

CERTIFICATE I

**DESIGN, DEVELOPMENT AND PERFORMANCE
EVALUATION OF SOLAR SPOUTED BED
DRYER FOR SAWDUST**

Thesis

Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of

MASTER OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

(Thermal Environmental Engineering)

(Minor Subject : Electrical Engineering)

DUPLICATE

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1999

CERTIFICATE I

This is to certify that the thesis entitled, "Design, Development and Performance Evaluation of Solar Spouted Bed Dryer for Sawdust" submitted for the degree of M.Tech in Mechanical Engineering (Thermal Environmental Engineering) of the Punjab Agricultural University is a bonafide research work carried out by Mr. Gurpreet Singh (L-94-AE-108-M) under my supervision and no part of this thesis has been submitted for any other degree.

The assistance received during the course of investigation has been fully acknowledged.

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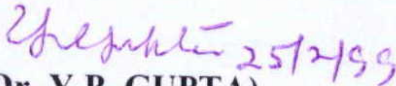
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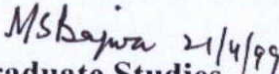
CERTIFICATE II

This is certified that the thesis entitled, "Design, Development and Performance Evaluation of Solar Spouted Bed Dryer for Sawdust" submitted by Mr. Gurpreet Singh (L-94-AE-108-M) to the Punjab Agricultural University in partial fulfilment of the requirement for the degree of M.Tech in Mechanical Engineering (Thermal Environmental Engineering) has been approved by the student's advisory committee after an oral examination on the same, in collaboration with external examiner.


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INTRODUCTION
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Gurpreet Singh
Gurpreet Singh

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Collector heat removal factor

Gram

Effective heat transfer coefficient ($W/m^2 \cdot ^\circ K$)

Heat transfer coefficient between bottom and air stream, ($W/m^2 \cdot ^\circ K$)

Radiative heat transfer coefficient ($W/m^2 \cdot ^\circ K$)

Bed height of saw dust in glass spout (cm)

Flux at different bed depth (W/m^2)

Instantaneous diffuse irradiation on a horizontal surface (W/m^2)

LIST OF ABBREVIATION

Abbreviation	:	Interpretation
A	:	Area of collector
cm	:	Centi metre
°C	:	Degree centigrade
C	:	Cone angle
db	:	Dry basis
Di	:	Inlet diameter
Dc	:	Column diameter
Dh	:	Hydraulic diameter
Dp	:	Particle diameter
EBA	:	Energy consumed by blower
EH	:	Energy consumed by solar assisted linear spouted bed dryer
EHT	:	Total energy consumed
F'	:	Collector efficiency factor
F _R	:	Collector heat removal factor
g	:	Gram
h _E	:	Effective heat transfer coefficient (W/m ² - ° K)
h _{fb}	:	Heat transfer coefficient between bottom and air stream, (W/m ² - ° K)
h _R	:	Radiative heat - transfer coefficient (W/m ² - ° K)
H	:	Bed height of saw dust in glass spout (cm)
I	:	Flux at different bed depth (W/m ²)
I _D	:	Instantaneous diffuse radiation on a horizontal surface (W/m ²)

I_T	:	Instantaneous flux incident on top cover of collector (W/m^2)
Kg	:	Kilo gram
kW - hr	:	Kilo watt hour
l	:	Length of linear spouted bed dryer (cm)
L_1	:	Length of collector
L_2	:	Width of collector
L_3	:	Duct depth
m.c.	:	Moisture content, % (db)
$(mc)_E$:	Effective heat capacity of collector (kJ/K)
M	:	Mass flow rate (Kg/s)
Nu	:	Nusselt number
q_u	:	Heat gain
R	:	Ratio of length to width
R_b	:	Tilt factor for beam radiation
R_D	:	Tilt factor for diffuse radiation
R_R	:	Tilt factor for reflected radiation
t	:	Time (min.)
T	:	Temperature ($^{\circ}C$)
T_A	:	Ambient temperature
T_C	:	Temperature of cover
T_{fo}	:	Temperature of fluid at outlet
T_{min}	:	Minimum temperature for the representative day of Nov.
T_{max}	:	Maximum temperature for the representative day of Nov.
T_{pm}	:	Mean plate temperature
T_{sky}	:	Sky temperature

Chapter I

U_B	:	Bottom loss coefficient ($W - m^2/^\circ K$)
U_L	:	Overall loss coefficient ($W - m^2/^\circ K$)
U_S	:	Side loss coefficient ($W - m^2/^\circ K$)
U_T	:	Top loss coefficient ($W - m^2/^\circ K$)
U_{T2}	:	Top loss coefficient for cover ($W - m^2/^\circ K$)
V	:	Velocity of air through duct
ϕ	:	Latitude angle in degrees
β	:	Slope of collector surface in degrees
δ	:	Declination angle in degrees
ω	:	Hour angle in degrees
γ	:	Surface azimuth angle in degrees
ρ	:	Reflectivity
θ	:	Cone angle in degrees

INTRODUCTION

The wide spread use of coal and other fossil fuels have resulted in their sharp depletion. Alternatives must be found to conserve these conventional energy resources as their supply is limited. Thus there has been a renewed interest in using biomass fuels. Most of the biomass fuels are cheap at the source but are relatively expensive to collect, process and haul. Materials like wood sawdust, rice husk, rice straw etc. can be used as inexpensive alternative sources of energy at site.

Sawdust is a low cost, low utility byproduct of the lumber industry and can be converted into useful fuel by making briquettes. The moisture content of sawdust varies from 35 to 55% wet basis. The high moisture causes fungal growth, decomposition and reduction in energy content. Therefore, before making briquettes, sawdust needs to be dried. Sawdust dries very slowly under natural ventilation and if not protected from rain, it may get spoilt.

Different types of dryers, such as rotary dryer, drum dryer, baffle type grain dryer, fluid bed dryer etc. have been used for drying of loosely packed waste materials such as sawdust. Deep bed dryer using solar air heater have already been developed but there is a problem of channelling effect. Another way to dry the sawdust is to force hot air through the material with a suitable fan. This dryer is a vessel open at the top and filled partially with sawdust. When air is injected vertically through a centrally located small opening at the base of the vessel, it

causes a stream of particles to rise rapidly in a hollowed central core within the bed of solids. As the particles reach somewhat above peripheral bed level, some particles fall back on to the annular region (between the hollowed core and column wall) and slowly travel downward as a loosely packed bed.

However, as the air carrying sawdust travels upward it flares out into the annulus. The overall bed thus becomes a composite of central core with upward moving solids entrained by concurrent flow of air and an annular region with counter current percolation of the air. This system is termed as "spouted bed". The advantage of such type of dryer is that heat and mass transfer are an order of magnitude faster in spouted bed than in bulk. The present work deals with drying of sawdust using spouted bed dryers. Spouted bed dryers of two types viz. conical dryer and linear dryer will be investigated. The specific objectives of investigation are :

- a) To design and fabricate conical and linear spouted bed dryers.
- b) To study the effect of cone angle, bed depth, bed air velocity and air temperature on drying.
- c) To develop a computer programme for design of solar spouted dryer for any place.

REVIEW OF LITERATURE

2.1 INTRODUCTION

The spouted bed has been regarded as a modified version of fluidized bed. It displays special characteristics which make it capable of performing certain useful cyclic operations on solid particles which cannot be performed in a fluidized bed, due to its comparatively random particle motion. The functioning of a spouted bed is described below :

Consider a vessel open at the top and filled with relatively coarse particulate solids. When fluid (air) is injected vertically through a centrally located small opening at the base of the vessel, it causes a stream of particles to rise rapidly in a hollowed central core within the bed of solids. As the particles reach somewhat above the peripheral bed level, some particles run back on to the annular region (between the hollowed core and column wall) and slowly travel downward as a loosely packed bed. As the fluid carrying particles travels upward it flares out into the annulus. The overall bed thus becomes a composite of central core with upward moving solids entrained by a cocurrent flow of fluid and an annular region with countercurrent percolation of fluid. This system is termed a "Spouted bed". The central core is called a spout, and the peripheral annular region is referred to as the annulus.

2.2 TYPES OF SPOUTED BED

The various types of spouted bed are as follows :-

- i) Simple or conical spouted bed
- ii) Multispouting bed
- iii) Circular triple spouted bed
- iv) Fluid lift solids recirculator
- v) Slot spouted bed
- vi) Hot grain popper
- vii) Top sealed spouted bed.

2.2.1 Simple or conical spouted bed

This has been shown in Fig. 2.1. It has already been discussed, in sec. 2.1.

2.2.2 Multi spouting bed

It has several individual spouting cells, each with its own spout and annulus in a large bed (Fig. 2.2). Peterson (1966) studied such a system and found that operations tended to be unstable except with shallow bed. Provision of vertical baffles, extending upward from the base of the vessel and covering one half to seven eighths of the height of the bed, brought about a marked improvement in multi spouting stability, presumably by cutting off lateral flow of gas between neighbouring cells.

