Design and analysis of economical & effective drying system for chemical gypsum

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Major Project Report - I

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By

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Guided By

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1. The thesis comprises of my original work towards the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) at Nirma University and has not been submitted elsewhere for a degree.

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Abstract

A cement plant requires fly-ash,gypsum and clinker as raw materials for production of cement.Gypsum is chemically written as "$CaSO_4 \cdot 2H_2O$". Different type of gypsum are available like mineral gypsum , synthetic gypsum and chemical gypsum. Mineral gypsum is a common mineral obtained from surface and underground deposits. Chemical gypsum is obtained as chemical waste from chemical plant. Gypsum is essential raw material for regulating the setting time. JK Lakshmi cement limited uses chemical gypsum as additive. Chemical gypsum is by product of chemical die plant. It contains high amount of moisture. It is causing problem in handling of gypsum. Plant needs system which remove moisture from gypsum and take it equal or below 10% w/w. Presently the plant use open drying but it is not helpful in all seasons and it consumes more time. Moreover, plant needs 80 ton/day gypsum. Hence, Plant requires economical and effective system for drying of chemical gypsum from all system.

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Nomenclature

k	Thermal Conductivity coefficient (W/(m. K))
s	Specific Gravity of material (kg/m^3)
t	Time (second)
T	Temperature (^oC)
c	Specific Heat (J /(kg K))
A	Area of C/S (m^2)
m	Mass flow rate (m/s)
CFM	Cubic feet per minute
V	Volume (m)
L_v	Latent heat (kJ / kg)
M_e	Equilibrium moisture content (% dry basis)
M_i	Initial moisture content (% wet basis)
m_i	Initial mass of the Gypsum (kg)
m_w	Mass of water evaporated (kg)
C_p	Specific heat at constant pressure (kJ / (kg . K))
T	Initial temperatures of the drying air (K)
m_a	Mass of drying air (kg)
m_w	Mass of water evaporated from the food item (kg)
Q_{conv}	Rate of convective losses from the absorber (W)
I	Rate of total radiation incident (W / m^2)
Q_{cond}	Rate of conduction losses from the absorber (W)
C_{pa}	Specific heat capacity of air (kJ / (kg . K))

Chapter 1

Introduction

JK Lakshmi Cement Limited is a company of JK Organization started in cement business from 1982. Main plant of JKLCL is in Jaykaypuram (Sirohi). It has capacity of 5 Million Ton Per Annual.JKLCL, Kalol is a cement grinding unit with annual capacity of 0.5 Million ton per annual capacity since 2009. It is ISO-9001 and ISO-14001certified.It maintains high level standards in Quality. The plant has got three level award by Center for Science Environment for State of Art Pollution Control Technology. It use fly-ash and solid waste generated from nearby thermal power plant and chemical industry. 53 Grade OPC and PPC are cement product of this plant.

1.1 Introduction of girding unit of cement industry

Cement production require raw material as clinker(lime Stone), gypsum and fly ash. Product of plant are 53 Grade PPC Cement and 53 Grade OPC Cement. Basically girding unit mix raw material in proper way for producing different type cement. Main constitute of cement are enlisted in table 1.1 on basis of composition by weight.

Table 1.1: Composition of Cement

Name of Chemical	Chemical Formula	Composition by Weight (%)
Tri-calcium Silicate	$3CaO \cdot SiO_2$	51
Di-calcium Silicate	$3CaO \cdot SiO_2$	25
Tri-calcium Aluminate	$3CaO \cdot Al_2O_3$	11
Tetra-calcium Aluminoferrite	$4CaO \cdot Al_2O_3Fe_2O_3$	9.5
Gypsum	$CaSO_4 \cdot 2H_2O$	4

1.2 Importance of gypsum in cement industry

Cement is important raw material in construction. Cement production require mainly three raw material which are clinker, fly-ash and gypsum.In past years cement has very short setting time. Very short time of setting create problem because it make short solidification time. This difficulty can be overcome by adding gypsum as raw material in cement production. It retard the time of setting. In modern technology different type gypsum is useful in cement production. It is useful as setting time retarder. Gypsum consumption is depend on purity of gypsum. Purity of gypsum means contain of sulfur trioxide. Composition of gypsum is stated in table 1.2. Cement plant requires average 4% w/w gypsum of the total cement produce per day. Chemical gypsum is shown in fig. 1.1.

Table 1.2: Composition of Gypsum

Chemical name	Content(%)
SiO_2	22
Al_2O_3	07
Fe_2O_3	03
CaO	63
MgO	02
SO_3	03

Figure 1.1: Chemical Gypsum

1.3 Gypsum related problem

Different types of gypsum are available for cement production. Here they use chemical gypsum which is comes from chemical industry. Basically it is a waste of chemical die industry. So,it's cost is very low but,chemical gypsum contain high amount of moisture. It cause problem in handling of chemical gypsum. A comparative study is done for selecting efficient and economical drying process. Many options are available for drying of chemical gypsum. From all option effective and economical system is require to select as drying system for chemical gypsum. Chemical gypsum plays important role of hardening of the cement and giving setting time. In cement manufacturing process, proper amount of gypsum is added during the final production process. Quantity of chemical gypsum is added on basis of sulfur trioxide. It is added to give control of the setting time of cement. It is important raw material for cement industry.

1.3.1 Problem statement

JKLCL, Kalol plant is using chemical gypsum as raw material for production of cement. Chemical gypsum contains high amount of moisture. It has excess amount of water which creates problems during handling. Due to high amount of moisture , it has tendency to get stick with other parts. Chemical gypsum gets stuck on conveying machinery parts. Chemical gypsum creates sometime blockage in hoppers which leads to stop supplying of chemical gypsum. For continuous running of plant they needs at least two to three labor near the conveyors. The manual cleaning of staged gypsum is done which waste more labor hours. Due to transportation and handling of chemical gypsum is require from open yard to storage yard and storage yard to feeding section make high cost of handling and transportation.

1.4 Present drying technique

To solve this problem of the high moisture contains of chemical gypsum plant use present drying system as open solar drying. It's require to reduce moisture content equal or below 10%. Figure 1.2 shows open drying of chemical gypsum.

Figure 1.2: Open drying

For cement production chemical gypsum with equal or below 10% doesn't create problem. The plant is using open sun drying system. Chemical gypsum is spread in the open yards with help of the tractors, loaders and cranes. Spreading is done by loaders and cranes at regular interval. Chemical gypsum is dried at least for three to four days on the basis of requirement of chemical gypsum for cement production. After open drying dried gypsum is stored in storage yard.

1.5 Motivation

Moisture inside a big shape particle may not get really evaporated but from the outer side it looks like it is dry. In a day due to high temperature evaporation of water from gypsum occurs. However due to it's hydrophilic properties chemical gypsum absorbs air moisture in night time and morning. It gains additional moisture. So,it require more time for drying chemical gypsum. Open drying is fully dependent on weather condition. In winter drying time is more then summer and in rain season the drying is impossible. For overcoming this issue plant has constructed storage space. It also puts an additional investment. Process of Transportation and handling of chemical gypsum is very much time consuming. So,making of system which can run in any condition and less drying time will overcome the issue of the plant.

1.6 Objective of project

Objective is to select economical and effective drying system for drying of chemical gypsum. After selecting drying system make a design of experimental model of drying system and perform experimental analysis on that model of selected system.

1.6.1 Methodology of selecting suitable system

Open sun drying is inefficient system. It isn't proper way of drying.So,proper drying system is require for drying of chemical gypsum. Control on the process of the system is require. It should take less drying time compare to open drying and less costly. Capital and operating cost of the system plays important role because present drying system is running with least cost. So, plant would mostly prefer low cost system. Literature study is carried out of different drying system for understanding the process of drying.

1.7 Drying effect on gypsum properties

Gypsum consumption for cement production is dependent on purity of gypsum. High purity makes low consumption of gypsum. Drying of gypsum makes purity of gypsum high compare to wet gypsum. Table 1.3,1.4,1.5 and 1.6 shows experimental result of moisture contain and purity at different temperature of chemical gypsum sample.

Table 1.3: Moisture of Gypsum at 70ºC and One Hour (IS 4032)

At 70ºC	Moisture(%)
Before drying	33
After drying	22

Table 1.4: Moisture of Gypsum at 80ºC and One Hour (IS 4032)

At 80ºC	Moisture(%)
Before drying	33
After drying	10

Table 1.5: Moisture of Gypsum at 90ºC and One Hour (IS 4032)

At 90ºC	Moisture(%)
Before drying	33
After drying	5

Table 1.6: Purity of Gypsum (IS 4032)

Sample No.	Purity
33% Moist	45.18
7% Moist	53.73
Dry	70.96

On basis of the practical analysis carried out as above we can say that dried chemical gypsum has high purity compare to wet chemical gypsum. So, gypsum consumption in cement production process mainly on basis of purity of gypsum. High purity makes low consumption of gypsum. Low consumption also makes cost saving in transportation and handling process.

1.8 Scope of study

Open drying system is ineffective and time consuming. Big particle of chemical gypsum are require to break in small pieces for effective drying. Comparative study is require for selecting dryer system. Main parameter for selecting of suitable system are efficiency and cost. Dryer selection is done on basis of literature study of different dryers. The further study includes selection of dryers and design and analysis of experimental model of selected dryers.

Chapter 2

Literature study

Drying mainly depends on drying material, drying time, mechanical and chemical properties of material. So,the selection of a drying technique depends on different parameters. In this problem literature study of different drying system is carried out. The selection process is depends on knowledge of selector and literature study of different system. Literature give real condition idea for comparing of different drying system. Options available of drying of chemical gypsum are rotary dryer, fluid bed dryer, spray dryer, microwave dryer and solar dryer. Literature study is deals with the selection of suitable drying system for chemical gypsum and design and performance analysis of experimental model of drying system.

2.1 Drying of gypsum

Following are the steps for selecting drying system.

1. List out all dryer which can dry material like chemical gypsum.

2. Out of all available dryer select suitable dryer of high capacity which can dry material like chemical gypsum effectively and economically because J.K.L.C. plant needs on an average 70-100 ton/day of chemical gypsum.

3. find out bulk density and other physical,chemical and thermal properties of material.

4. Comparison is carried out of different drying system on basis of cost and drying time.find out payback period of all drying system.

5. Design experimental model of selected drying system.

6. Carried out performance analysis on experimental model.

2.1.1 Property of gypsum affecting on drying process

1. **Tanacan Halit**r[1] analyzed the various effect on the properties of gypsum at high temperature. When gypsum is heated above 100°C it convert into POP. POP isn't useful as raw material in cement production.

