Optimization of Spray Dryer through Dehumidification

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***Abstract*- Spray dryer requires a large amount of energy for drying feed with low solid concentration. Thus in order to save energy exhaust air stream is recycled to recover the heat inside it. That is done by mixing recycled stream with the fresh air stream. This mixed stream is now heated at the required temperature to be able to evaporate the water. Only recycling of exhaust air is sufficient for the slurry feed with high solid content. But for the low solid content slurry feed, the exhaust air is containing high moisture content in it. Thus the absorption capacity of the mixed stream decreases by recycling exhaust air. This leads to high energy consumption in order to reach the required inlet drying air temperature thereby decreasing the efficiency. To overcome this problem of high moisture content in the exhaust air, it can be dehumidified. In dehumidification the temperature of the air raises thus requiring less energy for heating. Also Low moisture in the inlet drying air will provide greater driving force for drying.**

***Keywords*- Energy balance, Dehumidification, Energy recovery, Simulation**

I. Introduction

Spray drying is a highly heat consuming technique. But also it is an unavoidable method to be used for obtaining powder form products. It is carried out by contacting drying air with the fine droplets of the feed to evaporate the water. This contact takes place only for few seconds only. Thus the absorption capacity of the drying air must be very high in order to remove the required moisture during the contact time. Otherwise problems like wall deposition and agglomeration takes place there by reducing the product quality.

Product quality and energy efficiency are like the two sides of the coins. Quality of the product depends on the parameters like feed flowrate, inlet air flowrate and inlet moisture content of the air. Thus if we want to dry the feed with the air of higher moisture content than the inlet air flowrate has to be high and feed flowrate has to be low to achieve the desired product quality. This high inlet air flowrate will consume higher amount of energy to heat it up to the required drying temperature. On the other side if inlet air with lesser moisture content is used and if the feed flowrate is kept constant, then to achieve the product of same quality the amount of inlet drying air required will be lower. Therefore energy will be saved if we will decrease the inlet moisture content of the drying air. Thus in this way both high quality and high efficiency can be achieved.

While recycling the exhaust air in the spray dryer, no doubt efficiency increases but the inlet moisture content of drying air is also high, this compels to keep the feed flowrate lower. Thus production rate of dry powder is slowed down. Now in order to faster the rate by using drying air with low moisture content keeping constant inlet flowrate OR to save heating energy by decreasing the amount of drying air used by keeping the feed flowrate constant, the recycled air can be dehumidified before mixing with fresh air and heating. Dehumidifying will certainly decrease the moisture content by removing water vapor in form of condensed water by cooling. After cooling, heating can be done using the vent air stream, thus raising the temperature.

In this work possibility of saving energy has been explored by comparing the energy requirement of the conventional process and the proposed idea.

II. Energy Balance Calculation Without Using Dehumidification

Energy balance for the flow diagram as shown in the figure (1) was carried out. The drying of alumina-based ceramic composite slurry is investigated. The mathematical model developed by Boris Golman was used for reference. Hence according to his model here also recirculation ratio 70% is used as it was found to be the optimum.

INLET AND OUTLET PARAMETERS:

Inlet temperature of drying air (T_{da})	170ºC
Inlet flowrate of drying air (m_{da})	2500Kg/hr
Inlet temperature of atomizing and fresh air ($T_{aa} = T_{fa}$)	30ºC
Inlet flowrate of atomizing air (m_{aa})	90Kg/hr
Inlet flowrate of feed	90kg/hr
Inlet temperature of feed (T_{sl})	50ºC
Relative humidity of fresh and atomizing air	70%
Water content	60%
Moisture in the final product (X_p)	3%
Reference temperature	0ºC

$$T_{va} = T_{ra} = T_{ea} = T_p$$
$$Y_{va} = Y_{ra} = Y_{ea} \quad (1)$$
$$Y_{fa} = Y_{aa} = Y_{oa}$$
$$m_{sl,d} = m_{p,d}$$
$$T_{fa} = T_{aa}$$