2.2.3 Circular triple spouted bed

Circular triple spouted bed (Fig. 2.3) is based on same principle as

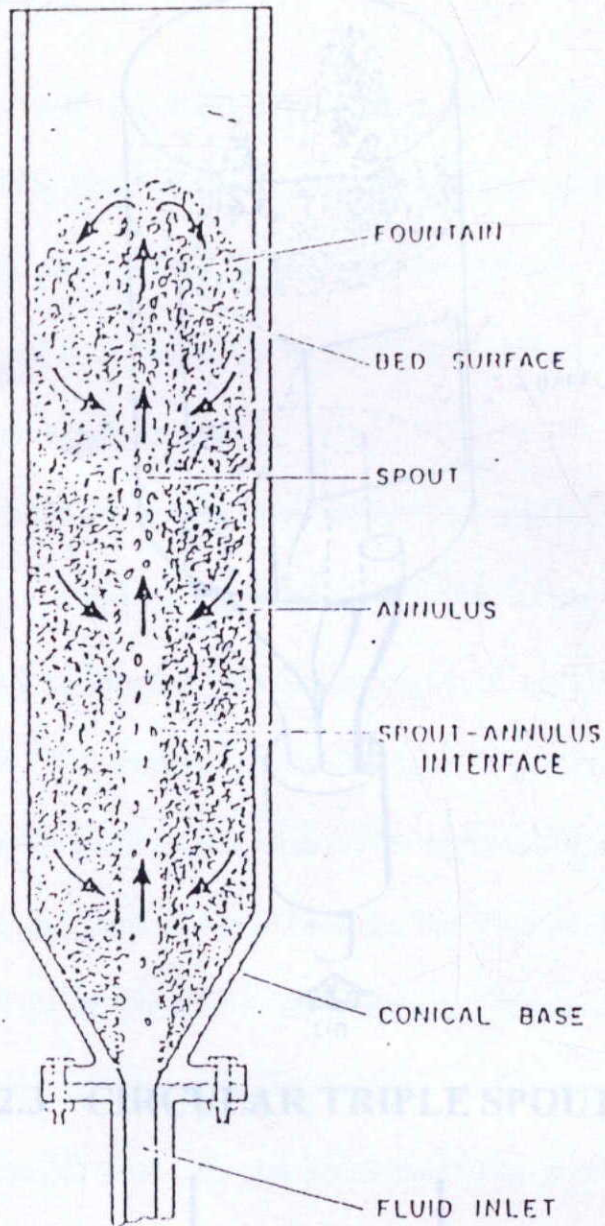


FIG. 2.1 CONICAL SPOUTED BED DRYER

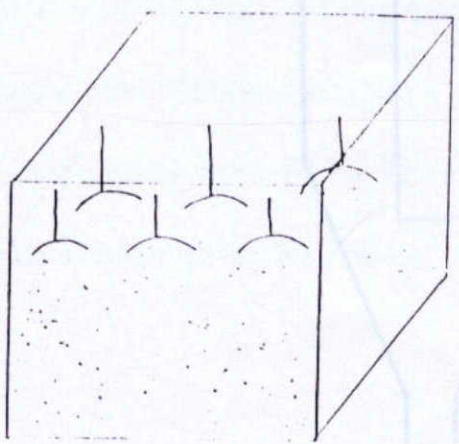


FIG. 2.2 MULTI-SPOUTING BED

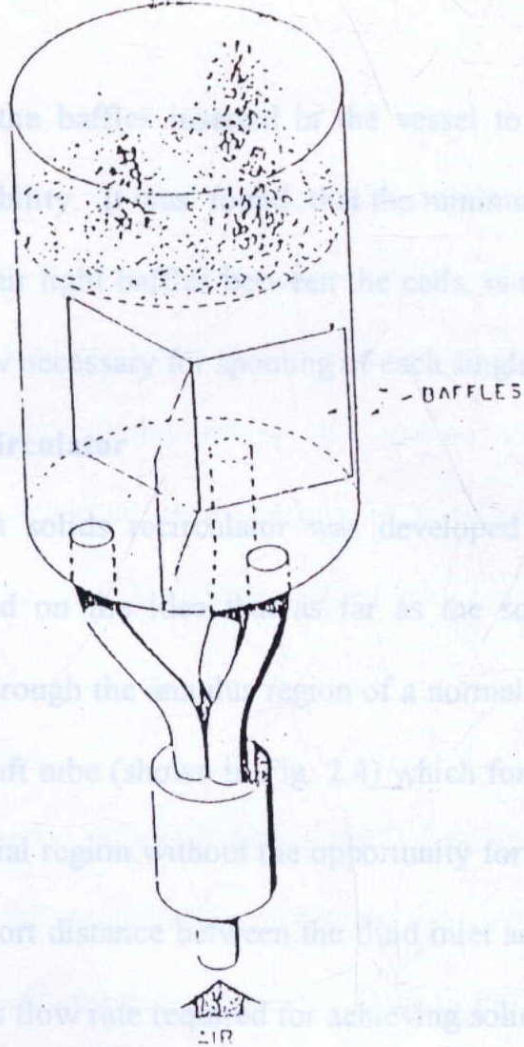


FIG. 2.3 CIRCULAR TRIPLE SPOUDED BED

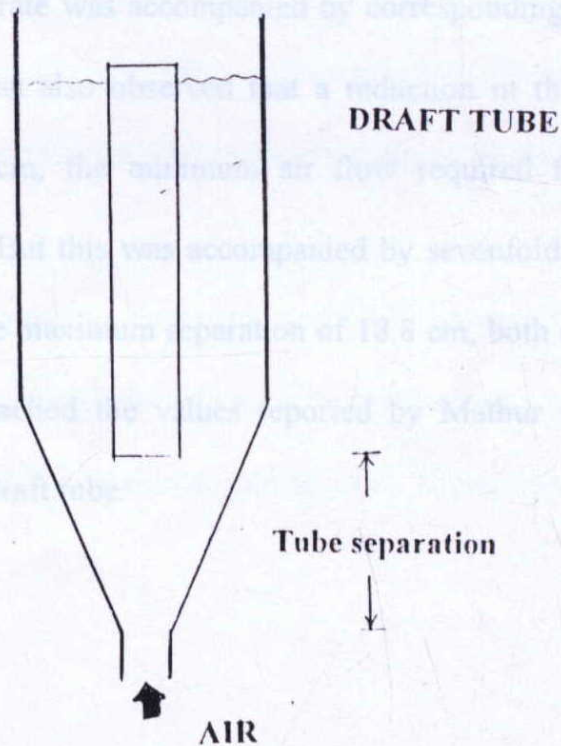


FIG. 2.4 FLUID LI FT SOLIDS RECIRCULATOR

multi spouting, but with the baffles inserted in the vessel to make partition for increasing the spouting stability. It was found that the minimum air flow required in multiple spouting with air tight baffles between the cells, is roughly 20% higher than the sum of the air flow necessary for spouting of each single spout cell.

2.2.4 Fluid lifts solid recirculator

The fluid-lift solids recirculator was developed by Buchanan and Wilson (1965). It is based on the idea that as far as the solid recirculation is concerned, flow of fluid through the annulus region of a normal spouted bed serves little purpose. It uses a draft tube (shown in Fig. 2.4) which forces most of the gas to travel up through the axial region without the opportunity for flaring out into the annulus except over the short distance between the fluid inlet and the lower end of the tube. It reduces the gas flow rate required for achieving solids recirculation in a given bed. The experimental results obtained in 15 cm diameter wheat bed, showed that any reduction in gas flow rate was accompanied by corresponding decrease in solids recirculation rate. It was also observed that a reduction in the draft tube separation from 18.8 to 3.3 cm, the minimum air flow required for spouting decreased by a factor of two. But this was accompanied by sevenfold decrease in solids circulation rate. With the maximum separation of 18.8 cm, both air flow and solids flow rate closely approached the values reported by Mathur and Gishler (1955) for similar bed with no draft tube.

2.2.5 Slot spouted bed

Leningrad (1968) introduced the gas into the base of the bed through a narrow slot running across the longer dimension of the containing vessel. The containing vessel is of rectangular cross-section with sloping walls as shown in Fig. 2.5. The slot may be either continuous or with spaced openings. The stable spouting of solids can be achieved within certain limits of the usual spouted bed parameters, namely, vessel, size, bed depth, slot width, gas flow rate and solid properties.

2.2.6 Hot air grain popper

The hot air grain popper is also a kind of spouted bed. The air jet blows the grain to the top of the chamber. The grain then falls like rain on to the sloping floor of the chamber and slides along the floor to the circumference from where it gets reentrained in the air stream. The chamber is divided into compartments. It revolves to allow continuous feeding and discharging of material. Since the popping process requires a very short contact time with the hot air (15-30 sec), a bed of solids is not allowed to build up in the chamber as shown in Fig. 2.6.

2.2.7 Top-sealed spouted bed

In this system, the spout vessel is top sealed as shown in Fig. 2.7. The entire spouting gas is faced downward through annular solids, giving more uniform treatment of gas than is achievable in a normal spouted bed. Though the presence of

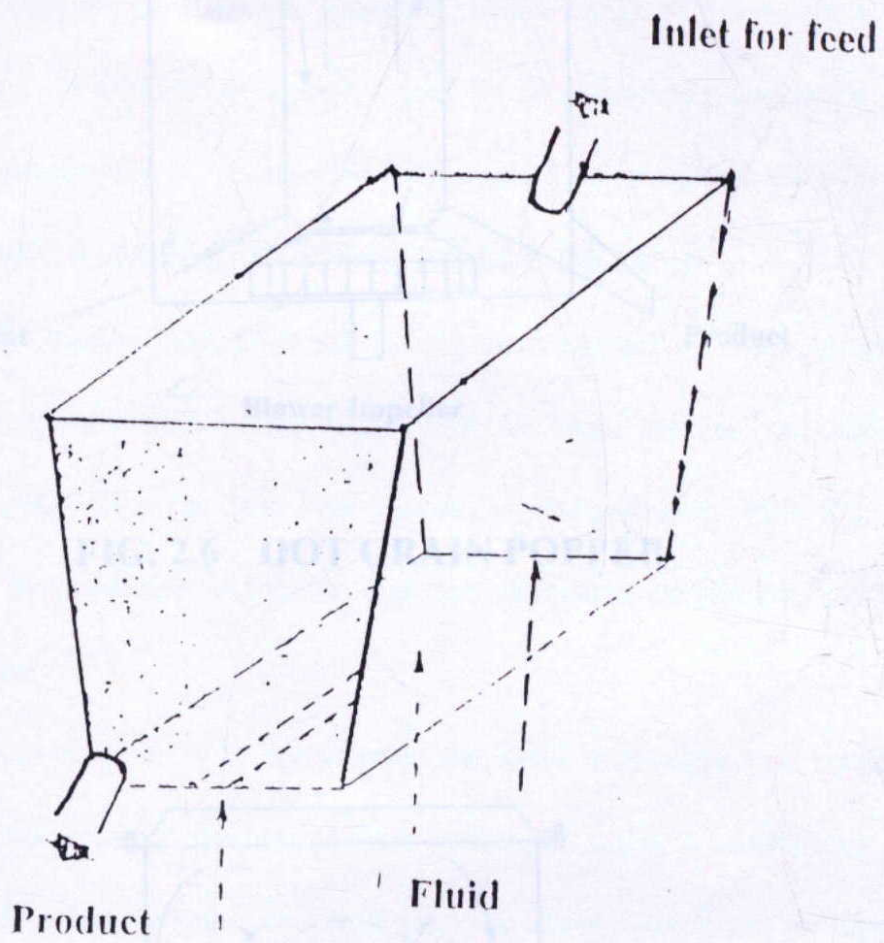


FIG. 2.5 SLOT SPOUTED BED

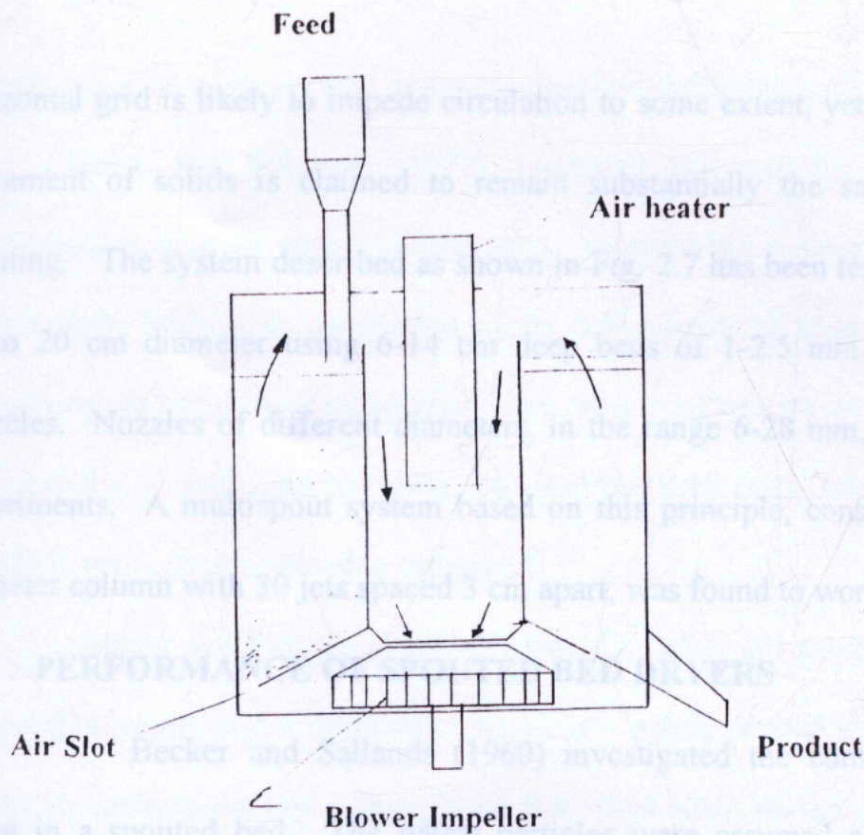


FIG. 2.6 HOT GRAIN POPPER

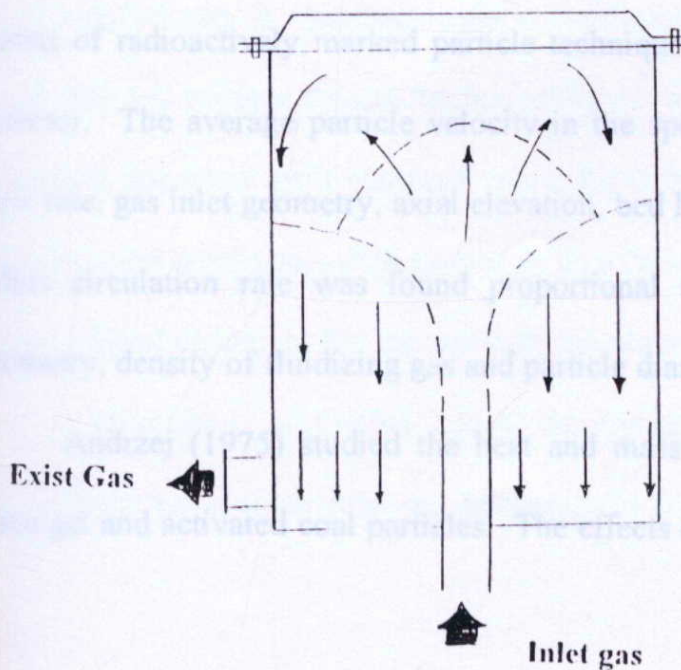


FIG. 2.7 TOP SEALED SPOUDED BED

horizontal grid is likely to impede circulation to some extent, yet the pattern of the movement of solids is claimed to remain substantially the same as in normal spouting. The system described as shown in Fig. 2.7 has been tested in columns of up to 20 cm diameter using 6-14 cm deep beds of 1-2.5 mm diameter catalyst particles. Nozzles of different diameters, in the range 6-28 mm, were used in the experiments. A multispout system based on this principle, consisting of a 20 cm diameter column with 30 jets spaced 3 cm apart, was found to work well.