2. **Iljins, Ziemelis etal**[2] suggested theoretical and experimental research on foam gypsum drying process in different condition. Mathematical drying model is made for analysis. The drying of gypsum products is requirement for process, that affects both its physical and mechanical properties.

2.2 Parameter of selecting drying system

Dryer are classified on the basis of heat source, drying material properties and capacity. Heat supply is possible by convection, conduction, radiation. Heat can be supply by using different combination of all possible way of heat transfer[2]. Drying temperature is also crucial parameter in selecting drying system. Chemical gypsum will losses the property of giving setting time for cement when it is heated above 100°C. So, it's require to keep drying temperature below 100°C.

2.3 Literature study of different drying system

From various available dryer some suitable dryer with their literature study is decried as follow.

1. **Rahmanta and Felani**[3] analyzed rotary drum dryer for drying coal in Indonesia. They designed rotary drum dryer for increasing HHV of low rank coal. Rotary drum dryer remove moisture from coal. This system use furnace for providing heat. Rotating test of various sped is also examined. Rotary drum dryer is used to increase high heating value of LRC by reducing total moisture of water in coal. Rotary drum dryer uses flue gas from its furnace as heat source. Graphs of drying Curve , rotating speed vs Moisture contain , rotating speed vs change in HHV are also made on basis of experimental analysis. Rotary dryer system is very efficient system but it is very expensive system.

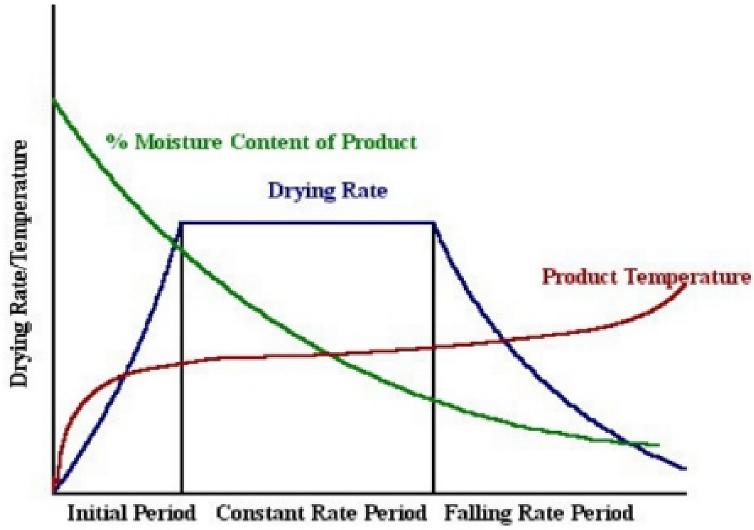

Figure 2.1: Drying rate of rotary drum dryer

2. Spray drying is a process of spraying gas in the liquid or slurry and producing a dry powder from that slurry[4]. It is the efficient method of drying of many temperature sensitive materials such as foods and chemicals. Limitation of spray drying is that system isn't useful for high capacity.

3. In fluid bed drying system air is supplied to the bed and pass to the bed of materials at a require velocity. High heat and mass transfer rates are obtained due to the intimate contact between particles and the fluidizing gas. It is useful for removal of moisture for many materials. It initial cost as well as operating cost is very high. Fig.2.2 shows heat losses of solar energy.

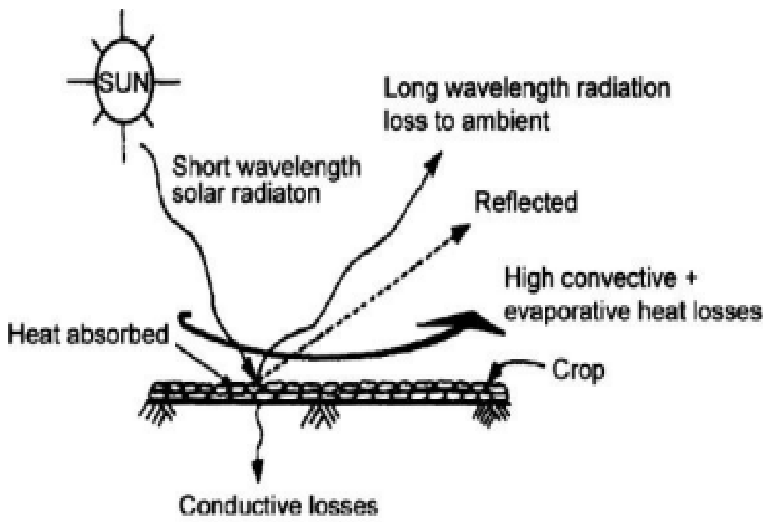

Figure 2.2: Heat losses of solar energy

4. **Ganesapillai and Regupathi** [5] analyzed dehydration characteristic of sand drying quality of gypsum using microwave heating process. Analysis of proper-

ties of gypsum sample before and after microwave drying. Analysis of different property like moisture content , porosity , bulk density ,drying time are also carried out.

5. **Lyes Bennamoun**[6] analyzed a review paper of Solar drying of wastewater sludge.Solar drying is useful for drying sludge. It is also low cost system. For effecient drying using of different components like fans, louvers and scraper makes system effecient. Ventilation is essential to remove the moist air and replace it by atmospheric air.Fig.2.4 shows solar drying model. Fig.2.3 shows solar drying model with thermal energy storage.

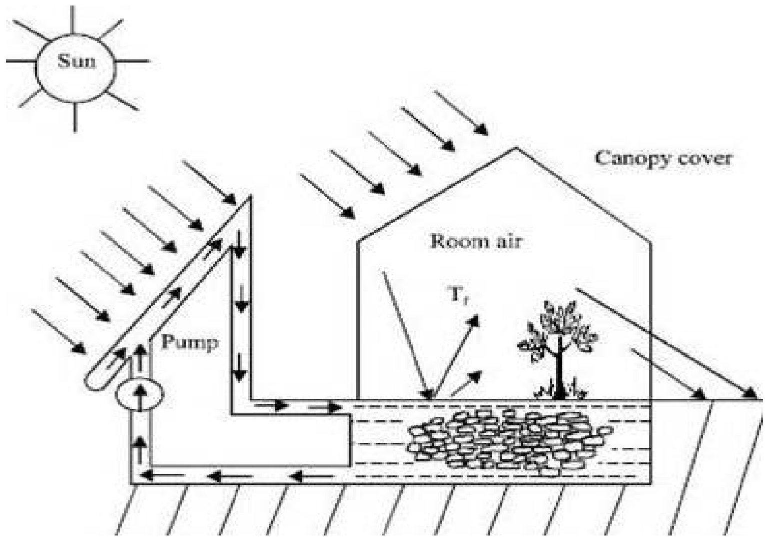

Figure 2.3: Solar Dryer with thermal storage

6. **Kamil , Salihoglu etal**[7] analyzed exact performance result of solar drying system. At least 27,000 tons of dry solids made out from sludge by solar drying per year in 2006 in Bursha,Turkey. This system remove moisture rapidly from sludge. It make reduction in overall cost. Closed solar drying plan can work in all season. While the open sludge drying plant can't work in monsoon and winter. It also provide storage space for storing of chemical gypsum. Fig.2.4 shows solar drying model.

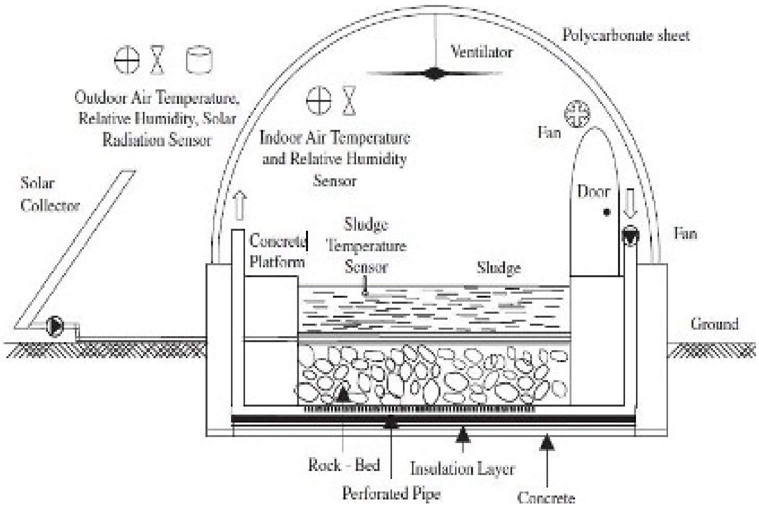

Figure 2.4: Solar Dryer , Turkey

7. **U. Luboschik**[8] suggested about sun drying system. Using a solar dryer we are able to dry with very little additional energy (Auxiliary Source). Typical sludge drying mass flow chart with all month drying details. Rotary scraper is the heart of the drying plant.

8. **Piotr Krawczyk** [9] analyzed about control strategy for ventilation system of sewage sludge solar dryer. Analysis of operating parameters of a sludge solar drying plant based on an approach that uses the concept of ventilation air drying potential. Analysis results are used to propose recommendations for control strategy for such facilities aimed at improving efficiency and lowering power consumption. The analytical work was based on experimental data collected during operation of a test solar sludge drying facility located at a waste water treatment plant in central poland.

9. **Yilmaz and Wzorek** [10] suggested assessment of the impact of various parameters on solar drying process in aydin in Turkey. To determine the optimum conditions for the process and undertake an analysis of kinetic drying of sewage sludge, a set of tests were performed under variable parameters, i.e. for various thickness of the dried sludge (5, 10, 15 and 20 cm) and with the application of various mixing intensity (without mixing, 3 and 9 times a day).

2.4 Drying performance

1. **Weiyu, Yulei etal** [11]suggested about the modeling and analysis of drying of sewage sludge of thin layer. They conduct experiments on the moisture

analysis for thin layer sludge. Drying rate at different temperature and thickness is analyzed.It indicated that the method can describe by process, cost and efficiency. Fig.2.5 describe about bound & unbound moisture.

