moisture content of the dried solidare determined.Determine the inclination of the drier.
- Collect the sample of dried product in a watch glass and put it in air oven at 1050to 1100C for one hour to obtain bone dry sample.
- Estimate the weight of sand before and after drying in oven to determine the moisture content of the product.Repeat the experiment for threedifferent inclinations of the drier.
- Experimental Data and observational data

Wt. of sand taken = 1000 g
Wt. of water mixed = 40 g
Wt. of the tray = 773 g
Diameter of the drier = 0.3048 m



1) L = 49.5 cm, R = 66 cm, D = 181 cm
2) L = 52 cm, R = 66 cm, D = 181 cm
3) L = 554.5 cm, R = 66 cm, D = 181 cm

$\theta = \sin^{-1}[(R-L)/D] = \sin^{-1}[(66-49.5)/181] = 5.23^{o}$

Table 1: Experimental data for drying in rotary drier

Sample No.	**Inclination (°)**	**Sample weight (kg)**		**Sample temp. (°C)**		**Air Velocity (m/s)**	**Air Temperature (°C)**	**Residence time (sec)**
		Initial	**Final**	**Initial**	**Final**			
1	5.23	1.035	0.997	26	32	10.75	58	202
2	4.44	1.038	0.998	27	33	10.75	59	272
3	3.34	1.038	0.996	27	34	10.75	57	314

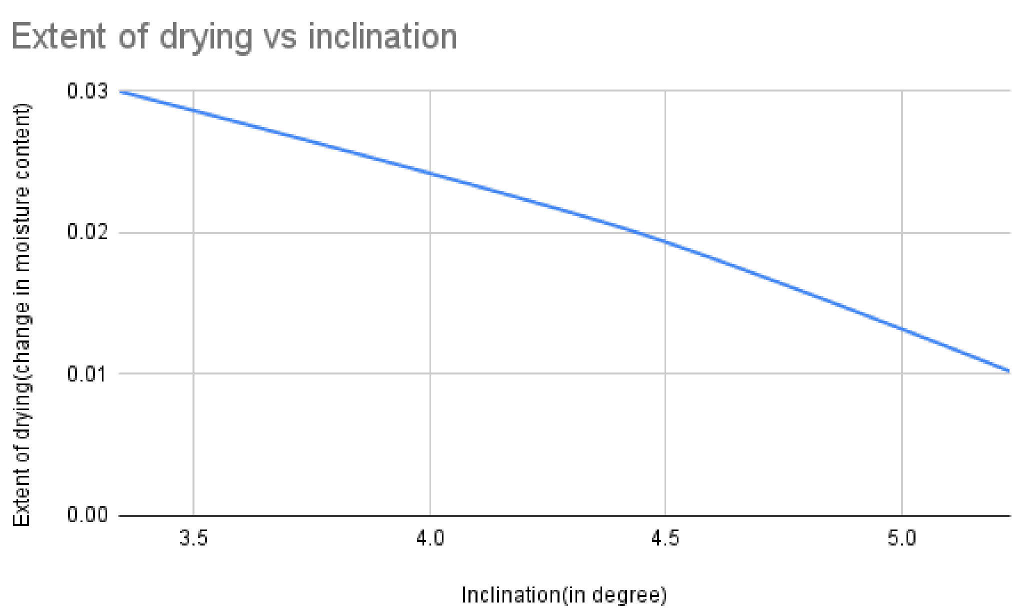
Table 2: Experimental data for batch drying

Sample No.	**Inclination (o)**	**Sample weight (g)**		**Initial Moisture content**	**Moisture content (g/g dry sand)**	**Extent of drying**
		Initial	Final			
1	5.23	50	48.5	0.0402	0.03	0.0102
2	4.44	50	49	0.04	0.02	0.02
3	3.34	50	49.5	0.04	0.01	0.03

Sample No.	Inclination (º)	Solid Hold-up (%)	Final Moisture Content (g/g dry sand)	Moisture Reduction (%)	QHeater (kJ/s)
1	5.23	0.98	0.03	25	20.66
2	4.44	1.93	0.02	50	20.79
3	3.34	2.89	0.01	75	20.93

<u>Plots</u>

Extent of drying vs inclination



Sample calculation:

Area of drier $= \pi D^2/4 = 3.14 \times \frac{0.3048^2}{4} = 0.0729\ m^2$

$$G_2 = \frac{10.75 \times 29 \times 0.0729 \times 273}{0.0244 \times 331} = 0.8868\ kg/s$$

Inlet Air : DBT $= 28°C$, WBT $= 26°C$

Humidity, $Y_2' = 0.02$ kg/kg dry air

$$G_s = \frac{G_2}{(1 + Y_2')} = 0.82\ \text{kg dry air/s}$$

$$S_s = \left[\frac{(1.035 + 0.997)}{2}\right] \times \frac{1}{202} = 5.029 \times 10^{-3}\ kg/s$$

$x_1 = 0.04$, $x_2 = 0.03$

$$Y_1' = Y_2' + (S_s / G_s)(X_1 - X_2) = 0.02006$$

$C_{p,sand} = 0.83\ kJ/kg\,K$, $C_{p,water} = 4.186\ kJ/kg\,K$

$$H_{s_1} = (0.83 + 0.04 \times 4.186) \times 26$$
$$= 25.93\ kJ/kg$$

$$H_{s_2} = (0.83 + 0.03 \times 4.186) \times 32$$
$$= 30.58\ kJ/kg$$

$$H_{G_2}' = (1.005 + 1.884\, Y_2') \times 34 + 2502\, Y_2' = 85.5\ kJ/kg$$
$$H_{G_1}' = (1.005 + 1.884\, Y_1') \times 58 + 2502\, Y_1' = 110.67\ kJ/kg$$

$$Q_{heater} = G_s (H_{G_1}' - H_{G_2}') + S_s (H_{s_2}' - H_{s_1}')$$
$$= 20.66\ kJ/s$$

<u>Results and Discussion</u>

Moisture content of the product increases with the increase in the angle of inclination. This is because with increase in the inclination angle, the residence time decreases and reduced contact time between the air and solid leads to less mass transfer. Hence the product moisture content increases.Power requirement to execute the operation increases with decrease in the inclination angle. This is because in case of less inclination angle more amount of vapour goes to the air and more energy is required to carry out this operation.With more inclination angle, the gravitational force along the slope is more hence the hold up time is less and hence the extent of drying is less. If the inclination angle is less, the gravitational force along the slope is less hence the hold up time is more and hence the extent of drying is more.Solid holdup decreases with increase in the inclination angle as with increase in inclination angle the residence time decreases so the extent of drying.