2.3 PERFORMANCE OF SPOUTED BED DRYERS

Becker and Sallands (1960) investigated the continuous drying of wheat in a spouted bed. The wheat particles were assumed as uniform, nearly spherical, solid particles in well mixed, isothermal bed, with the drying rate controlled by moisture diffusion and the diffusion coefficient independent of concentration.

Velzen *et al.* (1974) investigated the solid movement in a spouted bed by means of radioactively marked particle technique, using a scintillation counter as detector. The average particle velocity in the spout was found to depend on gas flow rate, gas inlet geometry, axial elevation, bed height and column diameter. The solids circulation rate was found proportional to the gas flow rate, gas inlet geometry, density of fluidizing gas and particle diameter.

Andrzej (1975) studied the heat and mass transfer in air spouted beds of silica gel and activated coal particles. The effects of gas velocity, particle size, bed

depth and cone angle on heat and mass transfers coefficients were studied.

Sucui and Patrascu (1977) estimated the particle velocity from the examination of high speed photographs. Simplifying assumptions regarding the state of the bed led to calculation of the bulk density of both annulus and spout. Graphical and analytical integration were used to obtain the average retention time of particles in each characteristic zone and the total retention time in the system. Particle recirculation was also estimated.

Littman and Morgan (1977) presented a theory for predicting the maximum spoutable height where fluidization of annular solids limited the penetration of the fluid jet entering the bed. They found that when small particles were spouted with air, the penetration of the jet was limited by the formation of a slug in the spout.

Grace and Mathur (1978) proposed a theoretical model, based on force - balance analysis, to describe the characteristics of the fountain region of spouted beds. The model was used to calculate the fountain height and vertical profiles of particles velocity and voidage in the upward-moving core of the fountain from spout velocity and voidage data at the bed surface level. Predicted fountain heights were in good agreement with observed values for wide range of experimental conditions. Under most conditions, drag proved to be of relatively small importance, leading to a simplified procedure for approximate calculations.

Brunello *et al.* (1974) studied the drying of barley malt in a batch spouted bed dryer using three inlet air temperatures (60, 80 and 90°C) and three initial

masses of malt (25, 30 and 35 kg). It was concluded that the drying could be conducted at higher temperatures than in the classical equipment. A general correlation was also obtained through the use of reduced moisture and reduced time. A model based on the assumption of semi-permeable membrane was found to be a good correlation for the data.

Suggs and Lanier (1985) evaluated the air flow resistance through variable height columns of wood chips and sawdust by means of the pressure drop across an orifice plate. Input pressure to the bottom of the column was controlled by means of damper on the supply fan air intake. Air flow through sawdust with respect to input pressure per unit depth also yielded a straight line on a log-log plot.

Viswanathan (1986) presented a mathematical model for predicting the dynamics of continuous drying of solids in fluidized and spouted beds. The average outlet solids moisture content, the outlet humidity and the solids temperature were predicted as a function of time for both falling and constant rate drying periods. It was shown that the initial moisture content of the solids in the beds was a critical variable. Analytical expressions were derived for the time required to reach steady state, the solids moisture content, and temperature at steady state.

Grace *et al.* (1994) used a fibre optic probe system to measure the profiles of vertical particle velocities in the spout and the fountain of half-column and full-column spouted bed. In addition, a fibre optic image probe was employed to measure vertical particle velocity profiles in the annulus of the full-column and to

determine the spout annulus interface in the full column. In spout region, the radial profiles are not parabolic. Particle velocities along the spout axis in the half column were 30% lower than in the full column under identical operating conditions. In the half column, particle velocities adjacent to the front plate were approximately 24% lower than a few millimeters away i.e. flat plate strongly affects particle velocity measurements. The upward solids mass flow in the annulus have been calculated by numerical integration based on measured local voidage and particle velocity measurements.

Murthy and Singh (1994) carried out studies in multiple spouted beds. Different fluid inlet orifices and different solids were used with air as spouting fluids. The minimum spouting velocity was found to be independent of the number of spout cells in a multi-spout system. He showed that the minimum spouting velocity was strongly influenced by bed depth, particle size and fluid properties.

Thorley *et al.* (1959) studied the air and solid flow pattern in a spouted wheat bed. Orifice size, cone angle, bed height and air flow were varied so as to establish their effect on the flow patterns. Air flow within the bed was obtained from pressure drop gradients, and solid flow was obtained from particle velocities measurements taken at the wall. Pressure drop, air flow distribution between spout and annulus, solid circulation rate and flow line data were summarized. A correlation was proposed which related pressure drop and particle velocity at the top of the bed. Particle velocity measurements in the spout were made from

photographs, and were calculated approximately from the drag equation for a single particle.

Lefroy (1969) made measurements of maximum spoutable bed depth and of overall pressure drop by using hopper size ranging 7.6 cm diameter to 61 cm. A spouted bed in a half cylinder - divided along its vertical diametral plane - was found to behave in almost the same way as a bed in a full cylinder of the same diameter. Applying momentum balance between particle and fluid of the spout with the assumption that the pressure was distributed vertically according to a quarter cosine wave, the pressure distribution was consistent with the requirements for equilibrium of the spout wall and this lead to approximate expressions for H_m and D_s .

Ayse Cecen (1994) studied the maximum spoutable bed heights of fine glass sphere spouted with air in flat based semi circular columns of 80 and 152.4 mm diameters using particles with average diameters ranging from 0.3 to 1.3 mm. New correlations were proposed to predict the maximum spoutable bed heights of air spouted fine particle systems. It was concluded that the influence of the column diameter on the maximum spoutable bed depth was significantly decreased compared to coarse particle systems and varied with particle size.

Ghosh (1965) has suggested that spouting action can be achieved for much finer particles, as long as the inlet diameter (D_i) does not exceed 30 times the particle diameter (D_p). Mathematically,

$$D_i / D_p = 30 \quad (3.21)$$

MATERIALS AND METHODS

This chapter deals with the details of the materials and methods used for experimental work conducted to obtain the required data for the proposed study. It includes design of spouted bed, selection of independent variables, experimental setup and the experimental procedure. A detailed description of whole experimental phase is given in the following sections.

3.1 DESIGN OF SPOUTED BED DRYER

The various dimensions involved in the design of a spouted bed are shown in Fig. 3.1. According to Mathur and Epstein (1974), the value of the ratio D_i/D_c is equal to 0.1.

$$\frac{D_i}{D_c} = 0.1 \quad (3.1)$$

Where,

D_i = Inlet diameter of spout

D_c = Column diameter of spout

Ghosh (1965) has suggested that spouting action can be achieved for much finer particles, as long as the inlet diameter (D_i) does not exceed 30 times the particle diameter (D_p). Mathematically,

$$D_i / D_p = 30 \quad (3.2)$$

Taking average size of particle (D_p) of sawdust as 0.27 mm (as found from

sieve test), we have,

$$\Rightarrow D_i = 30 \times 0.27 = 8.1 \text{ mm} \approx 8 \text{ mm}$$

Now by putting the value of D_i in equation (3.7), we get,

$$D_c = 30 \text{ mm}$$

Mahata (1955) suggested that the ratio of feed bed height (H) to diameter of the column (D_c) lies between 1 to 2.5.

$$H/D_c = 1 \text{ to } 2.5$$

Hence for $D_c = 30 \text{ mm}$

$$H = 30 \text{ mm to } 75 \text{ mm}$$

$$= 3 \text{ cm to } 7.5 \text{ cm}$$

In the present study, the feed bed height has been taken as 10, 15 and 20 cm.

3.2 THE INDEPENDENT VARIABLE

The time taken for drying of sawdust in a simple conical bed depends

initial moisture content of feed and the final moisture content required,

the temperature of hot air used for drying and

the height of feed (sawdust) bed and cone angle of the spout.

The initial moisture content of the sawdust was kept constant at 45% (db).

All feed samples were dried to final moisture content of 20% (db). Thus

independent variables in the above study reduce to

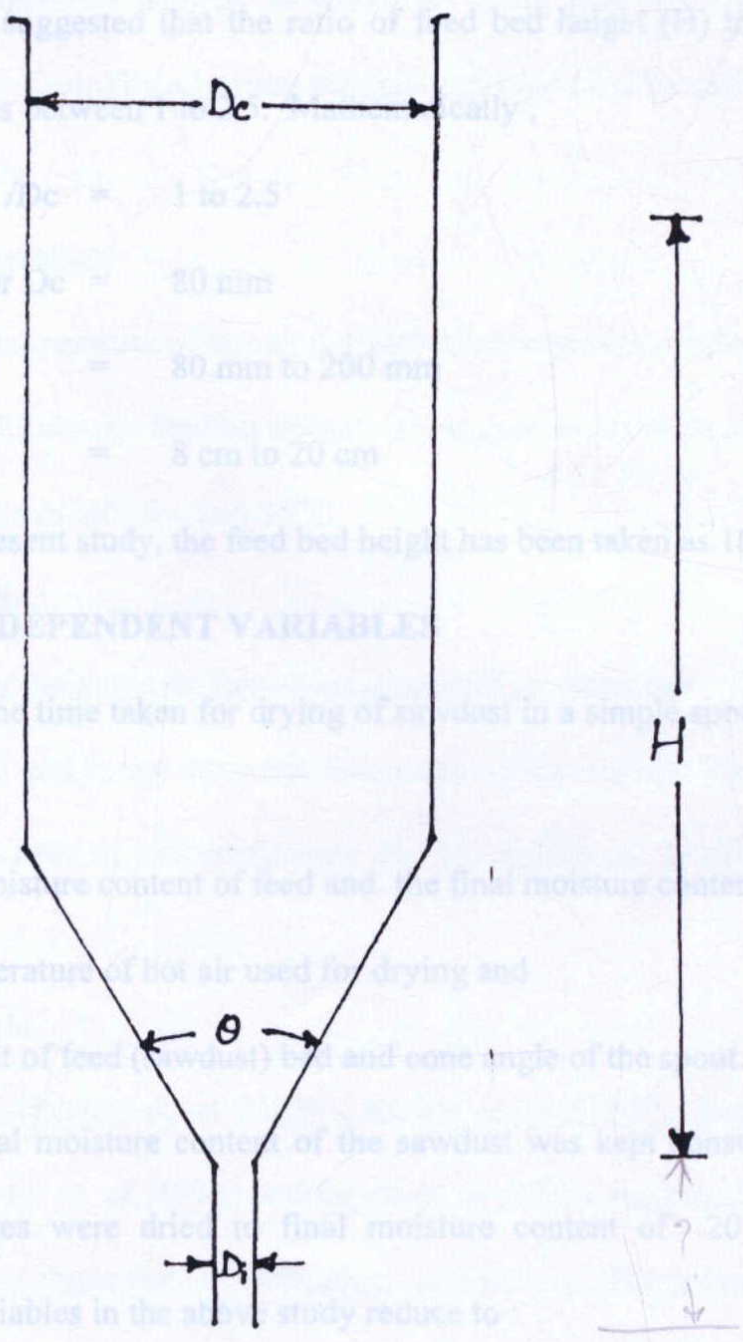


FIG. 3.1 CONICAL GLASS SPOUT

Taking average size of particle (D_p) of sawdust as 0.27 mm (as found from sieve test), we have,

$$\Rightarrow D_i = 30 \times 0.27 = 8.1 \text{ mm} \approx 8 \text{ mm}$$

Now by putting the value of D_i in equation (3.1), we get,

$$D_c = 80 \text{ mm}$$

Mathur (1955) suggested that the ratio of feed bed height (H) to diameter of the column (D_c) lies between 1 to 2.5. Mathematically,

$$H/D_c = 1 \text{ to } 2.5$$

$$\text{Hence for } D_c = 80 \text{ mm}$$

$$H = 80 \text{ mm to } 200 \text{ mm}$$

$$= 8 \text{ cm to } 20 \text{ cm}$$

In the present study, the feed bed height has been taken as 10, 15 and 20 cm.