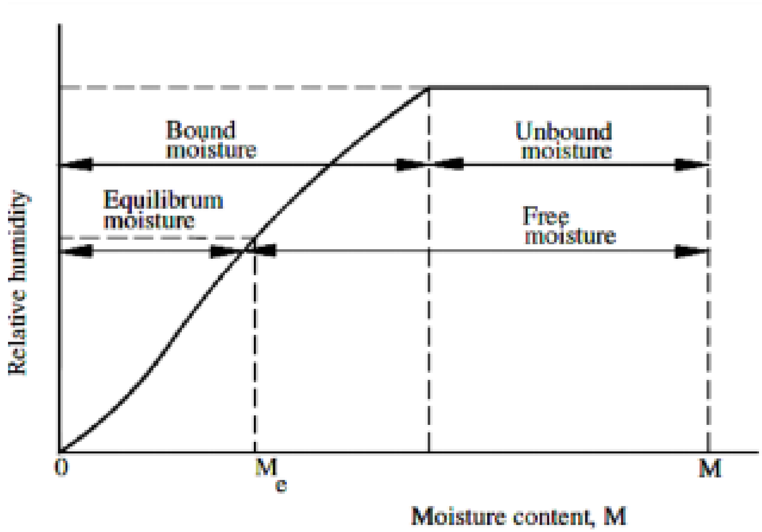

Figure 2.5: Bound & unbound moisture

2.5 Summary of literature review

Drying of chemical gypsum system must have temperature less then 100°C because above 100°C temperature properties of its change which isn't desirable for using as raw material for cement production. Solar drying is economical method for drying of chemical gypsum among all drying system. Hybrid system of solar drying is more effective in all season. Forced air circulation of air with the help of fan, louvers is very essential[12]. Rotary scraper is essential part of the system because without surface exposing drying of chemical gypsum is difficult. Using of solar air collector thermal storage make more effective drying system. Structure should be place in N-S direction and with east west facing roof slope of 20°.

Chapter 3

Methodology of selecting dryer system

This chapter gives detail comparative study of different dryer system on basis of their performance and cost. Wet chemical gypsum comes from nearby chemical industry to the plant. Wet chemical gypsum contain high moisture and low purity. Drying should be very helpful for overcoming the problem in handling and transportation of gypsum during the process as well as consumption of gypsum. So, selecting of low cost but effective drying system is essential for drying of chemical gypsum.

3.1 Different suitable drying system

Wet chemical gypsum problem can be solved by removing moisture from chemical gypsum from around 25-30% to 10% w/w. Cost of gypsum is very low because its waste of chemical plant. So, selection of drying system by understanding and comparing of different drying system on basis following main three parameter.

1. Cost of drying system
2. Drying capacity of system
3. Effective drying system

Different drying system which can be useful for drying of chemical gypsum are listed and described in following section.

1. Rotary dryer
2. Spray dryer
3. Fluid bed dryer
4. Microwave dryer

5. Solar dryer

3.2 Rotary dryer

Rotary dryer is very effective dryer among all different dryer. Drying is carried out by direct contact of heat energy(hot gases). Rotary dryer is very complex and heavy system. Rotary dryer has given some slopes slightly so that the discharge side is lower than the material feed side in order to supply the material to the dryer by means of gravity[3]. Capital cost of rotary sytem is very high. Fig.3.1 shows schematic view of rotary dryer.

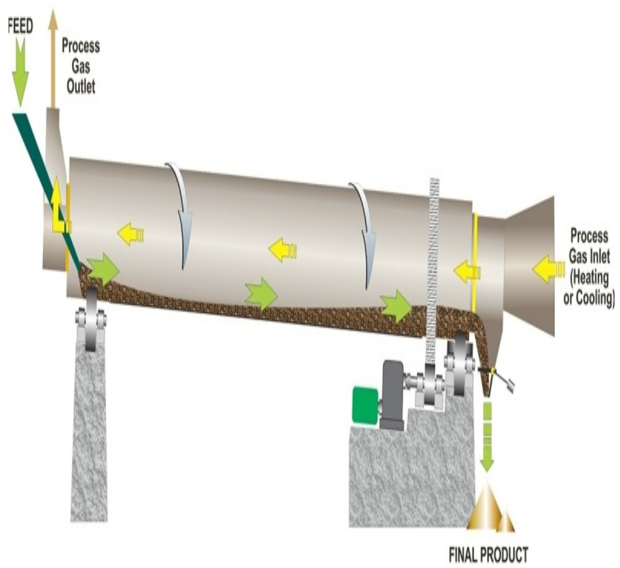

Figure 3.1: Rotary Dryer

Feeding of material in the dryer drom material feed side and giving rotary moment to the rotary dryer. The material is lifted up by internal thread lining of the dryer. Rotary dryers have many applications like drying of coal, chemical material, sludge drying, wood, limestone. Electrical consumption is also high for rotation, heat supply and fan draft flow system. Payback period of rotary dryer system is long[13].

3.3 Spray dryer

Spray drying is a system for delivering a dry powder from a fluid or slurry by blending with hot air. This is the successful and efficient technique for drying of numerous thermally delicate materials, for example food and pharmaceuticals. Effective framework for drying of drain powder, coffee, tea, eggs, grain and distinctive additives. Capital cost and working expense are high.It is not appropriate for drying conservative and furthermore for compound gypsum which is require for plant. Fig.3.2 shows schematic diagram of spray dryer.

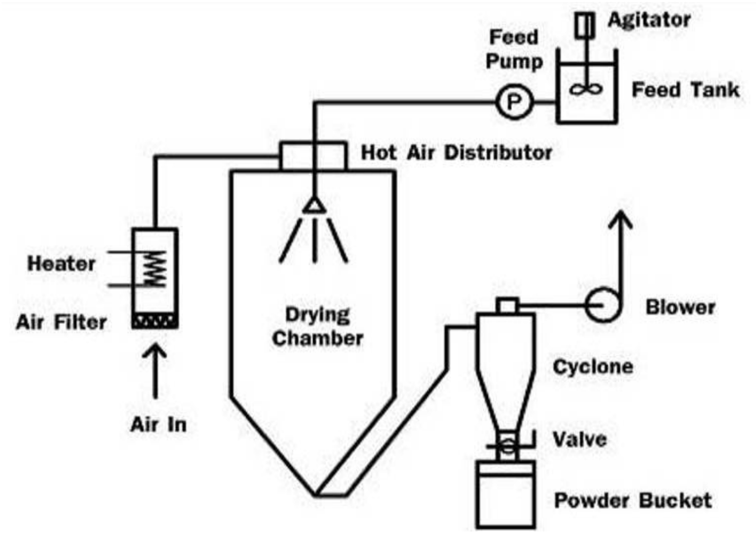

Figure 3.2: Spray Dryer

3.4 Fluid bed dryer

Fluid bed dryer is used for applications in chemical, pharmaceutical, dairy and other industries. Efficiency of this system is high.It's works on a principle of fluidization of the working materials. In this process, hot flue gas flow is passed in the bed section of solid particles. Gas will move upwards from the spaces between the particles. When velocity increases, upward forces on the particles increase. So,bed is known as fluidized bed and the particles are suspended in the fluid. Capital cost and operating cost is also high. Payback is Period / Benefit to cost ratio is not suitable[14]. Fig.3.3 shows schematic diagram of fluid bed dryer.

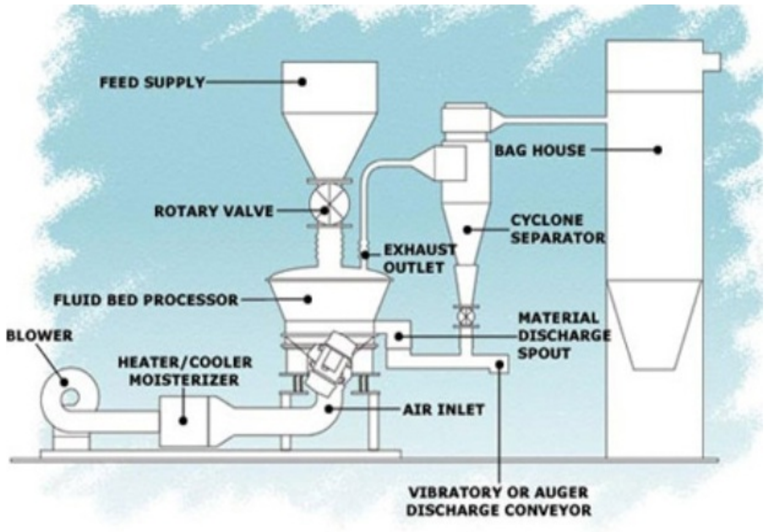

Figure 3.3: Fluid Bed Dryer

3.5 Microwave dryer

The microwave energy is mainly absorbed by liquid water present in material. The absorption of microwaves results in the temperature to rise. Some water gets evaporated moisture level reduces. Internal heating evaporation of liquid water takes places generate significant pressure[6]. Moisture is pumped to the surface due to pressure gradient. Due to high energy consumption, high capital cost and space issue it's not suitable.

3.6 Solar dryer

Solar drying uses the sun radiation for drying process. Total cost of solar drying system is very low compare to other system. Mostly Fully automated control system improve the drying rate of the system. It also capable of using waste heat to reduce the total drying area. Basic conceptual model of solar dryer is shows in fig.3.4.

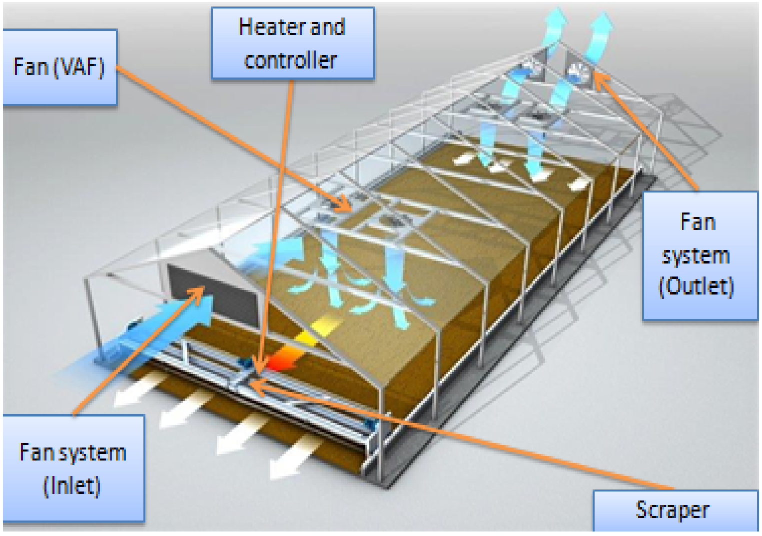

Figure 3.4: Solar Dryer

Using the sun as the main energy source, a scraper turns over and breaks up the material into small particle. It gives dried material. This material is taken outside of thesolar dryer. The rotary scraper continuously turns the material for expose more surface area of the gypsum. The moist air is removed outside by help of forced air circulation for keeping optimum moisture levels in the solar dryer. Drying system is economical and effective system[12].

