Mathematical Model and Simulation of Gypsum Dryer

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Mathematical Modeling and Design of Gypsum Dryer

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree or diploma.
2. Due acknowledgment has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, Bruhad S Naik, Roll. No. 13MMET09, give undertaking that the Major Project entitled **"Mathematical Modeling and Design of Gypsum Dryer"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere, it will result in severe disciplinary action.

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This is to certify that the Major Project entitled **"Mathematical Modeling and Design of Gypsum Dryer"** submitted by **Bruahd S Naik (13MMET09)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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“The secret of getting ahead is getting started.” - Mark Twain

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Abstract

The present work aims in encountering the problem associated with drying of chemical gypsum used by JK Lakshmi cement, Moti Bhoyan, Kalol Plant. JK Lakshmi cement's Moti Bhoyan Plant is a grinding unit which uses the chemical gypsum as a raw material in cement making process. The Chemical gypsum - containing high amount of moisture - is a waste product coming from near by plants. The moisture is causing problem in transportation of gypsum during the process. The problem can be solved by removing moisture from gypsum up to 10% w/w. The plant is using direct sun drying as a drying technique although being an inefficient process. Moreover, plant needs at least 70 ton/day gypsum drying resulting in a requirement of a big drying area. Hence a new technique of Inclined Rotary drum drying is suggested.

To design an Inclined Drum Dryer a mathematical model is generated. The mathematical model is divided in to two parts sizing model and rating model. The sizing of dryer is done by making heat balance and mass balance between gypsum and air. The result of which gives mass flow rate of air required for drying. The mass flow rate and velocity of air gives the required size of drum. The diameter of drum and hold up of drum gives the size of flights and number of flights required for required heat transfer to achieved. The size of flight and number of flights calculated by model is used to optimize the size of drum. The sizing model gives Length and Diameter of drum, Size and Number of Flights and Air flow rate required to reduce the moisture contain up to 10%.

The rating model takes input of geometrical parameters calculated from sizing model. The drum is divided in to small control volume (CV) and energy and mass balance is applied to each control volume. The output of one CV is input to the consecutive CV. The temperature and mass flow rate are taken as input parameters for each control volume. The mathematical model links each control volume to give actual Length of dryer required for specified output moisture contain. The model also give output moisture contain and temperature of air and gypsum.

The dryer is designed by combining sizing and rating model. The drum dryer is designed for 0.001m diameter particle size. Air temperature of 350°C, moisture contain and temperature of solid as 30% w/w and 30°C as input parameters for final gypsum moisture of 10 % and 65°C. A C++ program for sizing model and rating model is generated. The sizing model code give length of drum as 15.694 m and diameter of 1.889 m making L/D ratio as 8.30. The flight size as 0.51 m and number of flight as 19 is been selected to get above results. For rating model length of drum is taken as 8 m and diameter as 1 m making L/D ration 8. The rating model gives required length of drum as 8 m. The output of rating model gives the final moisture contain of air as 0.1089 w/w, the final product temperature as 63.87°C, air temperature as 77.96°C and final product moisture contain as 0.10 w/w. The study shows that with change in size of particle the required size of drum changes, to compensate the change the flight hold up must be changed.

Keywords: Inclined rotary drum dryer, Sizing model, Rating model, Effect of parameters on design.

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Nomenclature

A	Area of C/S of Dryer per Unit Length, m^2
A_f	Area of C/S of Fully Loaded Flight, m^2
$C^\star$	Non-Dimensional proportionality Constant in Equation 3.32
c	Specific heat , kJ/kgK
C^*	Saturated gas concentration
C_l	Dissolved gas concentration at temperature T
D	Diameter of Drum, m
D_e	Effective Diameter of Drum, m
D_{diff}	Coefficient of Diffusion of material, cm^2/s)
d_p	Diameter of a Particle, m
dz	Length of Control Volume, m
f	Fraction of time a particle is airborne, sec
$\mathring{G}_a$	Mass flow rate of air, kg/s
$\mathring{G}_m$	Mass flow rate of material, kg/s
h_c	Heat transfer coefficient, kJ/kgK
h	Depth of filling of a single flight, m
h_{fall}	Effective falling height of particle, m
H	Hold up of a single flight, m^3
H_o	% Hold up of Drum
J	Mass transfer Flux, Kg/sec
K_m	Mass Transfer Coefficient
k	Thermal Conductivity , W/mK
L	Length of Drum, m
L_1	Required Length of Drum, m
$\dot{m}$	Mass flow rate, kg/hr
N_f	Number of Flights
N_p	Number of Particle in a CV
n_{rpm}	RPM of Drum, rpm
P_{sat}	Saturation vapor pressure of water, kPa
P	Atmospheric pressure, kPa
$\mathring{Q}$	Heat flux, kW
R	Radius of Drum, m
s	Specific Gravity of material
t	Time, sec
T	Temperature, K
$u\,\&\,U$	Velocity of product in Drum, m/s
v	Velocity of Air in Drum, m/s
x	Moisture contain of Product, kg/kg of dry Solid
y	Moisture contain of Air, kg/kg of dry Air

Subscript

a Air
m Material
i Inlet
o Outlet

Greek Symbol

α Slop of Drum, rad
δ Empirical Constant in equation 3.85
θ_i Included angle shown in Fig. 2.6
θ_r Angle of Repose of Material
θ_n Included angle shown in Fig. 2.8
μ Coefficient of Viscosity, $PaSec$
ρ Density, Kg/m^3
τ Retention Time, min
ϕ Rotational angle of Drum from horizontal, rad
Δ Difference between two values

Non-Dimentional Numbers

Nu Nussult Number
Pr Prandtl Number
Re Reynolds Number

Chapter 1

Introduction

JK Lakshmi Cement's Kalol grinding unit requires 4% w/w gypsum of the total cement produce per day i.e. 70MT to 100MT consumption of gypsum per day. This gypsum needs to be dried before putting into process. A feasibility study is done for possible drying process. Two processes have been selected for detailed study. The problem of drying and possible solution is found out and explained in this chapter.

From ancient times in construction, cement is used as a raw material. After number of innovation and research the modern cement is come into existence. The 1^{st} cement has very short time of setting. The solidification time was so short that it was very difficult to use as construction material. This difficulty was solved by adding a substance which retard the time of setting. In modern day technology gypsum is used as setting time retarder and amount of gypsum decides the setting time.

1.1 JK Lakshmi Cement Limited, Moti Bhoyan, Kalol Plant

JK Lakshmi Cement Limited (JKLCL); a flagship company of the renowned JK Organization (EZ) is engaged in Cement Business since 1982. The company operates a cement plant of capacity 5 Million Ton Per Annum (MTPA) at Jaykaypuram in Sirohi District, Rajasthan. The plant is ISO-9001, ISO-14001, and OHSAS 18001 certified and maintains very high level standards in Quality, Environment and Safety fields. The plant has won number of National and International awards including Energy Efficiency Award – 2008 conferred by the Ministry of Power, GOI and Three Leaves Award by Centre for Science & Environment (CSE) for State of Art Pollution Control Technology.

The company believes in the concept of sustainable development and with this view had installed and commissioned a cement grinding unit of 0.5 Million Ton per Annum capacity at Kalol, Gandhinagar District in Gujarat in the year 2009 for meaningful utilization of fly ash, a solid waste generated from Gandhinagar Thermal Power Station and Torrent Thermal Power Station, Ahmedabad. The plant is ISO-9001, ISO-14001, ISO-50001 and OHSAS 18001 certified. The said unit consumes fly ash to the tune of about 500-600 Metric tons per day conserving equivalent quantity of natural resources, otherwise required and also saves on account of logistic cost due to proximity of the unit (with in 30 km.) with the thermal power stations. This Green initiative taken by the JKLCL has helped in reduction of about 1, 80,000 tons of Green House Gas Emissions. Charged with the Gujarat Plant's environmental contribution. The cement plant at Moti Bhoyan kalol was started production in 2009 with capacity of 5 Lakh ton per annum grinding unit. The products generated in this plant are 53 Grade Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC).

1.2 Gypsum: An Essential Raw Material and Associated Problem

1.2.1 Gypsum

In Ordinary Portland Cement(OPC) gypsum is used as setting time retarder. It had been shown that gypsum in cement making works as setting time retarder and strengthening agent by Bhanumathidas et al. (2004). Due to the rapid hydration of calcium aluminates to form calcium aluminates hydrate (CAH), ground clinker exhibits flash setting in a few minutes. It minimizes the chances of remixing due to hydration of C3A which generates high amount of heat due to exothermic reaction. The generated CAH, does not contribute for strength of the matrix and hampers the hydration of calcium silicate. The commercial use of this type of cement is that's why impossible . The reaction in absence of Gypsum

$$CaO \cdot Al_2O_3 + nH_2O \Rightarrow CAH + \text{Exothermic Reaction} \tag{1.1}$$

The reaction is so fast that its almost impossible to control. To prevent rapid setting, the reaction rate needs to be slow down, which can be done by adding sulfate salts. Gypsum is a waste generated by chemical plants which is a sulfate salt. In a way to solve the problem the gypsum is a best solution for cement making. The below reaction shows the chemical reaction after adding gypsum. The rate of reaction is slow down due to control reaction of C3A.

$$3CaO \cdot Al_2O_3 + 3CaSO_4 \cdot 2H_2O + nH_2O \longrightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 2H_2O \tag{1.2}$$

1.2.2 Problems Associated with Gypsum

There are two kind of gypsum available one is natural gypsum and other is chemically formed gypsum. JK Lakshmi cement, Kalol plant is using industrial waste chemical gypsum for this purpose. In chemical industries to dilute acids lime is used and as result gypsum is formed. Formed chemical gypsum always have high amount of water associated with it so the gypsum which is coming in the plant has excess amount of water which creates problems during process. As per the plant authorities it does not creates problem in cement making but the transportation of gypsum from storage to ball mill is problematic. Moist gypsum has tendency to get stick with metal parts. The gypsum gets stuck on belt conveyors and hoppers. Due to this sometimes it creates blockage in hoppers which leads to hopper over flow. The over flowing of hopper creates material loss. For ensuring the smooth running of plant they needs to put at least two to three person near the hoppers and conveyors. The manual cleaning of clogged gypsum is done which waste more man hours. The health of workers working for cleaning is also in danger. Though the worker is having full protection if due to some manual error gypsum goes in to inhalation there is changes of respiratory decides to the person. The over flowed gypsum fall on the floor and land this cause cleanliness problems and may affects the person working there.

1.3 Current Drying Technique

To solve this problem the moisture contains of gypsum needs to be reduced to at least 10% of total volume because for cement making 5% - 7% (of total volume) moist gypsum is best.The plant is using direct sun drying for gypsum drying. Open yards are created for drying. Chemical gypsum is spread on the ground with help of the tractors. Constant blending and mixing of gypsum is done with the help of tractors for proper drying. One lot is dried at least for three days. The dried gypsum then goes to storage with the help of tractors.

1.4 Motivation/Problem with Current Drying Technique

The current technique of drying is very ineffective. The gypsum comes in lumps which doesn't have any regular size. The moisture inside a big lump may not get evaporated though the outer side may looks dry. There it looses its effectiveness as drying technique. There is constant evaporation of water from gypsum but in night time and early morning in absence of sun radiation gypsum absorbs air moisture because of it's hydrophilic nature. Gypsum which was dried during day time gains it moisture back in night time that puts additional time for drying. There is no control over the process because it highly depends on weather condition. In highly moist days of year time of drying increases drastically and in monsoon the drying is almost impossible. To use gypsum in monsoon plant has created storage space. A storage space puts an extra investment and occupies unnecessary space. The transportation of gypsum from storage yard to drying yard and from there to storage facility is very much time consuming and hectic.

1.5 Scope of Study

The present situation of plant is so in favor of replacing direct sun drying with some other technique. The present technique of drying is ineffective, inefficient, time consuming and laborious. The study of gypsum as a material shows that it is need special requirement for drying. First of all the moisture makes it very sticky which creates problem in handling of the material. Lumps need to be break into small pieces for proper drying. There are thousands of dryer available for drying. There are at least 40-50 dryers available for fluidization based drying and each dryer is also divided into more number of dryers according to process requirements. In a way the choice of dryer needs to be precise according to the requirement. Numbers of criteria are defined for drier selection and with the help of available literature dryers are selected for study. The study involves selection of dryers and design of dryers according to requirement.

1.6 Objective of Project

The objective project is to select drying process that eliminates the said problem. The selected dryer will be designed based on process parameters. Optimize the dryer process parameters in order to fit the drying requirements.

1.6.1 Methodology to be Adopted

The solution of drying problem is encounter in two steps. The selection of dryer from available different dryers. Then design dryer based on process parameters.

1.6.2 Selection of Dryer

Plant requirements will be decided. The process parameters will be decided based on requirements of plant. The selection of dryer will be carried out based on process requirements.

1.6.3 Mathematical Model and Optimization

The dryer will be design in two parts. First part deals with the sizing of dryer and second part deals with rating of dryer. The combination of both model will give an optimized design of dryer.

1.7 Closure

Direct sun drying is not an effective way of drying. The technique is tedious and ineffective. There need a control over the process parameters for proper drying. A new drying practice needs to be created and implemented. The new technique should have control over process. It should at least dry the gypsum to 10% moisture of the total volume. The process should be an economical one. As the present technique is ineffective, moisture contain of gypsum remains around 22% to 25%. This is still on a higher side causing various problems as discussed earlier. To address this problems a literature survey is carried out with consideration of industrial requirement and process feasibility. The review of status is presented in next chapter.