3.2 THE INDEPENDENT VARIABLES

The time taken for drying of sawdust in a simple spouted bed depends upon :

- initial moisture content of feed and the final moisture content required,
- the temperature of hot air used for drying and
- the height of feed (sawdust) bed and cone angle of the spout.

The initial moisture content of the sawdust was kept constant at 45% (db).

All feed samples were dried to final moisture content of 20 % (db). Thus independent variables in the above study reduce to :

- i) temperature of hot air used for drying
- ii) the height of (feed) bed and
- iii) the cone angle of the spout.

Air velocity = ?

It may appear at the outset that the velocity of air should also be taken as a variable. However, it was observed that for a given height of feed bed and cone angle, there is only one velocity at which the spout was well formed and stable. This velocity was found by adjusting the inlet velocity of air by noting the quality of spout formed.

3.2.1 Air temperature

Temperature of hot air has direct influence on the drying time and the energy required to dry the feed (sawdust). The experiments were conducted at three temperature levels of 45, 50, and 55°C.

*Why higher temps
could not be taken?*

3.2.2 Bed height

Bed height is an important independent parameter. Larger bed height means more feed and hence more the time required for drying. The three levels of feed bed height used in this study were 10, 15, and 20 cm as designed in section

3.1. 3.2 Hot air supply system

3.2.3 Cone angle

B. Thorley et. al (1959), Reddy et. al (1968), Suciú and Patrascu (1977), David Roy et. al (1994) and Grace et. al (1994) suggested that cone angle of 60° was in good agreement in theoretical predictions. The spouted bed dryers of

cone angle of 50° , 60° and 65° were designed and fabricated.

3.3 MATERIAL PREPARATION

The moisture content of available sawdust was measured using hot air oven method. Make up water was added to the sawdust to increase the moisture content to 45% (db). The detailed procedure has been given in Appendix - A.

3.4 EXPERIMENTAL SETUP

3.4.1 Simple or conical spouted bed dryer

The schematic diagram of the experimental setup for simple or conical spouted bed dryer is shown in Fig. 3.2. It has two main parts.

- a) Drying chamber or spout
- b) Hot air supply and measurement system

3.4.1.1 Drying chamber or spout

The drying chamber or spout was fabricated of glassware material. It had a conical base and a cylindrical column. The conical base had a cone angle of 55° , 60° and 65° , with inlet diameter of 8 mm. Column diameter of the spout was 80 mm and its height was 350 mm.

3.4.1.2 Hot air supply system

It consisted of an electric blower and resistance heaters. Electric blower was used to suck fresh air from the ambient and blow it over the resistance heating coils. The temperature of hot air was controlled using a temperature controller. The hot air flowing in the spout was adjusted by adjusting the air inlet at

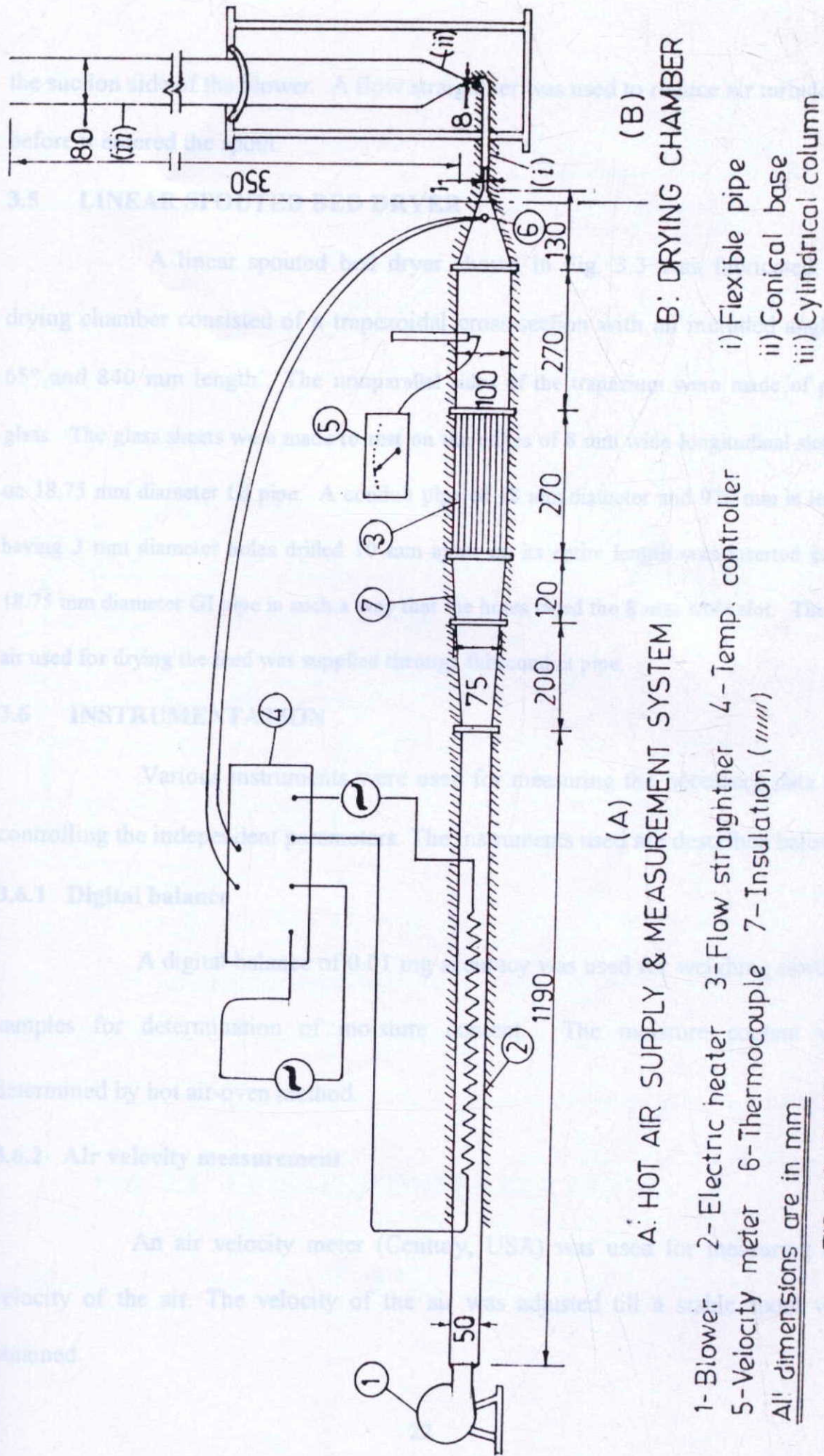


FIG. 3.2 EXPERIMENTAL SETUP FOR CONICAL SPOUDED BED DRYER

the suction side of the blower. A flow straightner was used to reduce air turbulence before it entered the spout.

3.5 LINEAR SPOUTED BED DRYER

A linear spouted bed dryer shown in Fig. 3.3 was fabricated. Its drying chamber consisted of a trapezoidal cross-section with an included angle of 65° and 840 mm length. The nonparallel sides of the trapezium were made of plane glass. The glass sheets were made to rest on the edges of 8 mm wide longitudinal slot cut on 18.75 mm diameter GI pipe. A conduit pipe of 18 mm diameter and 970 mm in length having 3 mm diameter holes drilled 10 mm apart on its entire length was inserted in the 18.75 mm diameter GI pipe in such a way that the holes faced the 8 mm wide slot. The hot air used for drying the feed was supplied through this conduit pipe.

3.6 INSTRUMENTATION

Various instruments were used for measuring the necessary data and controlling the independent parameters. The instruments used are described below :

3.6.1 Digital balance

A digital balance of 0.01 mg accuracy was used for weighing sawdust samples for determination of moisture content. The moisture content was determined by hot air-oven method.

3.6.2 Air velocity measurement

An air velocity meter (Century, USA) was used for measuring the velocity of the air. The velocity of the air was adjusted till a stable spout was obtained.

3.6.3 - Temperature controller

A temperature controller of OFF-ON type with provision to preset the desired temperature was used to supply hot air at the desired temperature to the spouted bed. The output of iron-constantan thermocouple installed in the inlet to the spouted bed was input to the temperature controller. The temperature controller received 230 volt direct current input.

3.7 EXPERIMENTAL PROCEDURE

The experimental work was divided into two phases. In the first phase, the electric heater controller was set at the desired temperature. The desired temperature was also indicated by the temperature controller. A weighed quantity of raw material for the required bed height was charged in the column. The height of the spout was varied to obtain a stable and well formed spout.

In the second phase, the glass spout was emptied by detaching the flexible pipe from hot air. The same quantity of raw material was charged in the glass spout for the same bed height. Samples of raw material were taken after 5, 10, 15, 20, 25, 30, 35 minutes and their moisture content was determined. Experiments

on conical spouted bed dryer were conducted for three feed bed heights of 10 cm, 15 cm and 20cm for drying temperatures 45°C, 50°C and 55°C with three different cone angles of the spout as 55°, 60° and 65°. All experiments were conducted in

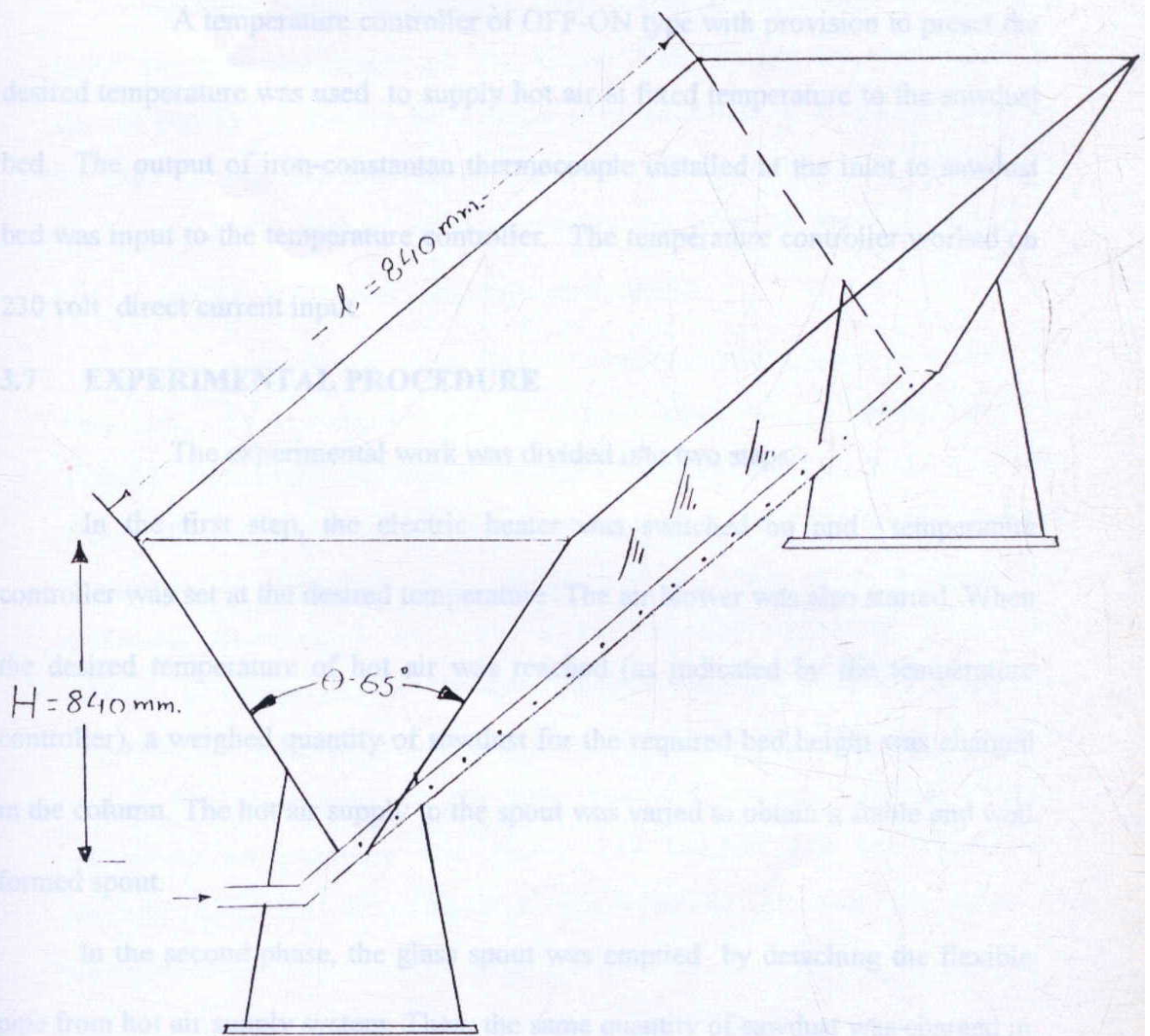


FIG. 3.3 LINEAR SPOUDED BED DRYER

3.6.3 Temperature controller

A temperature controller of OFF-ON type with provision to preset the desired temperature was used to supply hot air at fixed temperature to the sawdust bed. The output of iron-constantan thermocouple installed at the inlet to sawdust bed was input to the temperature controller. The temperature controller worked on 230 volt direct current input.