The movement of moisture from the inside of an individual material to the surface, and the vanishing of moisture from the surface to the encompassing air. The drying of an item is a perplexing warmth and mass exchange prepare which relies on upon outer factors for example temperature, moistness and speed of the air stream and inner factors which rely on upon parameters like surface qualities, synthetic piece, physical structure, size and state of items. The rate of moisture development from the item inside to the air outside contrasts starting with one item then onto the next and depends especially on whether the material is hygroscopic or non-hygroscopic. Non-hygroscopic materials can be dried to zero dampness level while the hygroscopic materials like the greater part of the material will dependably have lingering dampness content. This dampness in hygroscopic material, might be bound moisture which stayed in the material because of shut vessels or because of surface strengths and unbound dmoisture which stayed in the material because of the surface pressure of water. In non-hygroscopic material bound moisture which stayed in the material because of shut vessels or because of surface powers and unbound moisture which not stayed in the material because of the surface strain of water[15].

3.7 Comparison of different dryer

Comparison of different dryer on basis of different parameters like capacity, capacity cost, operating cost, efficiency, payback and remarks of system is carried out. Following table give comparison of different dryer according to use for gypsum drying system.

Among all these different dryer solar dryer is economical and effective system. Expect solar dryer all dryer capital and operating cost is very high.Plant has no limitation on providing space. Solar radiation is also high which is major factor for solar drying system. So, it can be useful for high capacity drying system.

Table 3.1: Comparison of different dryer

Dryer	Capacity	Capi. Cost	Opera.Cost	Efficiency	Payback	Remark
Rotary	High	High	High	High	Long	High Cost
Spray	Medium	High	High	Medium	Long	Capacity
Fluid bed	High	High	High	High	Long	High Cost
Microwave	High	High	High	High	Long	High Cost
Solar	High	Very Low	Low	High	Small	Preferred

Chapter 4

Design approach methodology and implementations

4.1 Basic concept of solar dryer

Sun based dryer is a sun based air warming framework. It is empowered by the sun's hot beams entering through the polyethylene sheet. Catching of the beams is upgraded by the covering of dryer by sheet. Impact accomplished inside the solar dryer drives the air current through the drying framework. In the event that the louvers are open, the hot air rises and escapes through the fan in the dryer while cooler air at encompassing temperature enters through the outlet fan. Solar drying framework is viable contrast two open drying framework due with low relative stickiness of air and high temperature. Solar drying framework with constrained air dissemination is more compelling in light of the fact that because of vanishing at certain day and age relative humidity inside dryer moved toward becoming low. So, proper air trade is essential.This will make quick drying of substance gypsum. Chemical gypsum originating from adjacent synthetic plants has greatest 30% dampness content. Hence, utilizing sun powered vitality shows up as a more economical, efficient and less mind boggling decision than the other drying systems. Tunnel-solar dryer hold the air temperature distinction most extreme at 10°C - 20° amongst inside and outside of the greenhouse. Solar vitality can be helpful for single source or it can be valuable for framework with assistant source. Additionally utilization of sun oriented authorities additionally makes quick drying rate of gypsum[13].

In the process of drying, heat is necessary to evaporate moisture from the material and a flow of air helps in carrying away the evaporated moisture. There are following two basic mechanisms involved in the drying process.

1) The migration of moisture from the interior of an individual material to the outer surface and

2) The evaporation of moisture from the surface to the surrounding air.

The output drying product is a complex heat and mass transfer process which depends on internal variables and external variable.

Internal variables listed are as under.

1) Surface characteristics ,

2) Chemical composition ,

3) Physical structure and

4) Size and shape of material.

External variables listed are as under.

1) Temperature,

2) Relative humidity and

3) Velocity of the air stream

Drying is the removal of moisture by the application of heat and air circulation. Solar drying is the elaboration of the traditional method of sun drying to enhance the effectiveness of the drying. Basic principle of thin layer drying, deep bed drying and continuous flow drying are essential for optimal design of solar drying system. Drying capacity of the air depends on the air temperature, moisture content of gypsum, the relationship between the moisture content and R.H. of the drying air and gypsum properties. The temperature of the drying air must be kept below some recommended value depending on the intended use of gypsum. Figure 4.1 shows the working concept of model of solar dryer[16].

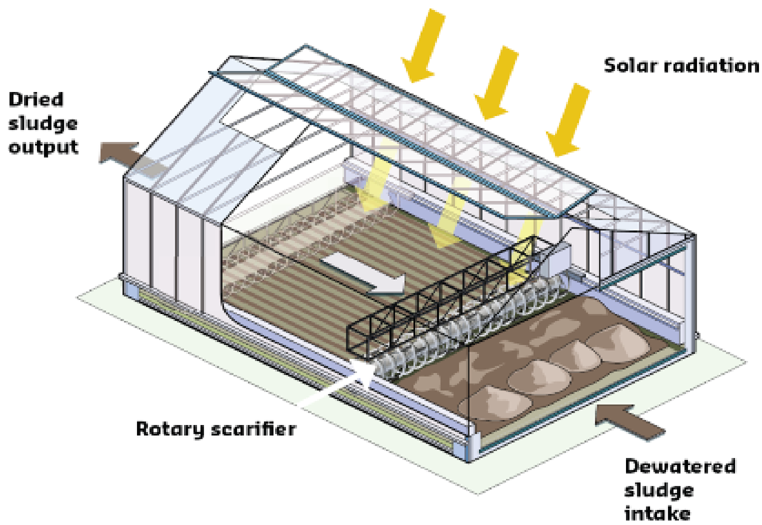

Figure 4.1: Concept of solar dryer working

4.2 Details of solar dryer model

Experimental model is been designed for analysis of working of solar drying system in actual condition.Model is designed for limited capacity of 23 tonne.If it work well then capacity should be increased it to 70 tones /day system.Some important data for making this model are listed as follow[17].

1. Capacity (Tones/ day) - 20
2. Gypsum Specific Heat (kJ/ (kg . K)) - 1.09
3. Water Specific Heat (kJ/ kg) - 4.184
4. Water Latent Heat (kJ/ kg) - 2257
5. Density (kg/ m^3) - 2300
6. Thickness of Gypsum Layer (m) - 0.20
7. Moisture Content (Initial Condition) - 30 %
8. Moisture Content (Final Condition) - 10 %
9. Volume (m^3) -10
10. Cross Section Area (m^2) - 50
11. Length (m) - 10
12. Width (m) - 5
13. Required Water to be remove (Kg) - 4000

4.3 Energy analysis

Solar dryer main aim is to increase the temperature of the 'air' in the dryer. Calculation of required energy for drying of chemical gypsum by using specific heat capacity of air, mass of air and temperature difference. Energy calculation are carried out in following subsection[18].

4.4 Energy balance calculation

Table 4.1 shows the monthly average direct normal solar irradiance data of ahemdabad.

Table 4.1: Monthly average direct normal solar irradiance

Month of the year	Monthly average direct normal solar irradiance (W/m^2)
Jan.	269.58
Feb.	302.91
Mar.	297.50
Apr.	282.50
May	303.33
June	229.16
July	110.00
Aug.	214.16
Semp.	104.58
Oct.	288.33
Nov.	264.58
Dec.	251.25

Solar dryer energy analysis is shown in following figure. Different type of heat energy balancing analysis is carried out in following section for understanding the real drying impact of solar radiation and heat losses.

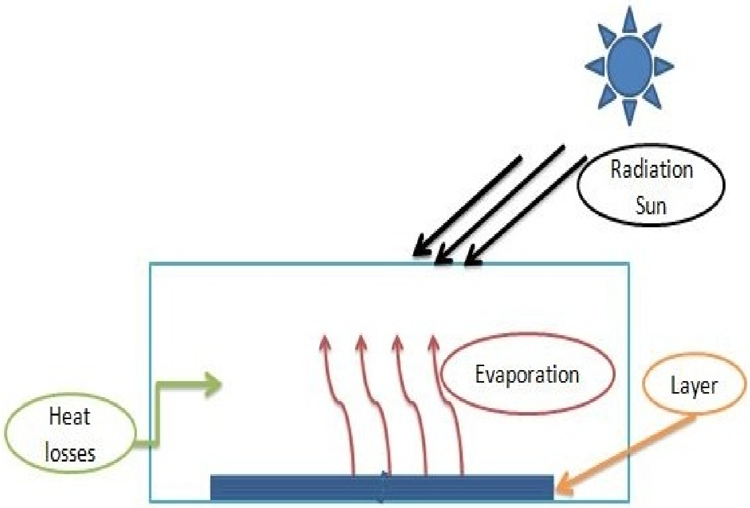

Figure 4.2: Energy analysis in solar dryer

Different types of energy are listed as follow for balacing.

1) Solar radiation (heat flux) ,

2) Sensible heat ,

3) Latent heat and

4) Heat losses

4.4.1 Solar radiation (heat flux)

$$I_g = I_b + I_d \tag{4.1}$$

where I_g= hourly global radiation , I_b(hourly beam radiation) = $I_{bn} cos\theta_z$ and I_d (hourly diffuse radiation) = C I_{bn}

I_{bn} = beam radiation in the direction of rays , θ_z= angle of incident on a horizontal surface (zenith angle) and C = Constant

Flux on a surface at any instant is given by ,

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r \tag{4.2}$$

where $I_b = 825W/m^2$, $I_d = 260W/m^2$

$$I_T = (825 \times 1) + (260 \times 1) + (1085 \times 0.0052)$$

$$I_T = 1095.642W/m^2$$

Transmisivity of the cover system:

$$\tau = \tau_r \times \tau_a \tag{4.3}$$

$$\tau_b = 0.91 \times 0.76 = 0.848$$

$$\tau_d = 0.84 \times 0.91 = 0.768$$

$$(\tau\alpha)_b = \frac{\tau\alpha}{1 - (1 - \alpha) \times \rho_d} \tag{4.4}$$

where $(\tau\alpha)_b$ = transmissivity-absorptivity product for beam radiation

$$(\tau\alpha)_b = \frac{0.848 \times 0.94}{1 - (1 - 0.94) \times 0.144} = 0.804$$

$$(\tau\alpha)_d = \frac{\tau\alpha}{1 - (1 - \alpha) \times \rho_d} \tag{4.5}$$

where $(\tau\alpha)_d$ = transmissivity-absorptivity product for diffuse radiation

$$(\tau\alpha)_d = \frac{0.768 \times 0.94}{1 - (1 - 0.94) \times 0.144} = 0.728$$

Incident flux absorbed by drying material:

$$S = I_b r_b (\tau\alpha)_b + \{I_d r_d + (I_b + I_d) r_r\} (\tau\alpha)_d \tag{4.6}$$

where S = Absorbed flux of Incident solar flux

$$S = 825 \times 1(0.804) + \{260 \times 1 + (1085)0.0052\}(0.728)$$

$$S = 856.68W/m^2$$

$$S = 42834W$$

, where area = 50 m^2

Total solar radiation in around two days = $42834 \times 3600 \times 50 = 7710120kJ$

4.4.2 Sensible heat

Energy must be added to increase the temperature or to melt it or to evaporate it. Heat energy from solar radiation increase temperature of solar dryer. So,it increase temperature and remove moisture from chemical gypsum. Sensible heat increase temperature of the chemical gypsum. Formula for calculating sensible heat is as follow.

$$H_s = m \times c_p \times \triangle t \tag{4.7}$$

where H_s= Sensible heat

$$H_s = 18000 \times 1.09 \times 7 = 137340kJ$$

4.4.3 Latent heat

During a constant-temperature process, energy released or absorbed, by a body or system is known as latent heat. Formula for calculating latent heat is as follow.

$$H_l = m_{vf} \times h_{fg} \tag{4.8}$$

where H_l= Latent heat

$$H_l = 2100(m_{vf})kJ$$

4.4.4 Heat losses

Some amount of heat is used to increase the temperature inside dryer. So, ultimately heat energy losses occurs in this system. Calculation of heat losses is decribed as under.