A. Inlet energy calculation

$$Q_{sl} = m_{sl,d}(C_{ps} + X_{sl}C_{pl})(T_{sl} - T_{ref}) = \underline{3542.5125 \text{ J/s}} \quad (2)$$

$$m_{sl,d} = 40/100 * 90 = 36 \text{ Kg\hr}$$

$$Q_{fa} = m_{fa,d}[(C_{pa} + Y_{fa}C_{pv})(T_{fa} - T_{ref}) + Y_{fa}\lambda_{ref}] \quad (3)$$
$$m_{ra} = 70/100 * 2590 = 1813 \text{ Kg/hr}$$
$$m_{fa} = 2500 – 1813 = 687 \text{ Kg/hr}$$

At 70% relative humidity and $T_{fa} = 30^oC$,
$$Y_{fa} = 0.0213$$
$$Q_{fa} = \underline{15130.8315 \text{ J/s}}$$

Nomenclature

C_p	specific heat capacity (J kg^{-1} K^{-1})
ES	energy saving (%)
h	specific enthalpy (J kg^{-1})
m	mass flow rate (kg s^{-1})
Q	amount of heat in unit time (J s^{-1})
RR	recirculation ratio (%)
T	temperature (K)
W	weight percentage of water on wet basis (%)
X	mass fraction of water on dry basis (kg kg^{-1})
Y	humidity on dry basis (kg kg^{-1})

Greek symbols

η_R	energy efficiency (%)
λ	latent heat of water (J kg^{-1})

Subscripts

a	dry air
aa	atomizing air
crit	critical
d	dry base
da	drying air
dew	dew point
ea	exhaust air
fa	feed air
h	wet base
i	*i*th stream
in	inlet
j	*j*th phase
l	liquid
loss	loss
ma	mixed air
oa	ambient air
out	outlet
p	solid product
ra	recirculated air
rec	recovered
ref	reference
req	required
s	solid
sl	slurry
v	vapor
va	vent air

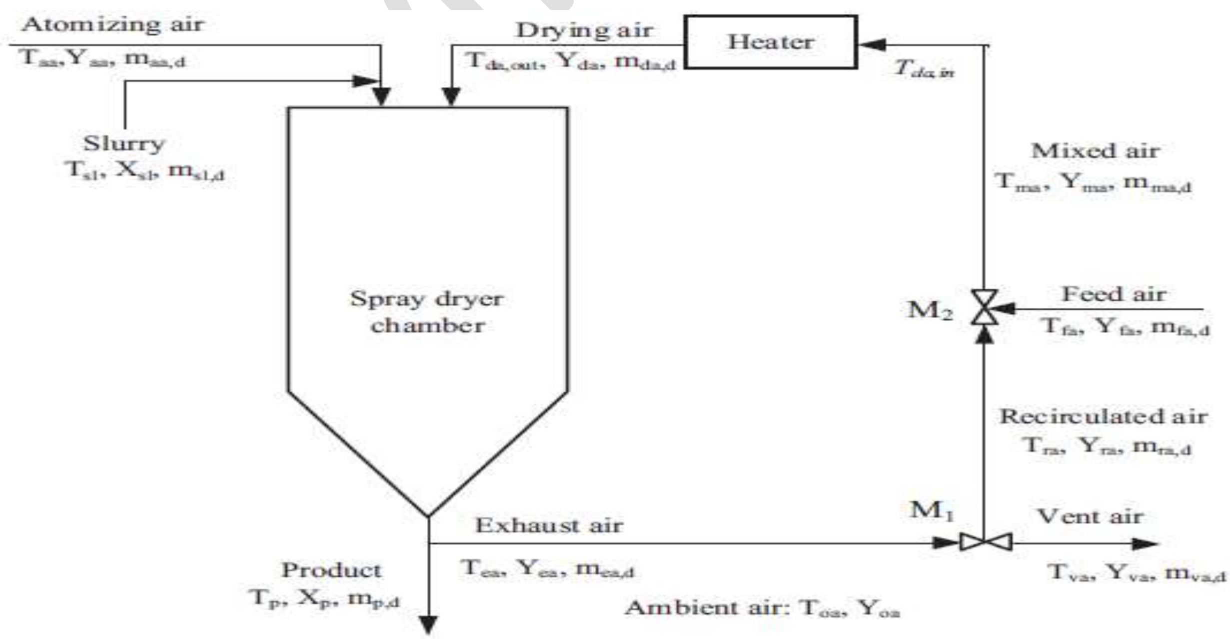


Fig. 1. Schematic diagram of the spray drying system with exhaust air recirculation.