3.7 EXPERIMENTAL PROCEDURE

The experimental work was divided into two steps.

In the first step, the electric heater was switched on and temperature controller was set at the desired temperature. The air blower was also started. When the desired temperature of hot air was reached (as indicated by the temperature controller), a weighed quantity of sawdust for the required bed height was charged in the column. The hot air supply to the spout was varied to obtain a stable and well formed spout.

In the second phase, the glass spout was emptied by detaching the flexible pipe from hot air supply system. Then, the same quantity of sawdust was charged in the glass spout for the same bed height. Samples of sawdust were taken after 5, 10, 15, 20, 25, 30, 35 minutes and their moisture content was determined. Experiments on conical spouted bed dryer were conducted for three feed bed heights of 10 cm, 15 cm and 20cm for drying temperatures 45°C, 50°C and 55°C with three different cone angles of the spout as 55°, 60° and 65°. All experiments were conducted in

triplicate and the average of the data was recorded.

Similarly the experiments were conducted on linear spouted bed dryer for feed bed height of 10, 15 and 20cm for hot air temperature of 45, 50 and 55°C. Samples of sawdust were taken after 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 minutes and their moisture content was determined. The experimental data of all experiments are given in Appendix B to E.

3.4 SOLAR ASSISTED SPOUTED-BED DRYER

The schematic of a Solar Spouted-Bed Dryer is shown in Fig.3.4. It consists of a Solar Air Heater connected to linear spouted-bed dryer (shown earlier in Fig.3.3) via the flow straightner. A computer programme predicting the hourly temperature of hot air delivered by the air heater has already ^{been} developed by the solar energy working group of P.A.U. will be used. If the temperature of hot air supplied by the air heater is less, auxiliary energy will be used to raise the temperature to the desired value. Total energy consumed in running the solar air heater and the auxiliary energy used in raising the temperature of hot air will be determined.

RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the experiments which were conducted to dry sawdust in a conical as well as linear spouted bed dryer. The results of a computer model to predict the performance of solar spouted bed dryer for drying sawdust at a given place have also been discussed.

The results of different experiments conducted on the drying of sawdust in both types of spouted bed dryers have been discussed as under :

4.1 Drying of sawdust in a simple or conical spouted bed dryer

Three number of conical spouted bed dryers having cone angle of 55° , 60° and 65° were made out of glass. Experiments were conducted to study the drying of sawdust at bed height of 10 cm, 15 cm and 20 cm. For each bed height, the tests were conducted by supplying hot air at 45°C , 50°C and 55°C temperature. Initial moisture content of sawdust was kept at 45% (db). For each run, moisture content of the sawdust was measured after every 5 minutes. Each test run lasted for 35 minutes. All tests were conducted in triplicate. Experimental data has been given in Appendix B to D. The results of the above study are discussed below :

4.1.1 Effect of temperature of hot air on drying of sawdust for given bed height and cone angle of the spout

Based on the experimental data given in Appendix B to D, the effect of temperature of hot air on drying of sawdust for a given bed height and cone

angle of the spout has been shown by plotting curves (Fig. 4.1 to 4.9) between moisture content and drying time. It was observed that in all tests, rate of drying (slope of moisture vs time) was faster at the beginning and as time elapsed, it slowed down. Further for a given bed height and cone angle of the spout, the drying curve, for the temperature of hot air at 45°C was at the top and that for 55°C was at the bottom-most. It showed that for the same drying time, the drying was more (less residual moisture) when the drying air was at higher temperature. Conversely, time taken to dry the sawdust to the desired moisture content was more when the temperature of drying air was less.

4.1.2 Effect of bed height on drying of sawdust for given cone angle of spout and temperature of hot air

Fig. 4.10 to Fig. 4.18 show the effect of bed height on drying of sawdust using hot air at temperatures of 45, 50 and 55°C in a conical spout of cone angle 55°, 60° and 65°.

It was observed from the figures that for a given cone angle of spout and temperature of hot air, as the height of sawdust bed increased, the time-taken to dry the sawdust to desired moisture content increased. For example from Fig. 4.10, it is noted that for a cone angle of 55°, as the bed height increased from 10 cm to 20 cm, the time required to reduce the moisture content from 45% (db) to 30% increased from 11 minutes to 34 minutes when hot air temperature was 45°C. Almost similar drying trends were observed in all experiments.

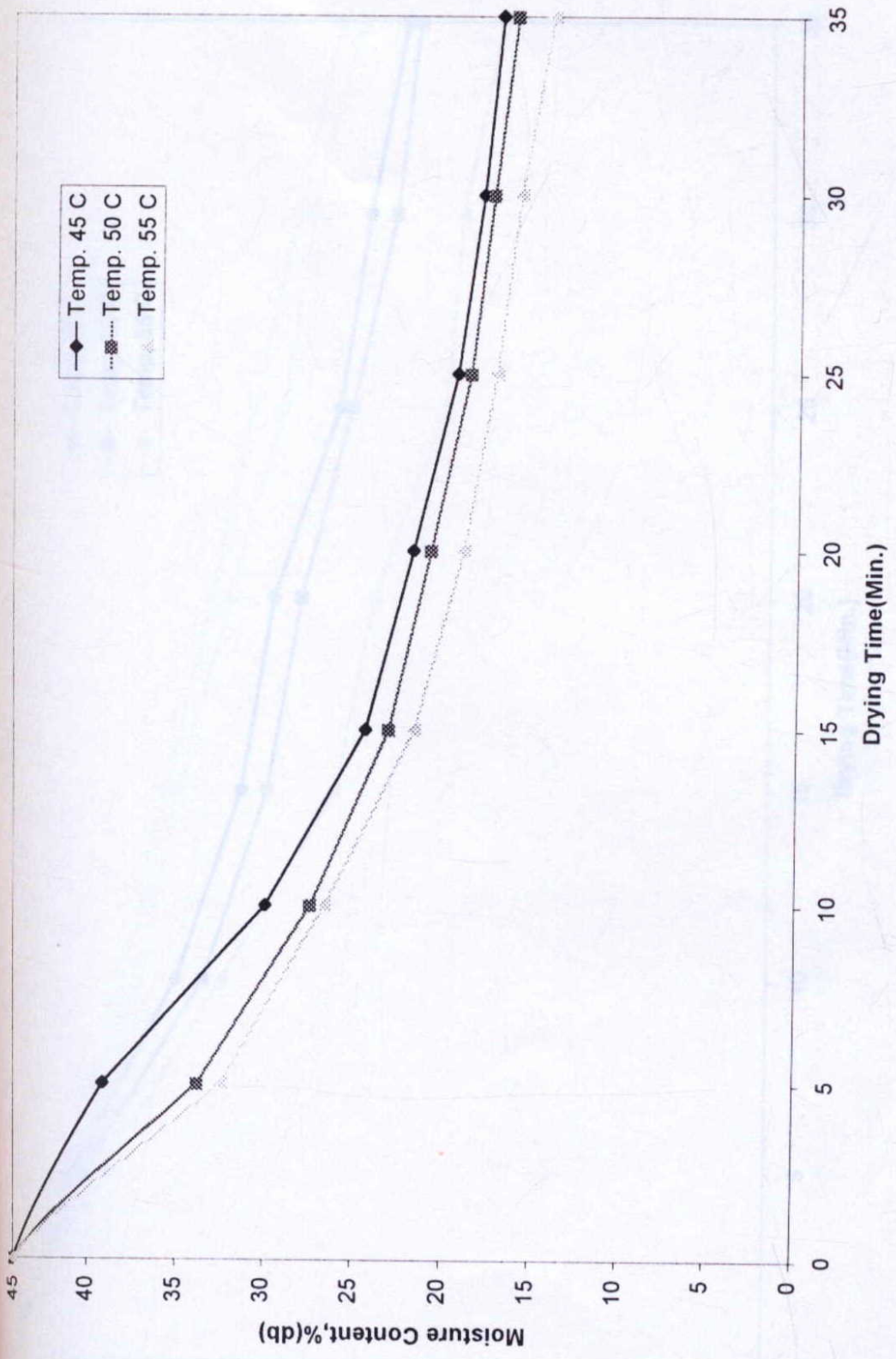


Fig. 4.1 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
 (Cone angle=55°, Bed height=10cm.)

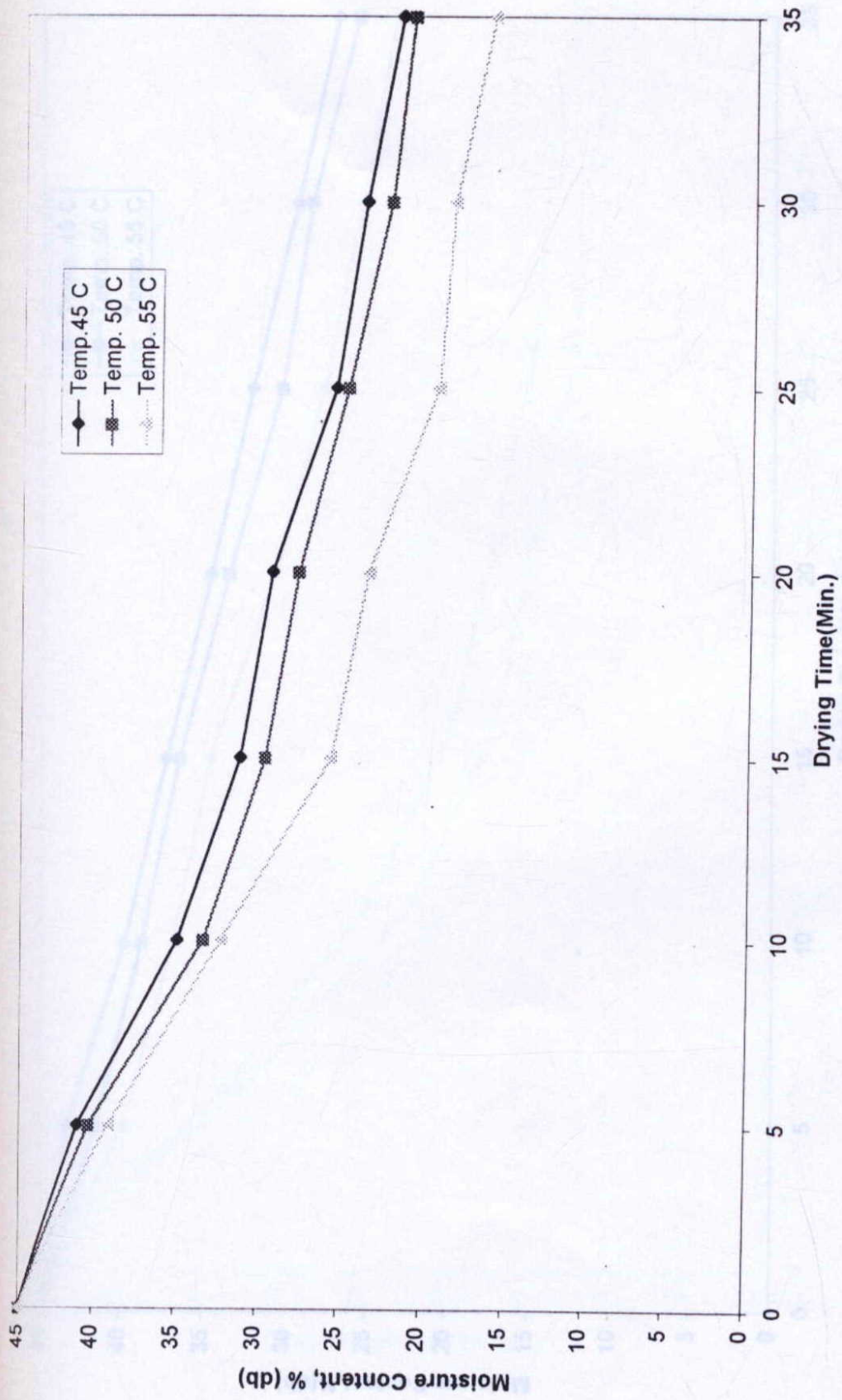


Fig. 4.2 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
(Cone angle=55°, Bed height=15cm.)