Chapter 2

Literature Review

Drying is a vast field of engineering. Drying practice change with change in conditions like material, drying time available, mechanical and chemical properties. Every change in parameter the drying practice changes. Hence the selection of a drying technique depends on more then one parameters. In order to resolve the problem a careful study is done and numbers of dryer are scrutinized. The selection and design of such dryer is described in this chapter

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To approach the problem of drying the 1^{st} and crucial step is selection of dryer. There are numbers of dryer available and being used by industries and each dryer is different in design because of the task they are performing. The selection process is more of an art then a science because it more depends on selectors knowledge and process requirement rather than a defined scientific approach. The criteria of selection are more dependent on actual condition then available literature i.e. world wide concentrated nickel ore is dried with the use of rotary drum dryer, fluid bed dryers and flash dryer. Each of the technique is as good as other but they are not interchangeable. Means if at one place it needs drum dryer than other two dryer may or may not be as effective as drum dryer. This part of literature deals with the selection of a dryer for drying of chemical gypsum of JK Lakshmi cement's Kalol plant.

2.1 Dryer Selection

Though there is no set procedure for selection of dryer Baker suggested a "structural approach" to selection process. 1^{st} list all the key process specification involved, which narrow down the selection to particular set of dryers i.e chemical gypsum comes in lumps so the selection process will consider only those dryer which can dry lumps or granular material. 2^{nd} there are numbers of dryer available which can dry granular or lumpy material so from selected set of dryers select some dryer which is appropriate i.e. JKLC plant needs on an average 70 ton/day of gypsum hence the selected dryer must have production rate in t/h. 3^{rd}carry out bench scale tests including quality test i.e determination of bulk density and other physical and chemical properties of material. 4^{th}estimate all the economic alternative for all the dryers. It includes cost from beginning of installation to the cost of running and maintenance. 5^{th} conduct pilot scale trials. It is more appropriate to do pilot scale test, it gives all the parameter and the effect of each parameter during running condition. If pilot scale facility is not available then there are mathematical model available for each type of dryer. Create a mathematical model by taking reference of mathematical model and check the effects of parameters. finally select a dryer which gives optimal results both economically and technically.

Dryers are classified according to sets of parameters. The parameters on which dryers can be classified were listed by Mujumdar (2006) and Van't Land (2012) in their respective work.The major classification of dryer is direct heated, indirect heated and indirect-direct dryers. Dryers are classified as batch type or continuous type this classification is on the basses of mode of operation. The heat supplied to the dryer can be by convection, conduction, radiation, electromagnetic field or different combination of all. The working pressure of dryer will indicate if it is a vacuum or atmospheric pressure dryer. There is a connection between material property, drying medium and temperature of drying. The selection process looks into if material is sensitive to the high temperature or to the medium of drying i.e. above 125°c gypsum will loss all its moisture and converters into Plaster of Paris and losses the property of time retarder for cement hence exit temperature of gypsum must be lower then 125°c. Most common drying medium are air, flue gas and super heated steam. Though air has a very low heat capacity air is most common drying medium because of its availability and nonreactive nature with the most of the material. Whereas flue gas and super heated steam are used for high temperature drying and indirect drying. The relative motion between material and drying medium is a crucial decision i.e a hydrophilic material will absorb moisture from environment so to avoid such conflict counter current dryer will be more appropriate because the dried material will never comes into contact with moisture environment. Retention time of a dryer is the length of the time material stays in the dryer. It is one of the most discussed parameter of drying because its the most crucial parameter. The retention time will be based on requirement of product quality and quantity. To match the quantity requirements the dryer can be made multistage. In some cases quality requirements are high at that time technical requirements will get more attention then economical i.e. suppose the drying output need air filters because of environment laws then economy attached to dust collector is neglected because its a necessary equipment.

2.1.1 Selection Parameters

The final selection may or may not be according to economy of the process or the energy input. The selection is influenced by so many other parameters also. The amount of product requirement will decide rather to make the process batch wise or continuous type. Then the feeding will be different in both cases which intern changes the other parameters of the process. The feeding process will influence the feed rate and output rate of the process. A continuous process needs continuous feeding and continuous feeding will need a heat input that can provide heat continuously. A heat source selection then will have to be according to output moisture requirements. An easily available source may not be a good choice if it does not fulfill the requirement of process. A low thermal capacity source like air can be used for drying if the flue gases are creating problems. A flue gas system needs an extra set of cleaning system which may not be economical. The system that runs on oil firing or coal needs approval from environmental bodies because of the pollution norms of government. The process then be checked for environment effects. Microwave and RF drying technique may be a simplest solution but the energy input is high not only that the process is having very low efficiency. The heat is generated by use of electric current the more then 50 % of which is used for generation of the RF and

Micro waves and from that generated waves the heat for drying is generated. The used electricity is itself having a very low efficiency. Finally the efficiency of the process will be drops to less then 10%. So a process like Micro Wave and RF heating is very clean and easy to maintain but it doesn't fulfill the criteria of overall process efficiency so it is been ruled out. The material that is been dried has different chemical properties which directly influence the selection of material of dryer. A highly reactive material may needs a special attention while selecting the dryers material which links to the selection of heat input and also the selection of feeding process.

2.1.2 Selection of Dryer for Gypsum Drying

By considering all the possible classification the selection criteria can be narrow down to output requirement, inlet and outlet moisture, fuel and drying medium, physical form of material, pre-processing requirements, direction of material flow, material of construction and drying time. JK Lakshmi cement, Kalol plant plant needs around 4% gypsum of total volume of cement production i.e nearly 70 MT/day to 100 MT/day. To meet this demand dryer must be of capacity in tons/hour. The moisture contain of gypsum in 40% - 38% and is need to be dry up to 8% - 10%. Above 125°C gypsum loose all is moisture and become $CaSO_4$which is Plaster of Paris and can not be used as time retarder. Choice of fuel can be Oil or Gas. Electric heating is highly inefficient way of generating heat so it must be eliminated as a choice. Gypsum comes in lumps the size of such lumps is in range of 100 mm to 1 mm so the dryer must be capable of dry such size of material. The big lumps will breaks in to small lumps by very little force so the dryer should be capable of handling this type of material. The dryer may not be capable of drying such big lumps then a pre-processing equipment may required for braking the lumps. The gypsum is hydroplilic material it absorbs moisture from environment so it is advisable to use concurrent drying method. The material of construction of dryer must be in such a that it doesn't alter the property of the product. The material should be non corrosive and non reactive. The drying time will decide the output rate of the material and that's why it is a the most important parameter. It directly affects size of dryer, size of material feed and flow rate and relative direction of material and drying medium.

A rotary drum dryer meets all the requirements discussed above. It can dry any shape and size of material with any temperature range. The capacity of dryer is in range of tons/hour. More over it has perfect for change of capacity of dryer. In case the capacity of drying need to change the changing parameters of drying will do the work. For gypsum drying of JK Lakshmi cement, Kalol Plant a rotary dryer s been design and simulated.

2.2 Rotary Drum Dryer

A slightly inclined drum having material feed through conveyor and using hot air stream of or flue gas as a drying medium with provision of lifter inside of drum for lifting material and rotating with a very slow speed is a convective rotary drum dryer. Inclined Rotary Drum Dryer can dry product of any size and any shape with any capacity, with few possible exceptions, rotary dryers are more widely used dryer then any other dryer. The parallel flow and counter flow rotary dryer are shown in the Fig. 2.1 and Fig. 2.2 respectivly.

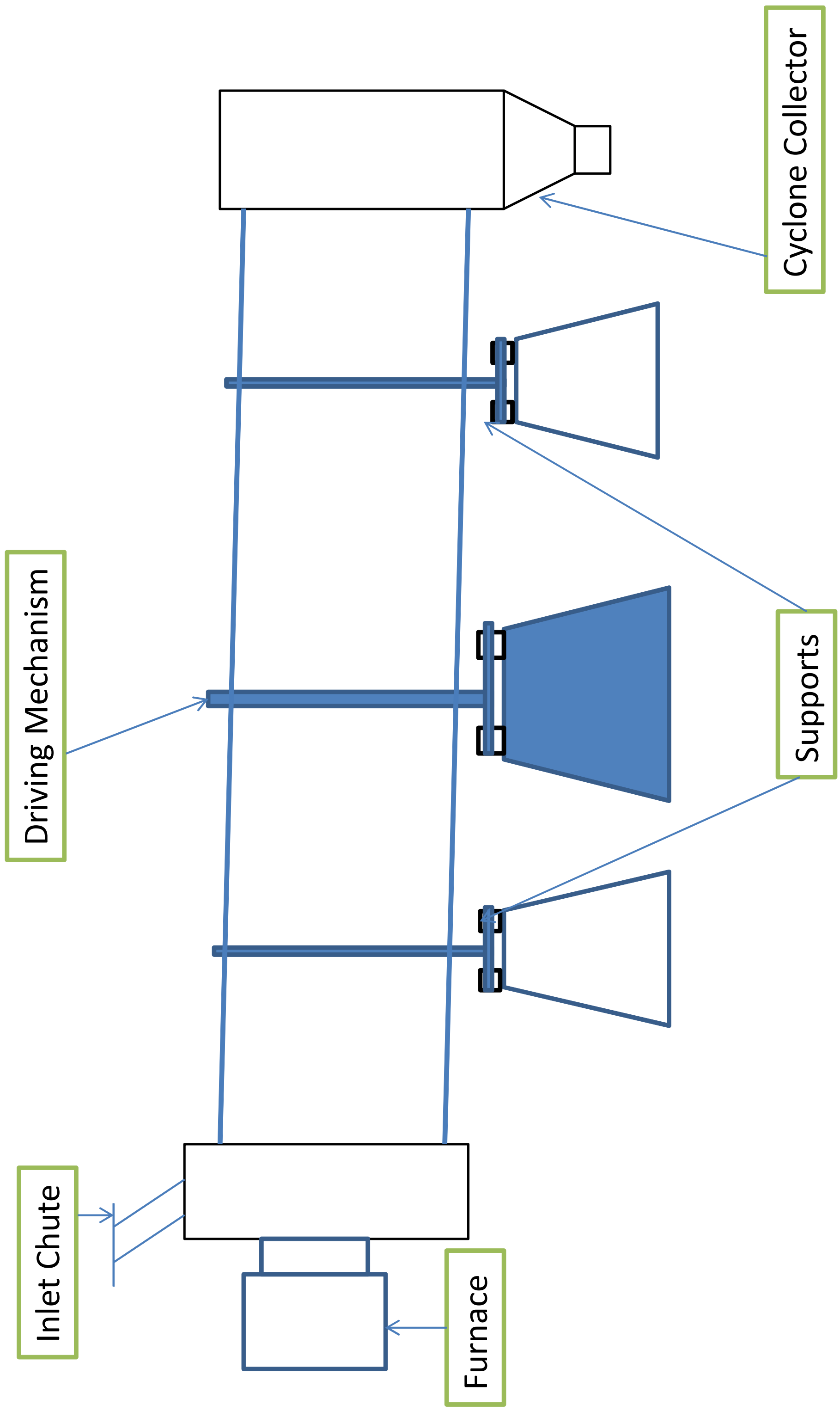

Figure 2.1: Rotary Inclined Drum Dryer Co Current Type

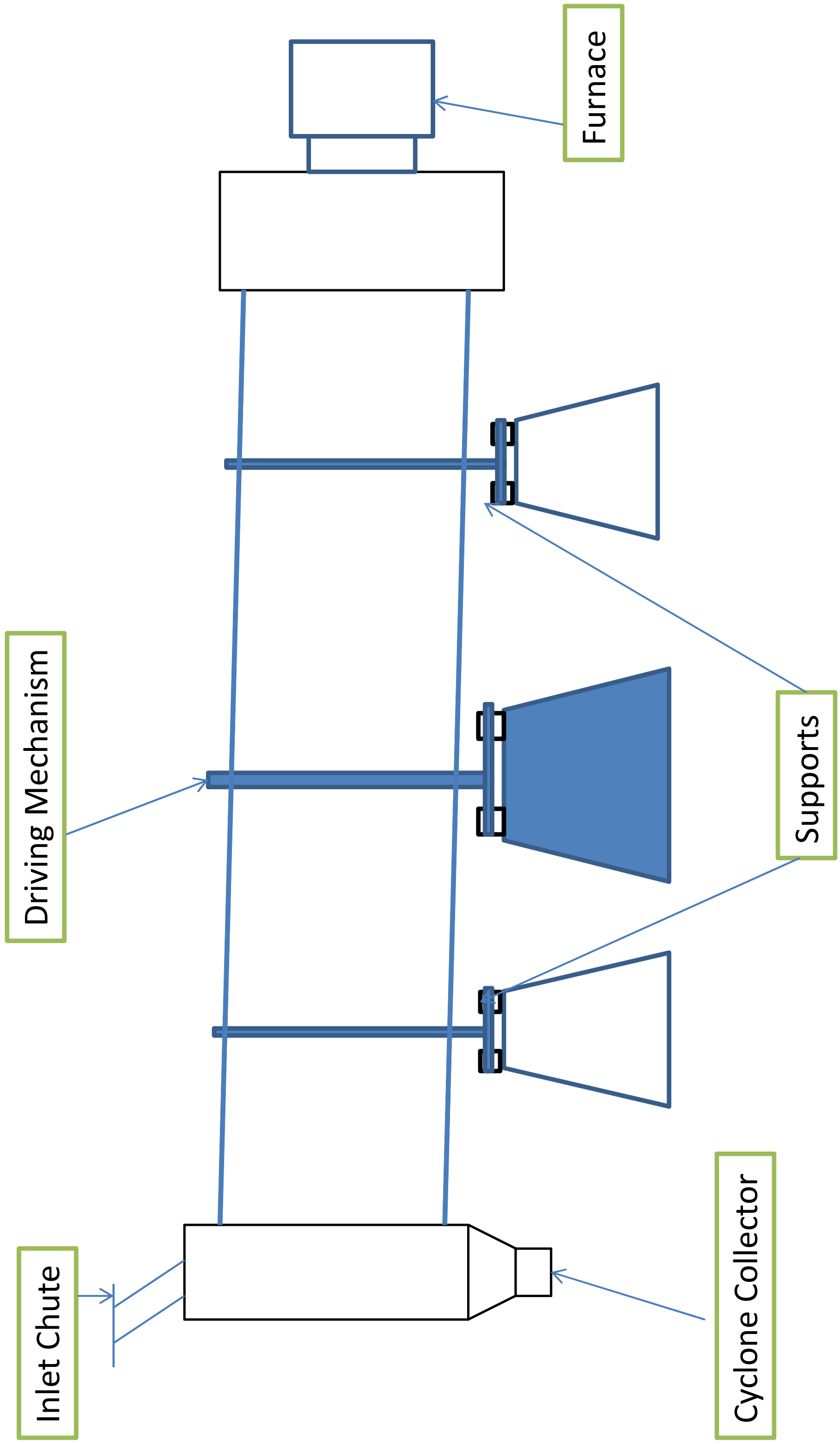

Figure 2.2: Rotary Inclined Drum Dyer Counter Current Type

2.2.1 Drying mechanism

Drying of solid is a result of two simultaneous mechanisms: heat transference and mass transfer. The simplest connection between them is, due to heat transfer moisture starts to evaporate and causes a potential difference for mass transfer to occur.