$$Q_{aa} = m_{aa,d}[(C_{pa} + Y_{aa}C_{pv})(T_{aa} - T_{ref}) + Y_{aa}\lambda_{ref}] \quad (4)$$
$$Q_{aa} = \underline{1982.205\ J/s}$$

$$Q_{da} = m_{da,d}(C_{pa} + Y_{da}C_{pv})(T_{da} - T_{ma}) \quad (5)$$
$$Y_{da} = 0.0707$$
$$T_{ma} = (687*303 + 1813*T_{ra}) / 2500$$
$$Q_{da} = \underline{281608.0066 - 567.7006T_{ma}}$$

B. Outlet energy calculation

$$Q_p = m_{p,d}(C_{ps} + X_pC_{pl})(T_p - T_{ref}) = 9.1103(T_{ra} - 273) \quad (6)$$
$$Q_p = \underline{9.1103T_{ra} - 2487.1119\ J/s}$$

$$Q_{va} = m_{va,d}[(C_{pa} + Y_{va}C_{pv})(T_{va} - T_{ref}) + (Y_{va}\lambda_{ref})] \quad (7)$$
$$Y_{va} = 0.0894$$
$$Q_{va} = \underline{250.5652T_{ra} - 268404.3087 + 44607.83J/}$$

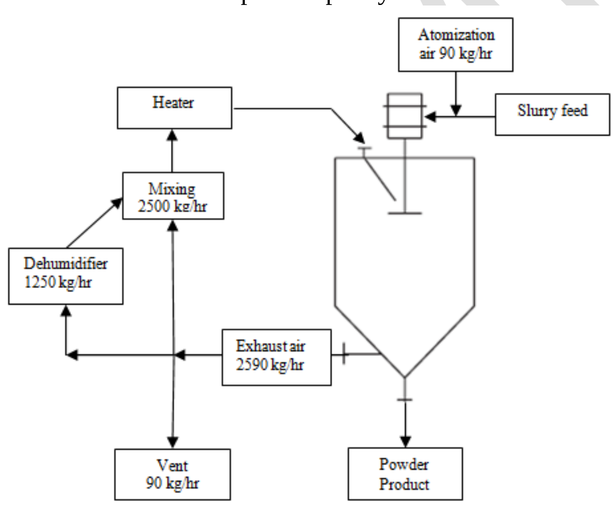
C. From (2)+(3)+(4)+(5)=(6)+(7)

$$827.3761T_{ra} = 328547.1462 \quad (8)$$
$$Tea = Tra = \underline{397.0952\ K} = \underline{124.1^oC}$$

$$T_{ma} = 98.24^OC$$
$$Q_{da} = \underline{56175.1201\ J/s}$$

III. ENERGY BALANCE USING DEHUMIDIFICATION OF EXHAUST AIR

The part of exhaust temperature at 124.1°C is dehumidified in order to increase its absorption capacity.



In this proposed work the use of fresh air stream has been completely eliminated. By doing so the inlet temperature at the air heater will remain higher compared to the process where fresh air is used. This can be done if and only if we can reduce the humidity of the exhaust air and then recycle it.

Here after venting 90 Kg/hr exhaust gas, 50% of the remaining exhaust gas i.e. 1250 Kg/hr of air will be sent to a condenser for dehumidification. Here in this condenser the exhaust air at 124.1°C will be cooled to 80°C by using cold water at 25°C. Thus by dropping the temperature of hot gas below 100°C will condense the water vapor in it leading to decrease in the humidity. This dehumidified air is than mixed with the remaining 50% of the exhaust air at 124.1°C forming a mixed stream of air T_{ma} at 102.05°C.