Energy balance :

$$S = H_s + H_l \tag{4.9}$$

$$7710120 = 137340 + 2100(m_{vf})$$

$$m_{vf} = 3606kg$$

After putting chemical gypsum in solar dryer for 2 days, 3606 kg mass of water vapour remove from system.

$$S = H_s + H_l$$

$$154202.4 \times hours = 137340 + 2100(4000)$$

$$hours = 55hours = 2.3days$$

For drying of 20 tonne chemical gypsum of intial moisture 30%. We have to get final moisture 10%. Solar dryer takes 2.3 days to remove 20% moisture.

4.5 Design procedure and implementation

Sun based drying is a procedure of moisture expulsion because of concurrent heat and mass exchange. As indicated by two sorts of water are available in sustenance things; the artificially bound water and the physically held water. In drying, it is just the physically held water that is expelled. The most essential explanations behind the fame of dried items are longer time span of usability, item virtue and generous volume lessening. This could be extended further with changes in item quality and process applications. The utilization of dryers in creating nations can diminish post gather misfortunes and essentially add to the accessibility of nourishment in these nations. Estimations of these misfortunes are for the most part cited to be of the request of 40% however they can, under exceptionally antagonistic conditions, be almost as high as 80%[19].

4.5.1 Structure of experimental model

Solar dryer experimental model is make on basis of the theoretical calculation. Type of structure is gothic arch type structure. Experimental model is of 10×5 square meter with roof height of 5 meter. It Will completely enclosed by 200 micron polyethylene sheet with light transmittance of 90%. Chemical Gypsum is spread out in floor of the solar drying plant in 0.25 meter thin layer. Fig 4.3 shows drawing of experimental model.

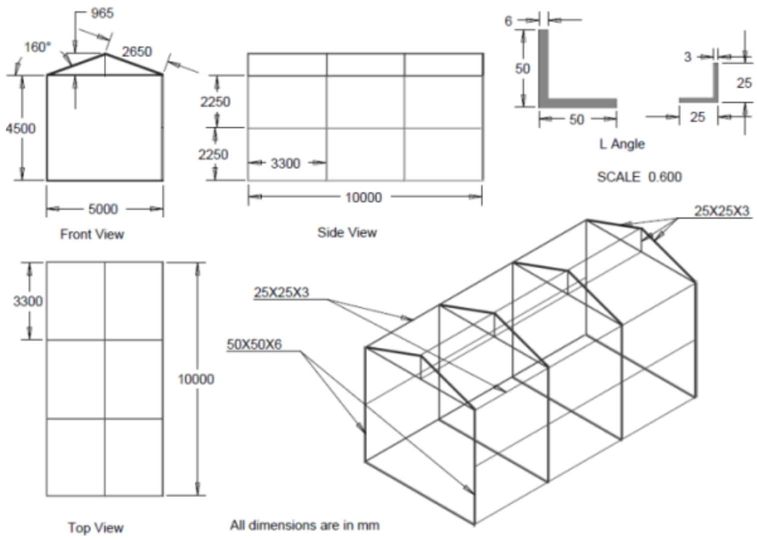

Figure 4.3: Drawing of experimental model

4.5.2 Experimental set up

From drawing we made a structure of10×5 square meter with height of 5 meter by using L angle of $25 \times 25 \times 3$ & $50 \times 50 \times 6$. Basic structure looks like as shown in fig 4.4.

Figure 4.4: Drawing of experimental model

Structure was completely enclosed by 0.2 mm thin transparent plastic film sheet with light transmittance of 85-90 %. After enclosed by sheet experimental model looks like as follow.

Figure 4.5: Experimental Model

4.6 Solar dryer components

Solar dryer consists of the many components. These components make solar dryer system more effective drying system because solar dryer has some limitation. Components of solar dryer system are described as follow.[18]

4.6.1 Fan system

Forced air circulation system with HAF and VAF. Thermostat is also implemented for automatic temperature, humidity and auxiliary source control. For forced air circulation around 15000 CFM flow is require. Fan with louvers are placed for controlling the air flow of the system[20]. Fig.4.6 and fig.4.7. shows fan system in solar dryer.

Figure 4.6: Fan System (HAF)

Figure 4.7: Fan System (HAF)

$$CFM = \frac{AEP \times Volume}{60minute} \tag{4.10}$$

Where AEP = air exchange rate per hour , CFM = air flow through the room (Cubic Feet per Minute) and V = volume of the room (Cubic Feet)

Solar dryer volume = 32.80 × 16.40 × 16.40 = 8821.888.

$$CFM = \frac{30 \times 8821.88}{60}$$

$$CFM = 4410.94$$

$$Flow - rate(m^3/hour) = 7494.23$$

Where, CFM = Cubic feet per minute

AEP = Air exchange per hour

Figures 4.8 shows VAF fan system implemented in the solar dryer for forced air circulation.

Figure 4.8: Fan System (VAF)

4.6.2 Fan - duct & louvers system

For better regulation of mass flow rate of air fan - duct system play importance role. It create sufficient pressure drop for entry of fresh air. It also helpful for getting some temperature rise of entering air into the drying system. For controlling of air flow rate louvers are placed with exhaust fan which remove air slowly depending on pressure difference. Figure 4.9 and 4.10 shows placing of fan-duct & fan-louvers systemin dryer.

Figure 4.9: Fan - duct system

Figure 4.10: Fan - Louver system

Duct length is 40 cm and cross section are is 196 cm^2. Pressure drop is also occurs in duct. Moody chart has main four parameters : pressure drop, air flow rate, air velocity, and duct diameter. Knowing two of these parameters, one can get the other two parameters.

Major losses in duct :

$$\triangle P = C_0 \frac{\rho v^2}{2g} = C_0 P_v \tag{4.11}$$

Minor losses (losses in fittings) :

$$\triangle P_f = f \frac{\rho l v^2}{2gD} = C_0 P_v \tag{4.12}$$

4.6.3 Scraper system

For effective drying, rotary scraper increase surface area by spreading it with help of its mechanism controlled by automatically / manually. It is main part of the system as spreading of chemical gypsum helps a lot for making rapid drying[18].

Figure 4.11: Scraper System

4.6.4 Thermocouple

Most regularly thermocuple are useful at everywhere. They are mainstream because of its straightforwardness, usability and their speed of reaction to changes in temperature, due chiefly to their little size. Thermocouples likewise have the vastest temperature scope of all the temperature sensors. Thermocouples are thermoelectric sensors that essentially comprise of two intersections of unique metals for example, copper and constantan that are welded or pleated together. One intersection is kept at a steady temperature called the reference (Icy) intersection, while the other the measuring (Hot) intersection. At the point when the two intersections are at various temperatures, a voltage is created over the intersection which is utilized to quantify the temperature sensor.

4.6.5 Controlling system

On basis of the practical experimental we set that if temperature go above certain temperature limit then inlet fan will start automatically. When R.H. of the inside area becomes high we need to remove moisture from drying system. So,outlet fan will automatic start and moist air will be go out of the drying system. Whole system is working with help of temperature & R.H. sensor and controlling circuit.

This system makes saving of money because this system is fully automatic compare to manual system where labour is necessary require.

4.6.6 Auxiliary system

In day off hours and monsoon season auxiliary system is most helpful system for getting particular drying capacity requirement. Using of small capacity heater of different type like gas burner, electrical fan heater and exhaust hot gases are useful for increasing drying efficiency[12]. Fig. 4.14 shows the eletrical fan heater.

Figure 4.12: Electrical fan heater

4.6.7 Solar air collector

For getting higher temperature difference in solar dryer system solar air collector is require. Flat plate solar air collector with small capacity can give 15-20% temperature difference[16]. Fig.4.17 shows basic strcture of solar collector.

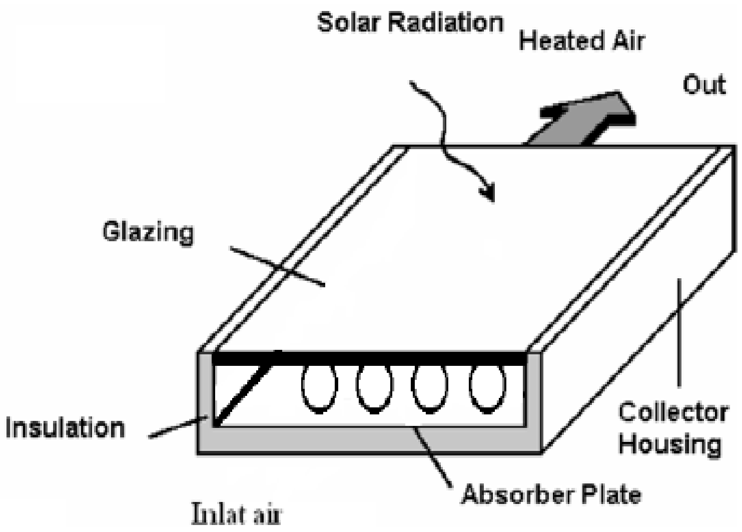

Figure 4.13: Solar air collector

4.7 Moisture level analysis

Determination of moisture content in sample of chemical gypsum is carried out in NABL accredited lab by using IS4032 testing procedure. In following section moisture calculation method of IS4032 is briefly described.