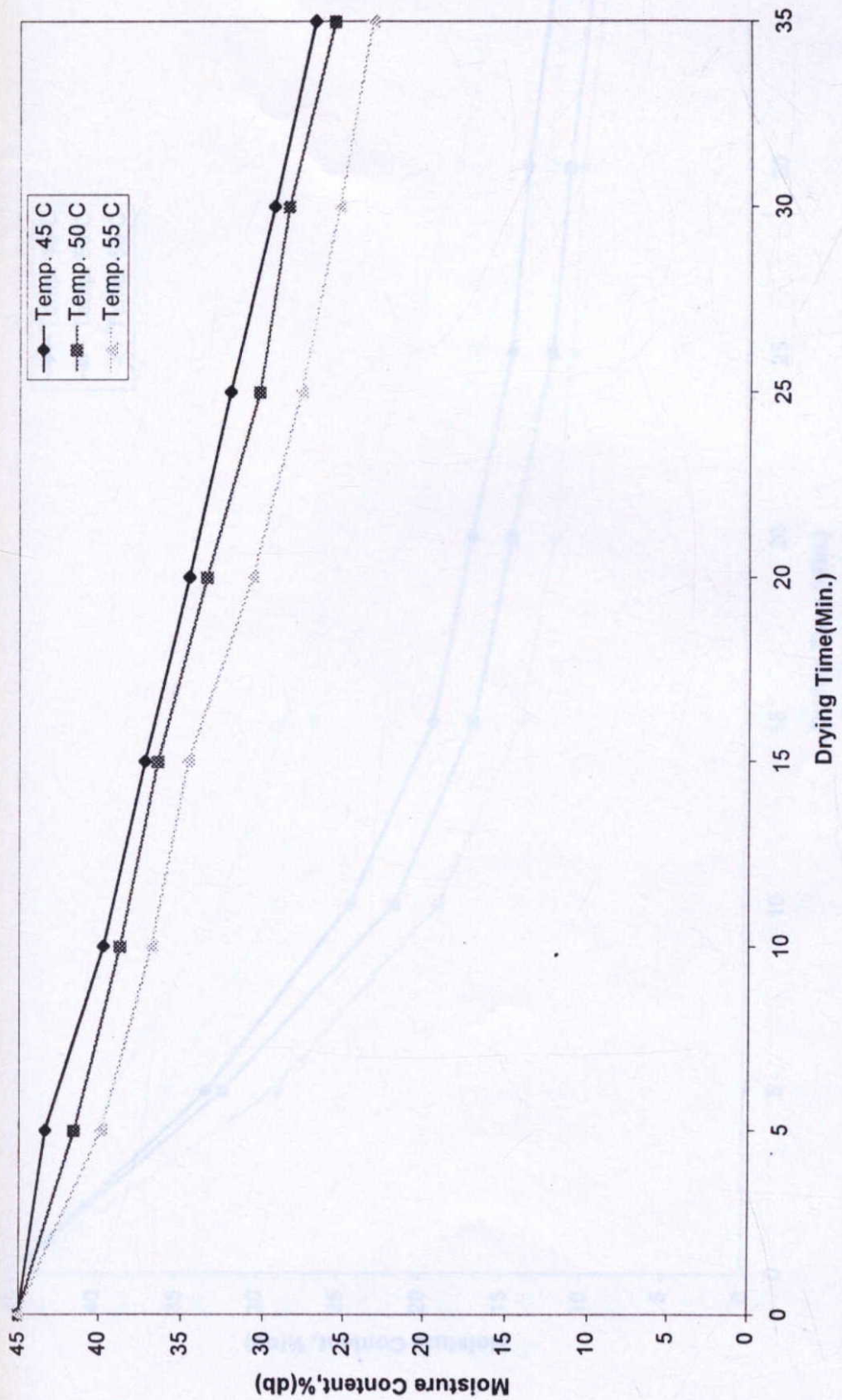


Fig. 4.3 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
(Cone angle=55°, Bed height=20cm.)

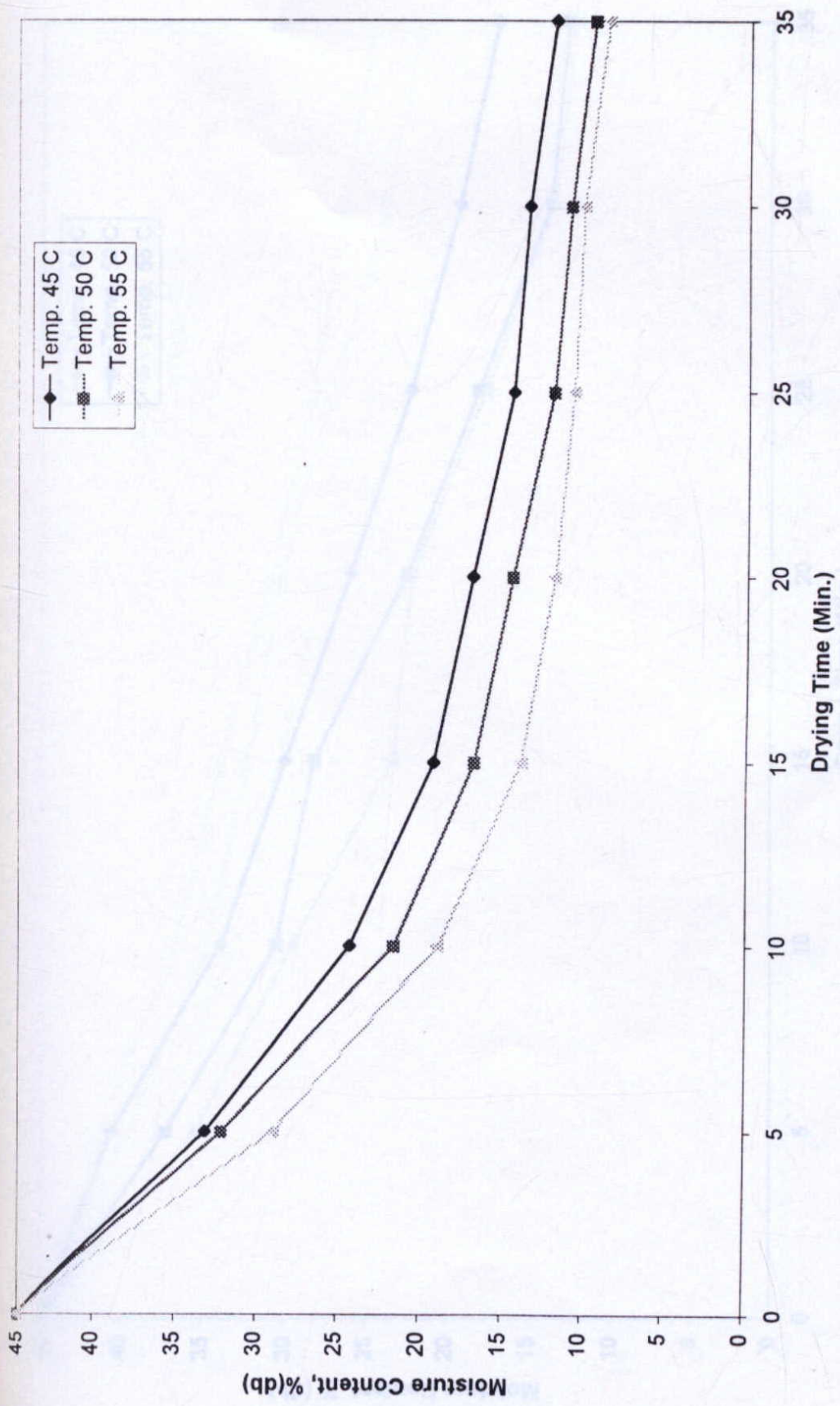


Fig. 4.4 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
 (Cone angle=60°, Bed height =10 cm.)

Fig. 4.5 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
 (Cone angle=60°, Bed height =10 cm.)

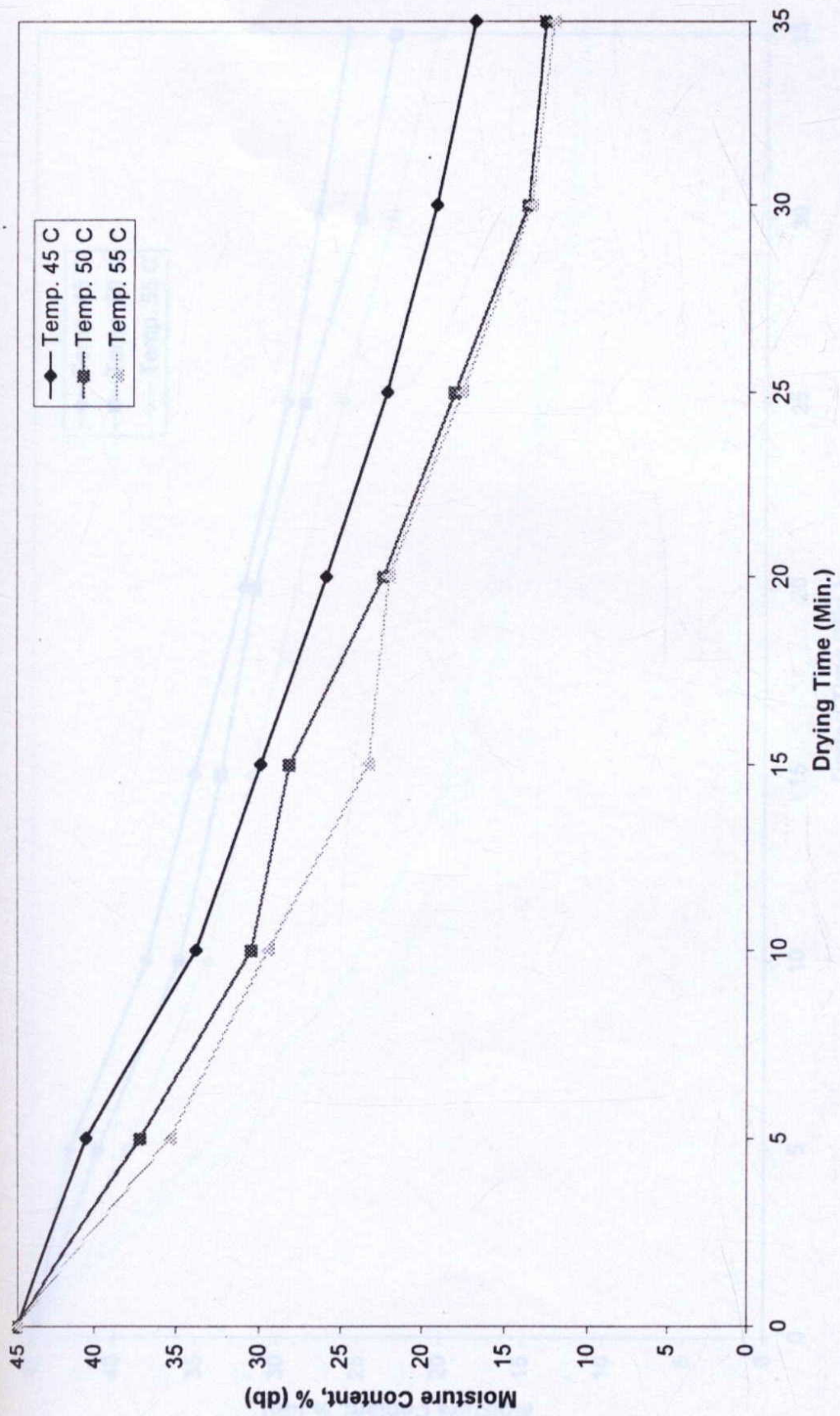


Fig. 4.5 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
 (Cone angle =60°, Bed height =15 cm.)

