DEVOLOPMENT OF A MECHANICAL DRYER FOR DRYING COCO PEAT TO USE GROWING MEDIA

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Declaration

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Abstract

Coir peat which is a by-product of extracting fibre from coconut husk is considered an excellent growing media in horticulture industry. The basic features of coco peat is having good water holding capacity, ability to control PH and EC (electric conductivity) and good air porosity. Demand for the coco peat is increased continuously due to the above reasons. In addition, use of sphagnum peat moss and rock wool is replaced by coco peat very easily due to scarcity and environment issues of those growing media.

In the present Sri Lankan context, sun drying is widely using to dry the wet coco peat up to the required moisture level before it is compressed. Since coco peat is having a low density (0.1 kg/L), it is needed to be compress before transportation. However sun drying is totally depending on the weather pattern and it is not advisable to depend on sun shine due to the present demand and reliability on the industry. Therefore possibility to look at thermal drying is important while retaining the relevant properties of coco peat.

Studies were carried out to evaluate the performance of combining both rotary drum dryer and flash dryer which are used in similar industries. Four key factors were taken into the study are moisture level, temperature, feed rate and residence time. A set of combinations of the above factors were tested and studied. More than two hundred samples were taken under different settings and corresponding output moisture percentages were measured. Compressed coco pellets were made out of dried samples and then expansion height of each sample was also measured for verification of the expansion quality of dry material.

The low moisture levels of feeding material affected the temperature of the system and feed rate. The frequency didn't play a major role. However feed material with high moisture, temperature and rotating frequency positively affected the output moisture while feeding rate was negatively affected. According to the research and considered input variable, this system shows coco peat can be dried when input material moisture is around 60% and temperature 90 -100^0 C and feed rate around 15 l/min and output material will be comply the requirement to use as growing media.

Coco peat with low moisture contents should be exposed to heat at low temperature with higher feed rates, but, material with high moisture content should be exposed to high temperatures and low feed rates as seen with this research. However, it is advisable to take more measurements with very close steps to fine tune the model parameters before implemented on the field.

Key words – Coir peat, Rotary drum dryer, Flash dryer, Moisture, Expansion property

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LIST OF ABBREVIATION

Abbreviation	Description
V/W	Volume Weight
PLS	Partial Least Regression
NIPLS	Nonlinear Iterative Partial Least Squares
PCA	Principle Component Analysis
RMSEP	Root Mean Square Error of Prediction

Nomenclature

Symbol	Unit	Description
α		Absorptivity of the product
S(t)	w/m^2	Solar intensity
h_l	$w/m^2\ c^o$	Heat transfer coefficient from product surface to ambient
Ta (t)	c^o	ambient air temperature,
k	$w/m\ c^o$	Thermal Conductivity of the ground
x	m	Thickness of the product
t	h	Time
h_{ev}		Heat Transfer coefficient
$P_s[Ta]$		Saturated vapour pressure at temperature of the upper layer of material
r		Relative humidity
ε		Bed porosity , decimal
k_p		Thermal Conductivity of product
k_{air}		Thermal Conductivity of air
c_p	$J/kg\ c^o$	Specific heat of the product
T	C^o	Temperature
X		Position
P		Density
C_p		Material of heat capacity
K		Thermal conductivity
k_f	$w/m^2\ c$	Thermal conductance of air film
A	m^2	Water surface area
h_{fg}	J/kg	Latent heat of vaporization
$\frac{dm_w}{dt}$	Kg/s	Drying rate
M		Moisture content at time
M_c		Equilibrium moisture content
X_w		Moisture content of wet basis

X_d		Moisture content of dry basis
$Ø_t$		Total drying time
$Ø_c$		Constant rate drying period
$Ø_f$		Falling rate drying period
t_m	k	Product temperature
t	k	Inlet temperature
h_a	k cal/s km^3	volumetric heat transfer coefficient
$(t-t_m)l_m$	k	logarithmic mean of the temperature difference between the hot air and the product at inlet and outlet
U	k cal/s km^2	overall heat transfer coefficient
A	m^2	Heating area contact with the product
t_k		Temperature of heat source
t_m	k	Product temperature
τ	min	Residence time
L		length of rotary drum
D		Diameter
N	rev/min	Rotational speed
Tan α		slope of the dryer
n		dynamic angle of repose of solid
Q	J/s	rate of heat transfer
$U_v a$	J/sm^3k	volumetric heat transfer coefficient
V	m^3	Dryer volume
$(\Delta t)_m$		true mean temperature difference between the hot gas and the material

CHAPTER 1

1.0 Introduction

The coco peat is extensively use as a growing media in green house farming in develop country. Coco peat is by product of fiber extraction process and it was a non-value added product before ten year back. But it become a good substitute for the growing media than present application like rock wool, sphagnum peat moss etc. Therefore demand for the coco peat increasing day by day and normally coco peat transport as a pressed block in dry form. It has certain amount of water when it is extracting which need to be removed. In present practices sun drying is used to dry the coco peat which cannot be practice while raining season. Therefore most suitable drying mechanism and drying model is essential to cater the present industry demand.

1.1 Background

Last two decade coco peat is developed as a growing media especially in greenhouse farming industry (controlled environmental agriculture) in western countries. But later it spread in other developing and developed countries in worldwide sine coco peat is a best media which can control the media than soil. In greenhouse industry peat moss and bark compost were used but both are non-renewable sources.

Coco peat is a by-products of coconut fiber extracting of the husk. Coco peat is a 100% natural, environmental friendly and renewable growing media and better substitute for peat moss or bark compost. Coco peat maintain excellent air porosity when saturated and bring better crop with faster developing roots. It has better water retention ability than other growing media [1].

Coir dust contained excessively high levels of sodium chloride which is minus point to develop as a growing media. To overcome this buffered coir dust was introduced. It is done by using Calcium Nitrate solution to leach out excess Sodium and Potassium from the coir dust and then leaching out excess calcium nitrate with fresh water.

At the same time excess potassium also be removed. After finishing the buffering process it is necessary to dry the coco peat prior to compress it. This is usually carried out by using sun light on drying yard which made by concrete or tar flow. The most prominent moisture level is 17 – 20 % in the dry material. After buffering it contains 90% moisture level. Some people put in to the drying after squeezing and some are not [1].

In practically nearly one day need to dry the coco pith. Further it depend on the lux level of the sun light, number of hours with the proper sun light, humidity and wind as well. The considering the last five years rain fall patterns has been drastically changed in North Western province where main raw material processing plants are located. Due to the uncertainty of weather pattern drying process become a challenge to the coco peat producers. The occasional rainfall also create a problem, as coco peat readily absorbs moisture. Under these circumstance half dry or spread material need to rapidly heap up. When the rain stops, it is spread out the drying yard again. These activity absorb much labour and machine cause unproductive cost are absorbed to without adding value to the raw material. Finally per kg cost rise especially in rainy days. Therefore it is essential to develop the mechanical dryer to dry the coco pith to face the unpredictable weather pattern.

Table 1.1 - Annual and monthly rainfall at observation stations- Kurunagala, 2008 – 2012 [2]

Month	2008 (in mm)	2009 (in mm)	2010 (in mm)	2011 (in mm)	2012 (in mm)
January	80.5	21.2	85.7	177.5	194.5
February	137.6	4.80	1.50	154.4	52.9
March	522.4	369.40	160.9	86.8	160.3
April	330.2	160.2	332.20	634.1	132.4
May	126.1	172.0	142.50	223.0	242.9
June	85.0	95.2	162.0	64.7	183.4
July	316.2	76.3	93.8	36.50	63.6
August	62.9	255.8	99.0	87.0	24.5
September	50.1	179.8	207.4	142.5	229.3
October	514.8	130.8	275.8	155.7	297.4
November	131.5	268.0	550.5	124.0	190.1
December	47.5	317.3	323.0	71.8	31.80
Total	**2404.8**	**2050.8**	**2434.3**	**1958.0**	**1805.4**

1.2 Objective of the Thesis

The aim of this research is to develop a drying model and make sure the drying behavior and quality of dried product. The data accumulate through prototype dryer use to develop the drying concept with respect to different moisture level, feeding rate, residence time and drying temperature.

Research objectives

- Main objective is select the suitable drying mechanism to dry wet coco peat with securing the property of dry material which is suitable for use as a growing media.
- To develop model of drying system and trial it.
- Optimize the test result by differentiate the control parameter.

1.3 Research Methodology

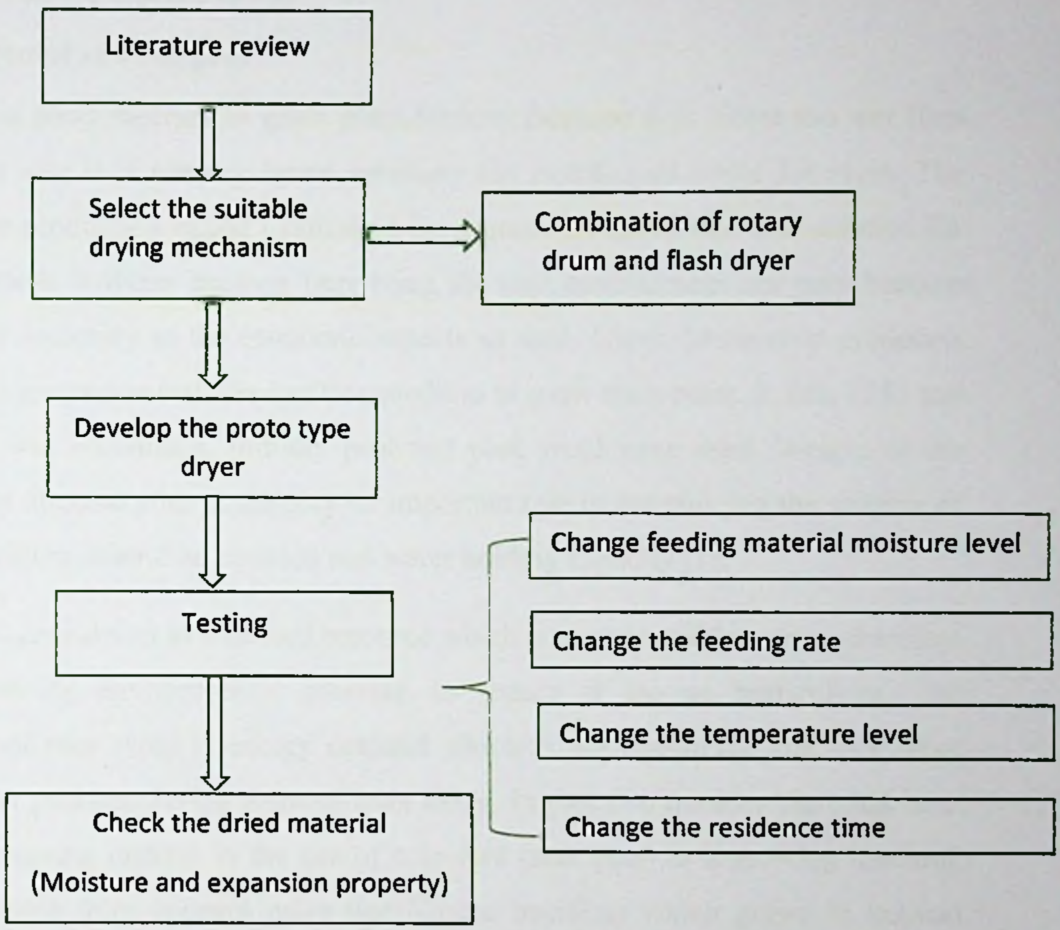

Figure 1.1 - Steps of Research Strategy

1.4 Summary of the Thesis

In This thesis Chapter 1 overview the background of the research, research objectives as well as methodology of the research. In the second Chapter, literature survey is conducted to search suitable drying method. In chapter 3 is described the material and method used in research. Result and discussion are discussed in chapter 4. Conclusion and recommendation for future studies are summarized in chapter 5.

CHAPTER 2

2.0 LITERATURE SURVE

2.1 Background of Coco peat

Soil is not a good medium to grow plant further. Because it is either too wet (less aeration) or else it is too dry (good aeration) but insufficient water for plant. The green house production called Controlled Environment Agriculture is a solution for overcome these problem because improving the root environment not only become feasible but necessary to the economic aspects as well. Green house crop producers have sought an economical, disease free medium to grow their plant. In late 1950 soil less media was introduced. Initially peat and rock wool were used. Weight of the medium and disposal after usage play an important role in determining the suitable of growing medium other than aeration and water holding capacity [1].

Peat is now considered as a limited resource which is nonrenewable source, therefore there are strong environmental pressure to reduce it use as horticulture. The production of rock wool is energy demand which is not encourage and rock wool crate a major problem during disposal after using. In past two decades there has been steadily increasing interest in the use of coir dust (coir peat) as a growing medium. Coir dust come from coconut palm tree (Cocos nucifera) which grows in tropical country like Sri Lanka, India, Philippine etc...Coir dust is a byproduct of coconut fiber extraction from the coconut husk [3]. Coconut Huck comprises of fiber and coir dust in a ratio approximately 1/3 : 2/3. Coir dust consists of mixture of short fibers and cork-like particles ranging in size from granules to fine dust. Coir dust is a waste product in earlier before use it as a growing media.

The coco peat is brown, spongy particle of low weight particle. It is rich in lignin and tannins. Under the high pressure and temperature these compounds softened act as thermoplastic binding material [3]. The physical and chemical properties are mentioned in the Table 2.1.

Table 2.1 Physical and Chemical properties of coco peat [4]

Property	Detail
Porosity	75%
Water Holding Capacity	500 percent/ 5 to 6 wt
Nutrient holding capacity	Good/ 5 tp 6 wt
Content	Natural rooting hormones
PH	5.2 to 6.8 ,ideal for plant growth/ 6 to 7
Electrical Conductivity	Not more than 500 µs/cm
Total pores space	28.2
Organic Carbon	80%
Nitrogen	1.08%
Phosphorus	0.19%
Calcium	1.92%
Magnesium	0.98%
C/N ratio	26.1%
Micro Nutrients (ppm)	
Iron	4140
Manganese	160
Zinc	42
Copper	706

Traditionally, coir fiber was obtained by retting the husks in water for few months, after which the fiber was separated from the coir dust by using simple machineries. For white coir, the retting was in slightly saline water, and for brown coir the retting was in fresh water. There is another method to obtain the coir fiber in industry by using decorticating machinery to break up the husk, and then to separate the fiber from the dust. The coir dust is initially sieved to remove any lumps and fiber.

About 23 MT of coir medium is required for every hectare of greenhouse use, which means that the current world supply of coco peat could provide the equivalent of 350,000ha of greenhouses. The world greenhouse industry (controlled environmental agriculture) is about 500,000ha, so there is still plenty of coir to go round. Not everyone will use it, and it is sometimes used to grow two or three crops before being discarded, so currently there is huge demand for the coco peat. [5]

The reasons and benefits of the coco peat as a growing medium.

* Environmentally Safe
* Economical
* Organic
* Biodegradable
* High water holding capacity - i.e. up to 5 times its volume
* Provides better aeration and enhances strong and healthy root growth
* Resistant to bacterial and fungal growth
* Retains and releases nutrients for extended period of time
* Uniform texture and consistency
* Better yield
* Odorless
* Environment friendly
* Enhances the organic content of the soil if mixed with soil
* Free from pathogens, weed seeds and toxins.

Coir dust contained excessively high levels of sodium chloride. It may be that the coir dust had been obtained from coir, which had been retted with saline water, or it may be that the coir dust had been obtained from coconuts grown near the sea, which had absorbed high levels of sodium. Whatever the reason, it resulted in coir dust as a horticultural growing medium getting very poor media [6].

Coco peat is then usually (but not always) treated with calcium nitrate solution to buffer it and remove sodium. This is done by applying a standard quantity of calcium nitrate solution to a fixed volume of coco peat, and then after applying water to wash out excess calcium nitrate. It is now necessary to dry the coco peat prior to compressing it. This is usually carried out by the sun on large concrete pads in areas of low rainfall; but where rains can occur, it requires artificial methods. Even in arid climates, the occasional rainfall can prove a problem, as coco peat readily absorbs moisture. Under these circumstances the coco peat is rapidly heaped up, so that only the top gets wet, and when the rain stops, it is spread out again on the concrete drying yards.

2.2 Economic value of the coco peat export

According to the Table 2.2 shows the statistics of export core peat in last two years respectively volume and export earnings are increased by 8%. Therefore coco pith industry

has good potential demand which is continuously increasing. To keep continues supply it is essential to develop the cost effective mechanical drying system to overcome the uncertainty of weather.