The basic mode of heat transfer are conduction, convection and radiation. Drying is a process of combination of all this mode of heat transfer a particular drying process is defined by the one which dominates the heat transfer process. In direct heated rotary dryer convective heat transfer dominates the heat transfer process hence it refers as convective rotary drying process.

Mass transfer occurs due to potential difference generated by evaporation provoked by heat transfer process. In rotary drum drying potential difference generates due to humidity difference between two streams and that causes moisture migration form solid to drying medium. The moisture migration process involves two simultaneous mechanism,migration of inner moisture to surface of the solid and evaporation of moisture from the surface of the solid. Internal moisture movement is a function of internal structure of material and moisture contain and external movement of moisture is a function of temperature, air velocity and area of exposed surface.

Thought there is extensive literature studies available, the overall internal drying mechanism has not yet been presented in a single model theory. Most discussed and recognized theory are diffusion theory, capillary theory, and the moving boundary theory. The diffusion theory says that the liquid moisture moves through the material due to concentration difference. The capillary theory says that the moisture movement through the capillaries is due to interaction between solid-liquid attraction. The moving boundary theory says that the moisture movement is a combination of capillary and diffusion effects. The solid is divided into two zones wet zone and dry zone and the zones are separated by a boundary. At boundary the moisture evaporation takes place. The moisture movement in the wet zone is due to capillary movement of liquid and in dry zone by diffusion of of water vapor. The boundary moves towards the wet zone as the drying process progresses. In solids on the other hand moisture migration is occurs due to capillary and diffusion action both may or may not occur simultaneously. The final result will be migration of moisture from inside to the surface of the solid.

The mechanism of external evaporation at the solid surface is essentially the diffusion of water vapor from the surface of the solid to the surrounding through a stationary film of air in contact with its surface. If we assume material is in particle shape and each particle is in spherical shape then due to gas flow a boundary layer will generate. The generated boundary provide the steady surface for evaporation on the other hand it works as the insulation for heat transfer. As the gas velocity is high the boundary layer will become thinner and rate of heat transfer will be higher. Hence the rate of diffusion is directly proportional to the exposed are of the solid, inversely proportional to the film thickness and directly proportional to difference in the vapor pressure of the moisture at the surface of the solid and the surrounding drying medium.Since the layer of the air film in contact with the solid during drying remains saturated, the temperature of the solid surface may assume to lie very close to the wet-bulb temperature of the air.

2.2.2 Effects of parameters on dryer performance

Direct heated rotary dryer may be operated with material flow parallel or counter to that of gas flow. The counter flow dryer will have more overall mean temperature and higher thermal efficiency than parallel flow dryer.

Design and performance of dryer is influenced by percentage loading, moisture contain, air/gas flow rate through dryer, physical property of material, slop of dryer, speed of rotating, dryer length, diameter of dryer, lifting flight arrangements and retention time. Each parameter is having its own influence on performance. The design of dryer is then become optimizing all the parameters in order to fulfill the requirement.

Influence of each parameter on the retention time and capacity of dryer with the help of large industrial data was shown by Keey (1978). The effect of each parameter is shown separately but the common denominator is retention time. Each an every parameter is affecting the retention time so it is obvious to optimize retention time. The effect shown through graph may or may not be point to point accurate but it gives an idea which parameter is more important and which parameter is manageable.

2.2.2.1 Effect of Air Velocity

At the end of the drying some material breaks in to smaller particles due to frequent falling and bouncing. Due to such action the exhaust gas carry this particles so the air velocity must be in a range that the carryover of particles is minimized. The material properties are more responsible for carryover so the selection of flow rate is will be more accurate if selected with test on accentual dryer rather then calculation. Effect of air velocity on retention time is shown by Fig 2.3 (a). It shows that retention time increases for counter current arrangement and decreases for parallel flow arrangement. This is because of the fact that in parallel flow forwarded movement of material is supported by parallel moving drying medium and on the other hand material material flow is restricted by counter flowing drying medium. Though the counter current arrangement have greater effective temperature of drying it suffers with the large pressure drop. To compensate the pressure drop velocity can be increase but it will increase the carryover of the material. The wise choice must be made for selection of working pressure and flow rate to minimize carryover for required retention time.

2.2.2.2 Effect Percentage Loading

Percentage loading is being defied as the ratio of hold-up with the dryer to the dryer volume per unit length. In layman language it is the quantity of material present in the drum at a given time. Influence of percentage loading on retention time is shown by Fig 2.3 (b). The material moves in dryer by two effects 1st by forward movement by gravity due to slop of drum and by drag movement due to falling from height and convening by flowing gas. Beyond a point material start to move forward by rolling effect so there is no effective contact between drying medium and material. In practice the effective loading in in between 15% to 17% of total drum volume per unit length.

2.2.2.3 Effect of Slop of Dryer

The material movement through the dryer is also by gravitation which is generated by slop of dryer. The gravitation movement must be such that material does flow through but not start to roll through the dryer.Effect of slop on retention time is shown by Fig 2.3 (d). Though the retention time decreases with increase of slop but on the other hand it decreases the effective contact of material with drying medium. In practice dryer slop is considered separately from the rotational speed of dryer.

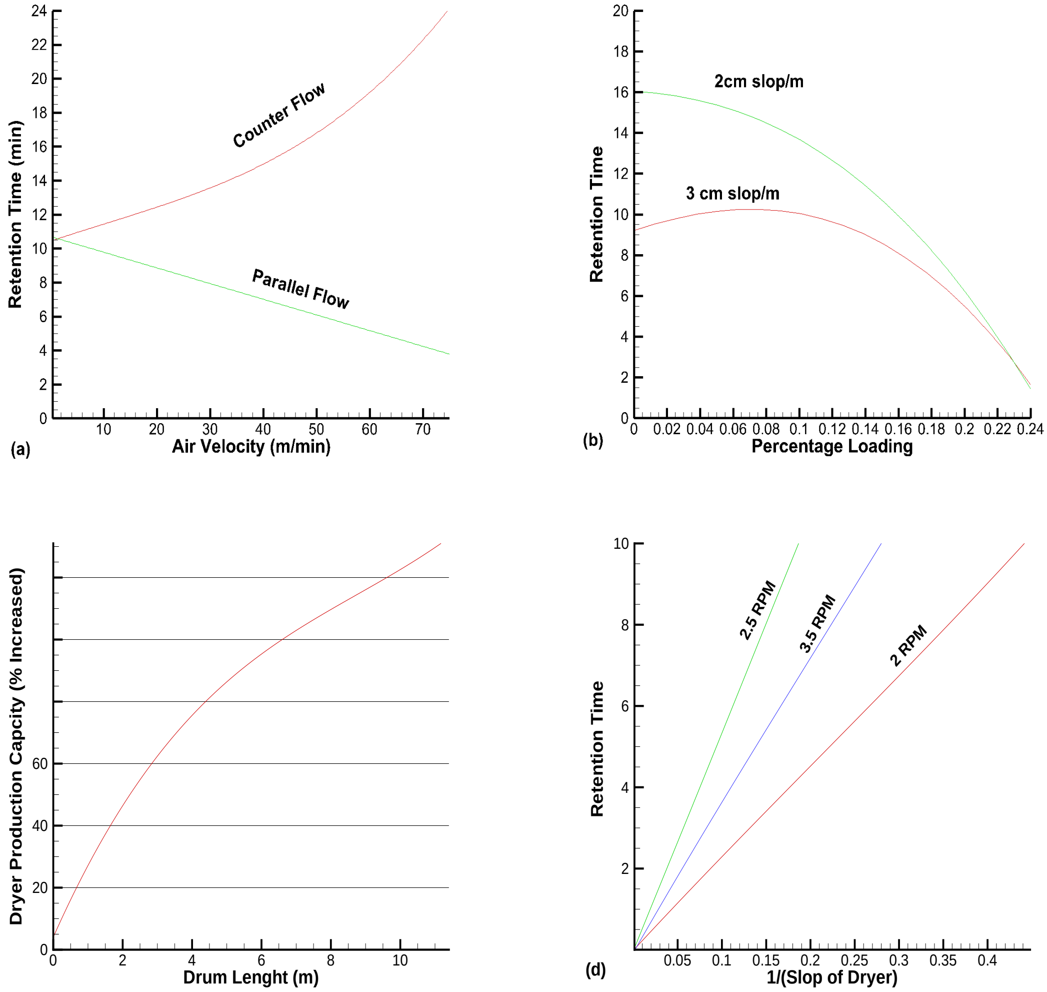

Figure 2.3: Figure shows (a) The change in retention time with change in air velocity (b) The change in retention time with change in percentage drum loading (c) The required change in length for different production capacity (d) Change in retention time with change of slop for diffident RPM of drum

2.2.2.4 Effect of Diameter and Speed of Drum

The dryer speed and diameter drum have effect on each other in a way that it influence the retention time. Fig. 2.4 shows the showering particle cascade in rotary drum, the total cascade time is combination of falling time which is directly proportional to the drum diameter and cascading time which is proportional to the rotational speed of drum. An increase in drum diameter increase the effective contact time between material and drying medium and increase in rotational speed decreases the total cascade time of material. Drum diameter times rotational time in rpm is in between 9 to 12. The drum diameter does effect on production capacity also which is shown by Fig 2.3 (c). It clearly seen that the production capacity of dryer increases with the increase in increased cross sectional area in direct proportion. On the other hand for the same diameter drum, increase in length the increase in capacity is not in direct proportion. Test performed on industrial dryer shows, increase the length by 50% by keeping other parameter constant the production only increases by 20.5 % this can be seen in chart in Appendix.

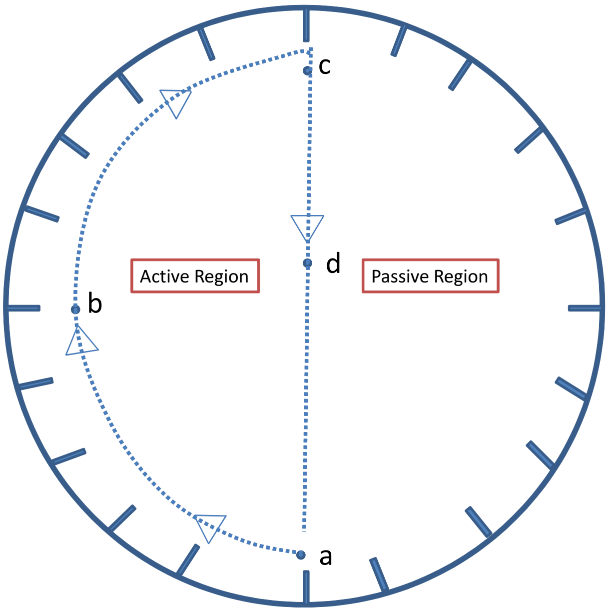

Figure 2.4: A operating drum is divided in to two region (a) Active region (b) Passive region. The particle travel in active region is shown in figure. Path a-b-c is lifting of the particle by the flights and path c-d-a is falling of particle by means of gravity.

2.2.3 Flight design

Drum hold up decide the flow rate requirements, which directly influence the retention time. The drum holdup is proposal to the individual flight hold up and , that also is directly proportional to the the flight size and shape. It is not exaggeration to say that flights of the rotary drum dryer is most important component and design of flight has very deep impact on performance of dryer. There has been extensive scientific studies done on rotary dryer with flights which is more then any other direct heated convective dryers may be because of there extensive use in industries. The Fig. 2.5 shows different shapes of flight generally used in practice. The most common in practice are first four flight from which radial flights without 90°lip are used for sticky materials and angled flights are used for used for free flowing granular material. The EAD and CBD are proposed on the basis of theoretical investigation by Kelly. The semicircular flights were proposed by Purcell. The flights are usually offset every 0.5 m to 2 m depends upon the material properties. For easy distribution of material in first meter or so at the material feed end the spiral flights are used also same flights are used at the material exit end for easy discharge.