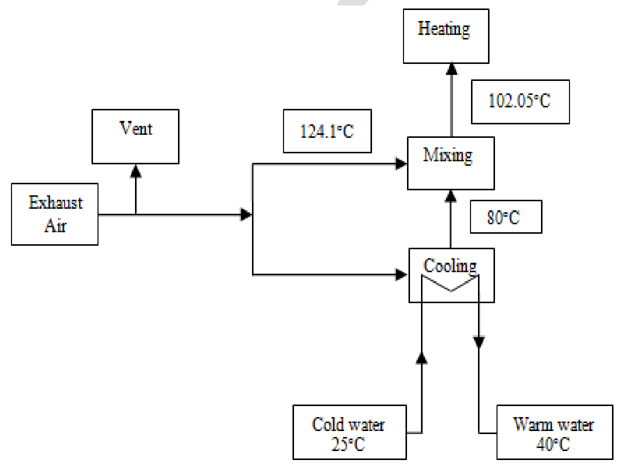


Fig. 2. Schematic diagram of spray drying system using dehumidification of exhaust air

$$Q_{rejected} = m_{water}C_{p,water}(40 - 25) \quad (9)$$
$$m_{water} = 1\ kg/s$$
$$Q_{rejected} = \underline{62790\ J/s}$$

$$Q_{rejected} = m_{cold\ air}(h_{c1} - h_{c2}) \quad (10)$$

$$h_i = 10^3(T_i - 273) + Y_i(2260*10^3 + 1.8*10^3(T_i - 273)) \quad (11)$$

h_{c1} = enthalpy of air before cooling at T_{ea} = 124.1°C and

$$Y_{ea} = 0.0894$$
$$h_{c1} = \underline{346114.172\ J/Kg}$$
$$m_{cold\ air} = 1000\ g/s$$

h_{c2} = enthalpy of air after cooling (12)

$$h_{c2} = \underline{165278.972\ J/Kg}$$

From equation (11) at T_{c2} = $\underline{80^oC}$

$$Y_{c2} = \underline{0.0355}$$

$$Y_{ma} = (0.0894*1250 + 0.0355*1250) /2500 \quad (13)$$
$$Y_{ma} = \underline{0.0625}$$

$$T_{ma} = (124.1*1250 + 80*1250) /2500$$
$$T_{ma} = \underline{102.05^oC}$$

From equation (5) Q_{da} = $\underline{52496.0938\ J/s}$

IV. SIMULATION AND VALIDATION

The above calculation is done for one particular value of amount of air to be dehumidified i.e. 50% for which energy saving is $\Delta Q = 3679.0263$ J/s. But to have the complete knowledge of the effect of the dehumidification on the energy consumption, energy balance for all the amount of air to be dehumidified has to be studied. Doing all these calculations manually is very time consuming. To avoid this scilab coding has been developed.

Scilab code once developed it has to be validated than only it is confirmed that the output values generated by it are true. Validation is possible only by matching the scilab output with the standard model's theoretically calculated values.

Firstly scilab code for the model representing recycling air without dehumidification has been developed. And its output values were matched with the theoretically calculated values. As the values were matching code developed was said to be validated. Then only this scilab code was modified for the model including dehumidification. Air to be dehumidified from 0 to 100% was plotted against the energy saving and humidity of the drying air.

V. RESULTS AND DISCUSSION

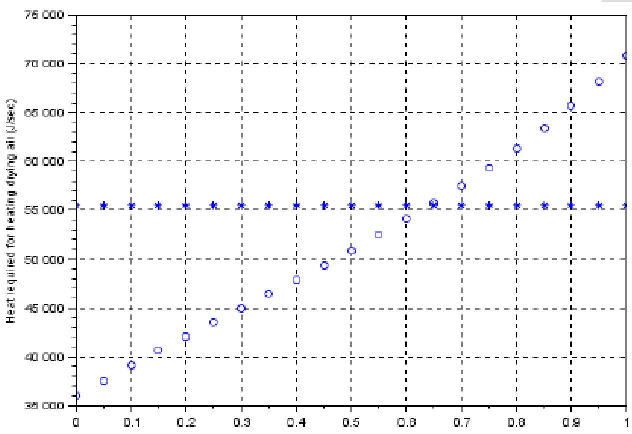


Fig 3: Energy requirement for heating air in proposed process for different amount of dehumidified air