Month	2014		2015	
	Volume (MT)	FOB Value (US$'000)	Volume (MT)	FOB Value (US$'000)
January	13,794	4,131.10	11,306	3,330.90
February	14,095	4,020.96	19,415	5,567.03
March	17,442	5,095.19	18,443	5,373.71
April	12,312	3,573.67	15,872	4,481.78
May	15,687	4,876.89	16,361	5,066.48
June	13,626	4,714.22	12,461	4,408.68
July	14,059	4,828.88	17,259	5,888.80
August	13,419	4,317.44	14,087	4,643.52
September	13,147	4,208.81	16,039	5,431.62
October	13,023	4,419.24	11,716	4,321.46
November	9,688	3,163.98	8,114	2,677.08
December	6,885	2,361.60	8,435	2,438.94
Total	**157,177**	**49,711.98**	**169,544**	**53,629.29**

Table 2.2 Monthly Statics of Export of coir peat 2014/2015 [7]

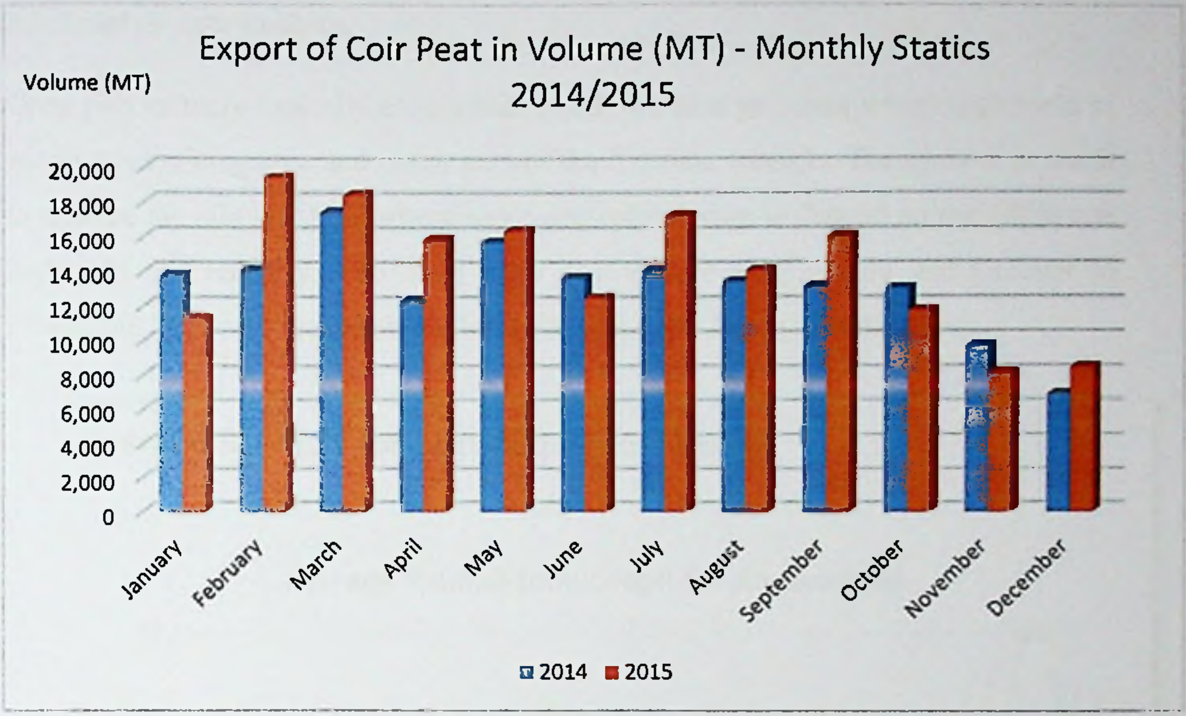

Figure 2.1 – Monthly statistic of export of Coir peat in volume basis – 2014/2015 [7]

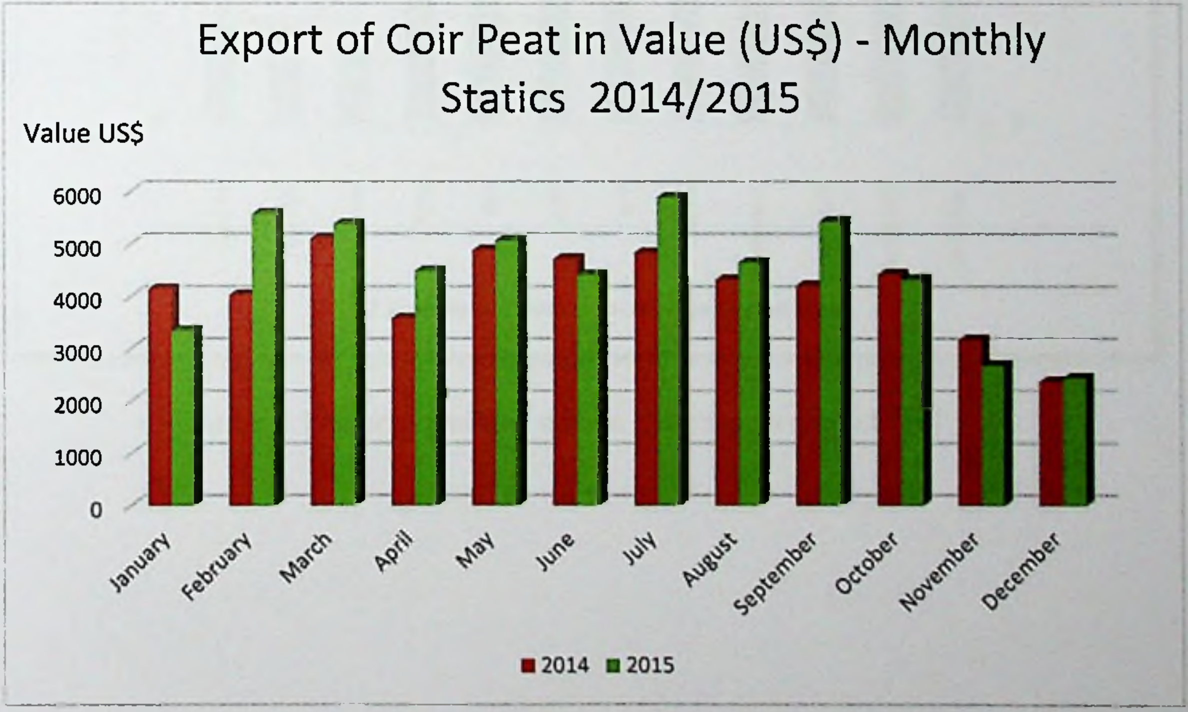

Figure 2.2 – Monthly statistic of export of Coir peat in value basis – 2014/2015[7]

2.3 Rainfall data analysis

Coco pith industry basically concentrate North Western province where high yield of coconut harvesting area and major part of the Coconut triangle. Therefore it is worth to analyze the rain fall data pattern since coco pith drying is depend on the 100% sun drying in this industry. The main rainy seasons are May – July and October to December. This cause respectively Inter Monsoon and North East Monsoon.

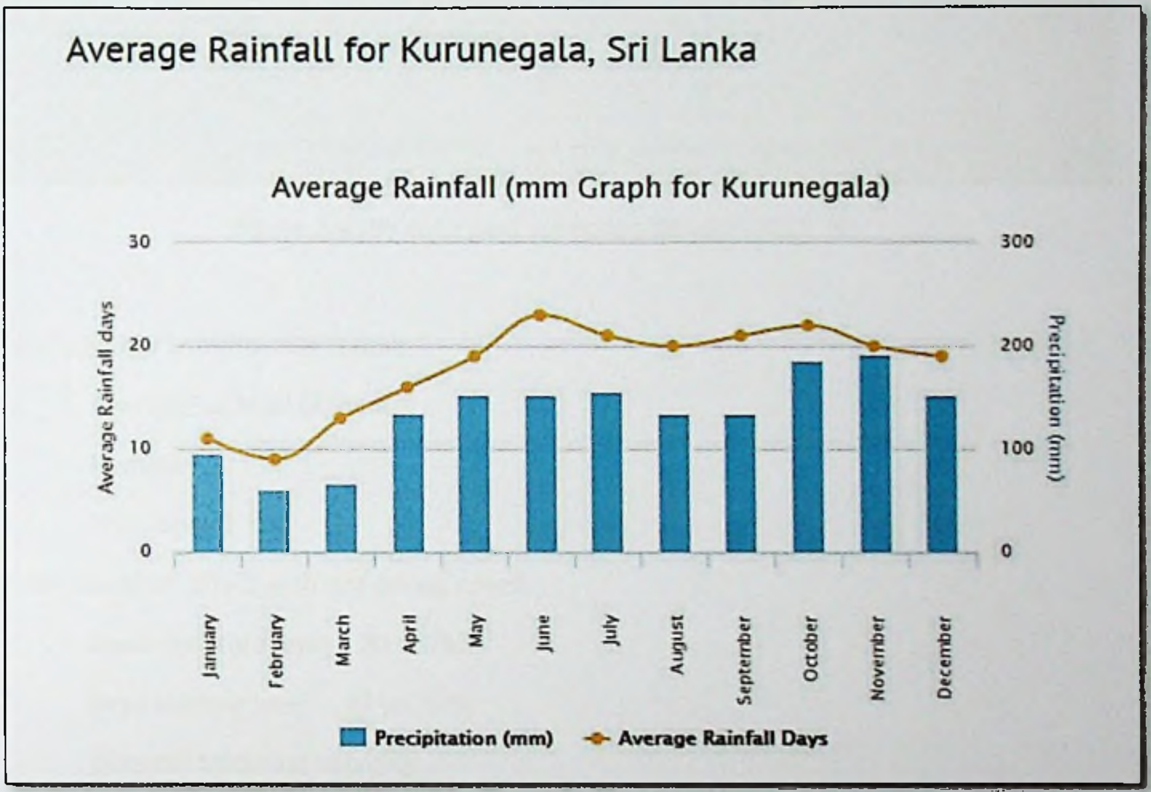

Figure 2.3 Average rainfall data in Kurunagala district [8]

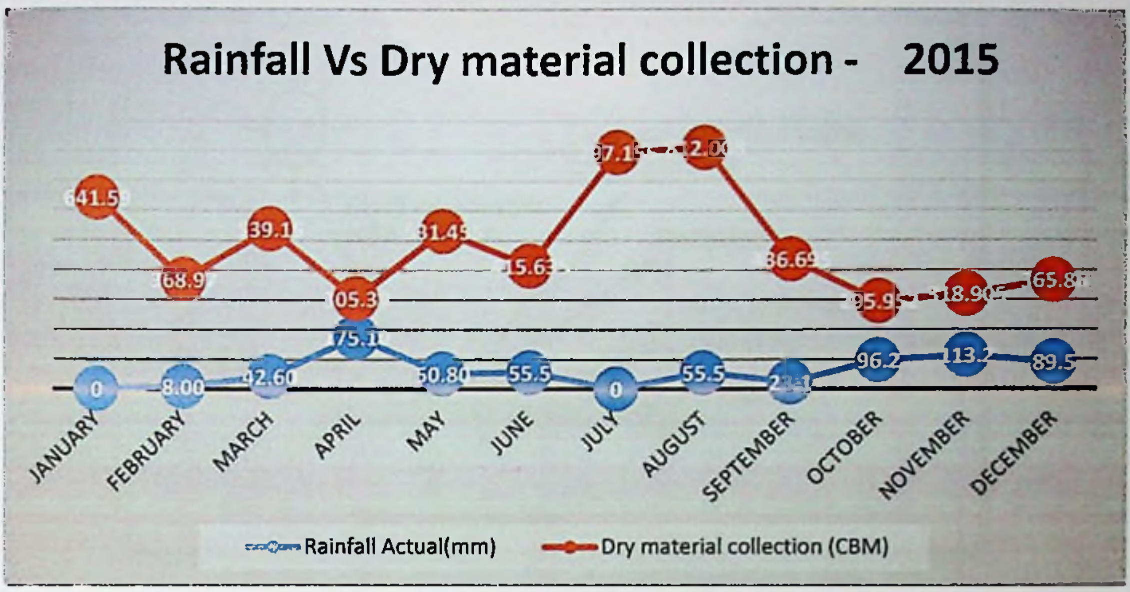

Figure 2.4 Dry coco peat collection detail in 2015 [9]

Basic weather considerable factors

Average lux level of the day

Humidity

Wind speed

Other condition affect with sun drying speed

Input moisture level – 70 to 75%

Dry moisture level - 17 to 20 %

Material thickness in laying

2.4 Theory of open sun drying process.

The customary technique of open sun drying involves spreading the material to be dried in a thin layer on ground or mat. It exposing sun and wind and product occasionally stirred to ensure uniform drying. Basically fruits, crop and agriculture surpluses has been widely sun drying for ages. The coco peat also drying under the sun in India, Sri Lanka, Indonesia, Philippines like tropical country where coco peat is produce extensively.

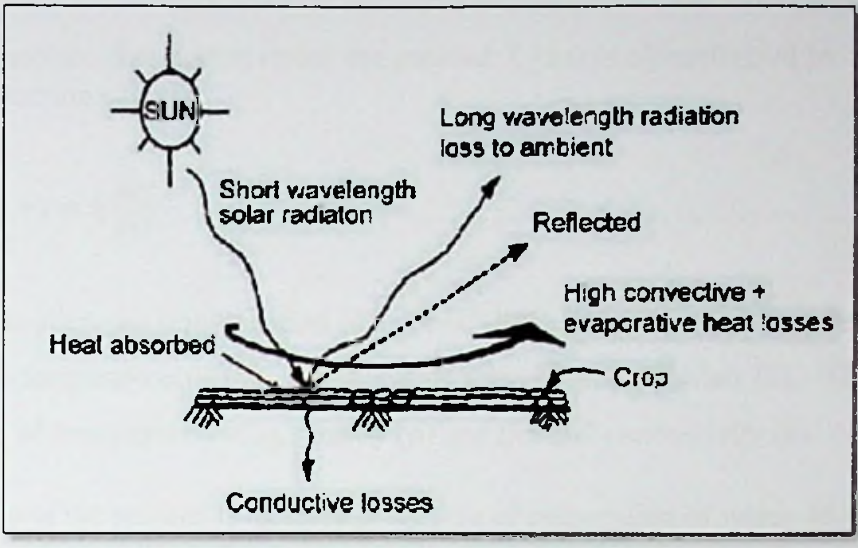

Figure 2.5 Illustration of Heat distribution in open sun drying on the ground [10]

A part of the energy is reflected back and the remaining is absorbed by the surface depending upon the color of product lay. The absorbed radiation is converted into thermal energy and the temperature of the material start to increase. Also include the phenomenon of mass transfer in terms of the difference in saturated vapors pressure of the product and the ambient air. The effect of wind speed, relative humidity, product thickness and heat losses the ground have been taken into account. The present model include both the constant rate and falling rate of regimes in drying. [10]

Solar radiation inserted on the product = {Heat Losses to the ambient due to convection and radiation} + {Heat loss to ambient due to evaporation} + {Heat conducted to the material} .... Eq (1)[10]

That is

$\alpha S(t) = h_1 [T(x = o, t) - T_a(t)] + Q_{ev} - K \frac{\delta T}{\delta x}(x,t)|x = 0|$ .... Eq (2)

$Q_{ev} = h_{ev} [P_s \{T(x = 0,t)\} - r P_s (T_a)]$ .... Eq (3)

The effective thermal conductivity of the product may be given as follows

$K = (1 - \varepsilon) K_p + \varepsilon K_{air}$ .... Eq (4)

The temperature distribution inside the product T (x,t) is characterized by the Fourier heat Conduction equation

$$C_p\, \rho \frac{\partial T}{\partial t}(x,t) = k \frac{\partial^2 T}{\partial x^2} \quad \text{.........Eq (5)}$$

Fourier's heat conduction equation is a partial differential equation that describes the change in temperature (T) as a function of time (t) and position (x). The material properties of heat capacity (C_p), density (ρ) and thermal conductivity (k).

The drying of the product is essentially the rate of evaporation of water which may be written as

$$\frac{dm_w}{dt} = \frac{k_f A}{h_{fg}} \{ T_a(t) - T(x = o, t) \} \quad \text{.........Eq (6)}$$

After evaporation of a certain amount of water from the product, internal resistance to moisture transport becomes larger than the external resistance. Therefore such circumstance the drying occurs in falling rate of regime which is expressed as below.

$$\frac{dm}{dt} = -k\,(M - M_e) \quad \text{.........Eq (7)}$$

The open sun drying for highly moistures products should be carried out for thickness less than 5 cm. because lesser the thickness, higher the product temperature and cause to higher drying rate [10]

2.5 Principles behind the drying

Drying is basically a phenomena of removal of liquid by evaporation from a product need to dry. Mechanical method for separating a liquid from a solid are not considered as drying. A major part of energy consumption during drying is for the evaporation of liquid water in to its vapors. The water may be contained in the solid in various forms like free moisture (unbound) or bound form. Moisture held in loose chemical combination, present as a liquid solution with in the solid which exert a vapor pressure less than that of pure liquid is called bound moisture. Moisture in excess of bound moisture is called unbound moisture. Moisture content is expressed either on dry or wet basis.

Moisture content in wet (X_w) basis is the weight of moisture per unit of wet material. It can be declared as below

$$X_w = \frac{m_w}{m_w + m_d} \quad \text{Eq (8)}$$

Moisture content on dry basis (X_d) is expressed as the ratio of water content to the weight of dry material.

$$X_d = \frac{m_w}{m_d} \quad \text{Eq (9)}$$

As mentioned above moisture in solid may be either bound or unbound. There are two method of removing in unbound moisture which are evaporation and vaporization. Evaporation occurs when the vapor pressure of the moisture on the solid surface is equal to the atmospheric pressure. In vaporization is carried out by convection by passing warm air over the product. The heat of the air is taken by the product and moisture is transferred to the air by the product and it carried away. In this case saturation vapor pressure of the moisture over the solid is than the atmospheric pressure. The drying behavior of solid can be characterized by measuring the moisture content loss as a function of time [11].