4.7.1 Moisture percentage calculation

The moisture content of the sample is calculated using the following equation

$$Moisture = \frac{(X - Y) * 100}{X} \tag{4.13}$$

Where: %W = Percentage of contain of moisture in the sample, X= Weight of wet sample (grams), and Y= Weight of dry sample (grams)

4.7.2 Equilibrium moisture content

At the point when the hygroscopic material is presented to air, it will assimilate either moisture or desorbs moisture relying upon the relative stickiness of the air. The balance moisture content will soon achieve when the vapor weight of water in the material winds up noticeably equivalent to the fractional weight of water in the encompassing air. The balance moisture content in drying is along these lines imperative since this is the base moisture to which the material can be dried under a given arrangement of drying conditions. A progression of drying trademark bends can be plotted. The best is if graph is plotted as drying rate versus time as shown in fig.4.17.

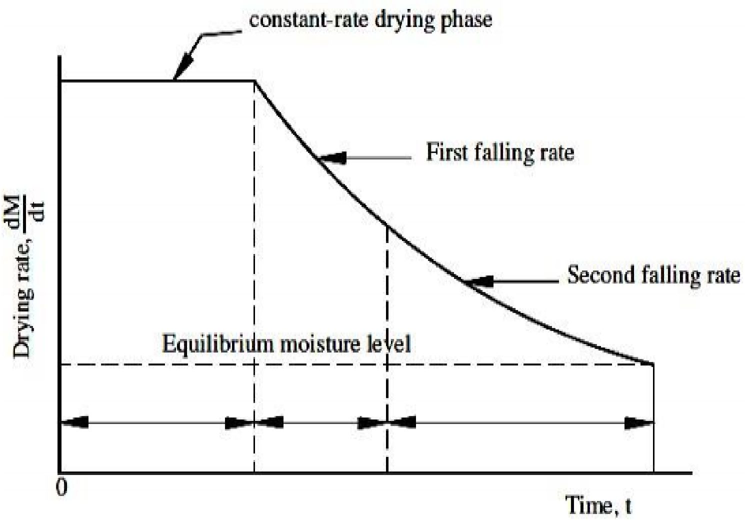

Figure 4.14: dM/dt versus time

4.8 Performance study of solar dryer model

Drying performance of solar drying model is better compare to open drying system. Solar drying system is effective compare two open drying system due to low relative humidity of air and high temperature. Solar drying system with forced air circulation is more effective because due to evaporation at certain time period relative humidity inside greenhouse became high. So,proper air exchange is essential. This will make fast drying of chemical gypsum. Chemical gypsum coming from nearby chemical plants has maximum 30% moisture content. Hence,utilizing solar energy appears as a more economical, efficient and less complex choice than the other drying systems. Tunnel-type greenhouse hold the air temperature difference at 10°C between inside and outside of the greenhouse. Solar energy can be useful for single source or it can be useful for system with auxiliary source. Additionally use of solar collectors also makes fast drying rate of system[15].

The height of the room is about 14.76 ft , the total volume of the room is $14.76 \times 537.92 = 7939.6992$ ft^3

1. Specific heat capacity of air = 1.0065kJ/kg.$^{\text{o}}$C, density of air = 0.036 kg/ft^3. mass and temperature difference = 10°C

$$m_a = density \times volume \tag{4.14}$$

$$m_a = 0.037 \times 7939.6992 = 293.76kg$$

$$Energy = m_a \times C_p \times \triangle T \tag{4.15}$$

$$Energy = 1.006293.76 \times 293.76 \times 10 = 2995.314kJ$$

Power is energy transferred / second. That means, your 1000W space heater can transfer 1000 J of energy / second.

So, time taken to heat up this space will be calculted as follow.

$Time = 2995000/1000 = 2995seconds$

In other words 1000 W space heater takes 50 minutes to rise 10°C.

Chapter 5

Result analysis of solar dryer model

Design and implementations of experimental model is discussed in last chapter. After implementations of experimental model practical study of drying is carried out. In this chapter gives result generated by practical study in experimental model of solar dryer. It include study of different parameter like moisture, purity, temperature and relative humidity of open drying and solar drying.

To meet the daily need of gypsum around 70 to 100 tones per day simple solar drying system can't be work well in all condition. So,advance solar dryer system is require for effective and less drying time rate solar drying which use forced air circulation spreading of material, auxiliary source and automatic moisture removal system.for effective drying. Increase surface area by spreading of chemical gypsum would make effective drying[12].

5.1 Experiment analysis of open drying and solar drying

Experimental analysis is carried out on two sample. From these two sample of same length, width and thickness layer are built. One is made in solar dryer and other is in open area. After spreading those both layer experimental analysis are carried out. Both sample are shown in fig.5.1 and 5.2.

Figure 5.1: Inside layer(solar drying)

Figure 5.2: Outside layer(Open Drying)

5.1.1 Temperature of drying system

Difference of temperature between drying system and open area is 4-12°C. Difference of temperature at different time is shown in graph of fig.5.3.

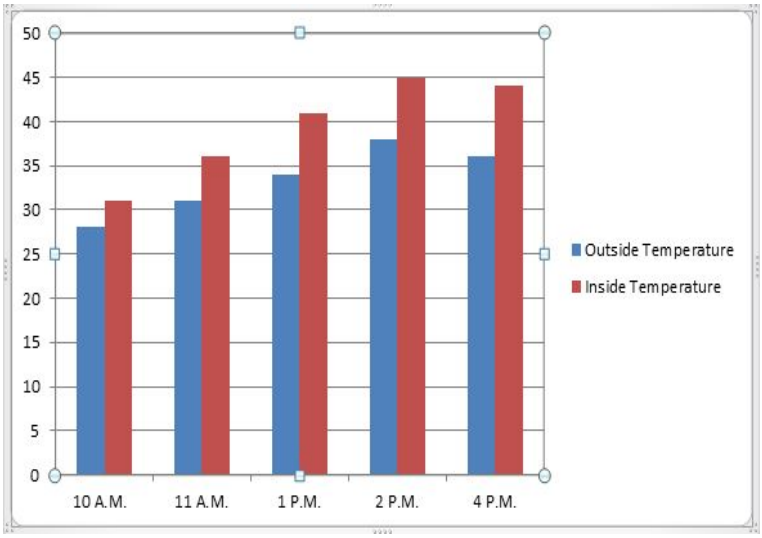

Figure 5.3: Graph of temperature of outside and inside

5.1.2 Relative humidity of drying system

Difference of R.H. of drying system and outside is average 5-22%. Difference of R.H. at different time is shown in graph of fig.5.4.

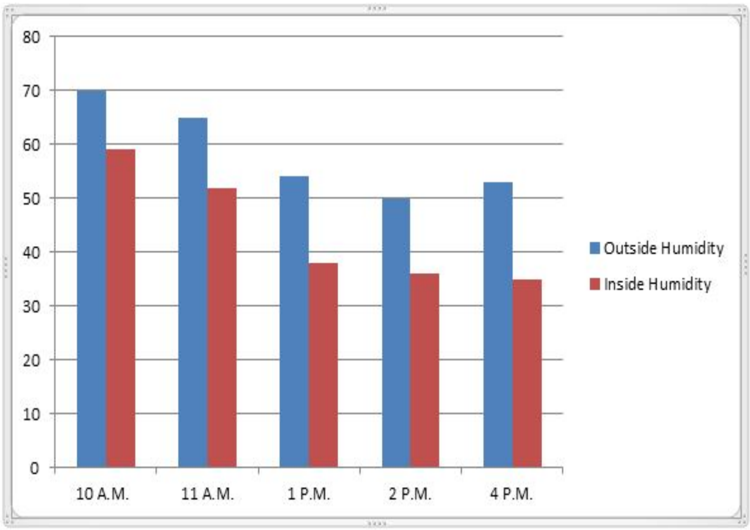

Figure 5.4: Graph of relative humidity of outside and inside

Taking two sample putting one inside solar dryer and other in open area. Experimental analysis of these sample is carried out in different condition and different season. From these experimental analysis we get result as shown in table 5.1.

Table 5.1: Moisture analysis using psychromatric chart

Time	Dry bulb tem.	Wet bulb tem.	R.H.	Specific humidity	Volume(m^3) / kg dry
10.00 A.M.	31	24	58	0.0132	0.87
12.00 P.M.	36	28	52	0.0185	0.90
02.00 P.M.	41	30	38	0.0200	0.91
04.00 P.M.	45	32	36	0.021	0.93
06.00 P.M.	44	32	35	0.02	0.92

5.1.3 Moisture removal rate analysis of drying system

Moisture removal rate of open system and solar drying system for different thickness of chemical gypsum layer like as 10 cm, 20 cm, 25 cm, 30 cm are carried out. From these experimental analysis we get following result. Graphical and numerical data of experimental analysis of all experiment are listed as follow.

1) Initial Moisture = 32%

Sample put for experiment on 15/10/2016 at 3.00 P.M.

$Length \times Width \times Thickness = 2.5 \times 2.5 \times 0.25$

Mass of Sample = 3.6 tonne

Table 5.2: Experiment result data shit - 1

Date	16/10/2016		17/10/2016		18/10/2016	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	3.00 PM	3.00 PM	3.00 PM	3.00 PM	3.00 PM	3.00 PM
Moisture(%)	25	28	17	21	10	16.50
Purity(%)	-	-	-	-	54.10	42.90
Temp.(°C)	42	35	44	36	41	35
RH(%)	41	52	57	48	60	51
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	7 % dry	4 % dry	8 % dry	7.50 % dry	22 % dry	15.50 % dry
Layer Size	Inside and Outside - $2.5 \times 2.5 \times 0.25$					

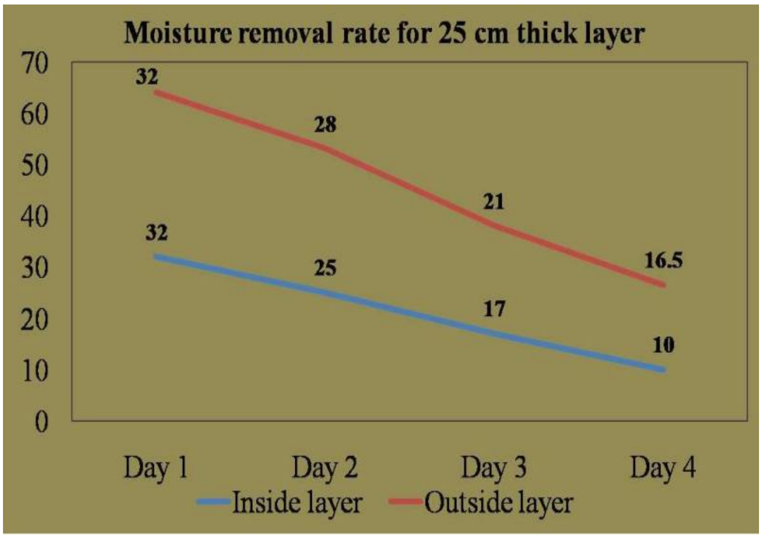

Figure 5.5: Graphical representation data shit -1

2) Initial Moisture - 30%

Sample put for experiment on 14/02/2017 at 10.00 A.M.