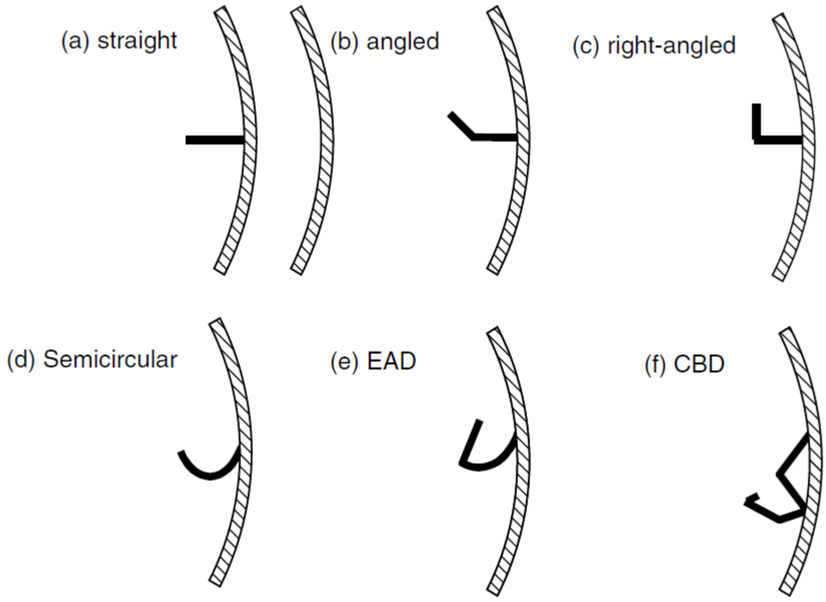

Figure 2.5: For different conditions the shape of flights is different. In above figure (a) Straight flights (b) angled flights (c) right angled flights (d) Semicircular (e) Equal Angular Distribution (EAD) (f) Centrally Biased Distribution (CBD). (a) is used for sticky material (b) , (c) & (d) are used for granular material (e) & (f) are advancement in flight design

The design of radial flights without lip can be design by the drum hold up and flight hold up. From extensive study of different dryer and including theoretical parameters an optimum design condition for flight is established. The results shows that the size of flight is a function of material physical characteristics and geometry of flight. For particular % of loaded area included angle θ_i of lifter can be determined from Fig. 2.6.

$$h = R(1 - cos\theta_i) \tag{2.1}$$

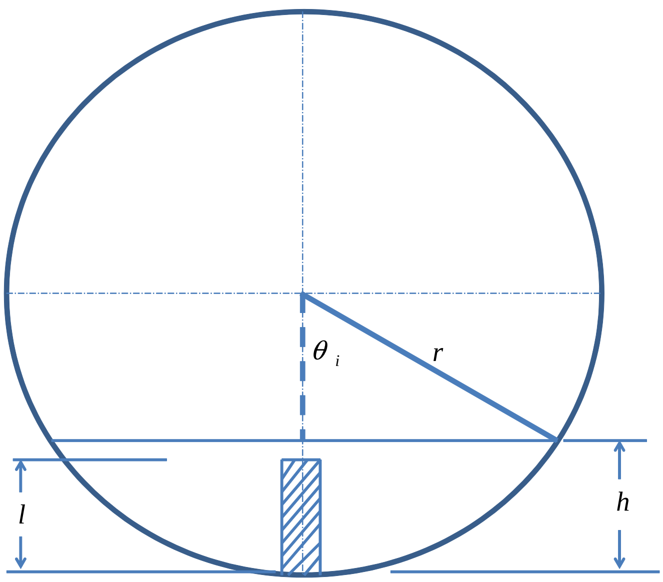

Figure 2.6: At no running condition material get filled in the bottom. The angle included by the material filling is shown in the figure

where,h is the depth of bed load in meter; r is the radius of the drum and θ_i is an angle shown in Fig .2.6, θ_i can be calculate with equation 2.2.

$$sin\theta_i = 0.3212H_o^{0.3544} \tag{2.2}$$

The above equation is obtained from Fig .2.7

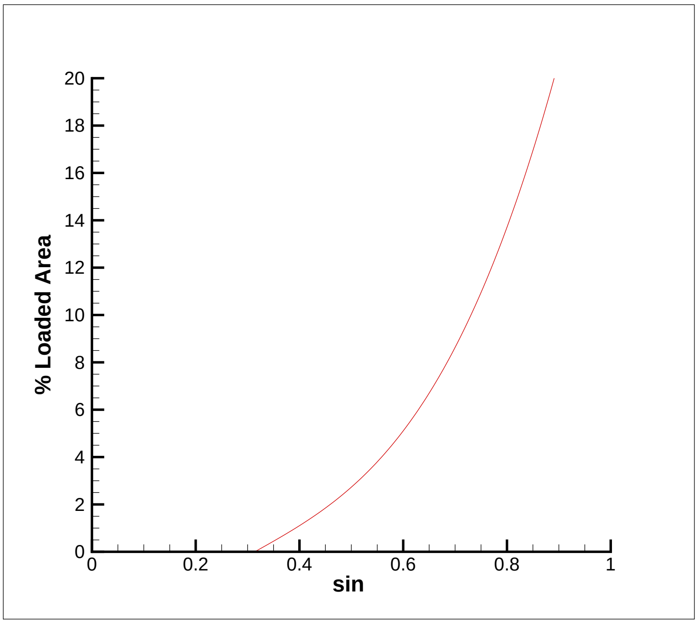

Figure 2.7: Figure shows percentage loaded area vs sin of angle θ_i

The amount of material showered by a single lifter is a function of physical shape and size of lifter and angle of repose of the material. Number of liters per meter of dryer can be determined graphically in a such a way that overlap of the lifter will not occur. From Fig 2.8 it is obvious that if angle θ_n , multiplied by the number of flights then multiplication should not be grater then $360^\circ$to avoid any overlap between flights.

From above discussion it is proven that the sizing of dryer is more influenced by flight design and hold up of flight. The parameter witch combines all other parameter is retention time. The Rotary drum dryer is been designed in two parts. 1^{st} the size of the drum is been calculated; sizing include finding out length and diameter of drum, size, shape and number of flights, inlet temperature requirement and flow rate requirements. In 2^{nd}step the dryer is been rated by dividing dryer drum into number of control volume and applying heat and mass balance to each section, where output of 1^{st} section becomes input to the next section.

2.2.4 Retention time

In a rotary dryer material movement is due to three separate motion cascade motion, kiln action and bouncing. Cascade motion occurs as a result of lifting of particles by flight and the slop of dryer. The advance of particle per cascade is equal to $D_e\,(sin\theta/tana)$ assuming that the descent path of particle is vertical when there is no gas flow. In a co-current flow dryer there is increase in advance of particle due to drag on the cascaded solids while the reverse action occurs with counter current dryer. Kiln action is forward movement of motion of particle due to slop of the drum during particle which remains on the bottom

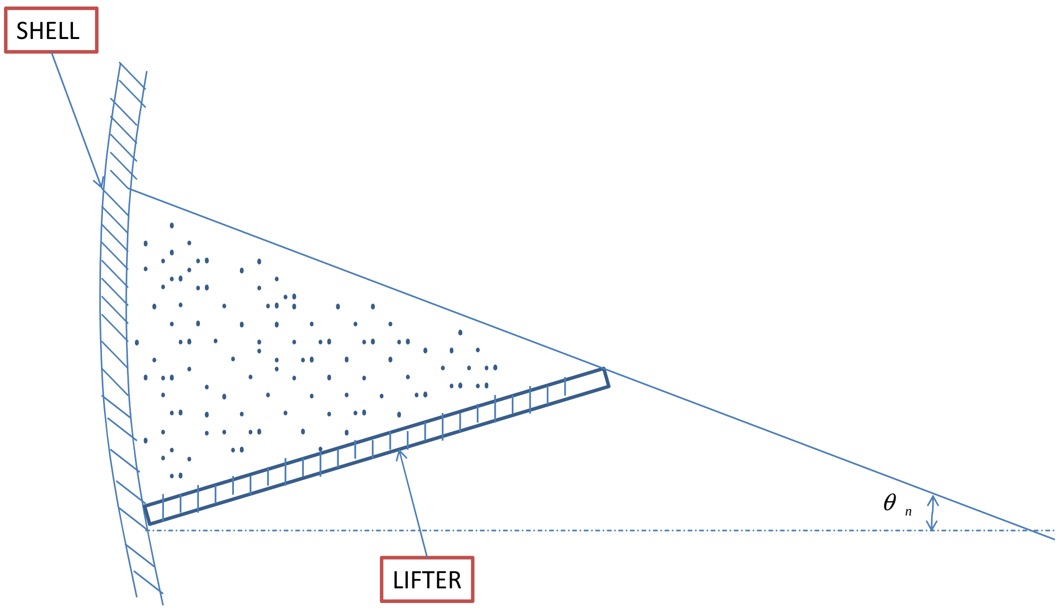

Figure 2.8: The cross sectional view of fully filled flight is shown by the figure. The included angle at the center of the drum gives angular length covered by the materiel at the fully filled condition.

of the drum during cascading moves forward due to slop of the drum. Bouncing motion occurs as the particle falls back to the bottom it bounce back due to impact and moves forward by kiln action instead of resting

Hold up of the dryer is defined as height of material present in the dryer at a particular time. Hold up can be measure by adding radioisotope or a small amount of detectable inert solid in a feed. In study the retention time and hold up are taken as an average values. Retention time and solid mass flow is rate related by equation 2.3 and the drum hold up is related to the flight hold up by equation 2.4.

$$\dot{m} = \frac{H_o}{\tau} \tag{2.3}$$

$$H_o = (1 - \varepsilon)\rho_p H \tag{2.4}$$

where ε is porosity of material, ρ_p is density of material and H is flight holdup.

The retention time is a function of diameter, length, rotating speed and slop of drum which can be shown empirically by equation 2.3

$$\tau = \frac{kL}{n_{rpm} D\alpha} \tag{2.5}$$

The k is empirical constant.

Sulliven et al. (1927) proposed equation for rotary kiln without flight which is known as “Bureau of mines” which is entirely based on practical data available. Johnstone and Singh modified the empirical constant as 0.0433 instead of 0.0310 for dryer with flights. Problem with this equation is that it is not generalized and it do not include the effect of mass flow.

$$\bar{\tau} = \frac{0.0310(Ln_{rpm})^{\frac{1}{2}}}{Dn_{rpm}tan\alpha} \tag{2.6}$$

A more extensive experimental study was done by Prutton. They correlated data by following empirical equation.

$$\bar{\tau} = \frac{kL}{Dn_{rpm}tan\alpha} + \frac{\dot{m}u}{60} \tag{2.7}$$

where k is a non-dimensional constant, which depends on flight geometry and number of flights i.e for 12 flight drum k is 0.375 where for 6 flight drum it is 0.275. m depends on size and density of the material particle and flow direction.Because “m” is not a function of particle properties and equation is more depended on practical data the equation can not be consider universal. Based on experimental data obtained by Friedman and Marshall (1947a), Parry and Clinton gave equation which actually includes fact that holdup is affected by number of flights.

$$\bar{\tau} = \frac{0.23L}{Dn_{rpm}^{0.9}tan\alpha} \tag{2.8}$$

After studding large industrial drying data retention time equation 2.9 was given by Friedman & Marshall (1947a) . The equation is modified number of times for fitting the results with the calculated values. The equation had been used for fertilizer dryer by Arruda et al. (2009). The equation is given by:

$$\bar{\tau} = L\left(\frac{0.1962}{\alpha n_{rpm}^{0.9}D} \pm \left(\frac{0.00036G_a}{G_m d_p^{0.5}}\right)\right) \tag{2.9}$$

where (+ve) sign for counter current dryer and (-ve) for co current dryer. The effect of 2^{nd} term is not much as compare to 1^{st}term but is added to compensate the effects of mass interaction. As the size of the particle decrees the effect of second term increases mean for co current flow dryer with big diameter particle the retention time will be small and vice-verse for counter current dryer. The effect will be reverse for product with small diameter.

The equation given by Foust et al. (1960) for drum dryer is used by Abbasfard et al.(2013) for study of ammonium nitrate plant. The equation 2.10 has very good fit with data measured from the dryer. The error between measured data and calculated values was only (+3.76%).

$$\bar{\tau} = L\left(\frac{13.8}{\alpha n_{rpm}^{0.9}D} \pm \left(\frac{614.2G_a}{\alpha d_p^{0.5}}\right)\right) \tag{2.10}$$

2.3 Sizing of rotary drum dryer

The sizing of dryer can is done by doing mass balance and heat balance of material and drying medium. The sizing of dryer decides length and diameter of drum. The size, shape and dimensions of flight. The rotary dryer suffer with the problem of heat loss from it surface due to its huge exposed surface area. The heat losses can be reduce by applying adequate insulation. The sizing of dryer is influenced by all the parameters which have been discussed above.

The design objective is to give the values of retention time, the dryer efficiency, moisture of exhaust gases, size of drum, size and number of flights, amount of drying medium requirement. The data need are material characteristic both physical and chemical, initial moisture content and final moisture content required, physical size of material and environmental conditions. Few important factors is discussed in this section related to the rating of dryer.

To calculate the heat transferred from the drying medium to the product the drying medium-inlet and exit temperature must be known. The selection of inlet temperature is very important not because of two reasons first the effect of inlet temperature on material property and second is exit temperature. The exit temperature of drying medium must be above dew point temperature in order to prevent precipitation. A relation is proposed between inlet temperature of air and out let temperature of air by van't Land (2012). The proposed relationship is

$$T_{a,o} = 0.05T_{a,i} + 64.5°C \tag{2.11}$$

The proposed equation is an out come of large industrial data studied for counter and co current dryer. The results of equation is very accurate for high temperature drying i.e above $100°C$. The equation was obtained by careful study of four different dryer. The measurement of temperature was done on same point of each dryer and plotted on graph. The accuracy of equation is found to be 0.916.

2.4 Rating of rotary drying

Rating of dryer is done by dividing dryer in number of control volumes and applying heat and mass balance to each control volume and solve it simultaneously. Output of one control volume is input to the constrictive control volume. In each control volume heat and mass balance was done to find out mass flow rate of drying fluid and material and temperature of drying medium and material.

The rating problem assumes that drying is been done in steady state. Very first such study was done by Myklested (1964). The study predicts the moisture contain based on drying air temperature, product feed rate and initial moisture contain. It was assumed that the heat transfer depends on dryer rotational speed and flight hold up by Sharples et al. (1924). The model used four differential equation of heat and mass transfer to predict the final moisture contain temperature of product and drying medium. The same idea was used but by using the equation of Saeman and Mitchell for retention time calculation a model was given by Thorpe(1972). On the other hand for solution of the differential equation drier was subdivided in number of control volume and equations was applied to each control volume till the required conditions achieved. Doglas et al did similar procedure for modeling of counter current sugar dryer but used Friedman & Marshall equations for calculation of retention time heat transfer. A computer simulated model of rotatory dryer with use of empirical equations given by Gilikin (1978) model to predict retention time was presented by Kamke et al. (1986). The study also involves heat and mass transfer model with the use of computer modeling.