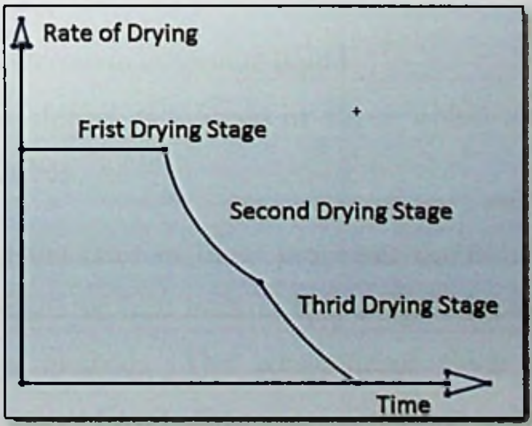

Figure 2.6 Characteristic drying rate curve [11]

A typical drying rate curves of a hygroscopic product contain water behave differently on drying according to the moisture content. The first stage of drying the drying rate is constant since free moisture of the surface vaporization take place.

The second drying stage unsaturated surface drying is occurred. In this stage proceed until the surface film of liquid entirely evaporated. In third drying stage moisture may move through the solid as result of concentration gradient between the deeper parts and surface is the controlling step. The heat transmission now consist of heat transfer to the surface and heat conduction in the product.

For slow drying material most of the drying may occur in the falling rate period. All the exposed surface of the solid ceases to be wetted, vapor movement by diffusion and capillarity from within the solid to the surface are the rate controlling steps.

2.5.1 Psychometric in Drying

An adequate supply of heat is provided for drying, the temperature and rate at which the liquid vaporization Occurs will depend on the vapors concentration in the surrounding atmosphere. The liquid must be heated to a temperature at which its vapor pressure equals or exceeds the partial pressure of vapor in the purge gas.

2.5.2 Mechanism of Drying

Drying basically compromise of two fundamental and simultaneous process.

i. Heat is transferred to evaporate liquid
ii. Mass is transferred as a liquid or vapor within the solid and as a vapor from the surface

The factors governing the rates of these processes determine the drying rate. The different dryer may utilize the heat transfer by convection, conduction, radiation or a combination of these methods. The conventional dryer except dielectric and microwave drying heat must flow to the outer surface first and then into the interior of the solid [12].

2.5.3 Internal mechanism of liquid flow

The movement of moisture within the solid result from concentration gradient which dependent on the characteristic of the solid, which may be porous or non-porous. Thus the structure of the solid determine the mechanism for which internal liquid flow may occur and these mechanisms for which internal liquid flow may occur in one or combination of below mechanism.

a. Diffusion in continuous, homogeneous solid.
b. Capillary flow in granular and porous solid.
c. Flow caused by shrinkage and pressure gradient
d. Flow caused by gravity
e. Flow caused by a vaporization - condensation sequence

2.5.4 Estimation for total drying time

The total drying time (Θ_t) consist with constant rate drying period (Θ_c) and falling rate drying period (Θ_f)

$$(\Theta_t) = (\Theta_c) + (\Theta_f) \qquad \text{Eq (10)}$$

Constant rate period moisture movement within the solid is proceed by diffusion of vapor from the saturated surface of the material across a stagnant air film into the environment. The falling rate period is started at the critical moisture content when the constant rate period ends [13].

2.6 Selection of dryers

Industrial dryers differ in type and design depend on the principle of heat transferring method. In most cases heat is transferred to the surface of the wet solid and then to the interior.

The removal of water as vapor from the material surface depend on the external condition such as temperature, air humidity, air flow rate, area of exposed surface and pressure. The movement of internal moisture within solid is a function of the physical nature of solid, the temperature and its moisture content. In a drying operation any one of these process may be limiting factors which govern the drying rate [14].

The methods heat transferred to wet material

By convection (direct dryers)

By conduction (indirect dryers)

By radiation

The 85% of industrial dryers are of the convective type with hot air or direct combustion gases as the drying media. All methods except the dielectric supply heat at boundaries of the drying object so that the heat must diffuse into the solid primarily by conduction. The liquid must travel to the boundary of the material before it transported away by the carrier gas. Transport of moisture within the solid may occur by one or more of the following mechanism.

Liquid diffusion (wet solid is at a temperature below the boiling point of liquid)

Vapor diffusion (liquid vaporizes within material)

Knudsen diffusion (drying at very low pressure and temperature)

Hydrostatic pressure difference

Combination of above mechanism

2.6.1 Classification and Selection of dryers

Most of the products in present industry need to dry at some stages. It may be pre drying or fully drying process. Material need to have a particular moisture content for processing, molding or pelleting. By considering of coco peat it is needed to dry reduce the cost of transport which is not value added to transport the water with the product and coco peat unable to compress under the high pressure in wet condition. There are three principle factors that could utilized in classifying dryers [15]

a. Manner in which heat supplied to the material
b. Temperature and pressure of operation.
c. Manner in which material handled in the dryer.

The dryer classification can be done on several ways

Method of heat exchanging (conduction, convection, radiant and dielectric)
Type of drying vessel (tray, rotating drum, fluidized bed, pneumatic, spray)
Physical form of feed (liquid, cakes, free- flowing solid)
Continuous or batch type
Dwell time of the product

Table 2.3 Dryer selection with considering feedstock. [11]

	Liquid			Cake		Free Flowing Material				
Nature of Feed	Solution	Slurry	Paste	Centrifuge	Filter	Powder	Granule	Fragile Crystal	Pellet	Fibrous material
Convection dryer										
Belt conveyor dryer							x	x	x	x
Flash dryer				x	x	x	x			x
Fluid bed dryer	x	x		x	x	x	x		x	
Rotary dryer				x	x	x	x		x	x
Spray dryer	x	x	x							
Tray dryer (batch)				x	x	x	x	x	x	x
Tray dryer (continuous)				x	x	x	x	x	x	x
Conduction dryer										
Drum dryer	x	x	x							
Steam jacket Rotary dryer				x	x	x	x		x	x
Steam tube rotary dryer				x	x	x	x		x	x
Tray dryer (batch)				x	x	x	x	x	x	x
Tray dryer(continuous)				x	x	x	x	x	x	x

2.6.2 Classification of heating methods

Convection – heat is supplied through heated air or gas flow over the wet product. Heat for evaporation is supplied by convection to the exposed surface of the material and evaporated moisture carried away by air. Direct combustion gases or superheated steam can be used in convective drying system. The initial constant rate drying period the solid surface takes on the wet bulb temperature and falling rate period the temperature approach to the dry bulb temperature. The fluid bed dryers, flash dryers, spray dryers, rotary dryers are in this category.

Conduction – conduction or indirect dryers are more appropriate for thin or very wet solid. Heat for evaporation is supplied through heated surface either move or stationary. Evaporated moisture is carried away by vacuum operation or steam of gas. Energy efficiency is higher in conduction dryers. Rotary dryers with internal steam tubes and drum dryers are example for this type.

Radiation – various sources of electromagnetic radiation with wave length ranging from the solar spectrum to microwave (0.2m – 0.2 μm) are used. Energy is absorb selectively by water molecules. Therefore the product get drier less energy is used. But capital cost and operation cost are high. Therefore high unit value of the product is or final moisture profile need to be accuracy control can be used in this kind of dryers. [11]

Prior information need to select the dryers

1. Flow sheet quantities – source of wet material, total liquid to be removed, flow sheet quantities
2. Batch or continuous feed – source of feed, previous dewatering stage, particle size distribution of wet material, physical characteristic and abrasive property.
3. Feeding material chemical property – Toxicity, order problem, fire and explosion hazard, corrosive property
4. Dry product specification property – moisture content, particle size distribution, bulk density, flow properties.
5. Drying data obtain from pilot plant or past experience.

For a preliminary estimate of dryer size gives a simple method based on data obtaining from operating industrial dryers. [13]

For convection dryers neat transfer is given as below

For batch type $q = h_a (V)(t - t_m)$ .... Eq (11)

For continuous type $q = h_a (V)(t - t_m)l_m$ ....Eq (12)

For conduction dryers $q = UA(t_k - t_m)$ ....Eq (13)

2.6.3 Application of Peat drying technology

Peat directly from the bog contain around 80 -90% moisture level. After harvesting peat kept in the bog to reduce the moisture around 50%. Further it is needed to reduce the moisture either use as Bio fuel or growing media in the nature of industry. In industry specially use as Bio fuel, flue gas or supper heated steam is using. Either rotary dryer or pneumatic/Flash dryers have been used to dry the peat for a long time. In these units are directly fired and the peat is conveyed by the flue gas flow through the dryers. Total length is 30 M long and gas velocity is 15-35 m/s [19] [23].

Table 2.4 Approximate value of ha (Kcal/h Cm^3) for various dryer type [11]

Type of dryer	H_a	$(t - t_m)\, l_m$	Inlet hot air temperature	Typical Evaporation capacity (kg H_2O/hm^2)	Typical energy consumption KJ/kg of H_2O evaporation
Convection					
Rotary	100 - 200	Concurrent 80 - 150	200 – 600	30 – 80 m^3	4600 - 9200
		Cocurrent 100 - 180	300 - 600		
Flash	2000 - 6000	Parallel flow 100 -180	400 - 600	5 – 100 m^3	4500 - 9000
Fluid bed	2000 - 6000	50 - 150	100 - 600		4000 - 6000
Spray	20 - 80	Counter flow 80 - 90	200 - 300	1 – 30 m^3	4500 - 11500
		Cocurrent flow 70 -170	200 - 450		
Tunnel	200 - 300	Counter flow 30 – 60	100 - 200		5500 - 6000
		Concurrent 50 - 70	100 - 200		
Jet Flow	100 - 150	30 - 80	60 - 150		
Conduction		$(t_k - t_m)$			
Drum	100 - 200	50 - 80		6 – 20 m^2	3200 - 6500
Agitated through rotary with heated steam	60 - 130	50 - 100			

Table 2.5 Solid exposure to Heat Conduction [14]

	Typical residence time within dryer				
	0 – 10 (s)	10 – 30 (s)	5 -10 (min)	10 – 60 (min)	1 – 6 h
Convection dryer					
Belt conveyor dryer				x	
Flash dryer	x				
Fluid bed dryer				x	
Rotary dryer				x	
Spray dryer		x			
Tray dryer (batch)					x
Tray dryer (continuous)				x	
Conduction dryer					
Drum dryer		x			
Steam jacket rotary dryer				x	
Steam tube rotary dryer				x	
Tray dryer (batch)					x
Tray Dryer (continuous)				x	

2.6.4 Guidelines for dryer selection

There are several things need to be considered to select the proper dryer. It is important to look on the pre drying stage. It may be mechanically dewatering, evaporation or preconditioning of the material. As same as post drying also important because it is needed to consider exhaust gas cleaning, product collection, partial recirculation of exhaust, cooling of product, etc. the optimal cost effective drying method also very important. On the other hand very low value product the choice of drying, so the lowest cost system is selected need to be done. The following quantitative information need to be evaluated right type of dryer to suitable the product.

Dryer throughput

Mode of feedstock production (batch or continues)

Physical, chemical and biochemical properties of the wet feed and desired product specification

Upstream or downstream processing operation

Moisture content of the feed material

Dry kinetic

Quality parameter (physical, chemical and biochemical)

Value of the product

Safety aspects

Need for automatic control

Toxicological property of the product

Turndown ration and flexibility of capacity

Type and cost of fuel

Environment regulation

Space of the plant

2.6.5 Typical dryer applications relevant to coco pet drying process

The below mentioned dryers are more or less similar to the above application.

Direct heat Rotary dryers - It is use to dry the sphagnum peat, saw dust and fibrous material in the similar industry. The rotary drum which is having the flap inside the drum in spiral way help to expose the wet material in more prominently with hot air. It increase the contacting with material and hot air and resulting to get the moisture out from wet solid. Apart from that angel towards the material flowing direction will help to carry the wet material forward.

The direct heat rotary dryer is the simplest and most economical and are used when the contact of hot air is not harmful. If the solid contain extremely fine particle, excessive entrainment losses in the exit gas is possible, due to the large gas volume and high gas velocity are required[18] [19].

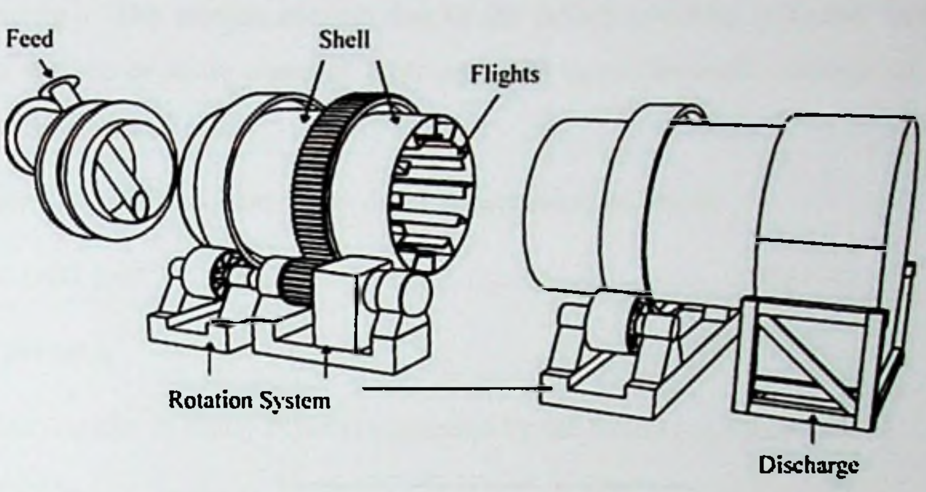

Figure 2.7 Convectional rotary cascade dryer

The particles move through the dryer is three independent mechanism which described as follows.

a. Cascade motion – the lifting action of the flights and the slope of the dryer crate the result of it. The cocurrent gas flow is cause to increase advance of the particles due to the drag on the cascading solids.

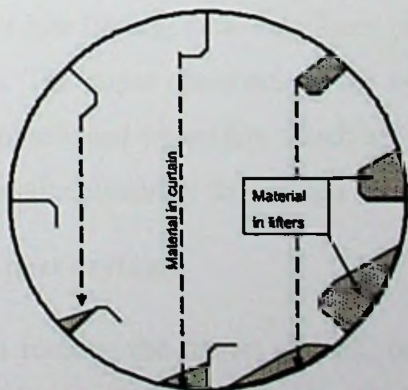

Figure 2.8 Flight Positioning in the drum

b. Kiln Action – It is the motion of the particle as they slide either over the metal surface or on top of material. The dry material passed through the dryer with the effect of slant of dryer.
c. Bouncing - The motion occuers due to the falling particles rebounds from the drum surface or settle material layer cause to move forwards because of dryer slope. [17]

The residence time of direct heat rotray dryer is expressed as below

$$\tau = \frac{0.0433\,(Ln)^{1/2}}{DN \tan\alpha} \quad \text{Eq (14)}$$

Heat and Mass transfer in rotary dryer is expressed by the following equation [21]

$$Q = U_u aV(\Delta t)_m \quad \text{Eq (15)}$$

Flash dryers – The residence time of the particles in the flash dryer is very short. It leads to remove the surface moisture containing on the product. Thermal contact between the conveying air and solid is usually very short time. Flash dryer is more suitable to dry the heat sensitive product. The gas velocity must be greater than the free fall velocity of the largest particle's velocity [21].

The coir pith industry has moved into finding new techniques such as flash drying which can produce the large quantities. The major drawback of the new drying techniques are affected the water absorption property and expansion which are more dominant factors in the horticulture industry. As a result demand of the foreign market is significant. [22]

2.6.6 Present practices of coco peat drying.

The coco peat need to wash to remove the tannin and EC to suitable as for growing media. After washing it containing 95% of moisture. But most of the large scale producer reduce the moisture by using mechanical dewatering method to reduce the moisture around 70 -75%. But dry material need to reach 15 – 20% moisture level to compacting. As a practice sun drying is using to reduce the moisture up to the required level. In commercial scale either concrete yards or tar floors are using. As a first step moisture material laying on the dry floor in thickness close to 5 cm. After regular intervals (every 30 minutes) laid material are stirring to expose the sun properly. If it expose good sun shine within 7-8 hours material can be dried. Except the sun shine (lux level of the sun light) humidity and wind also considerable factor for fast drying. If humidity is low evaporation is high and wind is high drying get faster since evaporation occur at higher rate.

Figure 2.9 Present drying method under the sun shine

CHAPTER 3

3.0 METHOD AND MATERIAL

The selected dryer model is consist with two parts. First part is rotary drum dryer and second part is flash dryer. The wet material is feeding in to the rotary drum and output of it become the input of the flash dryer. End of the flash connected to the cyclone separator and dry material collect out of it.

3.1 Rotary drum dryer

It has several components and function of those items described as follows

3.1.1 Rotary drum – Drum is 2 feet in diameter and 16 feet in length. Wet material feed through screw conveyor driven by geared motor (0.5 Hp 3 phase, gear ratio 1:30). The feeding rate is controlled by manually with respect to the feeding time. The feeding end of drum consist with teeth wheel which is engaging the teeth wheel attached to gear motor shaft. The power of gear motor is 3 Hp (3 phase) and gear ratio 1:30. That gear motor is used to rotate the drum with different frequency by changing the speed of the motor by using frequency controller. The angel flaps are consisting inside in the drum as a spiral way. Purpose of flaps is taking the wet material to forward with effect of the spiral arrangement and stirring properly to expose the heat air. Drum is place three degree angel from feeding end to discharge end to enhance the movement of the wet feedstock.

3.1.2 Heat source – Diesel burner is used as heat source. It couple to end of rotary drum. The flue gas directed in to the drum through tube and it open up to the close to feeding mouth. The temperature sensor set end of the discharge mouth of rotary drum to check the temperature of the discharge material from the drum. Temperature sensors pass the signal to the temperature controller. The temperature of material reach to the set value, burner automatically cut off.