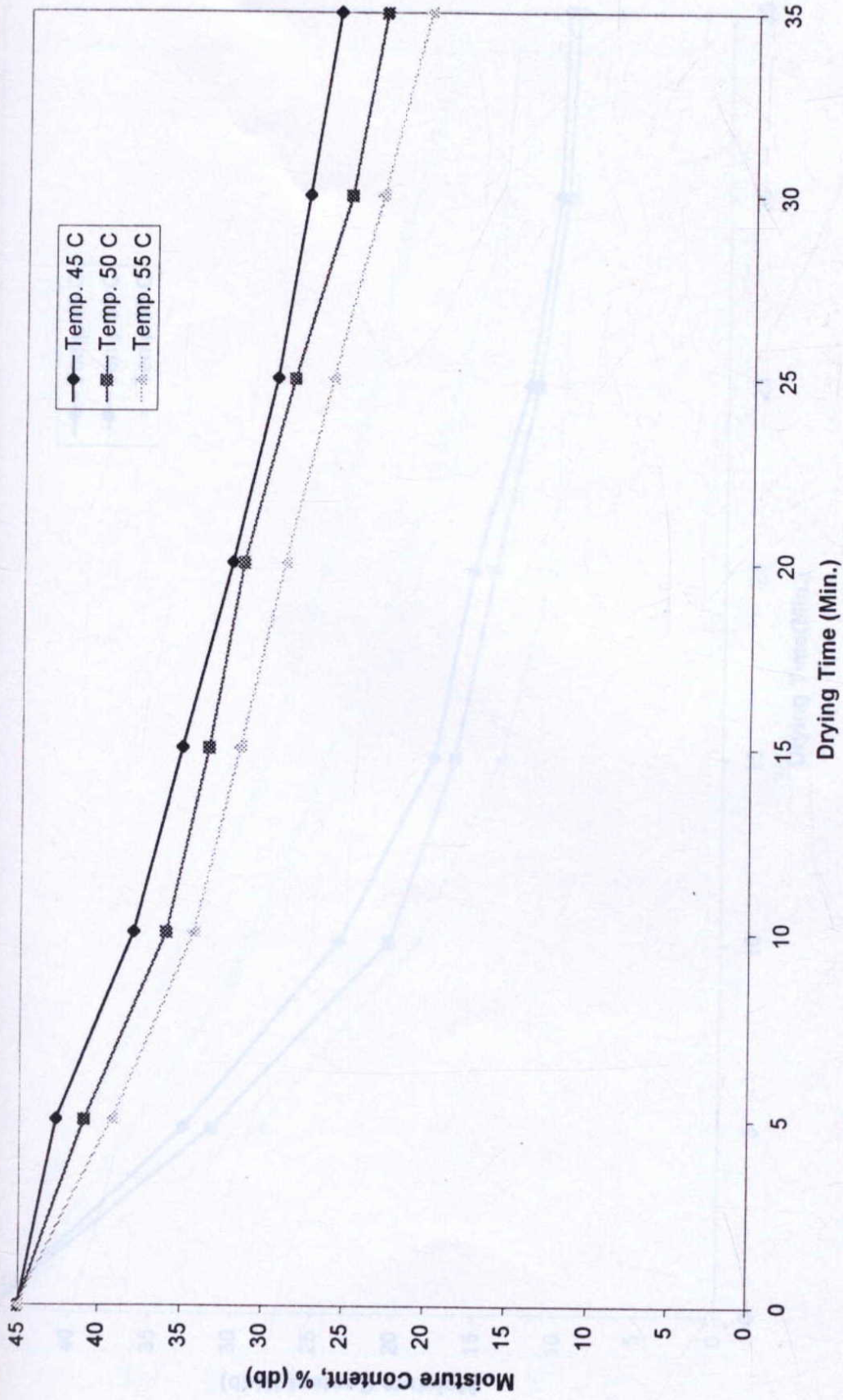


Fig. 4.6 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
(Cone angle = 60°, Bed height = 20 cm.)

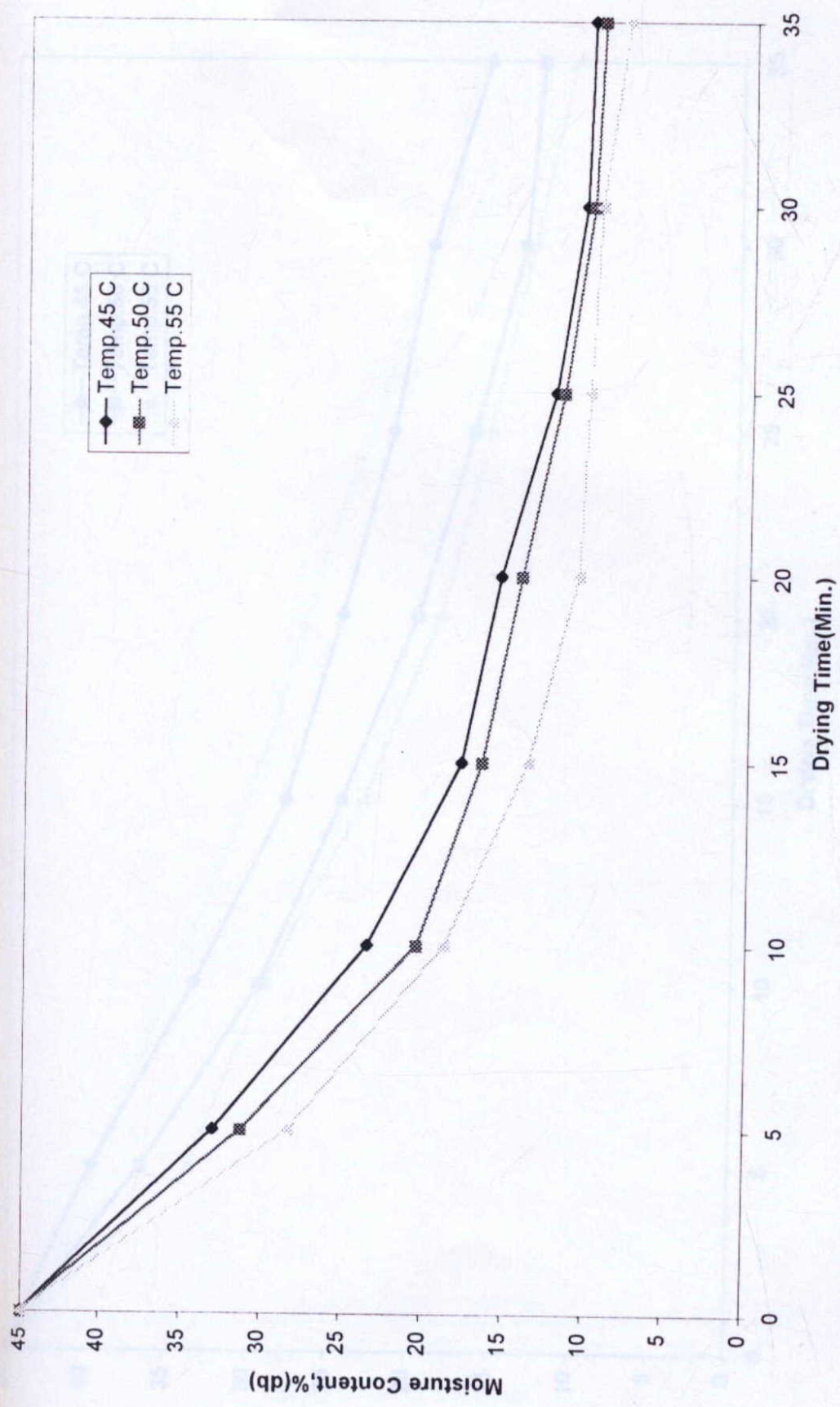


Fig.4.7 Effect of temperature of hot air on drying time of sawdust in conical spouted bed
 (Cone angle=65°, Bed height=10cm.)

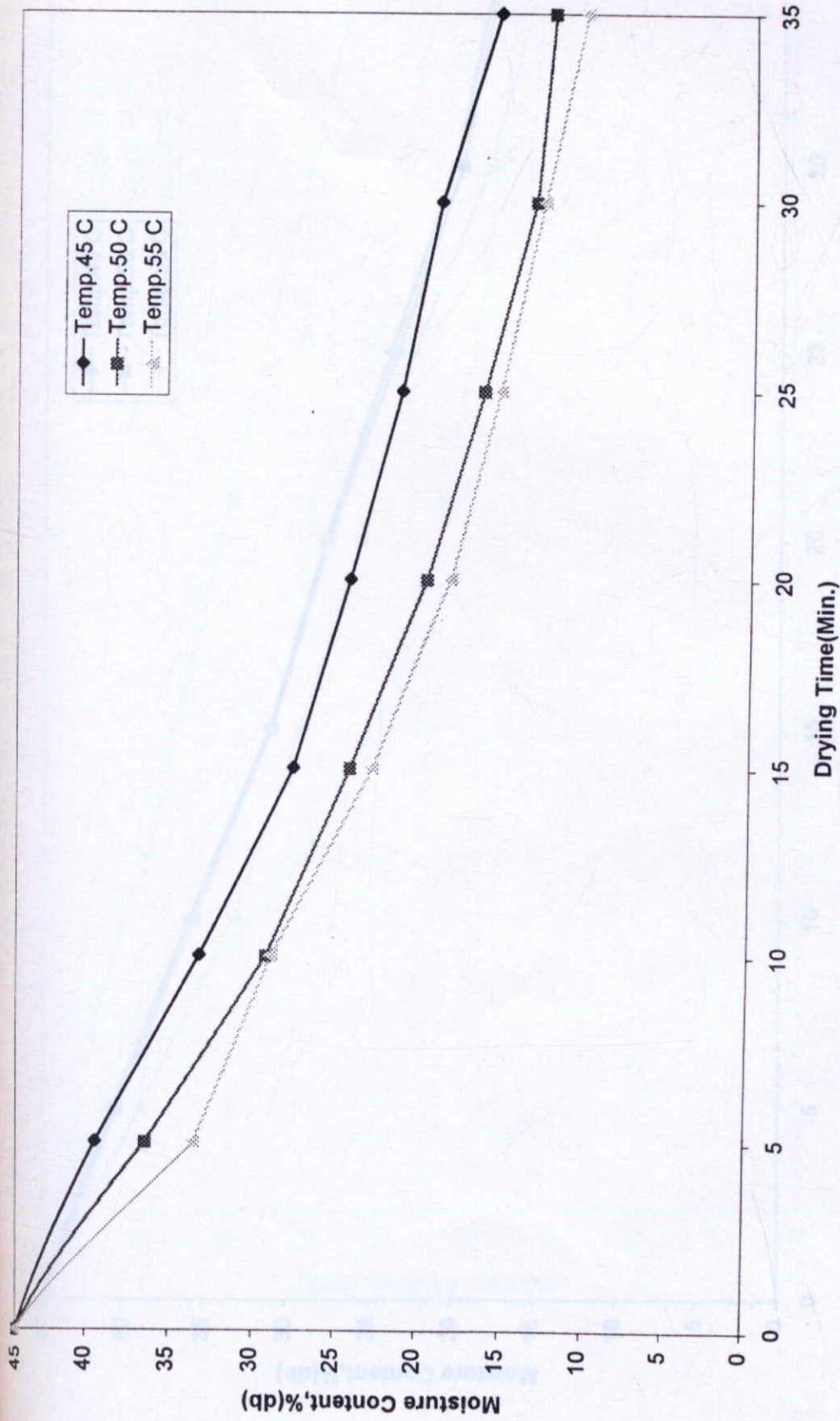


Fig.4.8 Effect of temperature of hot air on drying time of sawdust in conical spouted bed (Cone angle=65°, Bed height=15cm.)