2.5 Conclusion from Literature Review

The literature study show work on drum dryer for chemical products such as ammonia and fruit or vegetable products. The literature on gypsum drying with the rotary dryer is very less as compare to other products. The survey is in favor of creating a mathematical model base on heat and mass transfer process. The basic sizing of dryer can be done by making energy and mass balance of the running process. The parameters calculated from sizing can be optimized by another model the rating model. Several authors have tried to optimize the process parameters; the common practice is to divide the drum in to numbers of small control volumes and perform the energy and mass balance on entire system by confirming that each and every CV is conserving energy and mass balance. Abbasfard et al. (2013) has done modeling for amonium nitrate and Iguaz et al. has done for Vegetables products by dividing the drum into numbers of CVs. The results of each of the study is very much close to the practical conditions.The combination of sizing and rating gives the optimized result required for particular conditions.

2.6 Objective

The objective of study is to design and simulate dryer for gypsum drying. From physical and chemical properties and daily requirement (70 MT/day) of JK Lakshmi plant dryer will be selected for design. A mathematical model will be generated for sizing of dryer. The sizing involve the dimension of diameter base on the heat transfer requirements. The sizing of dryer will be rated by rating model. The rating model give value of moisture contain of product and drying medium and temperature of product and drying medium. The rating model gives approximate values of temperate and moisture contain which gives predicted value of dimension requirement of dryer. If the requirement does fulfilled then any of the parameter will be changed. . The said parameter is changed in limits provided by literature which is largely based on experimentation. The final dryer design will be based on optimized design parameters given by combination of both models.

2.7 Organization of Report

The report has been organized as

1. Chapter 3 discusses about mathematical model generated for drying; the out come of which is sizing of dryer and rating of dryer based on sizing. The later part of chapter gives algorithm of computer modeling of sizing and rating of dryer.

2. Chapter 4 discusses the results of computer simulation of dryer and effect of each parameter of dryer. The final design of gypsum dryer is outlined.

3. Chapter 5 discusses the final conclusion and future work.

Chapter 3

Mathematical Model

Mathematical model is been generated by considering heat and mass transfer process between drying medium and material. The drying medium is taken as air and material to be dried is gypsum. The model is been discussed in subsequent sections.

3.1 Rotary Drum Dryer

Rotary dryer is designed in two parts first part deals with the sizing of dryer. Sizing of dryer gives geometric parameters of dryer i.e length of drum, diameter of drum and shape and number of flights.

3.1.1 Sizing of rotary drum dryer

Objective of enclosed design is to find flow rates of entering air, final moisture contain of air, retention time, hoarse power requirement for motor and fuel consumption requirement. The required input data are capacity requirement of dryer in kg/h; final moisture requirement of product; specific heat of material; bulk density of dry and wet material and % screen analysis of material.

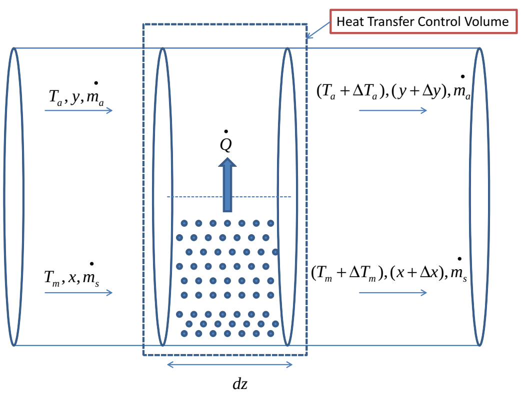

Figure 3.1: For a small CV of length "dz" the heat and mass interaction between the gypsum and air is shown by the above figure.

Heated air is entering the dryer in concurrent manner with the material. Due to direct interaction between material and air convective heat transfer occurs. The air leaves the dryer with lower temperature and high humidity as it evaporates the excess water of material and carry forward with it.

Considering whole drum as a control volume having two temperature input and two moisture input as shown in Fig. 3.1 than mass balance will be:

3.1.1.1 Mass balance

Dry solid rate in feed

$$\dot{m}_m = C(1 - x_i) \tag{3.1}$$

Water rate in feed i.e. inlet condition

$$\dot{m}_w = Cx_i \tag{3.2}$$

Lets assume water rate in product be $\mathring{m}$kg/h i.e. drying rate

$$\left(\frac{\dot{m}}{\dot{m} + \dot{m}_m}\right) = x_o \tag{3.3}$$

$$\dot{m} = \left(\frac{x_o \dot{m}_m}{(1 - x_o)}\right) \tag{3.4}$$

So the amount of water evaporated from martial

$$\dot{m}_e = \dot{m}_w - \dot{m} \tag{3.5}$$

3.1.1.2 Heat balance

It is assume that material is being dryer from $T_{m,i}$ to $T_{m,o}$ in such manner that the material properties not been altered at any point of time. Heat requirement for drying of $\dot{m}_e$kg/h material can be calculated as follows:

For Co-Current/Counter-Current drying the inlet temperature of dryer is selected and the outlet temperature then will be calculate from equation 3.6

$$T_{a,o} = ((0.05T_{a,i}) + 64.5) \tag{3.6}$$

Heat require to raise the temperature of feed to $T_{m,o}$,a safe material outlet temperature in kW

$$\dot{Q}_A = \dot{m}_m c_m (T_{m,o} - T_{m,i}) \tag{3.7}$$

Heat supplied to residual moisture in the product at bulk mean temperature of product in kW

$$\dot{Q}_B = \dot{m} c_m \left(\frac{(T_{m,o} + T_{m,i})}{2}\right) \tag{3.8}$$

Sensible heat supplied to evaporated moisture at bulk mean temperature of product in kW

$$\dot{Q}_C = \dot{m}_e c_m \left(\frac{(T_{m,o} + T_{m,i})}{2}\right) \tag{3.9}$$

Latent heat to evaporated water at bulk mean temperature in kW

$$\dot{Q}_D = \dot{m}_e(h_{fg}) \tag{3.10}$$

Drum dryer has very large exposed surface area due to which heat losses should be measure on an actual dryer. According to literature the heat loss by dryer is about 10 % of total heat requirements. Though it is not always accurate but when there is no actual data available the assumption is valid because it is a conclusion of large data simulation on other working dryers.

Heat loss from dryer surface in kW

$$\dot{Q}_E = 0.1(\dot{Q}_A + \dot{Q}_B + \dot{Q}_C + \dot{Q}_D) \tag{3.11}$$

Total Air requirement for heat transfer requirement in kg/sec

$$\dot{m}_a = \left(\frac{\dot{Q}_A + \dot{Q}_B + \dot{Q}_C + \dot{Q}_D + \dot{Q}_E}{c_a(T_{a,i} - T_a)}\right) \tag{3.12}$$

Exhaust gases has higher temperature then ambient atmosphere so heat loss in exhaust gases in kW

$$\dot{Q}_F = \dot{m}_a c_a \left(T_{a,o} - T_a\right) \tag{3.13}$$

Inlet air to the furnace is have inherent moisture which is heated to the inlet the temperature of the dryer. Assuming air inlet to the furnace is having some RH and having temperature as of ambient the from psychromatic chart the amount of moisture in kg/kg dry air can be obtain.

The heat loss due to moisture of air at bulk mean temperature of air in kW

$$\dot{Q}_G = \dot{m}_a c_a \left(\frac{T_{a,o} + T_{a,i}}{2}\right) \tag{3.14}$$

Actual total heat requirement in kW

$$\dot{Q}_{total} = (\dot{Q}_A + \dot{Q}_B + \dot{Q}_C + \dot{Q}_D + \dot{Q}_E + \dot{Q}_F + \dot{Q}_G) \tag{3.15}$$

Hence the total air requirement in kg/sec

$$\dot{m}_a = \left(\frac{\dot{Q}_{total}}{c_a(T_{a,i} - T_a)}\right) \tag{3.16}$$

3.1.1.3 Diameter of drum

The diameter drum depends on the total volume of gas present in the dryer. The velocity of gas and volume of gas can be calculated from mass flow rate of gas in the dryer. The heat requirement dryer will decide the mass flow rate requirements. To reduce the air requirement the volume flow rate need to be optimized, which can be done by reducing the heat losses from dryer. Major heat loss is from the surface of drum and exhaust gases. The losses can be control by adding insulation to the shell of the drum. The formula assume that the gas velocity will be equal to the velocity of the pickup particles at the discharge end of the dryer and all the size of the particles are picked up by the stream.

The diameter of the drum in meters

$$D = 2\sqrt{\left(\frac{V_{total}}{\pi v_c}\right)} \tag{3.17}$$

Where;
Total quantity of gases flowing in the drum in m^3/min

$$V_{total} = V_{air} + V_{water} \tag{3.18}$$

The gas quantities needs for the for heat transfer process to occurred.
Volume flow rate of air required in m^3/min

$$V_{air} = 0.06243\frac{\dot{m}_a}{60}\frac{359}{29}\left(\frac{T_{a,i}+273}{273}\right) \tag{3.19}$$

Volume flow rate of water vapor in air in m^3/min

$$V_{water} = 0.06243\frac{\dot{m}_{total,moisture}}{60}\frac{359}{29}\left(\frac{T_{a,i}+273}{273}\right) \tag{3.20}$$

Total water evaporated from system

$$\dot{m}_{total,moisture} = \dot{m}_{air,moisture} + \dot{m}_e \tag{3.21}$$

1. Moisture in material due to heat transfer $\dot{m}_e$

2. Moisture in the air $\dot{m}_{air,moisture}$

Hence the total density of gases in in kg/m^3

$$\rho_{gas} = \frac{\dot{m}_{air} + \dot{m}_{air}}{V_{total}} \tag{3.22}$$

Hence the absolute humidity of the exhaust gas in kg/kg dry air

$$Humidity_{absolute} = \frac{\dot{m}_{water}}{\dot{m}_{air}} \tag{3.23}$$

A particle can be conveyed by the aerodynamic effect of the gas stream. A relationship was developed between conveyed material velocities and equivalent diameter of the particles as a function of the bulk weight density.

In a horizontal pipe conveying velocity in m/min is given by

$$v_h = \left(\frac{6000sd_p^{0.4}}{s+1}\right) \tag{3.24}$$

The calculate velocity is corrected at the design gas temperature in terms of density ratio in m/min.

$$v_c = v_h\frac{1.2}{\rho_{air}} \tag{3.25}$$

3.1.2 Flight Design

The wet gypsum is a very sticky material so the best flight shape will be straight radial flights. The radial flight allows the material to fall easily and there is no other restriction for flow. The size of the flights depends up on % hold up of the drum. The relation between drum hold up and included angle discussed earlier in the report.

3.1.2.1 Depth of Drum Filling

The physical size and shape of each lifter and the angle of repose of the product determines the amount of the material showers by each lifter as it goes through its showering cycle. Chemical allis-Chalmers Ltd. (1960) provided the relationship between included angle and holdup.

So the equation can be written as

$$Sin\theta_i = 0.3212 H_o^{0.3544} \tag{3.26}$$

Angle of Repose of the material and height of filling of drum is related as

$$h = R(1 - cos\theta_r) \tag{3.27}$$

3.1.2.2 Area of Flight Filling

The cross sectional area of the material retained by each lifter is determined from geometrical calculation. A flight can carry maximum amount of material in horizontal position. Assuming the shape of material cross section is triangular. In operating condition there are three condition possible as under loaded flights (l<h), over loaded flights (l>h) and design loaded flights (l=h). As the hold up of the drum is already decided hence the length of the flight should be selected near to the or equal to the height of drum fill. If the length of flight is higher then the flights will be under loaded which reduces the efficiency of drying. An over loaded flight will causes the additional material to flow by kiln action which also reduces the effectiveness of drying. It is necessary to select flight length near or equal to the drum fill depth h.

$$A_f = \frac{1}{2} l^2 tan\theta_r \tag{3.28}$$

3.1.2.3 Number of Flights

Usually the number of flights is between 2D to 4D where Diameter is measured in feet. It is more appropriate to select number flights by considering geometry then directly from empirical formula because the motive is to design dryer not optimize. The optimization will be done in latter part of report but to optimize flight count the selection must be based on geometry.

As shown in Fig. 2.8 on page 16 the material filling of flight will include angle θ_n at the center of drum. Hence the maximum number of flights will be $\frac{360}{\theta_n}$. From geometry angle θ_n can be given by

$$tan\theta_n = \frac{l tan\theta_r}{R} \tag{3.29}$$

$$N_f = \frac{360}{\theta_n} \tag{3.30}$$

In one full rotating of drum all the flights will not take part in drying. As shown in Fig. 2.4 on page 13 the the drum can be divided in two parts active part and passive part. The flights in passive parts has no material in side. The active part flights are the flights which takes part in drying. The effective number of flights can be calculated with equation (3.31)

$$N_{eff} = C^{\star} N_f \tag{3.31}$$

C is a proportionality constant which relates cascading time and speed of drum. The speed of drum is rated to the diameter of drum. As the diameter in creases the peripheral speed of drum decreases i.e drum of diameter 2 m with 5 rpm has peripheral speed of 0.52 m/sec; where as drum of 4 m with same 5 rpm has peripheral speed of 1.04 m/s. Hence the diameter of drum and rpm of drum are inversely proposal to each other. From experimentation and experience the range of $(n_{rpm}D)$is between 9 to 12.

As the diameter of drum is already decided the n_{rpm} of drum must be selected that satisfy the criteria. The proportionality constant $C^{\star}$ can be defined as ratio of total cascade time of particle in sec to the period of rotation in sec.

$$C^{\star} = \frac{t_c}{t_r} \tag{3.32}$$

Time of rotation of drum in second

$$t_r = \frac{60}{n_{rpm}} \tag{3.33}$$

Total time of cascade of particle in drum is sum of time of falling and time of lifting as shown in Fig. 2.4 on page 13

$$t_c = t_f + t_l \tag{3.34}$$

3.1.2.4 Falling time of particle

Time of fall of the particle can be calculate as, particle falling from height by gravitational pull only and assuming there is no force present in the system and starting velocity is zero.

$$h_{fall} = \left(\frac{g t_f^2}{2}\right) \tag{3.35}$$

whereh_{fall} is height of fall of fall considering on drag force along the longitudinal direction.