3.1.3 Flash dryer – It connect to the end of rotary drum. Dry material out from rotary drum become the input to the flash dryer. The blower driven by 5 Hp, (3 phase) motor is coupled to the end of flash dryer and it succeed the dry material trough flash. Finally dry material collect in to the cyclone separator and vapor is out from the open in top of cyclone separator.

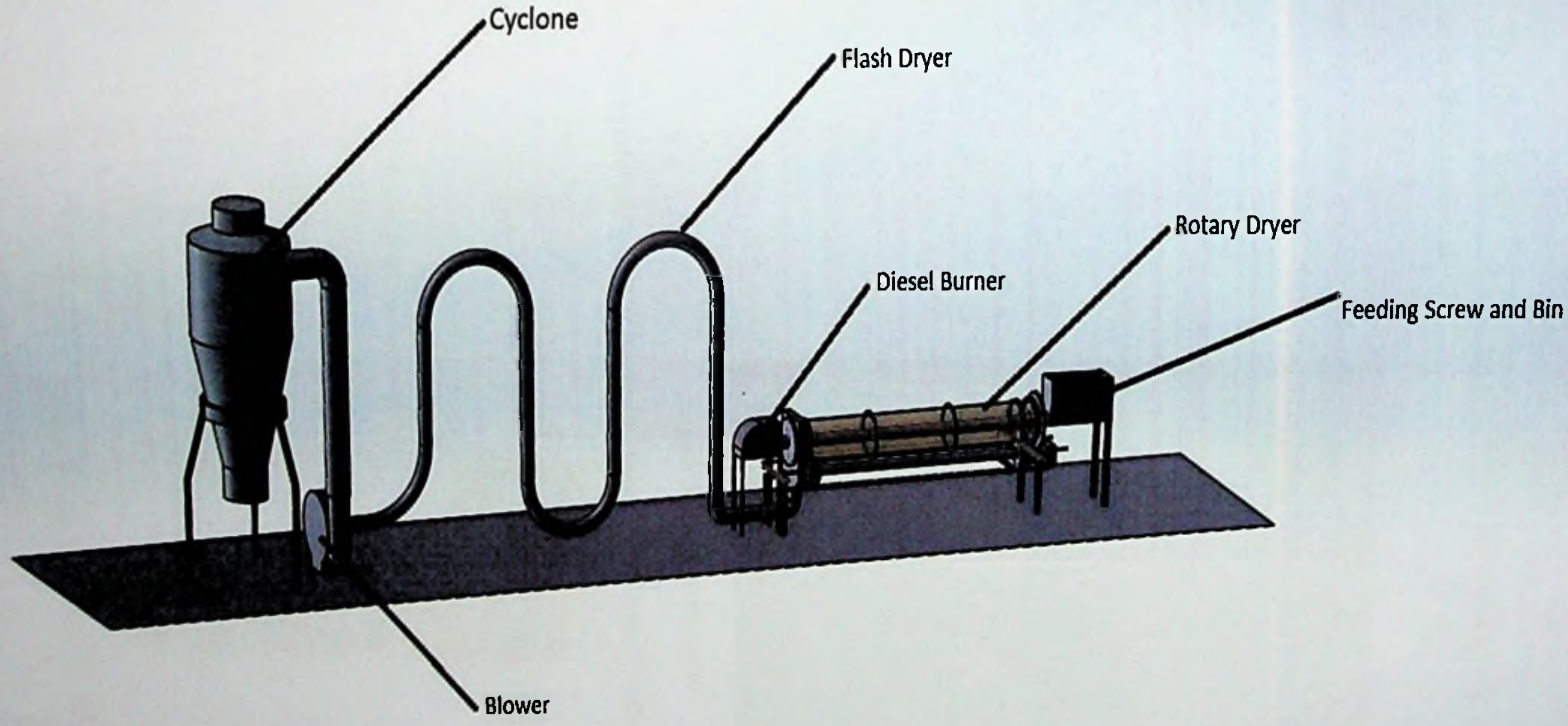

Figure 3.1 Photo of model dryer arrangement

3.1.4 Other equipment

a. Moisture meter – it is used to measure the moisture level of input wet coco peat and output dried material

Figure 3.2 Moisture meter

b. IR temperature gun – it is used to measure the temperature of the rotary drum

Figure 3.3 IR temperature gun

c. Dry material press unit – coco pellet using by dry matrial is compressed by using this unit.

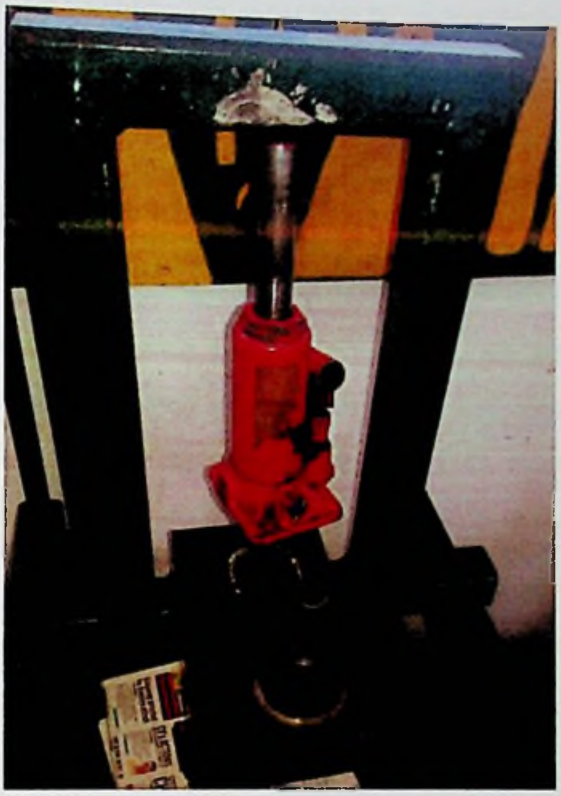

Figure 3.4 Coco peat pellet pressing jig

3.2 Experiment Procedure

1. Wet material drying Steps

    Feed wet coco peat in different moisture levels

    Change the feeding rate

    Change the rotating speed of the rotary drum

    Change the heating temperature (of rotary drum)

2. Collect the dry material of each trail and measure the moisture level and volume weight (V/W)
3. Make the coco pellet of each material batches (below 40% moisture)
4. Expand the compressed pellet and check the expansion height

3.2.1 Step of wet material drying – The coco peat receiving from fiber mill is used as an input raw material. The three different moisture levels are considered to the experiment.

55 % moisture

65% moisture

75% moisture

The coco peat adding the water made different moisture levels and measured it using by moisture meter. The coco peat receiving from fiber mill has around 55% moisture. The industries which are washing the coco peat is having 75% moisture after mechanical dewatering. In between 65% moisture level also considered in to the experiment.

The diesel burner switch on and barrel heated up to before feeding the wet material. Once it reaches the required temperature material feeding was started. The three different feeding rate was considered.

10 l per minute

15 l per minute

20 l per minute

Material feeding was done by manually to the screw conveyor with respect to the time (with in one minute). Three times of trial was done per each test.

Three different rotating speed was considered to examine the impact of Frequency (residence time) of wet material.

One revolution per 20 seconds

One revolution per 13 seconds

One revolution per 7 seconds

The diesel burner was a heating source and temperature of output material (end of rotary drum dryer) measured by using thermocouple. Three different temperature setting was considered as follows.

90 C^0 of discharge end and 150 C^0 of rotary drum temperature

100 C^0 of discharge end and 165 C^0 of rotary drum temperature

110 C^0 of discharge end and 180 C^0 of rotary drum temperature

3.2.2 Collect the dry material and measure the volume weight and moisture level

End of each cycle dry material collected separately and kept two hours to reduce the heat accumulated in the material. After that measure the moisture level and check the volume weight.

3.2.3 Make the coco pellet – Sample mold cavity made out of steel (cavity size is 50 x 60 mm) and hydraulic jack used to compress the filled coco pellet. Two compressed coco pellet (compression ratio 1: 5) made in each batch. The moisture level less than 40% sample batches was selected to compress because moisture level is more than 40% can't be compressed and not retain the thickness.

3.2.4 Expansion test – Compressed coco pellet put in to the water and kept in to expand. The heights are recorded.

Figure 3.5 compressed coco pellet

Figure 3.6 Expansion test

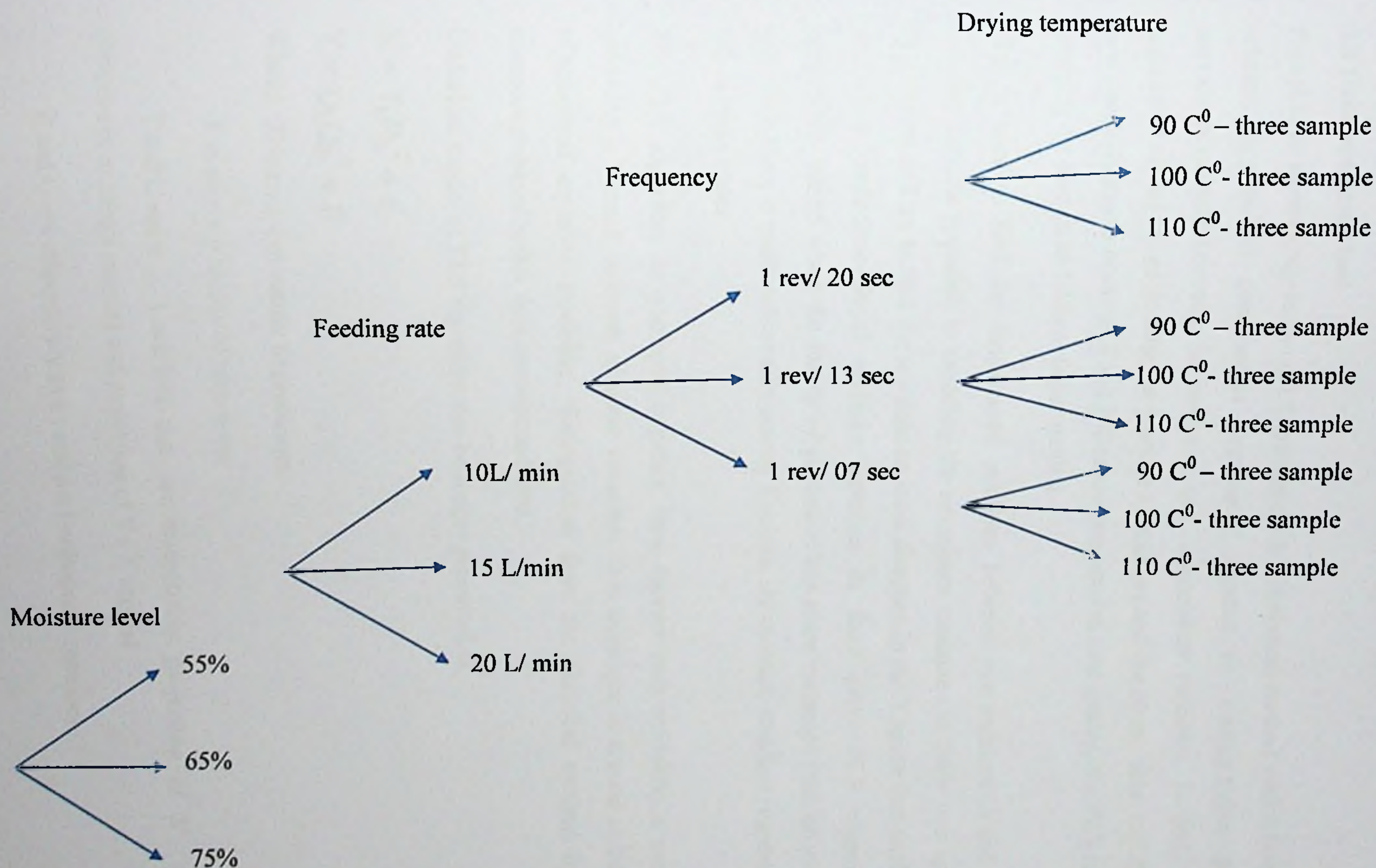

Figure 3.7 Model of the Experiment

3.3 Data analyzing tool

Partial least squares regression (PLS regression) is a statistical method which bears some relation to principal components regression; instead of finding hyper planes of maximum variance between the response and independent variables, it finds a linear regression model by projecting the predicted variables and the observable variables to a new space. Because both the *X* and *Y* data are projected to new spaces, the PLS family of methods are known as bilinear factor models.

PLS is used to find the fundamental relations between two matrices (*X* and *Y*), that is latent variable approach to modeling the covariance structures in these two spaces. A PLS model will try to find the multidimensional direction in the *X* space that explains the maximum multidimensional variance direction in the *Y* space. PLS regression is particularly suited when the matrix of predictors has more variables than observations, and when there is multi collinearity among *X* values. By contrast, standard regression will fail in these cases

The PLS algorithm is employed in partial least squares path modeling, a method of modeling a "causal" network of latent variables. This technique is argued to be a form of structural equation modeling, distinguished from the classical method by being component-based rather than covariance-based.

Underline model of PLS algorithm can be simply presented as,

$$X = T_k P_k^T + E$$

$$Y = U_k Q_k^T + F$$

Where X is an n x m matrix of predictors,

Y is an n x p matrix of responses;

T and U are n x l matrices that are respectively projection of X (X score, component or factor matrix) and projection of Y (Y scores)

P and Q are respectively m x l and p x l orthogonal matrices

E and F are the error terms of matrices

Assumed to be independent and identically distributed random normal variables. The decompositions of X and Y are made so as to maximize the covariance between T and U. The detail derived from PLS is used to generate the graph in MATLAB.

There are several methods to find these matrices. In Unscrambler NIPLS algorithm is used for the PLS analysis. Then model equation will be

$$Y = B0 + XB^{T}$$

Where Y, X are 1xn, 1xm row vectors. B0 and B are 1xn and mxn matrices. n is number of variables in Y and m is number of variables in X [25].

3.4 Variables of the data set

The captured measurements are input moisture percentage, feed rate, and drum rotating frequency, temperature of the feed and moisture of the output.

The variables are described below,

1. Drum rotating frequency
2. Feed rate
3. Input moisture
4. Temperature

There are 69 objects (number of measurement samples) in the data set. There are input moisture, feed rate, drum rotating frequency and temperature of the material are grouped in X-variable and average moisture of the output is picked as Y variable.

Cross validation handles using only available training set objects, splitting model in parts (one is data set, other for testing on it). We are going to use full cross validation which means The Unscrambler will make as many parts as there are observations. It will be just one observation for testing [25].

3.5 PLS Analysis

Calibration

A model using the PLS (partial least square) method is developed, since it is having significant advantages over the other multivariate regression method. Since we have one Y (output moister percentage) variable this is a called as PLS1 model.

Weighting

Since the data are having different ranges different units some displays large variances compared to others. So scaling was done to remove this behavior. Then no one variable is capable of dominating over other variables solely because of its range.

Validation

69 objects were used to make this model. Since cross validation was going to be used, it will gives better realistic results than leverage correction method.

But objects which are having some similar properties are staying close to each other in the data set so we had to take a special care when doing the validation. After doing the several tests we decided to do the fully cross validation to get a better validation results [25].

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Principle Component Analysis

A quick run through the PCA analysis with Cross Validation was performed in PLS1 with all 69 samples. The spread of the data in the scores and loading looked somewhat complex and hence decided to make three different data sets for each three input moisture group.

4.2 Analysis of input moisture in 55% (group 1)

First 55% input moisture group is studied. The score and loading plots of the optimal principal components (factor 1- factor 2 and factor 2- factor 3) are shown here in Figure 4.1 and 4.2. The X variables are segregated from the Y variable and we want to see how we can understand this model and use it for the estimation of output moisture percentage.

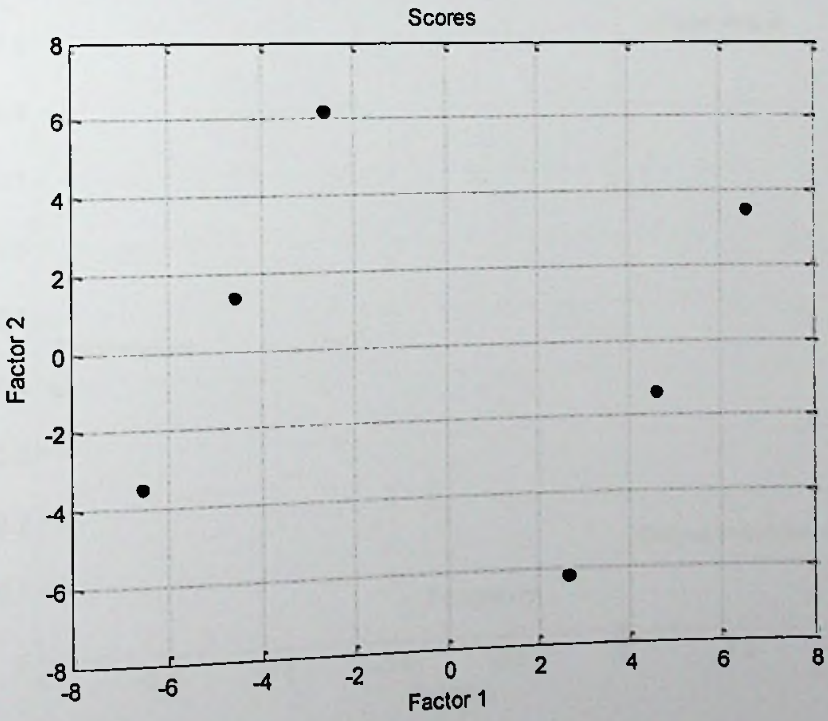

Figure 4.1 - Score plot, factor 1 vs factor 2 (group 1)

The score plot for factor 1 vs factor 2 shows a scattered distribution around origin but with about 6 distances from the origin. Even though it looks there are only 6 objects, there are 18 of them in the 55% input moisture category. Simply 3 objects lay on top of each other. Since the score values along factor 1 as well as factor 2 are large, the effect of each sample is strongly presented in the components. The loading plot, Figure 4.2 shows that all the x-variables are influenced in factor 1 and factor 2. This can be stated, since Temperature and Feed rate are staying away from the center of loading plots shown in Figure 4.2. Temperature is highly represented in factor 1 (close to -1) but it will give negative contribution to the target which is output moisture. Feed rate is mainly represented in factor 2 (loading value is bit over 0.9) and hence positively contribute to the output moisture. Both temperature and feed rate variables are contributing to the factor 2 and factor 1 as well but contribution is relatively less. Frequency is not explained in any of the 2 factors.