$Length \times Width \times Thickness = 5 \times 5 \times 0.30$

Mass of Sample = 17.25 tonne

Table 5.3: Experiment result data shit - 2

Date	15/02/2017		16/02/2017		17/02/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM
Moisture(%)	24	26	16	20	7.50	13
Purity(%)	-	-	-	-	-	-
Temp.(°C)	37	25	35	25	35	27
RH(%)	38	52	36	51	35	53
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	6 % dry	4 % dry	8 % dry	6% dry	8.50 % dry	7% dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.30$					

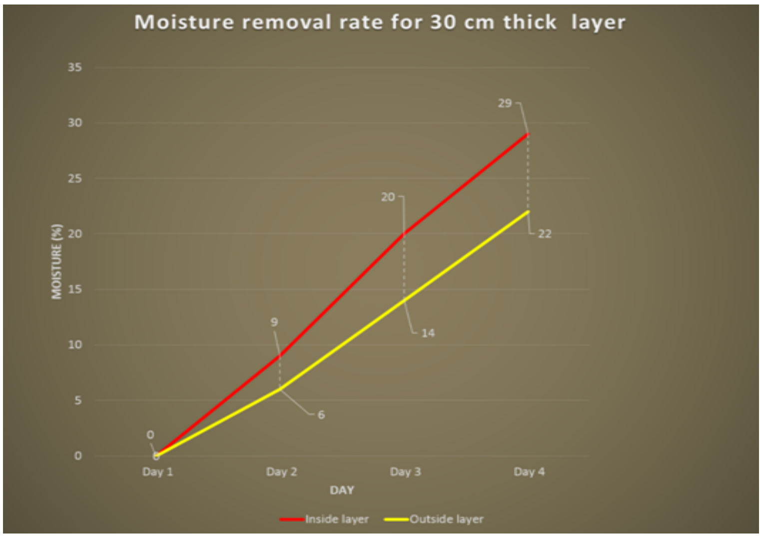

Figure 5.6: Graphical representation data shit -2

3) Initial Moisture - 30%

Sample put for experiment on 14/02/2017 at 10.00 A.M.

$Length \times Width \times Thickness = 5 \times 5 \times 0.20$

Mass of Sample = 11.50 tonne

Table 5.4: Experiment result data shit - 3

Date	15/02/2017		16/02/2017		17/02/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM
Moisture(%)	22.5	25.5	14	19	4.50	11
Purity(%)	-	-	-	-	-	-
Temp.(°C)	37	25	35	25	35	27
RH(%)	38	52	36	51	35	53
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	7.5 % dry	4.5 % dry	6 % dry	11 % dry	15.5 % dry	19 % dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.20$					

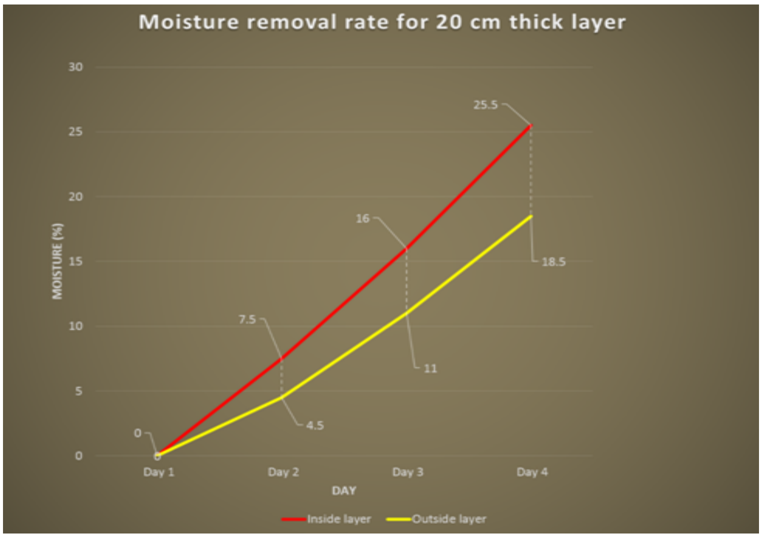

Figure 5.7: Graphical representation data shit -3

4) Initial Moisture - 30%

Sample put for experiment on 14/02/2017 at 3.00 PM

$Length \times Width \times Thickness = 5 \times 5 \times 0.10$

Mass of Sample = 5.7 tonne

Table 5.5: Experiment result data shit - 4

Date	15/02/2017		16/02/2017		17/02/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM	10.00 AM
Moisture(%)	21	24	10	16	1	8
Purity(%)	-	-	-	-	-	-
Temp.(°C)	37	25	35	25	35	27
RH(%)	36	50	36	51	35	53
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	9% dry	6% dry	20% dry	14% dry	29% dry	22% dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.10$					

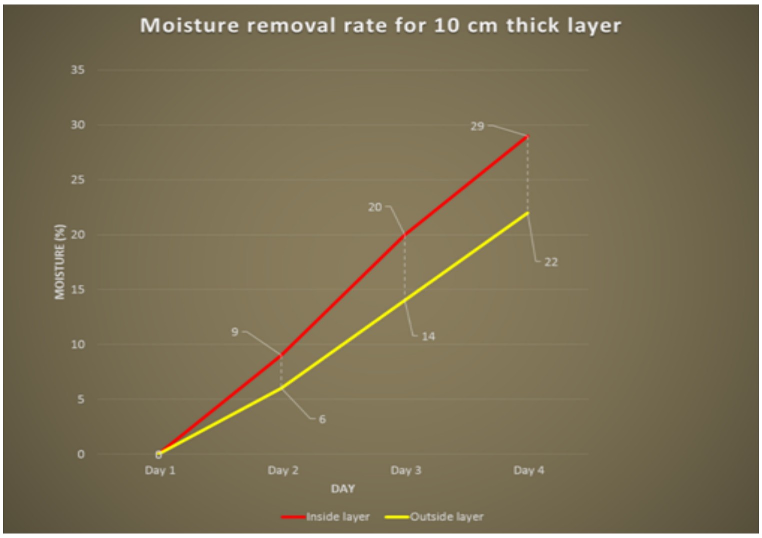

Figure 5.8: Graphical representation data shit -4

5) Initial Moisture - 29%

Sample put for experiment on 21/03/2017 at 11.00 AM

$Length \times Width \times Thickness = 5 \times 5 \times 0.30$

Mass of Sample = 17.25 tonne

Table 5.6: Experiment result data shit -5

Date	21/03/2017		22/03/2017		23/03/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	11.00 AM	11.00 AM	11.00 AM	11.00 AM	11.00 AM	11.00 AM
Moisture(%)	29	29	22	24.50	13	18
Purity(%)	-	-	-	-	-	-
Temp.(°C)	40	33	43	35	42	35
RH(%)	30	42	43	35	42	35
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	Initial	Initial	7% dry	5.50% dry	16% dry	11% dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.30$					

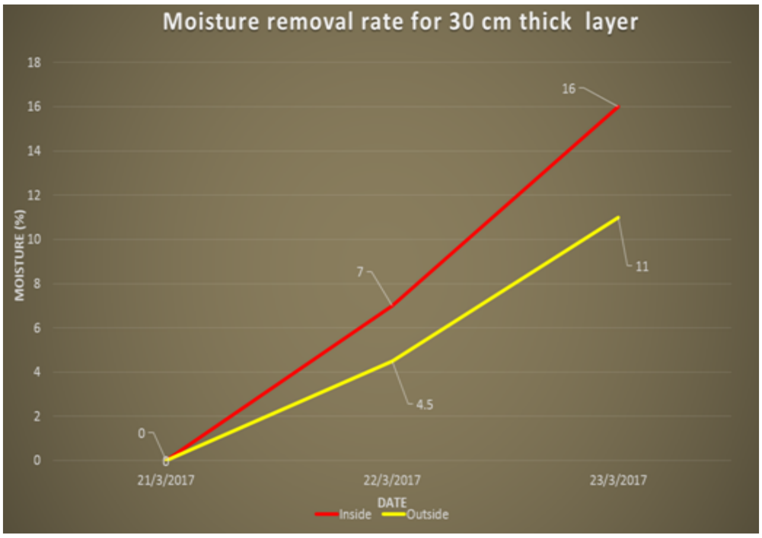

Figure 5.9: Graphical representation data shit -5

6) Initial Moisture - 26%

Sample put for experiment on 04/04/2017 at 2.00 PM

$Length \times Width \times Thickness = 5 \times 5 \times 0.20$

Mass of Sample = 11.50 tonne

Table 5.7: Experiment result data shit - 6

Date	04/04/2017		05/04/2017		06/04/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	2.00 PM	2.00 PM	2.00 PM	2.00 PM	2.00 PM	2.00 PM
Moisture(%)	26	26	17	21	7	16
Purity(%)	-	-	-	-	-	-
Temp.(°C)	50	41	52	42	50	40
RH(%)	17	25	16	24	18	25
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	Initial	Initial	9% dry	5% dry	10% dry	5% dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.20$					