The height of fall and drum diameter can be related by equation 3.36

$$h_{fall} = D sin\phi \tag{3.36}$$

Where, ϕ is rotational angle from the horizontal, the particle starts falling when the angle included by flight with center of drum excised angle of repose of the material. So ϕ can be taken as angle of repose of the material θ_r. From equation 3.35 and equation 3.36.

Falling time of particle t_f in sec

$$t_f = \sqrt{\frac{2Dsin\theta_r}{g}} \tag{3.37}$$

3.1.2.5 Lifting time of particle

The lifting velocity of particle depends on rpm of drum. The lifting velocity of particle is peripheral speed of drum in m/s.

$$v = \frac{n_{rpm}\pi D}{60} \tag{3.38}$$

The peripheral speed of drum and falling time can be related by

$$v = \frac{2D\theta_r}{t_l} \tag{3.39}$$

Hence Lifting time of particle t_l in sec

$$t_l = \left(\frac{120\theta_r}{\pi n_{rpm}}\right) \tag{3.40}$$

3.1.3 Length of Dryer

The heat transfer process can be equated as equation 3.41. As seen from equation 3.41 that heat transfer process is affected by total heat requirement and overall temperature difference. The length of drum is related with total heat requirement, as the length of drum increases the heat loss increase. Hence to reduce heat requirement the length must be optimized. The optimization can be done by increasing overall temperature or by increasing overall heat transfer rate.

$$\dot{Q}_{total} = U_a AL(\Delta T)_m \tag{3.41}$$

3.1.3.1 Logarithmic mean temperature for dryer

Overall temperature difference can be taken as logarithmic mean temperature difference (LMTD). The LMTD of counter-current arrangement is more as compare to parallel arrangement for same conditions. The choice of counter of parallel arrangement depends on material properties. In counter current arrangement the at exit the low temperature of air may fall below dew point temperature which is not a desirable condition. So for hydrophilic material like gypsum the parallel arrangement is more advisable. LMTD can be given by eq

$$(\Delta T)_m = \left(\frac{(\Delta T)_1 - (\Delta T)_2}{ln\left(\frac{(\Delta T)_1}{(\Delta T)_2}\right)}\right) \tag{3.42}$$

Where;

$$\text{For parallel flow} \begin{cases} (\Delta T)_1 = (T_{air,in} - T_{m,in}) \\ (\Delta T)_2 = (T_{air,out} - T_{m,out}) \end{cases}$$

$$\text{For parallel flow} \begin{cases} (\Delta T)_1 = (T_{air,in} - T_{m,out}) \\ (\Delta T)_2 = (T_{air,out} - T_{m,in}) \end{cases}$$

3.1.3.2 Volumetric heat transfer coefficient

The volumteric heat transfer rate of dryer can be calculate by empirical equation which ignores the effects of conduction and radiation heat transfer.

$$U_a = \frac{U_k G^n}{D} \tag{3.43}$$

where U_k and n are empirical constant. They are depends on the dryer geometry. where in general $n = 0.67$ is taken and U_k is taken from practical test of dryer and the value 0.2 to 0.3 in general.

In case the test data is not available then it can be calculated from Reynolds number and Prandtl number of flow as discus below. The overall heat transfer coefficient is sum of individual heat transfer coefficient of particle with the drying medium. Hence to total heat transfer coefficient is number of particle times the individual heat transfer coefficient given by equation 3.44.

$$U_a = (h_c N_p) \tag{3.44}$$

where h_c is heat transfer coefficient of individual particle; N_p is number of particles in the dryer.

In actual condition all the particle will not be in contact with drying medium. The effective number of particle per meter length of dryer can be given by $\left(\frac{N_e A_m}{A}\right)$where A is cross sectional area of dryer per unit length.

$$U_a = \left(K \frac{h_c A_m N_p}{A}\right) \tag{3.45}$$

Heat transfer coefficient can be calculate by using falling equation 3.46.

$$Nu = \frac{h_c d_p}{k_g} = 2 + (0.6 Re^{0.5} Pr^{0.33}) \tag{3.46}$$

where Reynolds number is given by

$$Re = \frac{v_a \rho_a d_p}{\mu_a} \tag{3.47}$$

where,

$$v_a = \sqrt{v_p^2 + v_c^2} \tag{3.48}$$

Falling velocity of particle

$$v_p = \sqrt{\frac{Dg}{2}} \tag{3.49}$$

The material being dried is in lumps of different sizes, for calculation purpose the average particle size is used. To calculate average particle size screening analysis of material was done. The average particle size can be calculated with equation 3.50

The average diameter of particle can be calculated from screen analysis by following equation.

$$d_p = \sum ((d_p)_i p_i) \tag{3.50}$$

where $i = 1, 2, 3...$ number of size of diameters and p is % of material of particular diameter.

3.1.3.3 Air properties

Air properties can be calculate from following. The equation are having accuracy of 0.99 at any temperature. The equation are taken from The Handbook of Shock Absorber given by Dixon, J.C. (2007).

$$Tk = \left(\frac{101325}{(287.05\rho_a)}\right) \tag{3.51}$$

$$c_a = (0.001(1002.2 + (0.000275(Tk - 200)^2)) \tag{3.52}$$

$$ka = \left(0.02624\left(\frac{T_k}{300}\right)^{0.8646}\right) \tag{3.53}$$

$$\mu_a = \left(0.000001458\frac{T_k^{1.5}}{T_k + 110.4}\right) \tag{3.54}$$

$$Pr = \left(0.680 + \left(0.000000469(Tk - 540)^2\right)\right) \tag{3.55}$$

3.1.4 Rating of Drum dryer

The rating of dryer deals with validation of the dimensions find out from sizing. The rating of dryer gives value of exit temperature of air, exit temperature of material, exit moisture contain of air and exit moisture contain of product. The dimensions found by sizing model is sufficient or not is decided by rating it may happens that length of dryer may be not sufficient or may be it larger then required.

The drum of dryer is divided in to N number of small elemental control volume having "dz" length. Heat and mass balance is done on each control volume and final temperature and moisture contain is obtain as following.

Material and Air is considered as two separate control volume interacting with each other and transferring moisture and heat with each other as shown in Fig. 3.1

3.1.4.1 Solid Control Volume

Consider a control volume of "dz" is have N_p numbers of particles and each particle is taking part in heat and mass transfer process. The interaction process of heat and mass transfer is shown in the Fig. 3.2. Material is loosing moisture to air i.e. mass loss and gaining heat from air i.e. temperature increase.

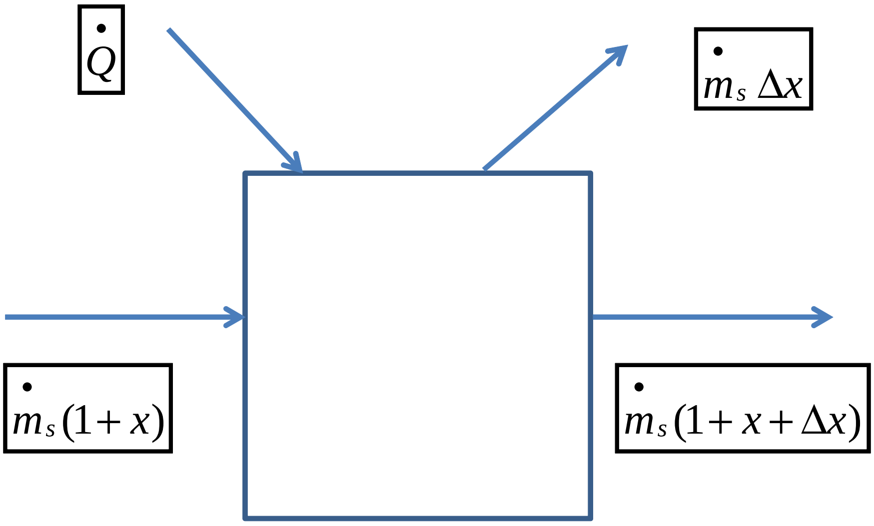

Figure 3.2: Solid Control Volume

Lets increase of temperature be ΔT_m (+ve) and loosing moisture Δx (-ve). The total heat transfer at steady state can be calculate by energy balance of control volume.

$$\dot{Q} = (\dot{m}_s C_{p,m} \Delta T_m) - (\dot{m}_s \Delta x h_{fg}) \tag{3.56}$$

where;
$\dot{m}_s$= mass of product in kg/s.
$C_{p,m}$=$C_{p,s}$+($xC_{p,l}$).
h_{fg} = Latent heat of vaporization of water.
The heat transfer to an individual particle of gypsum by air:

$$\dot{Q}_n = hA_P \left(T_a - T_m\right) f \tag{3.57}$$

Where
h =heat transfer coefficient.
A_P= Area of particle = πd_p^2.
f= fraction of time a particle is airborne.
Fraction of the time a particle is directly in contact with drying medium is in-between it falls from flight tip to reach the hit the bottom of the drum. As the effective diameter of drum $D_e = (D - (2l))$
Fraction of time a particle is airborne :

$$f = \left(\frac{t_{fall}}{t_{total}}\right) = \left(\frac{\sqrt{\frac{2D_e sin\theta_r}{g}}}{\left(\frac{\left(\frac{60}{n_{rpm}}\right)}{2}\right)}\right) \tag{3.58}$$

where $t_{total}$is total time of particle in motion here assuming that only half portion of dryer is working as active part.
From continuity equitation mass of solid

$$\dot{m}_s = (\rho A v) = \left(\frac{N_p \dot{m}_p A u_{eff}}{Adz}\right) = \left(\frac{N \dot{m}_p u_{eff}}{dz}\right) \tag{3.59}$$

Where $m_p$is mass of particle and N_p is number of particles.
Equation 3.56 can be modify to calculate change of material temperature as follows:

$$Q = N_p \dot{Q}_n = \left(\frac{N_p \dot{m}_p u_{eff}}{dz} \right) \left(\left(C_{p,s} + \left(x C_{p,l} \right) \Delta T_m \right) - \Delta x h_{fg} \right) \tag{3.60}$$

$$\Delta T_m = \left(\frac{\left(\frac{\dot{Q}_n dz}{\dot{m}_p u_{eff}} \right) + \left(\Delta x h_{fg} \right)}{C_{p,s} + \left(x C_{p,l} \right)} \right) \tag{3.61}$$

According to definition of mass transfer Mass tarfer rate=$\frac{\text{Rate of transfer}}{\text{Unit gas-liqued interface area}}$
During constant rate drying period it is assumed that the drying takes places from a saturated surface of the material by diffusion of the water vapor through a stationary air film.

$$J = \frac{dC_l}{dt} = K_m A_m (C^* - C_l) \tag{3.62}$$

J= Mass transfer flux.
K_m=Mass transfer coefficient.
C^*= Saturated gas concentration.
C_l= Dissolved gas concentration at temperature T.
Modifying 3.57 for N_p numbers of particle loosing moisture then combine moisture removal rate can be given by:
Mass flux of moisture at any time = $\dot{m}_m \Delta x$;
$C^* = \frac{P_{sat}}{R_1 T_s}$ where $R_1 = 0.4614$ kPa·m^3/kg/k.
$C^* = \frac{YP}{(Y+0.62)(R_2 T_a)}$ where $R_2 = 0.287$ kPa·m^3/kg/k.

$$\dot{m}_s \Delta x = -N_p K_m A_p f \left[\left(\frac{P_{sat}}{R_1 T_m} \right) - \left(\frac{yP}{\left(y + 0.62 \right) R_2 T_a} \right) \right] \tag{3.63}$$

$$\therefore \Delta x = -\left(\frac{K_m A_p f dz}{\dot{m}_p u_{eff}} \right) \left[\left(\frac{P_{sat}}{R_1 T_s} \right) - \left(\frac{yP}{\left(y + 0.62 \right) R_2 T_a} \right) \right] \tag{3.64}$$

The saturation of water vapor can be found out from Antonia Equation:

$$P_{sat} = e^{\left(A - \left(\frac{B}{T_s - C} \right) \right)} \tag{3.65}$$

Where A = 16.709; B = 4090 and C = 237.