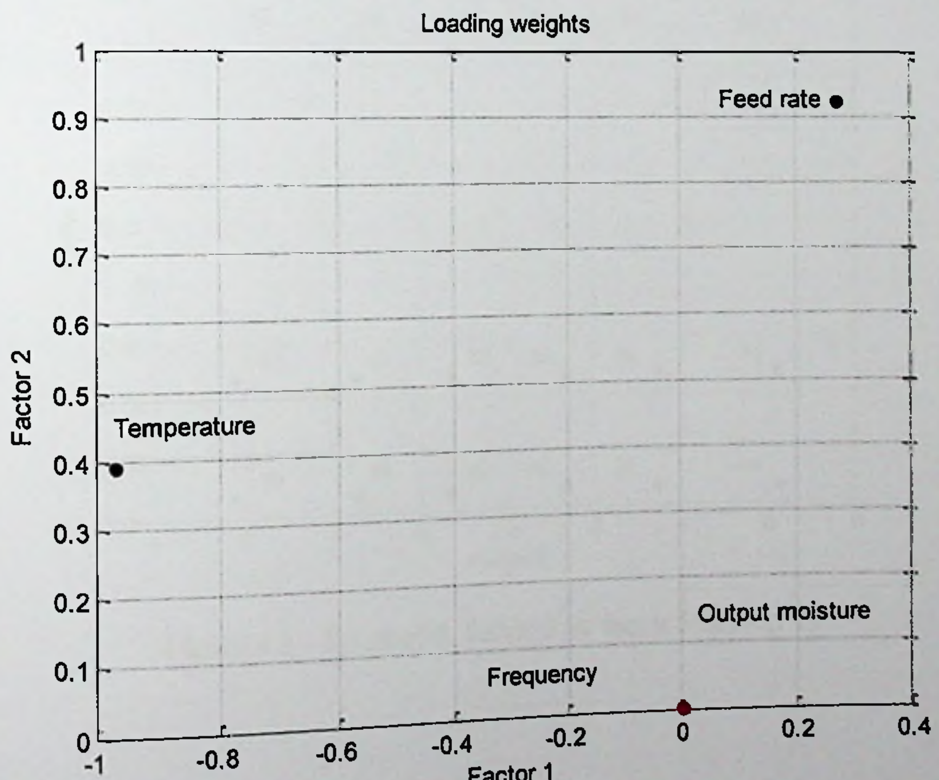

Figure 4.2 – Loading weight, factor 1 vs factor 2 (group 1)

The Y variable 'output moisture' is also influenced by both factor 1 and factor 2. Similar to the Figure 4.1, the score plot for factor 2 vs factor 3 shows a scattered distribution of object around the origin in Figure 4.3. Unlike factor 1 vs factor 2 scores, it can be easily identify as factor 3 represent frequency in Figure 4.4. It can be seen that feed rate and temperature explained along the factor 2 direction. Since there are two sets of temperatures used here in this analysis, they can also be seen as two clusters overlapped. The loading plot shows that all the x-variables are influenced. But both factor 2 and factor 3, as all the variables are with 0 to 0.9 or 1 on each x and y axes, as compared to the score plot where most of the objects are within -6 to 6 on factor 2 in Figure 4.3.

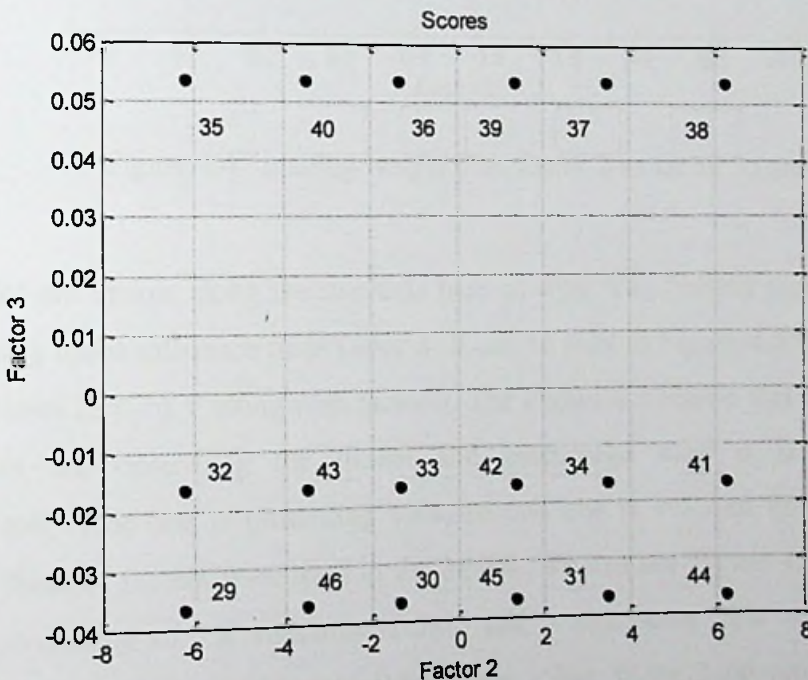

Figure 4.3 - Score plot, factor 2 vs factor 3 (group 1)

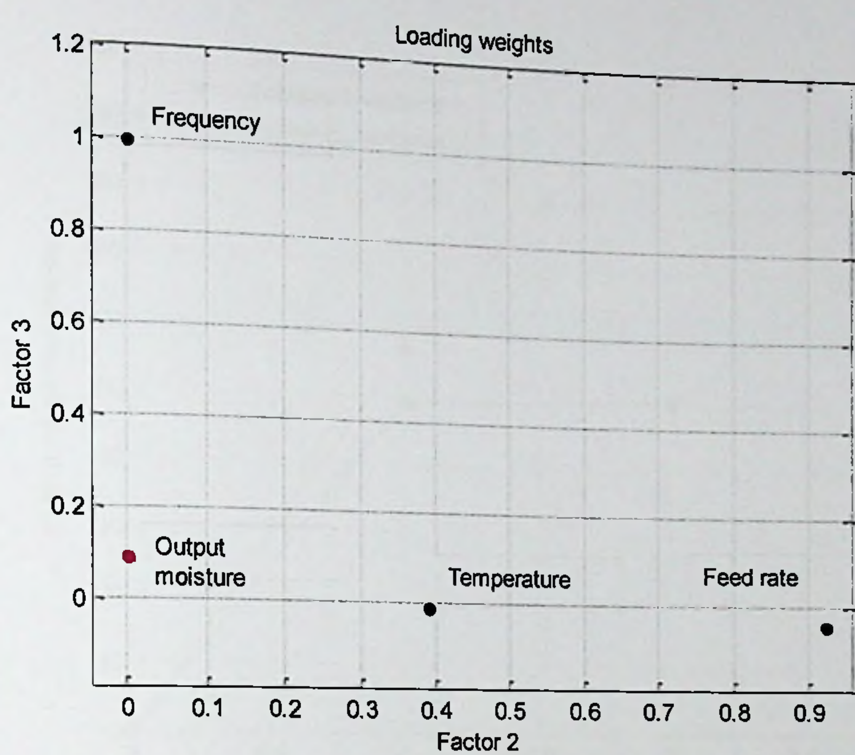

Figure 4.4 - loading weight plot, factor 2 vs factor 3 (group 1)

X Variables are visible along the two axis here as well. The 'output moisture' variable seems having much influence from factor 3. It can be seen in Figure 4.5 with Y variance which explains 29% of Y along with factor 3. The Figure 4.5 Shows that first 3 principal components are describing the model and percentage wise it is around 80%. Approximately first one is presenting 49%, second one is 1% and third one is 29%. Hence all three of factors were used in the model. We can see Figuer 4.5 the explained variance percentage of X variables is 58% and it represents 49% of the expalined variance of Y variable (output moisture) for factor 1. For factor 2 the explained variance percentage of X variables is 42% and it represents just 1% of the expalined variance of Yvariable. In Total 100% of the explained variance percentage of X variables represents 50% of the expalined variance of Y variable (output moisture).

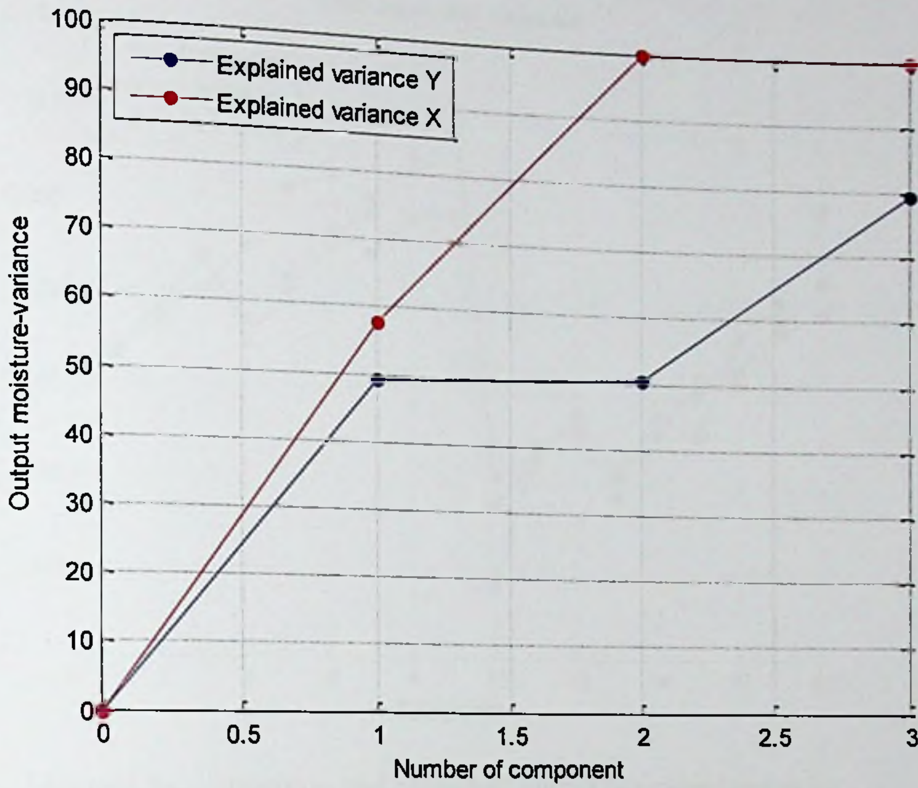

Figure 4.5 – X, Y variance explained in each of the three factors (group 1)

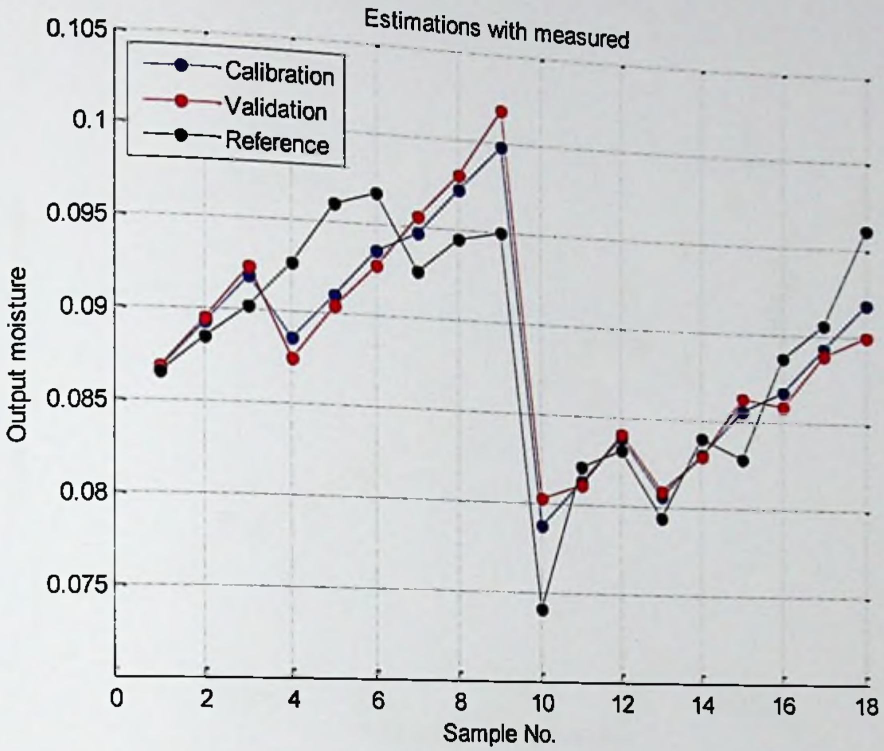

Figure 4.6 – Estimation and Measured output moisture (group 1)

The Figure 4.7 shows the predicted vs measured Y (output moisture). Slope of the plot is 0.7944. Correlation is 0.79. RMSEP 0.0037. we can't find a perfect model for a real data set like this, but this model is good because the models which have slopes close to 1 may not be a good model if much more objects are lying away from the regression line but here even though the slope of the model is not much close to the 1 it shows that its objects are more close to the regression line and for the higher values it shows some deviations. RMSEP is a measurement of the average difference between predicted and measured response values at the prediction or validation stage. Here it is 0.0037. To be a good model it should be close to the zero. Since, in this model the magnitude of the y variable is below 0.1, this RMSEP is about 3%. Correlation is the amount of linear relationship between measured and predicted Y variable. If it is close to 1 the model is good. Here it is 0.79 and this means acceptable

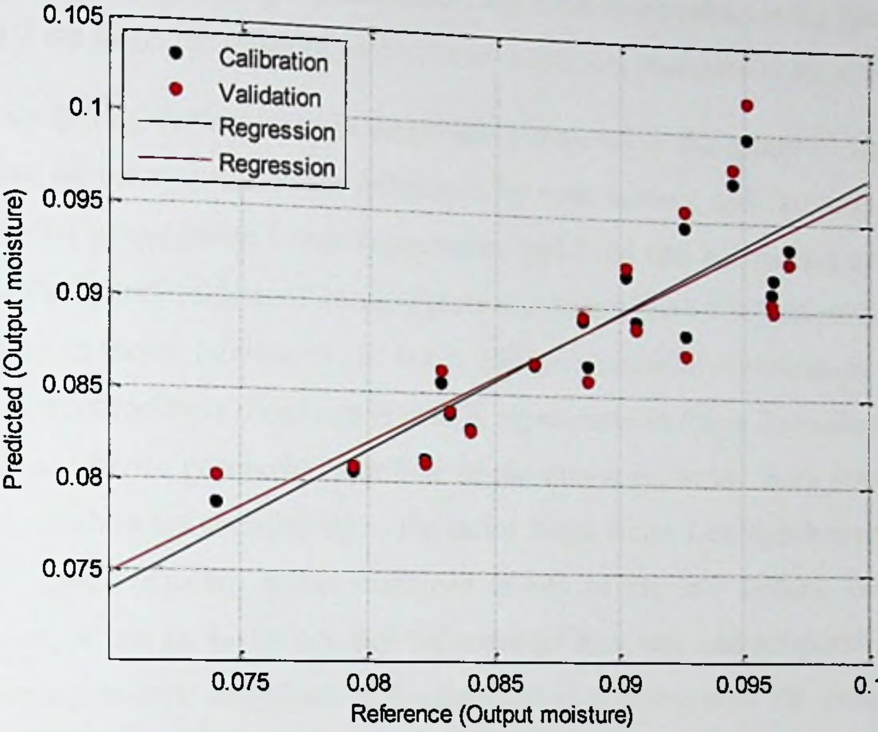

Figure 4.7 – Predicted vs Measured output moisture (group1)

The estimated Output moister percentage is given by $Y = B0 + XB^T$ equation.

Where B0= 0.14913, and X is frequency, federate Temperature and respective B values are B= [0.0885945, 0.0005072, 0.0007985].

4.3 Analysis of input moisture in 65% (group 2)

Second group is 65% input moisture group. Similar to the above analysis, score and loading plots of the optimal principal components (factor 1 and factor 2 and factor 2-factor 3) are studied corresponding figures are shown as Figure 4.8 and 4.9. The distribution of samples in the space of factor 1- factor 2 is much similar with the group 1 (moisture 55%) study.

The Figure 4.8 shows factor 1 vs factor 2 in a scattered distribution around zero but with about 6-8 distances from the origin. Even though it looks there are only 9 objects, there are 27 of them in the 65% input moisture category. It was shown like 6 objects in group

1. Here, 3 objects lay on top of each other. Since the score values along factor 1 as well as factor 2 are large, the effect of each sample is strongly presented in the components.