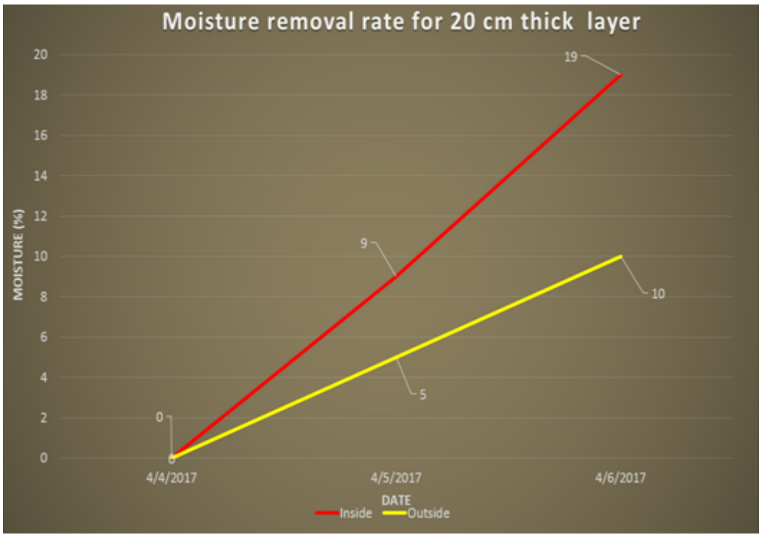

Figure 5.10: Graphical representation data shit -6

7) Initial Moisture - 26%

Sample put for experiment on 04/04/2017 at 2.00 PM

$Length \times Width \times Thickness = 5 \times 5 \times 0.10$

Mass of Sample = 5.75 tonne

Table 5.8: Experiment result data shit - 7

Date	04/04/2017		05/04/2017		06/04/2017	
Place	Inside	Outside	Inside	Outside	Inside	Outside
Time	2.00 PM	2.00 PM	2.00 PM	2.00 PM	2.00 PM	2.00 PM
Moisture(%)	26	26	15	20	4	14
Purity(%)	-	-	-	-	-	-
Temp.(°C)	50	41	52	42	50	40
RH(%)	17	25	16	24	18	25
Fan Flow(CFM)	9000	9000	9000	9000	9000	9000
Remarks	Initial	Initial	11% dry	6% dry	11% dry	6% dry
Layer Size	Inside and Outside - $5 \times 5 \times 0.10$					

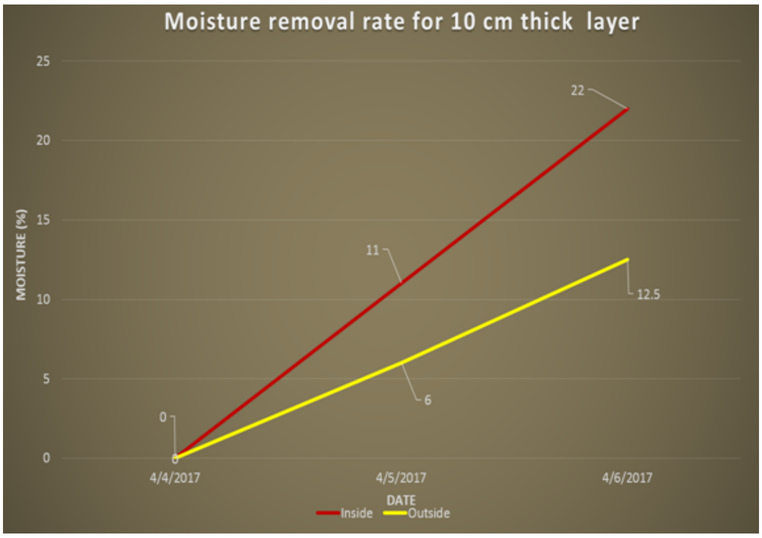

Figure 5.11: Graphical representation data shit -7

5.2 Analysis of result of experimental study

Analysis of result of practical study solar dryer system lead to many parameter but from all parameters following study consider important parameters only. Solar drying system has following three main important parameter.

1) Solar radiation (Season)

2) Thickness of drying matter bed and

3) Automatic fan and auxiliary heating system .

5.2.1 Solar radiation (season),

In different month experimental study is carried out for getting impact of solar drying system compare to other system. From result we can say that in summer time and winter time solar drying system impact is high and effective and high performance oriented result are getting but in rainy season and night time auxiliary source is require for make system feasible in all condition.

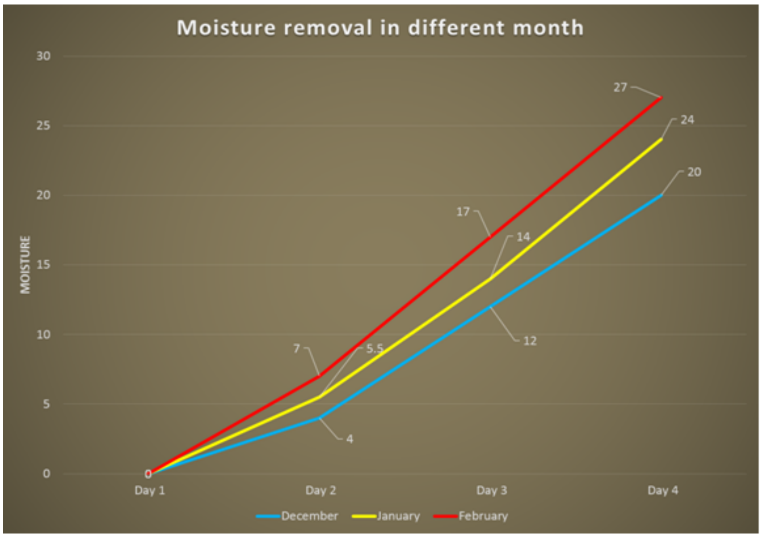

Figure 5.12: Moisture removal in different month

5.2.2 Thickness of drying -bed of material

Thickness of the layer also play important role.Impact of thickness on drying rate. Drying of thin layer chemical gypsum is fast compare to thick layer because of surface of thin layer expose more easily. So, moisture removal is fast compare to thick layer of chemical gypsum. We can also shown in following graph.

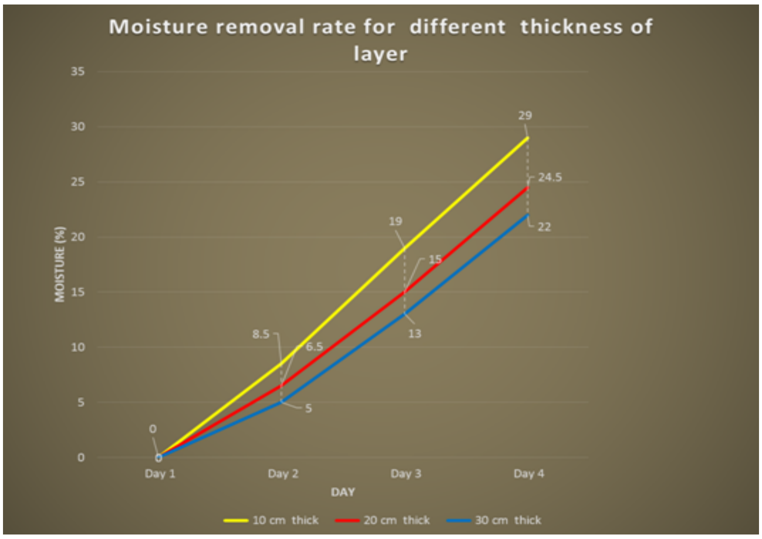

Figure 5.13: Moisture removal for different thickness of layer

5.2.3 Fan-auxiliary heating automatic system

Solar drying system with advance technique like scraper, auxiliary source and collector also improve the performance of the solar drying system. Solar drying system of forced air circulation with rotary scraper give faster result in short time period because it expose surface for drying. Solar drying system of forced air circulation with rotary scraper give faster result in short time period. Table 5.8 gives result of drying system in different condition.

Table 5.9: Total Moisture Removal (Average)

System (layer thickness - 20 cm)	Moisture removed / Day
Normal system	5.00%
Normal system with Forced air circulation	6.30 %
Advance system of forced air circulation and scraper	8.00%

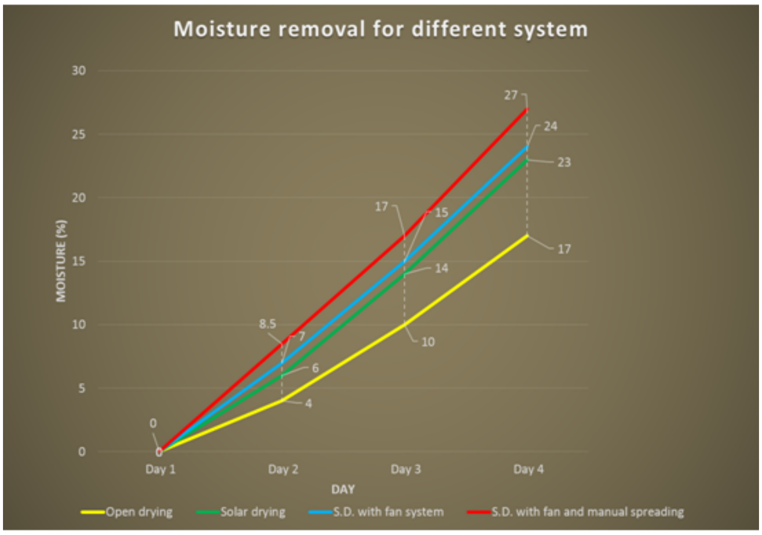

Figure 5.14: Moisture removal in different system

5.3 Summary

This chapter covers result analysis of various test carried out on experimental model of solar dryer. Moisture contain and purity were calculated in N.A.B.L. accredited physical lab in plant.

Chapter 6

Conclusion and future work

6.1 Conclusion

1. Selecting of drying system for chemical gypsum is mainly based on high capacity, low cost, efficient working. Solar dryer system has fulfilling all the important factor. So,it has been selected for the design.

2. Solar dryer system experimental model is designed for experimental analysis of the system.Using of forced air circulation, surface exposing and auxiliary heat source make system run in all condition with low drying time.

3. From the study of different type experimental analysis we can say that solar drying system is more efficient and economical system.

4. Industry needs daily 70 tonne gypsum for cement production. So, for effective working of solar dryer we need gypsum layer volume of $30m^3 = 15 \times 10 \times 0.20(L \times W \times T)$. Expansion of pilot solar dryer is require for fulfill the requirement of drying of 70 tonne chemical gypsum.

5. It also helpful for temporary storing of gypsum. So, transportation and handling cost also decreases.

Present drying system	Solar drying system
Drying time - 3 to 4 day	Drying time - 2 to 3 day
Rainy season system face problem	Feasible for all season
It doesn't give storage facility	It does give storage facielity

Table 6.1: Conclusive table

6.2 Future Work

In the future, it would be beneficial to extend the analysis of the system with auxiliary system and solar air collector to get high temperature difference. It is also pollution free type drying system of solar energy. If the system is controlled with automated system like thermosensor then we can control on the indoor temperature, fan flow and humidity. For example, if the indoor air become moist after evaporation water from chemical gypsum then forced air circulation system will throw this moist air outside and fresh air intake stars.In monsoon, winter and sun log off hour periods an auxiliary is heat source is useful for continuous drying.

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