3.1.4.2 Air control volume

Air is transferring heat to the material and losing heat to atmosphere via shell of drum. The loss of heat can be reduce by adding insulation to the shell. The loss of heat is taken directly from sizing of drum because there is no actual system on which can losses can be measured. In actual dryer heat loss must be measured to get an accurate result. The interaction process of heat and mass transfer is shown in the Fig 3.3

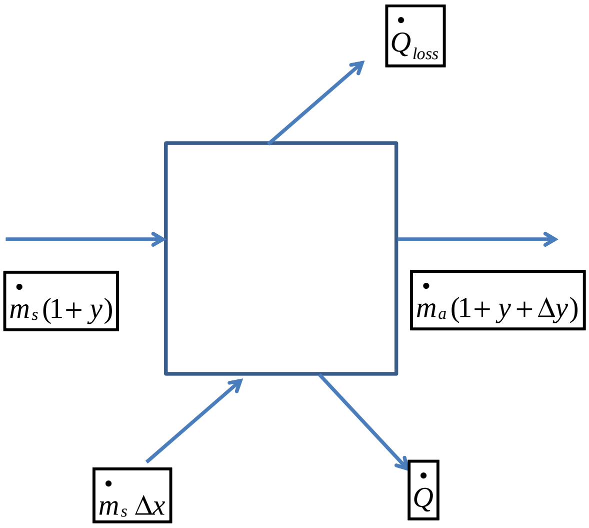

Figure 3.3: Air Control Volume

The Drying air is losing heat so heat transfer is (-ve) and gaining moisture so mass transfer is (+ve). Mass balance is given by.

$$(\dot{m}_s \Delta x) = -(\dot{m}_a \Delta y) \tag{3.66}$$

The energy balance can be give by:

$$-\left(\dot{Q}_{loss} + \dot{Q}\right) = \dot{m}_a\left[(C_{p,g}\Delta T_a) + (\Delta y C_{p,v}(T_a - T_m))\right] \tag{3.67}$$

where $C_{p,g} = (C_{p,a} + yC_{p,v})$
Substituting value of $\dot{Q}$ and rearranging terms to get Δt_a

$$-\Delta T_a = \frac{\dot{m}_s(C_{p,m}\Delta T_m) + \dot{m}_a\Delta y\,(h_{fg} + C_{p,v}(T_a - T_s)) + \dot{Q}_{loss}}{\dot{m}_a C_{m,g}} \tag{3.68}$$

To avoid numerical instabilities Crank-Nicolson metod is applied.
The equation 3.61 will be modify as:

$$C_{p,s}\Delta T_m = \left(\left(\frac{fdz}{m_s u_{eff}}\right) hA_p\left[\frac{T_a - T_m + T'_a - T'_m}{2}\right]\right) + (\Delta x h_{fg}) \tag{3.69}$$

The equation 3.68 is of form

$$T'_a = T_a + A_1 + A_2\Delta T_m \tag{3.70}$$

and

$$T'_s = T_s + \Delta T_s$$

Modified 3.70

$$T'_a - T'_m = ((T_a - T_m) + A_1 + (A_2 - 1)\Delta T_m) \tag{3.71}$$

Substituting equation 3.71 in equation 3.69

$$C_{p,s}\Delta T_m = \left(\left(\frac{fdz}{\dot{m}_s u_{eff}}\right) hA_p \left[\frac{2\left(T_a - T_m\right) + A_1 + \left(A_2 - 1\right)\Delta T_m}{2}\right]\right) + \left(\Delta x h_{fg}\right) \quad (3.72)$$

Making 3.64an implicit function:

$$\Delta x = -\left(\frac{K_m A_p f dz}{\dot{m}_p u_{eff}}\right)\left[\left(\frac{P_{sat,i} + P_{sat,(i-1)}}{2R_1 T_m}\right) - \left(\frac{yP}{\left(y + 0.62\right) R_2 T_a}\right)\right] \quad (3.73)$$

for small steps

$$P_{sat,(i-1)} = P_{sat,i} + \left(\frac{dP_{sat}}{dT_s}\Delta t_s\right) \quad (3.74)$$

Modifying 3.72

$$\Delta T_s = \frac{\left[\left(hA_p\left\{T_a - T_s + \left(\frac{A_1}{2}\right)\right\}\right) - \left(h_{fg}A_p\left(\frac{P_{sat}}{R_1 T_s} - \frac{Py}{(y+0.62)R_2 T_a}\right)\right)\right]}{\left[\left(\frac{m_p v}{fdz}C_{p,m}\right) - \left(\frac{hA_p(A_2-1)}{2}\right) + \left(\frac{h_{fg}K_m A_p}{2Rt_s}\frac{dP_{sat}}{dT_s}\right)\right]} \quad (3.75)$$

3.1.4.3 Heat transfer and Mass transfer coefficient:

The heat transfer coefficient can be calculate from Nusselt number

$$Nu = \frac{h_c d_p}{k_g} = \left(2 + 0.6Re^{0.5}Pr^{0.33}\right) \quad (3.76)$$

Reynolds number of a particle

$$Re = \left(\frac{4\dot{m}_a dp}{\pi D^2 \mu(1-f)}\right) \quad (3.77)$$

$$v = \left(\frac{\dot{m}_a}{\left(\frac{0.628\pi D^2(1-f)}{4}\right)}\right) \quad (3.78)$$

All the parameters can be calculate as discus in sizing model.
The Mass transfer and heat transfer coefficient are related by following equation given

$$\frac{h_c}{K_m} = \rho C_p \left(\frac{\alpha}{D_{diff}}\right)^{\frac{2}{3}} \quad (3.79)$$

Diffusion coefficient can be calculated from

$$D_{diff} = 435.7\left(\frac{t_a^{\frac{3}{2}}}{P_{atm}\left(M_A^{\frac{1}{3}} + M_W^{\frac{1}{3}}\right)}\sqrt{\left(\frac{1}{M_A} + \frac{1}{M_W}\right)}\right) \quad (3.80)$$

Instantaneous equations:

$$x(i+1) = x(i) + \Delta x \quad (3.81)$$

$$y(i+1) = y(i) + \Delta y \tag{3.82}$$

$$T_s(i+1) = T_s(i) + \Delta t_s \tag{3.83}$$

$$T_a(i+1) = T_a(i) + \Delta t_a \tag{3.84}$$

3.1.5 Retention time

Retention time of dryer is needed to be calculate from a pilot scale dryer. The reason is that each and every material act differently during drying so retention time of dryer can not be predicted by a generalized equation i.e. for drying of ammonium nitrate a study is presented by Abbasfard et al. (2013) in which the retention time was calculated with five different model equation and the retention time given by each model was different. Friedman & Marshall model is giving error of (-64.73 %) where as Fost et al model give an error of (+3.76 %) between calculated and measured value. On the other hand a study done by Fernandes et al. (2009) on an industrial dryer and retention time for the mathematical model was taken as given by Friedman and Marshall is giving (+6%) difference between calculated value and measured value.

For drying of gypsum by rotary dryer the retention time is calculate with following retention time model.

3.1.5.1 Matchett and Sheikh Model

A model was proposed for under loaded and design loaded drum by relating retention time with geometry and rotational speed of drum by Matchett and Sheikh (1990). The model makes more sense then other model because it is based on geometry of dryer rather then based on experimental data.

$$\bar{\tau} = \left(\frac{L(n_{prm}t_{fall} + \delta)}{n_{prm}t_{fall}\left(U_1 + (aD\delta(tan\alpha)/t_{fall})\right)} \right) \tag{3.85}$$

where; U_1 is velocity of solid particle in airborne phase

$$U_1 = U_{1a} + U_{1d} \tag{3.86}$$

Axial velocity of airborne phase:

$$U_{1a} = 0.5 g t_{fall} sin\alpha \tag{3.87}$$

Drag velocity in the direction of the flow

$$U_{1d} = 0.000745 Re^{2.2} \left(\frac{\mu u t_{fall}}{\rho_s d_p^2} \right) \tag{3.88}$$

Velocity of gypsum particle through the dryer can be calculated by:

$$u = \left(\frac{L}{\tau} \right) \tag{3.89}$$

Effective flow velocity will be during fraction of the time the particle is airborne:

$$u_{eff} = \left(\frac{u}{f}\right) \tag{3.90}$$

3.2 Algorithm

3.2.1 Sizing Model of Drum Dryer

- Calculate mass flow rate of solid at feeding point with equation 3.1; mass flow rate of water in the solid at feeding point with equation 3.2; Evaporation rate of water with equation 3.4. The Evaporation rate of the solid will give the amount of water evaporated from solid after drying, that can be calculated with equation 3.5.

- Assume the safe temperature for solid up to which it can be heated from the thermal properties of material. Calculate outlet temperature of the air from the empirical relationship given with equation 3.6.

- Calculate total heat required for evaporation of amount of water calculated earlier. The heat required for heating the material calculated with equation 3.7. The heat supplied to the remaining water in the material at bulk mean temperature with equation 3.8. Calculate sensible heat gain by the evaporated water bulk mean temperature of material with equation 3.9. Calculate the latent heat supplied to water vapor at bulk mean temperature of solid with the equation 3.10. Calculate heat losses form the dryer with equation 3.11.

- Calculate mass flow rate of air required with equation 3.12. Calculate loss of heat because of temperature difference between exhaust and ambient air with equation 3.13. Calculate the amount of residual moisture flow rate inside the air with equation . Calculate amount of heat taken away by residual moisture with equation 3.14. Calculate mass flow rate required after adding additional losses with equation 3.16. Calculate total amount of moisture flow rate in air stream.

- Calculate Volume flow rate of air and water with equation 3.19 and 3.20 respectively. Calculate density and humidity of exhaust air with equation 3.22 and 3.23 respectively. Calculate conveying velocity for particle with equation 3.24. Calculate diameter of drum with equation 3.17.

- Calculate included angle shown in Fig. 2.6 on page 14 with the equation 3.25. Calculate depth of filling of drum with equation 3.26.

- Assume appropriate length of flight.

- Calculate Angle included by fully filled flight with the center of drum with equation 3.27. Calculate area of flight and numbers of flight from equation 3.28 and 3.30 respectively.

- Select number of flights lesser or equal to calculated number of flights.

- Calculate falling time of particle and lifting time of particle with equation 3.37 and 3.40respectively. Calculate time of rotation of drum with equation 3.33. Calculate Effective number of flights with equation 3.31.

- Calculate Logarithmic mean temperature difference with equation 3.42. Calculate Reynolds number with equation 3.47. Calculate air properties at calculated density with equations 3.51 to 3.55. Calculate heat transfer coefficient with equation 3.46. Calculate overall heat transfer coefficient with equation 3.45.
- Calculate length of the drum with equation 3.41.

3.2.2 Rating Model

- Calculate mass flow rate of material. Calculate mass flow rate of air. Calculate area of a single particle. Calculate mass of a single particle.
- Calculate fraction of time a particle is airborne with equation 3.58. Calculate falling time of the particle with equation 3.37.
- Calculate Reynolds number for flow with equation 3.77. Calculate velocity of air with equation 3.78. Calculate falling velocity of particle with equation 3.87. Calculate drag velocity of "particle" with equation 3.88. Convert rotation of drum from rpm of to rps. Calculate retention time with equation 3.85. Calculate effective particle velocity with equation 3.90
- Calculate air properties with equations from 3.51 to 3.55. Calculate P_{sat} and dP_{sat} from equation 3.62 and 3.74 respectively. Calculate Coefficient of diffusion with equation 3.80.
- Calculate change in product moisture Δx with equation 3.73 . Add Δx to instantaneous value of product moisture to get next value of product moisture with equation 3.81.
- Calculate change in air moisture Δy with equation 3.66. Add Δy to instantaneous value of air moisture to get next value of air moisture with equation 3.82.
- Calculate change in product temperature ΔT_s with equation 3.75. Add ΔT_s to instantaneous value of product temperature to get next value of product temperature with equation 3.83.
- Calculate change in air temperature ΔT_a 3.68 with equation . Add ΔT_a to instantaneous value of air temperature to get next value of product temperature with equation 3.84.

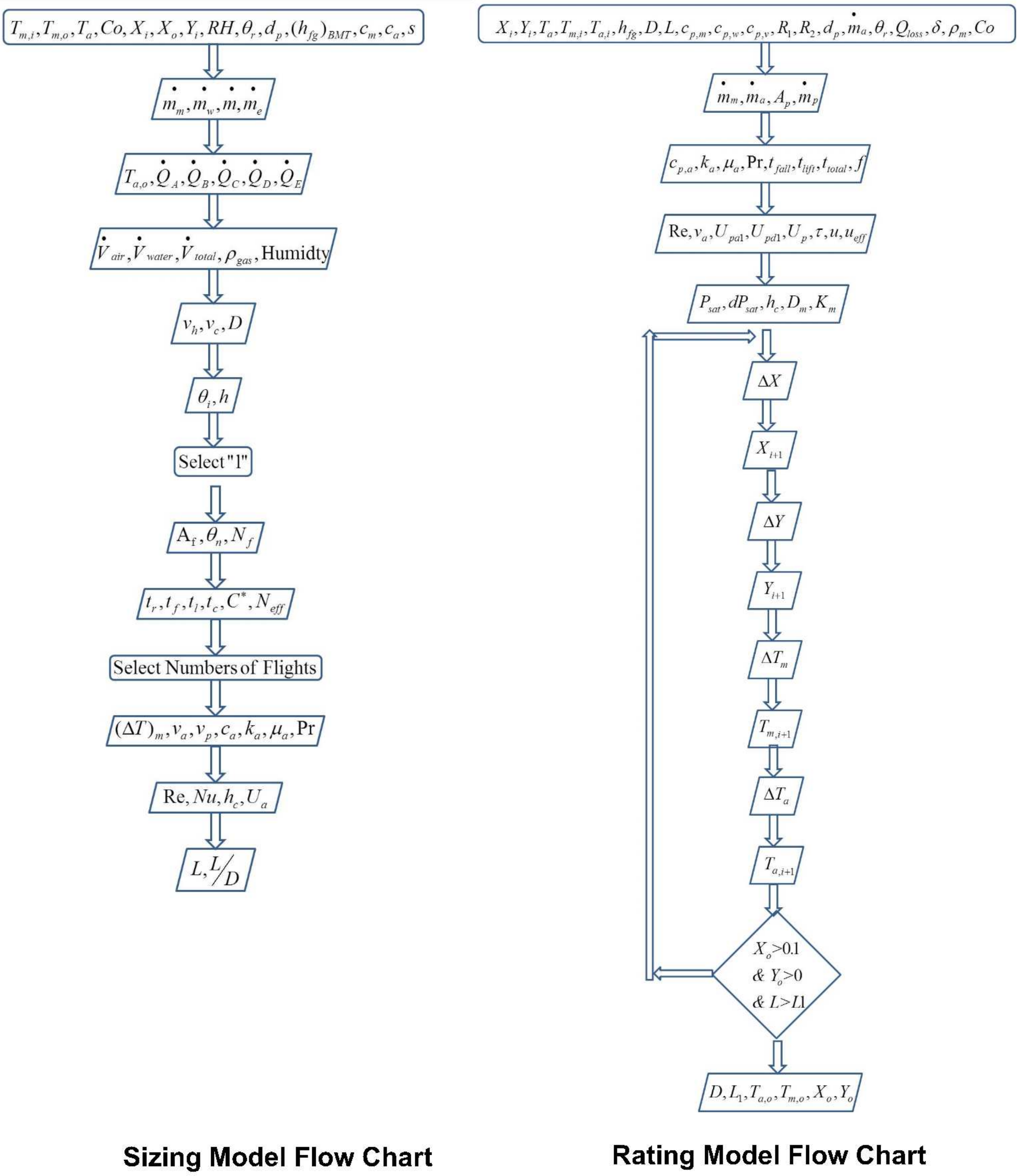

Figure 3.4: Mathematical model is converted in to a C++ program and the Flow Chart for Sizing Model and Rating Model is shown in the figure. Both the codes are used in such a manner that the final result is optimized.