They even getting further large in magnitude compared to the group 1. The Figure 4.9 shows that all the x-variables are influenced by both factor 1 and factor 2. This can be stated similar to the group 1 that Temperature and Feed rate are staying away from the center of the factor1 vs factor 2 loading plots shown in Figure 4.9. Temperature is highly represented in factor 1 (close to -1) but it will give negative contribution to the target which is output moisture. Feed rate is mainly represented in factor 2 (loading value is bit over 0.9) and hence positively contribute to the output moisture. Both temperature and feed rate variables are contributing to the factor 2 and factor 1 as well but contribution is relatively less. Frequency is not explained in any of the two factors. With a careful observation, it can be easily say that influence of feed rate and temperature is getting further strong as their magnitude in loading plot is growing with the increase of input moister content.

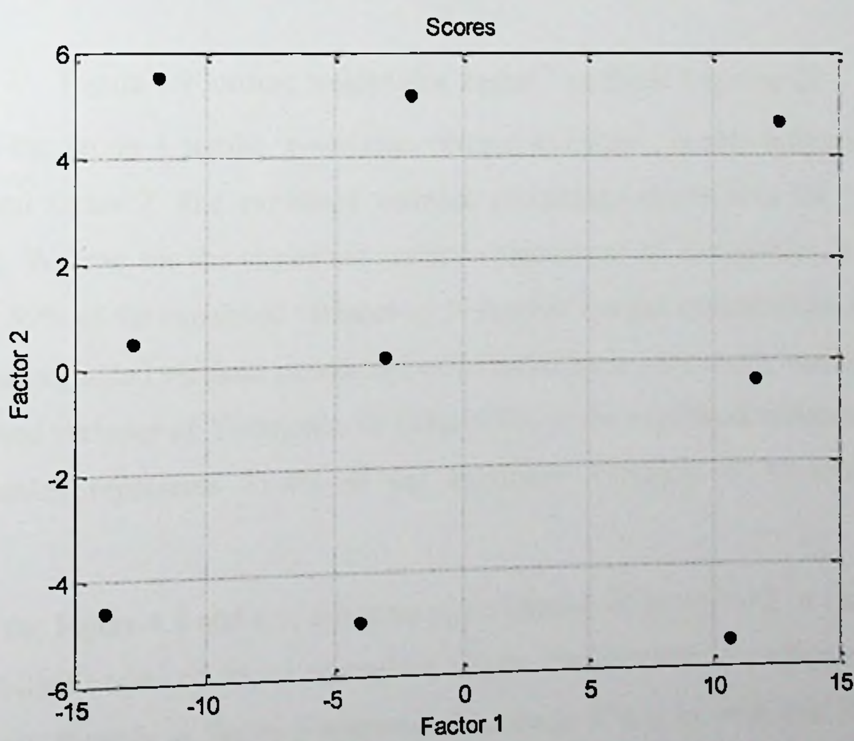

Figure 4.8 Score plot - factor 1 vs factor 2 (group 2)

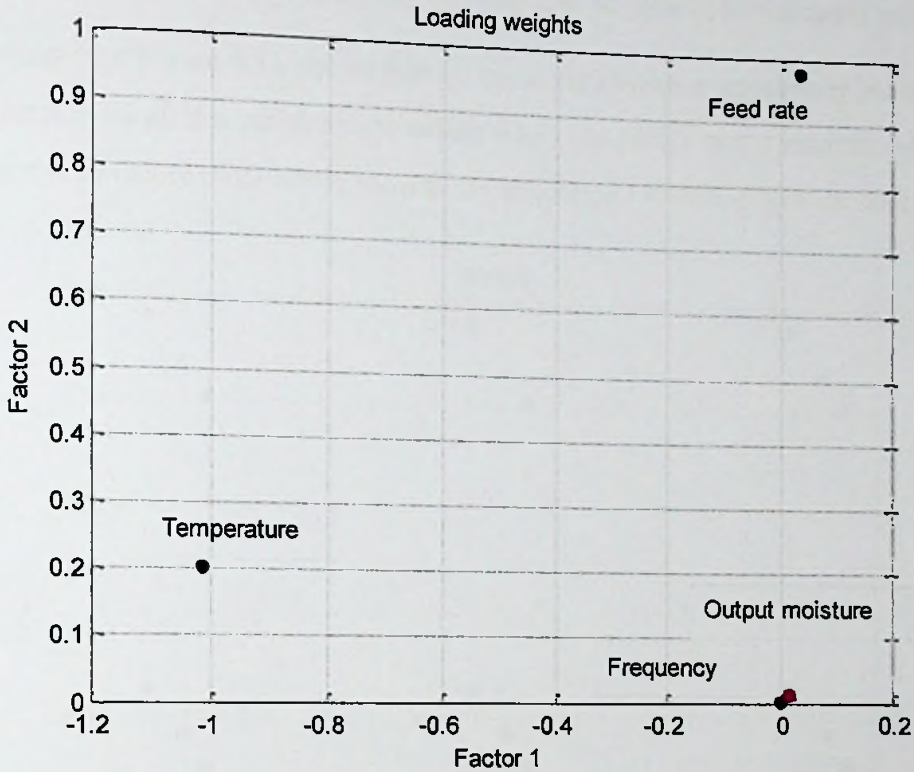

Figure 4.9 loading weight plot, factor 1 vs factor 2 (group 2)

Similar to the group 1 results, y-variable, 'output moisture', is also influenced by both factor 1 and factor 2. The explained variance percentage shows how the y-variable is influenced. We can see the explained variance percentage of X-variables is 60% and it represents 59% of the expalined variance of Y-variable (output moisture) for factor 1. For factor 2 the explained variance percentage of X-variables is 14% and it represents 10% of the expalined variance of Y-variable. In Total 100% of the explained variance percentage of X-variables represents 71.8% of the expalined variance of Y-variable (output moisture).

Similar to the Figure 4.8 and 4.9, the score plot Figure 4.10 for factor 2 vs factor 3 shows a scattered distribution of object around the origin. Unlike factor 1 vs factor 2 scores, it can be easily identify as factor 3 represent frequency. It can be seen that feed rate and temperature explained along the factor 2 direction. Since there are two sets of temperatures used here in this analysis, they can also be seen as two clusters overlapped.

The loading plot Figure 4.11 shows that all the x-variables are influenced but both factor 2 and factor 3, as all the variables are within 0 to 1 on each x and y axes, as compared to the Figure 4.10 (score plot) where most of the objects are within -6 to 6 on both axes.

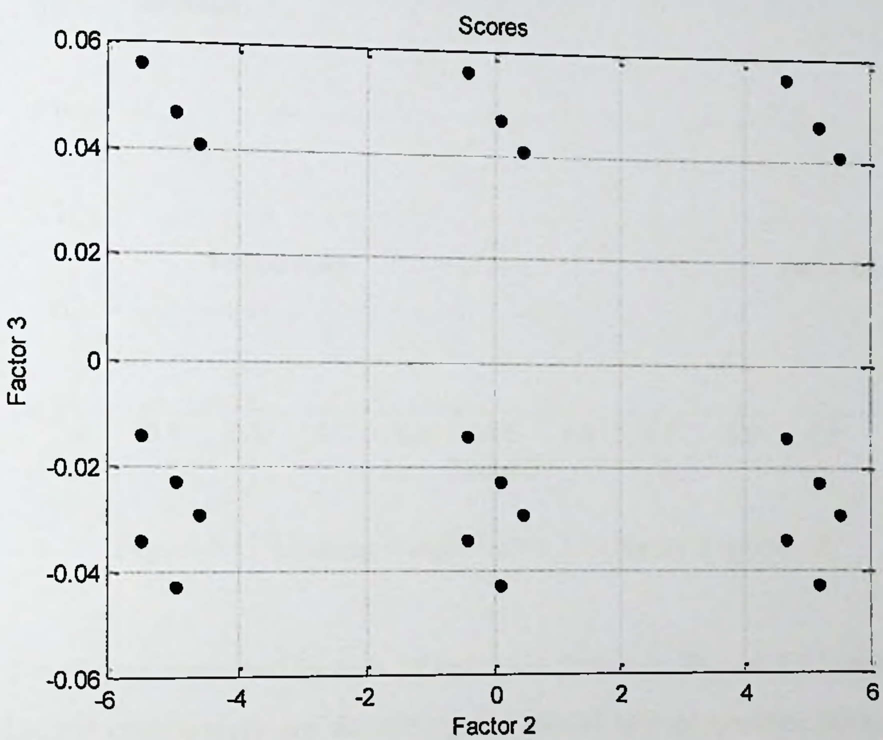

Figure 4.10 Score plot factor 2 vs factor 3 (group 2)

X-variables are visible along the two axis in Figure 4.11 as well. The 'output moisture' variable seems having much influence from factor 3. It can be seen with y-variance which explains 2% of y along with factor 3. Unlike group 1 here y-variable, output moisture, shows better representation.

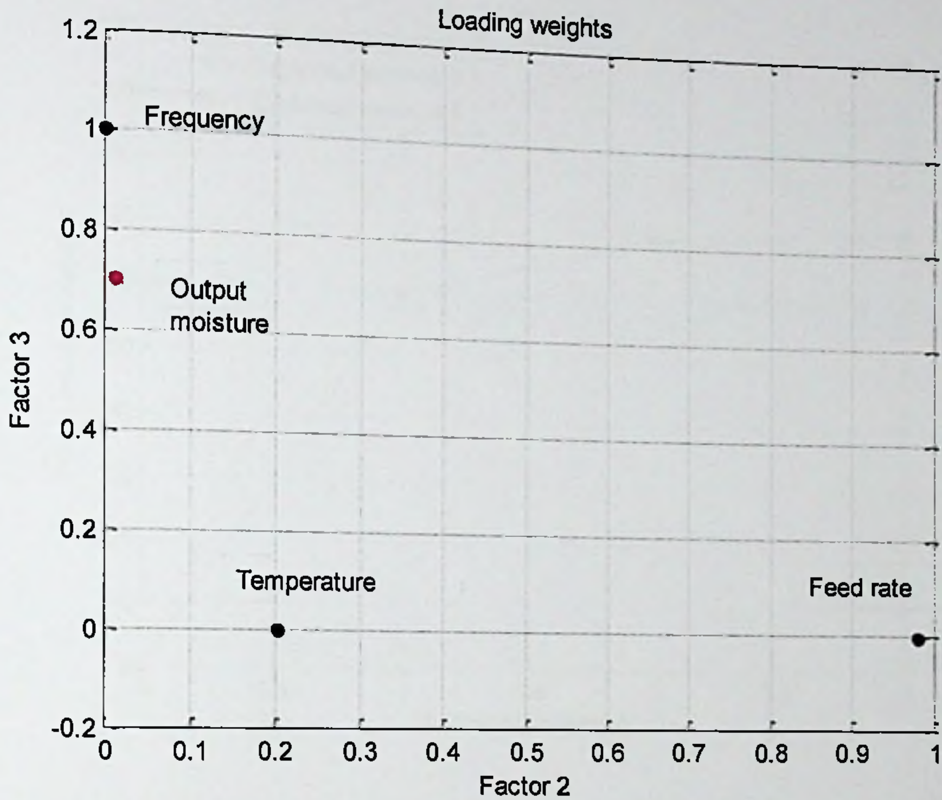

Figure 4.11 Loading weight factor 2 vs factor 3 (group 2)

The X, Y variance explained in each of the three factors in Figure 4.12 Shows that first three principal components are describing the model and percentage wise it is around 71.8%. Approximately first one is presenting 59%, second one is 10% and third one is 2.8%. Hence all three number of factors were used in the model.

The explained variance percentage shows how the Y variable is influenced. We can see the explained variance percentage of X-variables is 85% and it represents 59% of the expalined variance of Y-variable (output moisture) for factor 1. For factor 2 the explained variance percentage of X-variables is 14% and it represents 10% of the expalined variance of Y variable. In Total 100% of the explained variance percentage of X variables represents 71.8% of the expalined variance of Y-variable (output moisture).

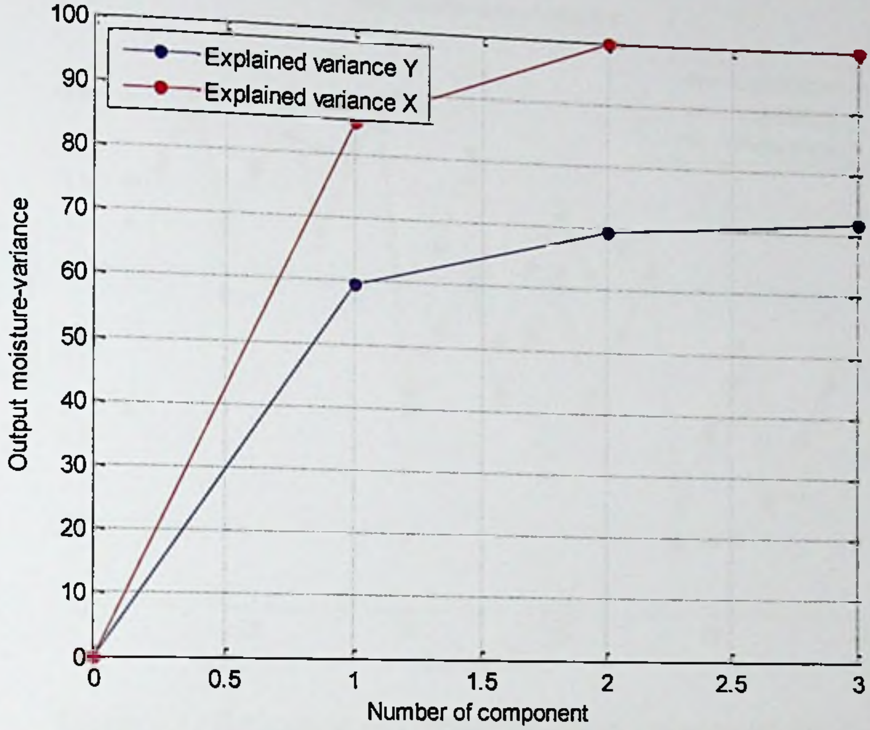

Figure 4.12 X, Y variance explained in each of the three factors (group 2)

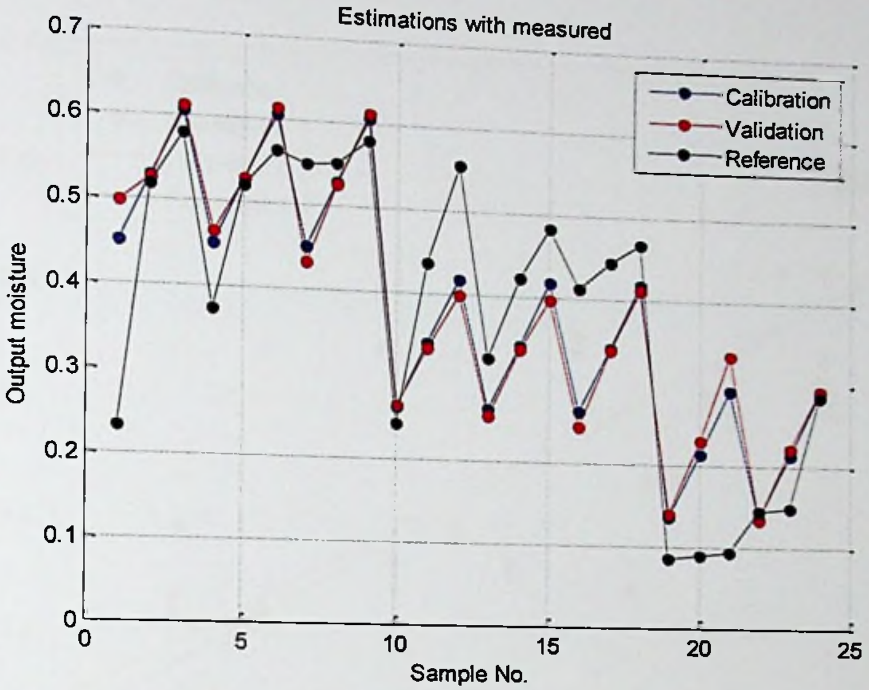

Figure 4.13 Estimation and Measured output moisture (group 2)

The Figure 4.14 shows the predicted vs measured y (output moisture). Slope of the plot is 0.71845. Correlation is 0.79. RMSEP 0.0037. we can't find a perfect model for a real data set like this, but this model is good because the models which have slopes close to 1 may not be a good model if much more objects are lying away from the regression line but here even though the slope of the model is not much close to the 1 it shows that its objects are more close to the regression line and for the higher values it shows some deviations. RMSEP is a measurement of the average difference between predicted and measured response values at the prediction or validation stage. Here it is 0.0897. To be a good model it should be close to the zero. Unlike in group 1, the magnitude of the Y variable is not in the range 0 to 0.1 and hence the RMSEP is also relatively large (about 8%). Correlation is the amount of linear relationship between measured and predicted Y variable. If it is close to 1 the model is good. Here it is 0.79 and this means acceptable.