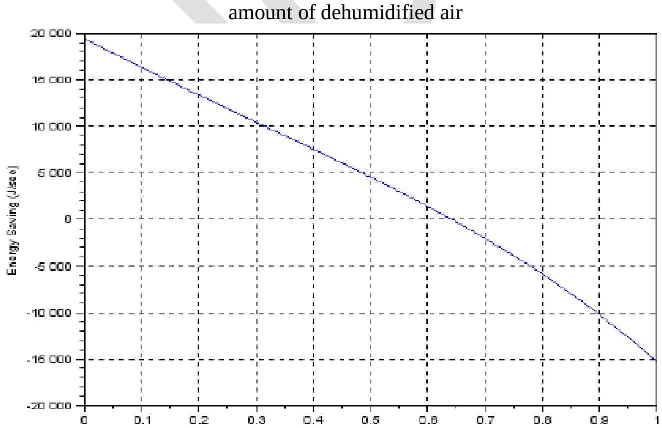


Fig 3: Amount of energy saving in the proposed technique for different amount of dehumidified air

From the fig. 3 and fig. 4 it is clear that energy requirement for heating the inlet drying air increases with the increase in the percentage of the exhaust air dehumidified. From0 to 65 % of dehumidified air the energy requirement is less than the conventional process, above 65 % energy requirement in the proposed process is more than the conventional process. Thus 64 % is the maximum level up to which exhaust air should be dehumidified in order to save energy. But again the humidity is very high for low value of amount of dehumidified air. Hence the minimum level up to which amount of air must be dehumidified is determined from the humidity graph.

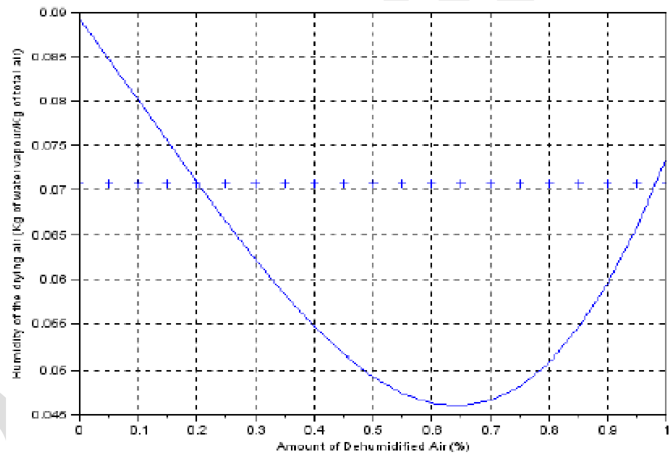


Fig 5: Change in humidity in the proposed process for different amount of dehumidified air

From fig.7.3 it is clear that inlet air humidity is highest at 0 % of dehumidified air and there by decreases with the increases in the amount of the dehumidified air till 65 %. After 65 % humidity again starts increasing till 100 % of the dehumidified air. Also below 20 % and above 98 % of the dehumidified air, humidity of the inlet air is more compared to the inlet humidity of the conventional process. Thus minimum level to which % of exhaust air must be dehumidified is 20%.

VI. CONCLSIONS

- The optimum range to which the exhaust air can be dehumidified is between 20% to 65%.
- In between these extremes only there is energy saving as well as reduction in the inlet air humidity.
- This process does not require major changes in the prevailing process. It can be simply implemented by placing a dehumidifier between the exhaust air recirculation and the heater for heating the inlet air.
- This proposed technique is also a closed system due to the elimination of the use of fresh air.
- The amount of vented air (90 Kg/hr) is also less compared to the conventional process (777 kg/hr). Thus amount of energy wasted with the vented air is also less.

- In case if the exhaust air contain substances that cannot be released directly into atmosphere it has to be incinerated. Thus this process will require less energy for incineration.
- Also reduction in inlet air humidity gives us opportunity of reduction in flow rate of inlet air due to increase in the absorption capacity.

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