3.3 Closure

The mathematical model discussed above is converted to C++ programs. One program gives the size of the dryer and other gives the rating of the dryer. The code so generated is used for different input parameters and the most reasonable is selected as final design. A detail discussion is shown in the next chapter.

Chapter 4

Result and Discussion

A mathematical model is created as discussed in chapter 3 the generated model was converted to code. Two separate code is generated for sizing and rating. This chapter discusses the result generated with code. It also discusses the effect of change of parameter on final temperature and moisture contain of air and product. The chapter is divided in to two section first section shows design of an inclined drum dryer. The second section shows effect of change of parameters.

4.1 Problem Statement

In order to design the Inclined drum dryer for gypsum below mentioned assumption are taken for calculation.

To meet the daily need of 70 ton/day a dryer of 5 ton/hr is been designed. The drying medium for gypsum drying is selected as air. The air is entering the heating furnace with 50% RH and 30°C having 0.01 kg/kg dry air moisture contain and leaving with 350°C and moisture contain of 0.01 kg/kg dry air. The same air enters the drum dryer with 350°C and 0.01 kg/kg dry air moisture contain. From the same end of the dryer material is coming with 30°C and moisture contain of 0.3 kg/kg dry solid. It has been decided to dry the material up to 12 % to 10 %. The material outlet temperature is selected to be 65°C for sizing problem.

4.1.1 Sizing Model

The sizing model gives Length and Diameter of drum by making heat and mass transfer between air and material. The sizing gives length of flight required as 0.4903 m that has been rounded off to 0.51 m and maximum number of lifters required as 19.67 hence 19 numbers of lifter were selected. The code gives diameter of drum as 1.88 m and length of drum as 15.694 hence having L/D ratio of 8.30. The calculated mass flow rate of air required is 9711 kg/h. All the parameter given by sizing model is manipulated for optimization in rating model. Table 4.1 shows result of Sizing Model.

Table 4.1: Results of Sizing model

Parameters	
Diameter of Drum (m)	1.88
Length of Drum (m)	15.694
Maximum Numbers of Flights	19.31
Effective Numbers of Flights	7.66
L/D Ratio	8.30
Outlet Temperature of Air ($^{\circ}C$)	82
Required Air Mass Flow rate	9711 Kg/hr
Humidity of outlet Air	0.124 kg/kg dry air

4.1.2 Rating Model

The rating model uses data from sizing model and manual modification is done to fit the requirements. The Length of Drum is reduce to 8 m and Diameter to 1 m keeping L/D ratio 8 near to 8.30 which was given by sizing model. The air flow rate requirement is 9711 kg/h as given by sizing model is changed to 9800 kg/h. The Table 4.3 gives the result of dryer parameters after rating, the result of simulation the final temperature of air as 77.96 near to 82 given by sizing model. The moisture contain of air is 0.1089 kg/kg dry air near to 0.124 given by sizing model. .

Table 4.2: Parameters for Rating Model

Parameter	
Diameter of Drum	1 m
Length of Drum	8 m
Rotation of Drum	3 rpm
Length of Flight	0.5 m
Numbers of Flight	18
Angle of repose of Gypsum	32°
Average size of particle	0.001 m
Mas flow rate of air	9800 kg/hr
Heat loss from Dryer Shell	23 kW
Ambient temperature	25 °C
Inlet temperature of Air	350 °C
Inlet temperature of Material	30 °C

Table 4.3: Result of Rating Model

	Parameters	Inlet	Outlet
Air	Temperature ($^{\circ}C$)	350	77.96
	Moisture (kg/kg dry air)	0.01	0.1089
Material	Temperature ($^{\circ}C$)	30	63.8798
	Moisture (kg/kg dry solid)	0.3	0.10599

Table 4.5: Effects of Temperature on Process Parameters

d_p(m)	$T_{a,i}$(°C)	x_o(w/w)	y_o(w/w)	$T_{a,o}$(°C)	$T_{m,o}$(°C)	L_1 (m)	(L/D) Ratio
0.001	300	0.1427	0.099	73.48	60.40	8	8
	350	0.105	0.108	77.46	63.87	8	8
	400	0.099	0.11	119.982	62.08	4.08	4
0.003	350	0.2162	0.05	214	46.9	8	8
	400	0.1954	0.06	233.8	48.99	8	8

4.2 Effect of Change of Parameters

The final selection of operating parameters done by making different combination of parameters. Thought the combination is not perfect there is no question on the reliability of the results. For gypsum dryer the parameters selection is done as follows.

4.2.1 Particle Size

The material is in lump form so it has been assume that each particle is in spherical shape. In calculation the average particle size is considered and for that the screening analysis of material has been done. Table 4.4 shows the effect of particle size on the sizing of drum. For the particle size of 0.001 m at flight length of 0.51 m the result is optimum. As the size of particle increases the required length of flight decreases but the length of drum also increases. Here only two results are shown for comparison but for selection of drum size more then one diameters were checked.

Table 4.4: Effect of Particle Diameter on Process Parameters

d_p (m)	$l_{calculated}$	$l_{selected}$	N_f (calculated)	N_f (selected)	D (m)	L (m)	L/D Ratio
0.001	0.4903	0.49	20.049	20	1.88	16.15	8.54
		0.51	19.31	19	1.88	15.69	8.30
		0.52	18.9688	18	1.88	15.93	8.43
0.003	0.3936	0.39	20.21	20	1.51	48.47	31.95
		0.43	18.45	18	1.51	44.30	29.2076
		50	16.07	16	1.51	36.86	24.3

4.2.2 Temperature of Drying Medium

The diameter of particle is fixed as 0.001 m so the next step is to decide the inlet temperature. The Table 4.5 shows the effect of inlet temperature on the size of drum. For selection purpose number of temperature were checked. For 0.001 m diameter the temperature were changed from 300°C to 600°C. The best range is found to be in between 300°C to 400°C. It can seen from Table 4.5 that as the temperature increases the L/D ratio is decreasing after 350°C so the temperatures after 350°C gets eliminated. On the other hand as the temperature increases from 300°C to 350°C the outlet temperature is also increases. The sizing model gives outlet temperature as 82°C and rating model gives 77.96. Though the lower outlet temperature indicates better heat utilization but it also increases the chances of precipitation hence 350°C is selected as inlet temperature.

Table 4.6: Effect of Drum Diameter on Process Parameters

d_p(m)	D (m)	x_o(w/w)	y_o(w/w)	$T_{a,o}$(°C)	$T_{m,o}$(°C)	L_1 (m)	(L/D) Ratio
	1	0.105	0.10	77.95	63.87	8	8
0.001	1.1	0.099	0.11	72.63	64.3	6.65	6.04
	1.20	0.099	0.11	74.44	64.56	4.61	3.84

Table 4.7: Effect of Drum RPM on Process Parameters

d_p(m)	n_{rpm} (rpm)	x_o(w/w)	y_o(w/w)	$T_{a,o}$(°C)	$T_{m,o}$(°C)	L_1 (m)	(L/D) Ratio
0.001	3	0.10	0.16	77.96	63.87	8	8
	3.3	0.10	0.107	81.18	63.47	8	8

4.2.3 Drum Diameter

The diameter of drum has direct effect on the flow rate of material and falling time of the material. As the falling time increases the heat transfer rate increases the same effect is seen in the calculated data. As the diameter increases the outlet temperature increases. The increase of diameter also decrease the L/D ration so to maintain L/D ration near to 8.3 diameter was selected as 1m.

4.2.4 Drum RPM

The diameter of drum and rpm of drum are related, as the diameter increases for same rpm the peripheral speed of drum decreases. It can be seen from Table 4.7 that, as drum rpm increases the outlet temperature of air also decreases. The above results are shown in Tables 4.4 to 4.5 is calculate at the 3 rpm and found good as compare to 3.3 rpm. Hence 3 rpm is selected in final design.

4.2.5 Selected parameters and results after regression

Table 4.8: Final Selected parameters

d_p (m)	D (m)	L (m)	l (m)	N_f	N_{rpm}	x_o(w/w)	y_o(w/w)	$T_{a,o}$(°C)	$T_{m,o}$(°C)
0.001	1	8	0.51	19	3	0.10	0.16	77.96	63.87

The selected parameters are with 3 rpm rotational speed and chart 4.1 shows the final result. The length calculated and selected are almost equal, the final temperature difference between air and gypsum is good and there is no over heating of material. Overall the results are matching with plant requirements.

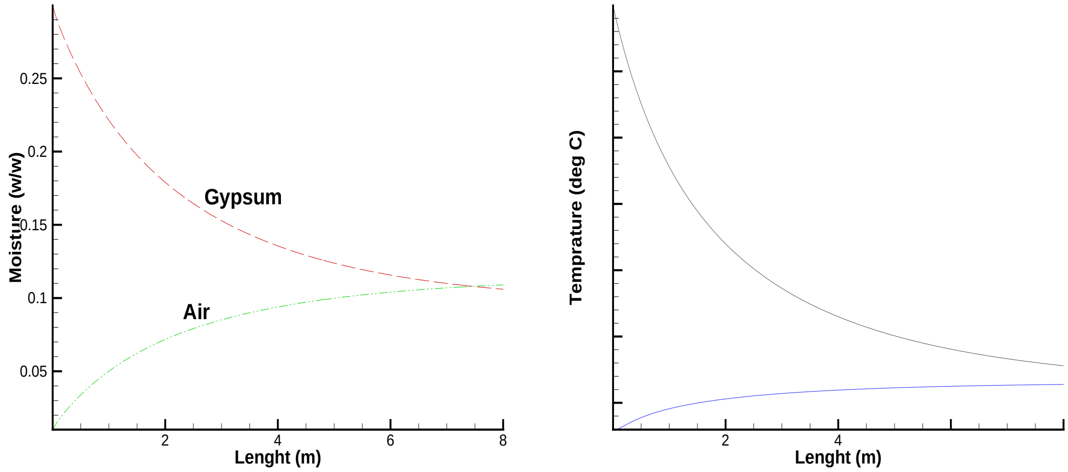

Figure 4.1: Change of parameters with length: A) The change of moisture contain of air and material B) The Chang of temperature of air and material

4.3 Closure

The code generated for sizing and rating combined for the final design. The combination is so done that it fulfill the plant requirements The final design is in good fit with the conditions requires for the plant.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

1. The gypsum is a very sticky in nature and form large lumps so the selection of dryer is so done that the dryer fulfills this requirements. The output requirements of dryer is needed in ton/hr and the use is frequent. The Inclined Drum Dryer is fulfilling all the conditions required by the process hence it has been selected for the design.

2. The Inclined Drum Dryer is designed by generating two separated mathematical model for sizing and rating. The final design is done by combining both models. The sizing model gives the geometrical parameters of the dryer i.e. Length and Diameter of Drum and Size and Number of Flights.

3. The geometrical parameters calculated from the sizing model is checked by the rating model. The change of input parameters is manual in order to get a desirable result. The rating model gives the design in such a way that all the parameters of the dryer is optimized.

5.2 Future Work

Drum dryer is one of the most widely used dryer in industries. In order to reduce the energy requirements the dryer can be insulated and parameters can be changed. After many efforts by many engineers and researchers still the heat required is not been reduced. The other alternative can be solar energy. The air that is entering in to the furnace of the drum can be preheated by solar air heaters. The combination of which can reduce the heat required for incensing the temperature of drying medium.

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Appendix

Appendix A

Drier shell:

The thickness of dryer shell can be calculated from below expression:

Thickness of Dryer

Design Pressure = 1.5 × Working Pressure P

$$t_d = \frac{P_d D_d}{2fJ + P_d} \tag{1}$$

Thickness of Insulation

Heat Supplied to the dryer can be calculated from:

$$Q_d = \frac{T_1 - T_2}{(\frac{t_1}{K_1 A_1}) + (\frac{t_2}{K_2 A_2}) + (\frac{1}{hA_3})} \tag{2}$$

Where;

$$A_1 = \pi(D_1 + D_2) \times \frac{L}{2} \tag{3}$$

The insulation Thickness "y" can be calculated from below equation:

$$D_3 = D_2 + (2y) \tag{4}$$

Power to drive the driver

$$Power_{driver} = \frac{r(4.75dw + 0.1925DW + 0.33W)}{100000} \tag{5}$$

Live load "w" can be calculated from:

Volume of the drum:

$$V_d = \frac{\pi L(D_2^2 - D_1^2)}{4} \tag{6}$$

Wight of live Load w = Volume of Drum × Holdup
Weight of Drum W_d = Volume of Drum × Density of dryer Material

Volume of the dryer filled with the material:

$$V_m = \frac{\pi L D_i^2}{4} \times HoldUp \quad (7)$$

Total Rotating Load can be calculated from:
Volume of Insulation:

$$V_i = \frac{\pi L(D_3^2 - D_2^2}{4} \quad (8)$$

Weight of Insulating Material W_i= Volume × Density
Total Wight of Rotating parts $W = W_d + W_i + W_m$

Power required by blower

$$Power_{blower} = 2.72 \times 10^{-5} \times Q \times P \quad (9)$$

Power required by exhaust fans

$$Q_{ef} = \frac{(TotalQuantityOfAir) \times 22.4 \times Humidity}{29/298} \quad (10)$$

$$Power_{ef} = 2.72 \times 10^{-5} \times Q \times P_{ef} \quad (11)$$

Diameter of Feed Pipe

$$d_{feed} = \sqrt{\frac{4 \times A_{c/s}}{\pi}} \quad (12)$$

cross section area = (Volume feed rate)/(Assumed Velocity of feed)

Diameter of Inlet and Outlet pipe

Cross Section area of Inlet pipe = (volume flow of air)/(Volume of air enter)

$$d_i = \sqrt{\frac{4 \times A_i}{\pi}}$$

Cross Section area of outlet pipe = (volume flow of air)/(Volume of air Leaving)

$$d_o = \sqrt{\frac{4 \times A_o}{\pi}}$$