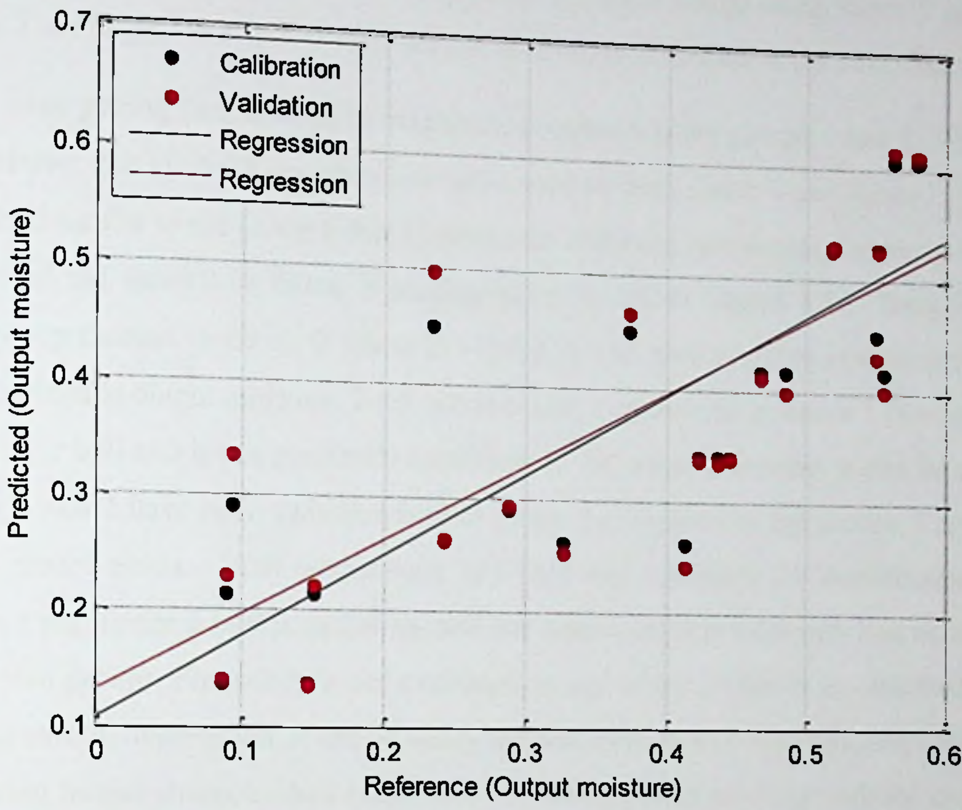

Figure 4.14 Predicted vs. Measured plot (group 2)

The estimated Output moister percentage is given by $Y = B0 + XB^T$ equation.

Where B0= 1.3662, and X is frequency, federate Temperature and respective B values are B= [-0.000368, 0.015545, 0.01259].

4.4 Analysis of input moisture in 75% (group 3)

Third group is 75% input moisture level. Similar to the above two sets of analysis, score and loading plots of the optimal principal components (factor 1 – factor 2 and factor 2-factor 3) are studied corresponding figures are shown as Figure 4.15 and 4.16. The distribution of samples in the space of factor 1- factor 2 is much similar with the group 2 study. The Figure 4.15 in factor 1 vs factor 2 shows a scattered distribution around but with about 6-10 distances from the origin. Even though it looks there are only 9 objects, there are 27 of them in the 75% input moisture category. It was shown like 6 objects in group 1.

Here, 2 objects lay on top of each other. Since the score values along factor 1 as well as factor 2 are large, the effect of each sample is strongly presented in the components.

They even getting further large in magnitude compared to the groups 1 and 2. The Figure 4.16 shows that all the X-variables are influenced by both factor 1 and factor 2. This can be stated similar to the group 1 that Temperature and Feed rate are staying away from the center of the factor1 vs factor 2 loading plots shown in Figure 4.16. Temperature is highly represented in factor 2 (close to -1) but it will give negative contribution to the target which is output moisture. Feed rate is mainly represented in factor 1 (loading value is bit over 0.9) and hence positively contribute to the output moisture. It can be seen that factor 1 and 2 have been switched here in grope 3 compared to the groups 1 and 2, but same model exists. Both temperature and feed rate variables are contributing to the factor 1 and factor 2 in this model as well but contribution is relatively less similar with other two groups. Frequency is not explained in any of the 2 factors as observed earlier. With a careful observation, it can be easily say that influence of feed rate and temperature is getting further strong as their magnitude in loading plot is growing with the increase of input moister content

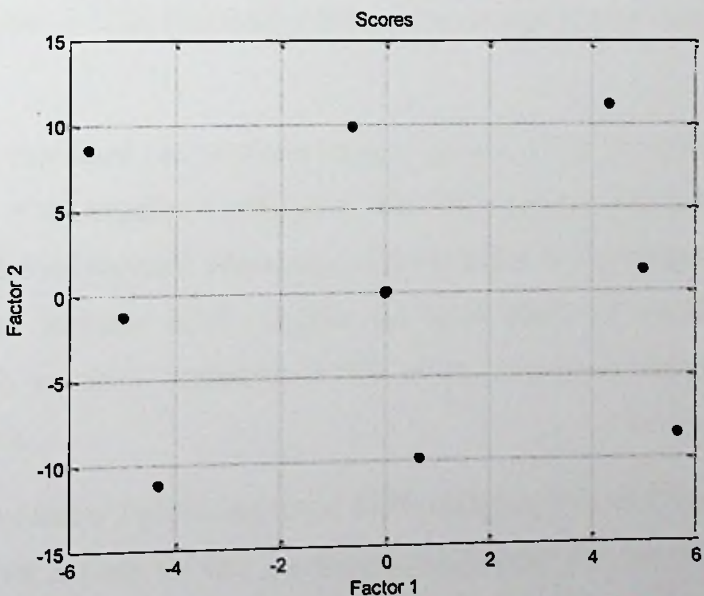

Figure 4.15 Score plot - factor 1 vs factor 2 (group 3)

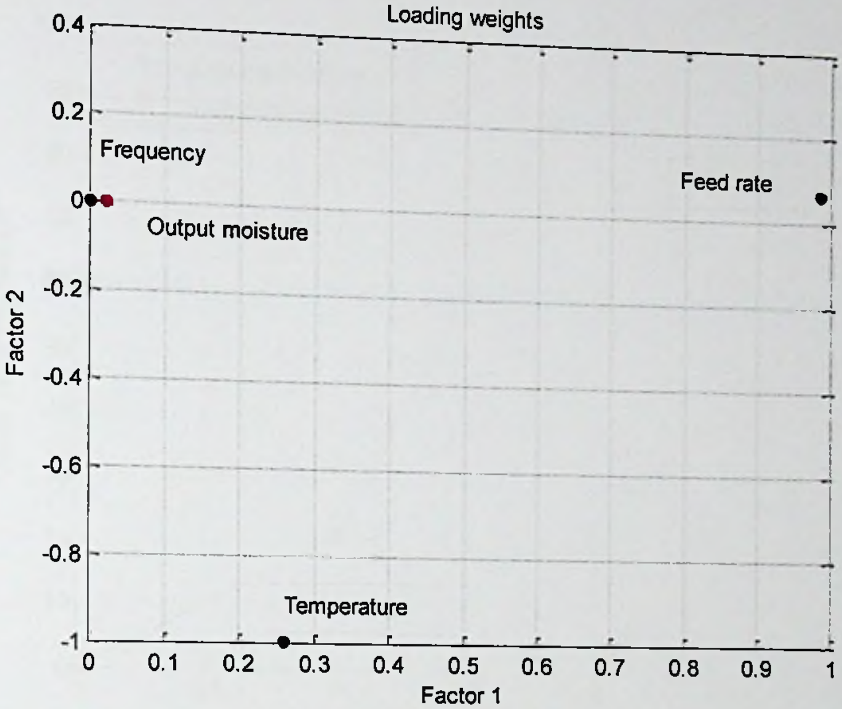

Figure 4.16 Loading weight factor 1 vs factor 2 (group 3)

Similar to the group 1 results, Y-variable is output moisture, also influenced by both factor 1 and factor 2. The explained variance percentage shows how the Y-variable is influenced.

We can see the explained variance percentage Figure 4.17 of X-variables is 85% and it represents 20% of the expalined variance of Y-variable (output moisture) for factor 1. For factor 2 the explained variance percentage of X-variables is 14.5 % and it represents 80% of the expalined variance of Y-variable. In Total 100% of the explained variance percentage of X-variables represents 100% of the expalined variance of Y-variable (output moisture).

As the factor 1 vs factor 2 plots, explained 100% varience of X and Y, there is no point in studying the factor 3. Only the first 2 principal components are describing the model and percentage wise it is around 100% and the third component (factor 3) does almost nothing. Hence, first 2 factors were used in the model.

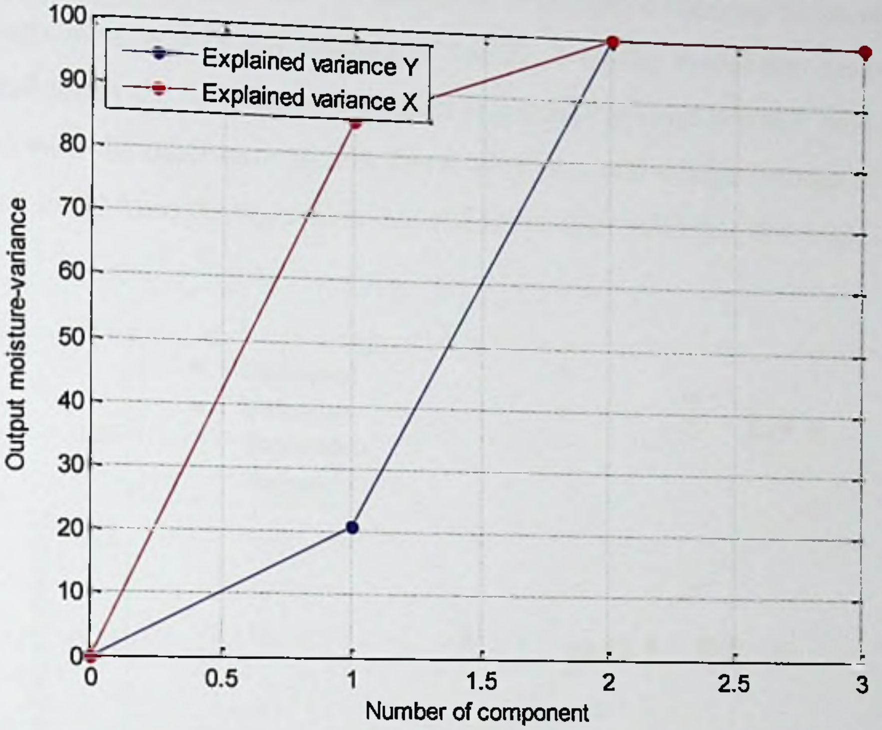

Figure 4.17 X,Y variance explained in each of the three components (group 3)

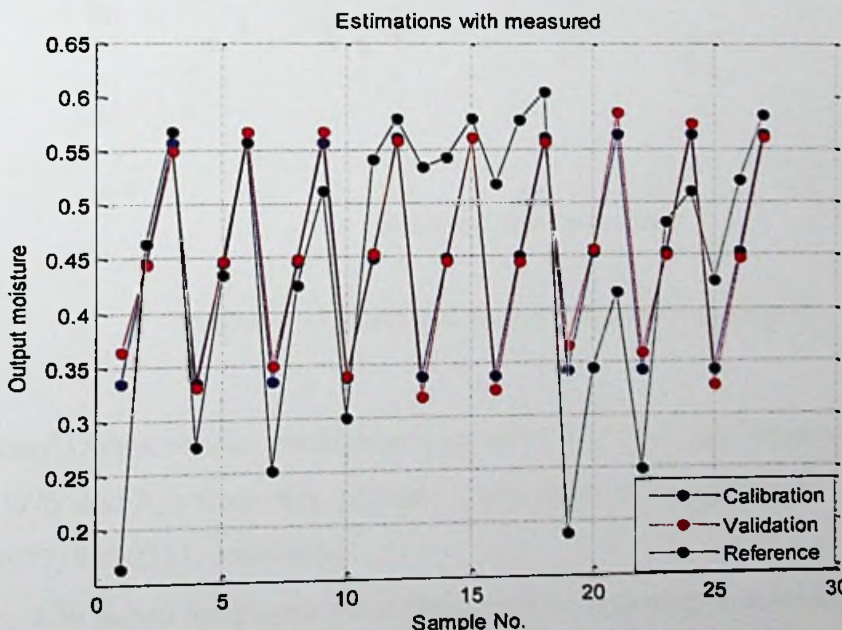

Figure 4.18 Estimation Vs Measured (group 3)

Figure 4.19 shows the predicted vs measured Y (output moisture). Slope of the plot is 0.489. Correlation is 0.79 and RMSEP is 0.0928. It clearly shows that model is getting depreciated when the input moister content is getting high and RMSEP error also swells compared with the other two models, this is very poor and a large number of data points are staying away from the regression line and hence their influence also high.

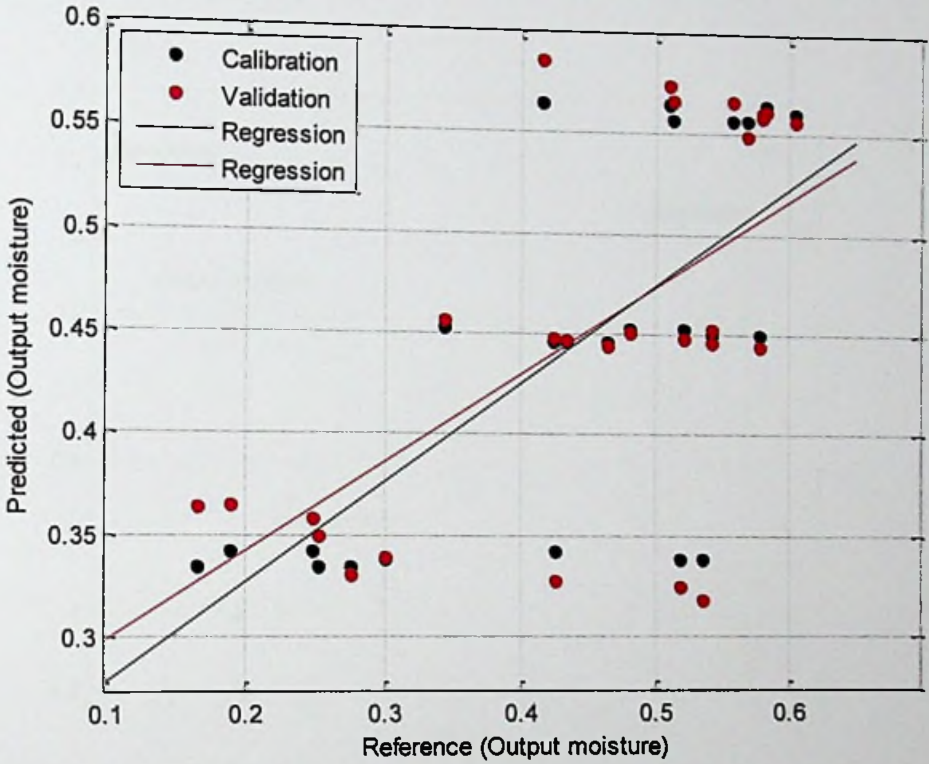

Figure 4.19 Predicted vs. Measured plot (group 3)

The estimated Output moister percentage is given by $Y = B0 + XB^T$ equation. Where B0= 0.003076, and X is frequency, federate Temperature and respective B values are B= [0.883977, 0.022237, 0.000365].

The Figure 4.20 shows the placement of input viables in three groups which are moisture 55%, 65% and 75% with considering factor 1 and factor 2. If selected each input variabls seperately, there is a negative trend in temperature but we need more figuers with considering continous incremental values to forcast better resukt rather than having three temperature. As same as frequency and feed rate also group in two location with respect to the factor 1 and factor 2 but number of data points need to be more than present situation to see the better rlationship with changing the values in each input variable parameter.

4.5 Analysis of three groups together

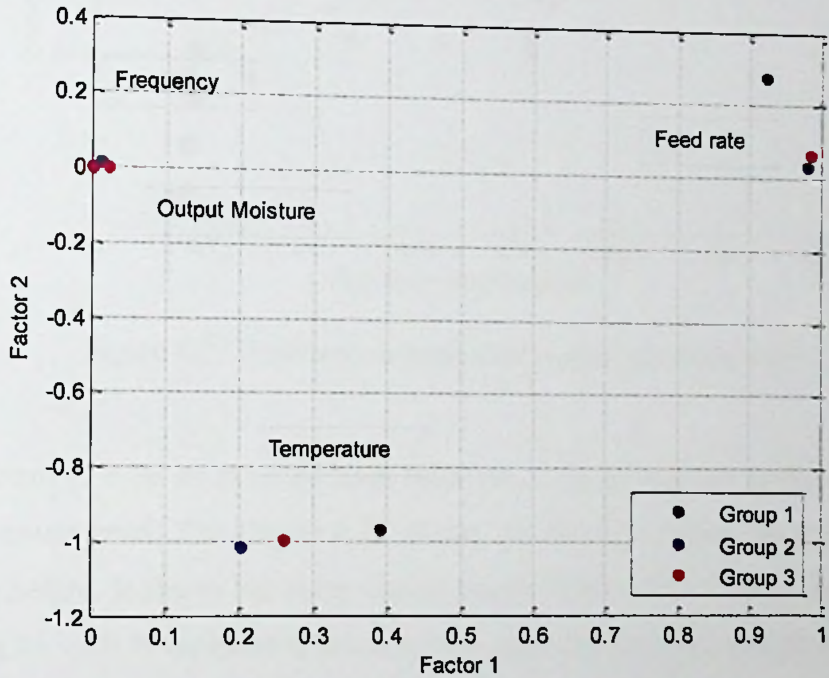

Figure 4.20 Effect of input variables for three groups

The Figure 4.21 shows the regression line of output moisture values against the predicted moisture values. The line indicate the regression line of data set and it can be used to predict the output moisture level against the input moisture level.

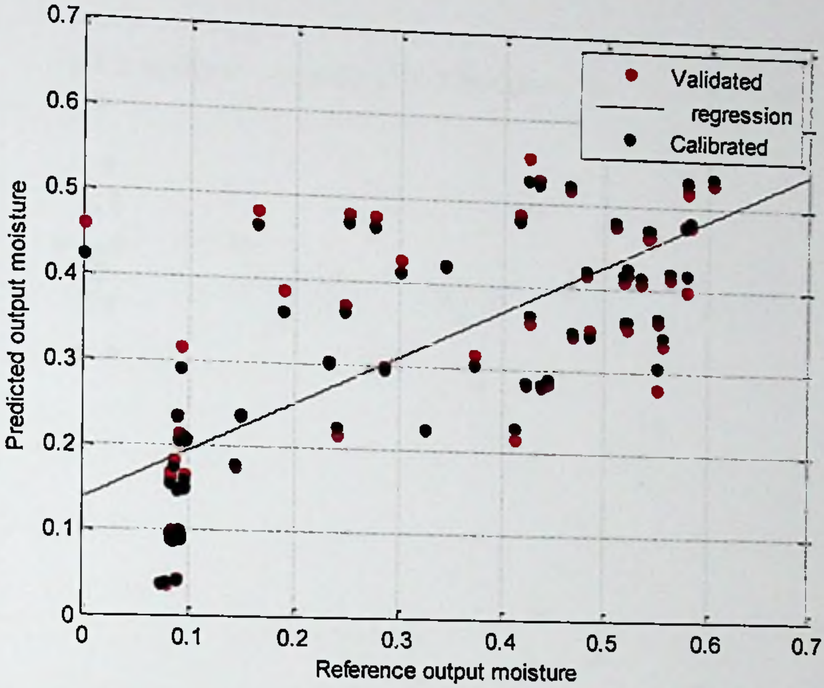

Figure 4.21 Predicted vs Reference output moisture level

It is important to look on the expansion behavior of dried material with considering the output moisture level. The Figure 4.22 shows the average output moisture vs average expansion height. It shows the three degree polynomial curve. If consider the effect of sun drying 15 – 20 % moisture level shows the highest expansion height which is 55-60 mm. The curve shows the similar trend but it peak point behave around 10% output moisture where 50 mm expansion height. It shows the requirement of more data in experiment with incremental data set to see the same effect which is getting through sun drying.

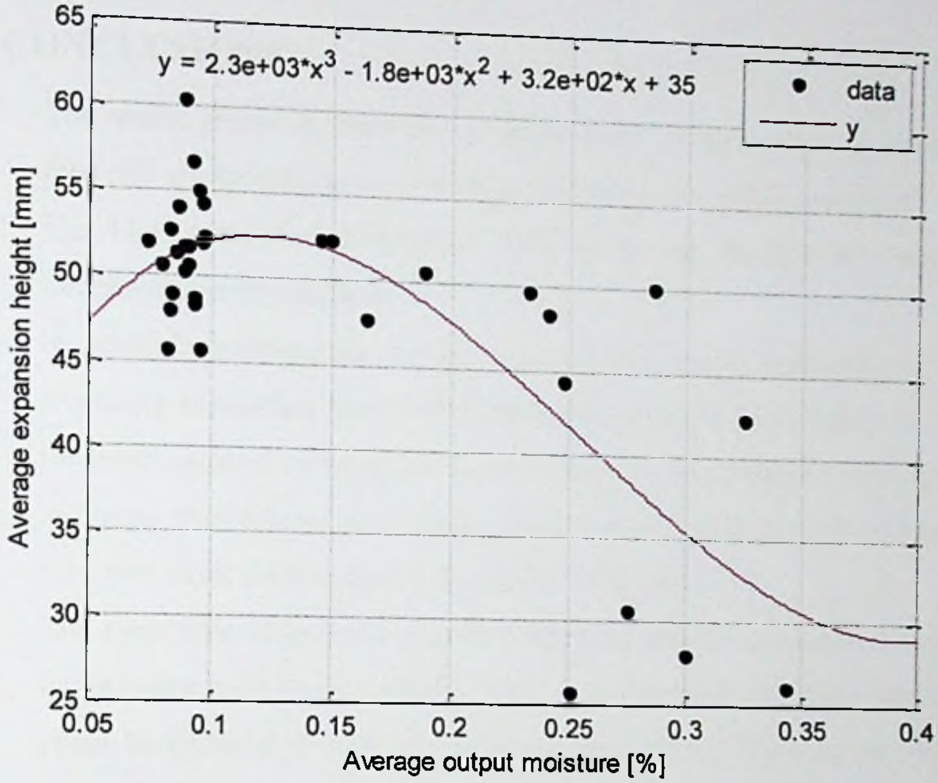

Figure 4.22 Average expansion height vs average output moisture

CHAPTER 5

5.1 CONCLUSIONS

1. The model shows if lower the moisture level of feed material, temperature and feed rate are the key factors which are affecting output moisture level.
2. The higher moisture level (like 75%) is deviate the linearity and higher the uncertainty in this method.
3. In generally temperature and feed rate contribution is comparatively higher than frequency (residence time) which is having minimal contribution with respect to the input material moisture level. However, feeding material with higher level of moisture, temperature and rotating frequency are positively affected to the output moisture while feeding rate is negatively affected.
4. The coco peat with lower moisture contents should be exposed to heat at low temperature with higher feeding rates, but, material with high moisture content could be exposed to high temperatures and low feeding rates as seen with this research
5. The property should remain with the material after thermal drying is utmost important to use as growing media. The expansion height of dried material shows the deviation (around 10 mm at 10% moisture in dry material) from the sun dried material. But trend of curve shows closer relationship towards the required expansion height which can achieve through thermal drying at 15% - 20% output material moisture level.
6. According to the research and considered input variable, this system shows coco peat can be dried when input material moisture is around 60% and temperature 90 -100^0 C and feed rate around 15 l/min and output material will be comply the requirement to use as growing media.
7. Generally we can use $Y = B0 + XB^T$ equation to predict the output moisture relevant to each moisture group. This model is good for the moisture level below 65%. If it is more than that linear relationship cannot find in this method. That is the drawback of this method.

5.2 RECOMMENDATION

The research has done based on three set of values in each feed material moisture level, material feed rate, temperature of the system and frequency. According to the analysis of data it shows the relationship of those variables. But it is needed to get the more values in incrementally in each variables. That helps to create better correlation among those variables. Therefore it is recommended to take more data point with varying the input variables.

The changers of dryer feature like dryer length, heat supply direction, angel, and blower capacity could help to further improving and suggest to evaluate the contribution of those factors in another research.

Instead of drum rotating speed/frequency and feeding rate, residence time also can be used as dependent variable and continue the trail to see the effect of it.

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Appendix A.1 Test result of drying cycles -1 (Copy right by Jiffy products SL (pvt) Ltd)

	Sequence	Frequency (rev/second)	Feed rate (l/min)	Input moisture	Temperature C	Out put moisture			Avg. output moisture	Averge volume weight (W/L)	Expansion height (mm)		
						sample 1	sample 2	sample 3			sample 1	sampe 2	sample 3
1	29	0.05	10	55%	90	8.85%	8.50%	8.62%	8.66%	125.80	55	51	56
2	30	0.05	15	55%	90	8.70%	8.90%	8.95%	8.85%	128.30	50	50	51
3	31	0.05	20	55%	90	8.90%	9.01%	9.15%	9.02%	113.60	55	52	48
4	32	0.07	10	55%	90	9.21%	9.25%	9.34%	9.27%	128.10	48	50	48
5	33	0.07	15	55%	90	9.62%	9.50%	9.70%	9.61%	114.10	53	50	53
6	34	0.07	20	55%	90	9.65%	9.58%	9.81%	9.68%	122.10	51	53	53
7	35	0.14	10	55%	90	9.25%	9.15%	9.37%	9.26%	116.80	50	50	45
8	36	0.14	15	55%	90	9.43%	9.47%	9.45%	9.45%	121.90	55	52	58
9	37	0.14	20	55%	90	9.56%	9.46%	9.50%	9.51%	128.00	47	45	45
10	46	0.05	10	55%	100	7.56%	7.20%	7.45%	7.40%	137.70	43	43	40
11	45	0.05	15	55%	100	8.10%	8.20%	8.35%	8.22%	106.80	40	35	32
12	44	0.05	20	55%	100	8.35%	8.45%	8.16%	8.32%	114.50	35	41	38
13	43	0.07	10	55%	100	8.05%	7.85%	7.90%	7.93%	139.30	40	41	41
14	42	0.07	15	55%	100	8.15%	8.85%	8.20%	8.40%	117.90	50	48	49
15	41	0.07	20	55%	100	8.45%	8.55%	7.85%	8.28%	135.10	50	55	53
16	40	0.14	10	55%	100	8.60%	9.15%	8.85%	8.87%	125.10	55	48	52
17	39	0.14	15	55%	100	9.15%	8.95%	9.10%	9.07%	131.40	52	48	52
18	38	0.14	20	55%	100	9.30%	9.45%	10.10%	9.62%	133.40	57	53	53
19	2	0.05	10	65%	85	24.00%	23.20%	22.57%	23.26%	95.30	49	50	50
20	3	0.05	15	65%	85	52.00%	51.50%	52.12%	51.87%	138.70			
21	4	0.05	20	65%	85	58.00%	58.20%	57.63%	57.94%	170.30			
22	5	0.07	10	65%	85	38.15%	36.25%	37.43%	37.28%	95.0	46	48	47
23	6	0.07	15	65%	85	52.56%	51.34%	52.15%	52.02%	107.6			
24	7	0.07	20	65%	85	56.43%	56.52%	55.94%	56.30%	175.3			
25	8	0.14	10	65%	85	55.26%	54.53%	55.28%	55.02%	159.60			
26	9	0.14	15	65%	85	56.00%	56.24%	53.17%	55.14%	164.50			
27	10	0.14	20	65%	85	58.00%	58.34%	57.92%	58.09%	176.50			

Appendix A.2 Test result data of drying cycles -2 (Copy right by Jiffy products SL (pvt) Ltd)

	Sequence	Frequency (rev/second)	Feed rate (l/min)	Input moisture	Temperature C	Out put moisture			Avg. output moisture	Averge volume weight (W/L)	Expansion height (mm)		
						sample 1	sample 2	sample 3			sample 1	sampe 2	sample 3
28	11	0.05	10	65%	100	24.00%	24.52%	23.95%	24.16%	100.00	48	50	47
29	12	0.05	15	65%	100	43.62%	44.52%	42.92%	43.69%	139.50			
30	13	0.05	20	65%	100	56.75%	55.45%	54.65%	55.62%	136.50			
31	14	0.07	10	65%	100	32.46%	33.56%	31.48%	32.50%	128.20	40	40	47
32	15	0.07	15	65%	100	42.95%	41.50%	42.30%	42.25%	122.20			
33	16	0.07	20	65%	100	48.52%	47.95%	48.90%	48.46%	111.80			
34	17	0.14	10	65%	100	40.05%	41.31%	42.56%	41.31%	117.40			
35	18	0.14	15	65%	100	44.15%	44.90%	44.20%	44.42%	121.00			
36	19	0.14	20	65%	100	46.50%	46.35%	47.25%	46.70%	123.00			
40	23	0.07	10	65%	110	8.50%	8.46%	8.75%	8.57%	128.2	52	50	52
41	24	0.07	15	65%	110	8.90%	8.64%	9.10%	8.88%	120.9	60	61	60
42	25	0.07	20	65%	110	9.20%	9.15%	9.30%	9.22%	116.1	60	57	53
43	26	0.14	10	65%	110	14.50%	14.75%	14.25%	14.50%	119.2	55	52	50
44	27	0.14	15	65%	110	14.75%	14.90%	15.10%	14.92%	131.4	52	55	50
45	28	0.14	20	65%	110	28.00%	28.75%	29.15%	28.63%	116.0	49	50	51
46	47	0.05	10	75%	90	16.00%	16.85%	16.50%	16.45%	104.6	48	50	45
47	48	0.05	15	75%	90	46.50%	45.95%	46.75%	46.40%	107.6			
48	49	0.05	20	75%	90	56.55%	56.75%	57.10%	56.80%	113.8			
49	50	0.07	10	75%	90	27.65%	26.90%	28.10%	27.55%	119.3	30	32	30
50	51	0.07	15	75%	90	43.60%	42.75%	43.85%	43.40%	116.2			
51	52	0.07	20	75%	90	56.75%	55.40%	54.80%	55.65%	116.8			
52	53	0.14	10	75%	90	25.70%	24.85%	24.90%	25.15%	106.2	25	23	29
53	54	0.14	15	75%	90	42.40%	41.85%	42.80%	42.35%	124.8			
54	55	0.14	20	75%	90	52.45%	51.45%	49.85%	51.25%	126.8			
55	56	0.05	10	75%	100	30.00%	28.95%	31.10%	30.02%	109.3	30	27	27
56	57	0.05	15	75%	100	54.45%	53.85%	54.10%	54.13%	124.5			

Appendix A.3 Test result of drying cycles - 3 (Copy right by Jiffy products SL (pvt) Ltd)

	Sequence	Frequency	Feed rate	Input moisture	Temperature C	Out put moisture			Avg. output	Averge volume weight	Expansion height (mm)		
		(rev/second)	(l/min)			sample 1	sample 2	sample 3	moisture	(W/L)	sample 1	sampe 2	sample 3
57	58	0.05	20	75%	100	56.50%	57.35%	59.85%	57.90%	149.7			
58	59	0.07	10	75%	100	54.00%	53.85%	52.45%	53.43%	113.5			
59	60	0.07	15	75%	100	56.00%	54.35%	52.25%	54.20%	152.4			
60	61	0.07	20	75%	100	58.50%	57.45%	57.95%	57.97%	172.1			
61	62	0.14	10	75%	100	52.75%	51.65%	50.90%	51.77%	133.6			
62	63	0.14	15	75%	100	58.15%	56.45%	58.75%	57.78%	145.1			
63	64	0.14	20	75%	100	60.35%	59.28%	61.70%	60.44%	152.3			
64	65	0.05	10	75%	110	18.45%	18.90%	19.25%	18.87%	101.5	49	52	51
65	66	0.05	15	75%	110	34.45%	34.75%	33.82%	34.34%	93.5	30	25	23
66	67	0.05	20	75%	110	42.58%	41.45%	40.65%	41.56%	104.6			
67	68	0.07	10	75%	110	24.45%	25.16%	24.80%	24.80%	99.8	46	45	42
68	69	0.07	15	75%	110	48.50%	47.45%	48.23%	48.06%	92.5			
69	70	0.07	20	75%	110	50.50%	51.35%	51.05%	50.97%	103.5			
70	71	0.14	10	75%	110	42.45%	41.85%	43.50%	42.60%	96.3			
71	72	0.14	15	75%	110	52.65%	52.10%	51.65%	52.13%	117.1			
72	73	0.14	20	75%	110	58.70%	57.65%	58.35%	58.23%	141.6			

Appendix B.1 NIPALS Algorithm

https://documents.software.dell.com/statistics/textbook/partial-least-squares#nipals

The standard algorithm for computing partial least squares regression components (i.e., factors) is nonlinear iterative partial least squares (NIPALS). There are many variants of the NIPALS algorithm which normalize or do not normalize certain vectors. The following algorithm, which assumes that the *X* and *Y* variables have been transformed to have means of zero, is considered to be one of most efficient NIPALS algorithms.

For each $h=1,\ldots,c$, where $A_0=X'Y$, $M_0=X'X$, $C_0=I$, and c given,

1. compute q_h, the dominant eigenvector of $A_h'A_h$
2. $w_h=C_hA_hq_h$, $w_h=w_h/||w_h||$, and store w_h into *W* as a column
3. $p_h=M_hw_h$, $c_h=w_h'M_hw_h$, $p_h=p_h/c_h$, and store p_h into *P* as a column
4. $q_h=A_h'w_h/c_h$, and store q_h into *Q* as a column
5. $A_{h+1}=A_h - c_hp_hq_h'$ and $M_{h+1}=M_h - c_hp_hp_h'$
6. $C_{h+1}=C_h - w_hp_h'$

The factor scores matrix *T* is then computed as $T=XW$ and the partial least squares regression coefficients *B* of *Y* on *X* are computed as $B=WQ$.

SIMPLS Algorithm

An alternative estimation method for partial least squares regression components is the SIMPLS algorithm (de Jong, 1993), which can be described as follows.

For each $h=1,\ldots,c$, where $A_0=X'Y$, $M_0=X'X$, $C_0=I$, and c given,

1. compute q_h, the dominant eigenvector of $A_h'A_h$
2. $w_h=A_hq_h$, $c_h=w_h'M_hw_h$, $w_h=w_h/sqrt(c_h)$, and store w_h into *W* as a column
3. $p_h=M_hw_h$, and store p_h into *P* as a column
4. $q_h=A_h'w_h$, and store q_h into *Q* as a column
5. $v_h=C_hp_h$, and $v_h=v_h/||v_h||$
6. $C_{h+1}=C_h - v_hv_h'$ and $M_{h+1}=M_h - p_hp_h'$
7. $A_{h+1}=C_hA_h$

Similarly to NIPALS, the *T* of SIMPLS is computed as $T=XW$ and *B* for the regression of *Y* on *X* is computed as $B=WQ'$.