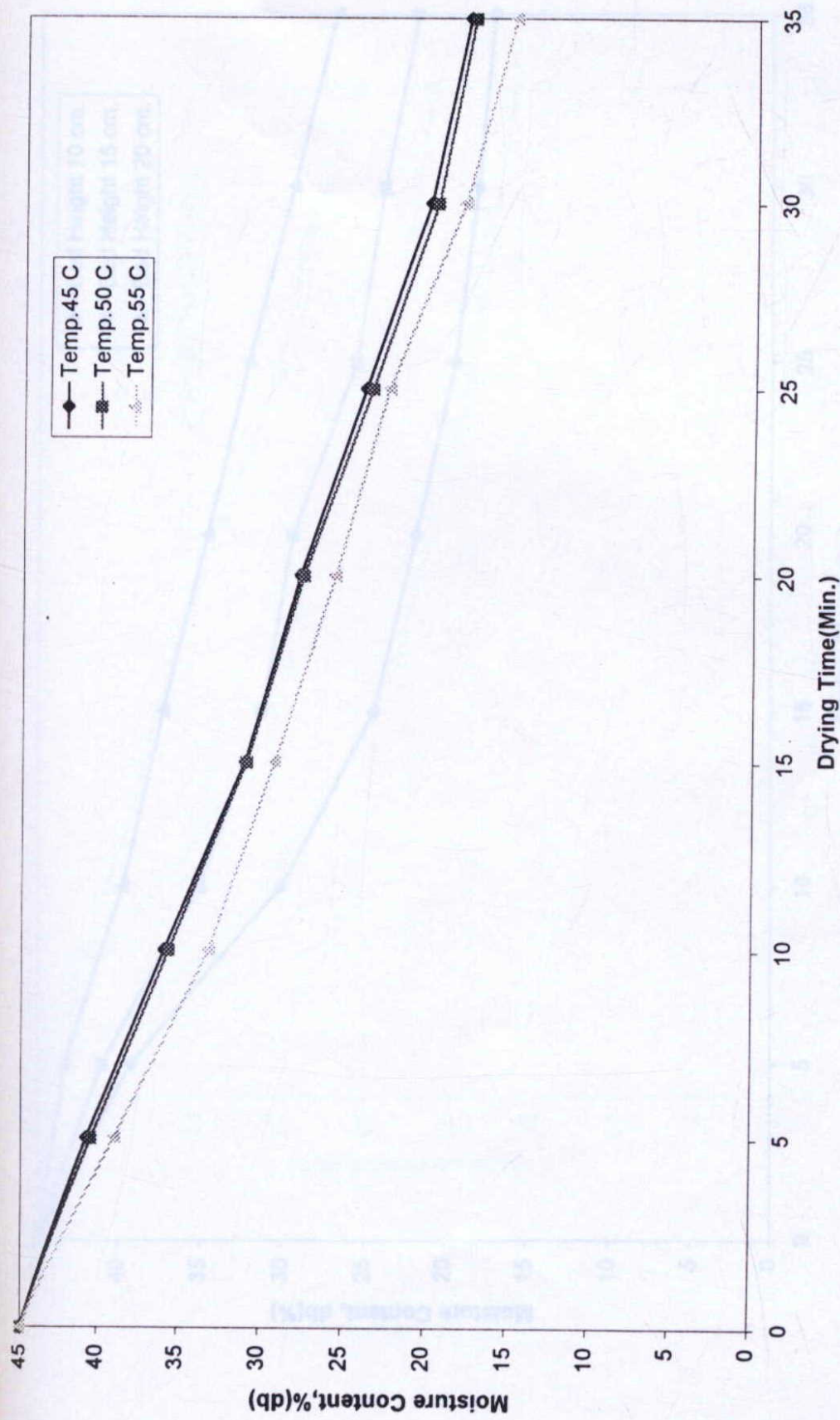


Fig. 4.9 Effect of temperature of hot air on drying time of sawdust in conical spouted bed (Cone angle=65°. Bed height=20cm.)

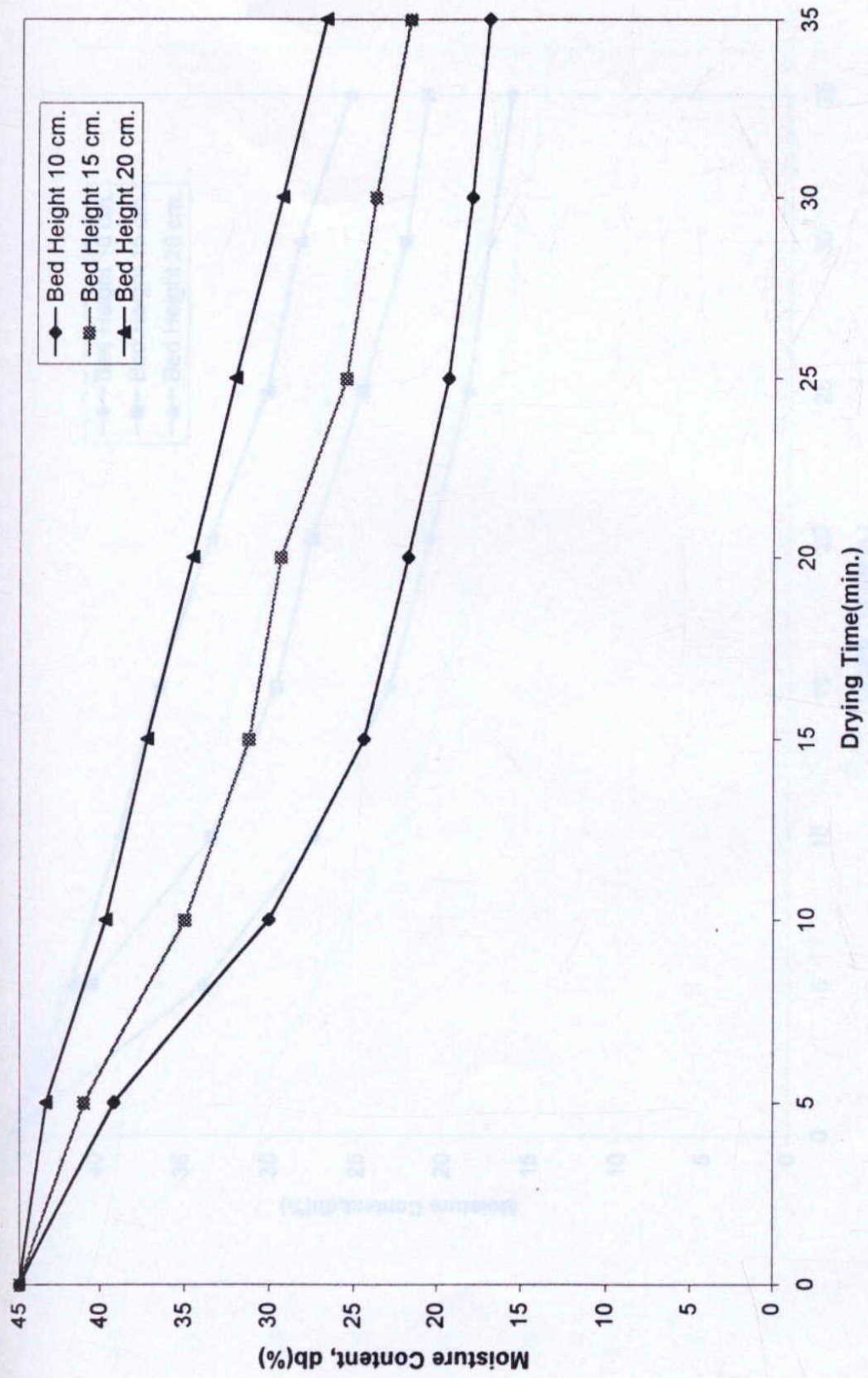


Fig. 4.10 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle = 55°, Temp. of hot air = 45°C)

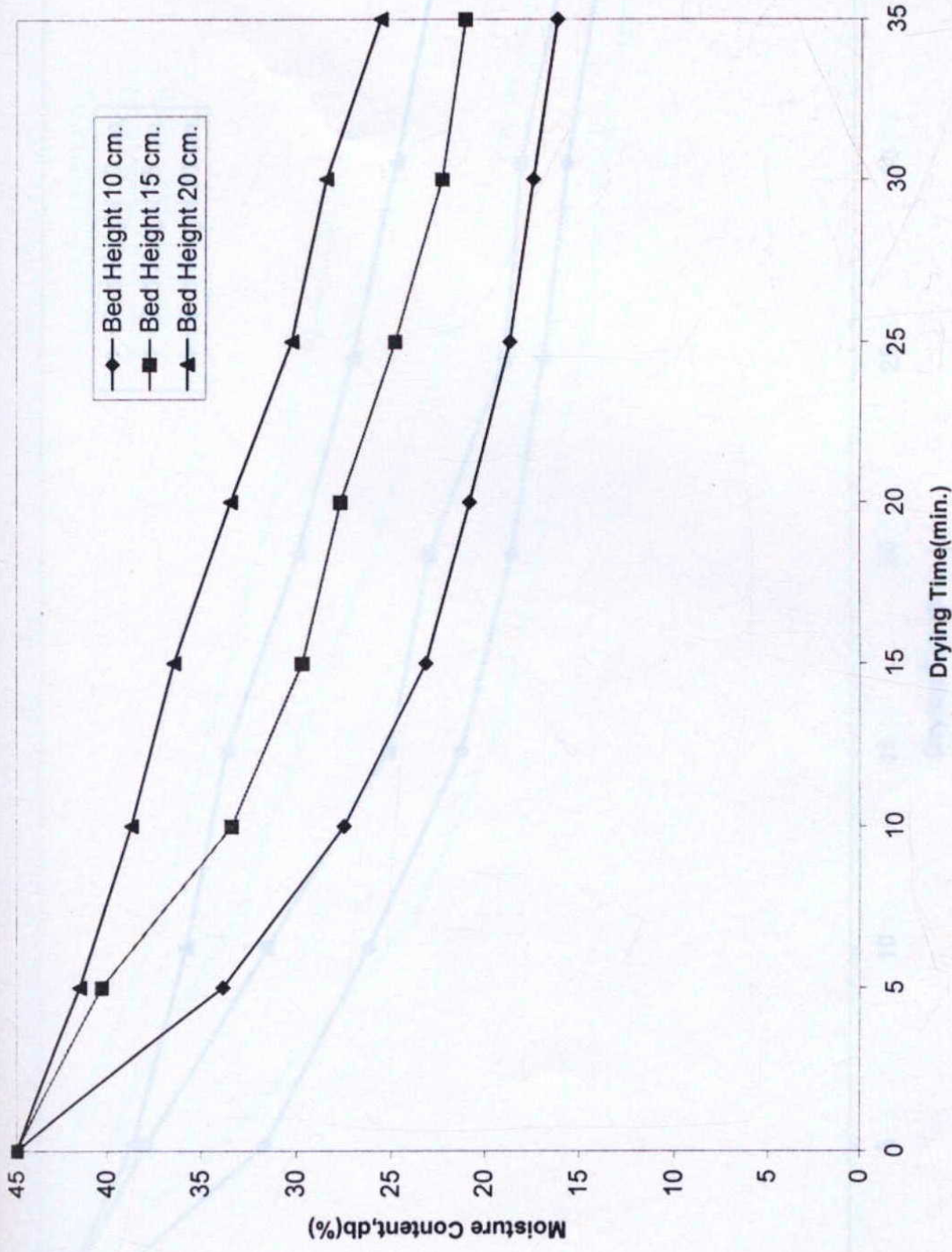


Fig. 4.11 Effect of bed height on drying time of sawdust in conical spouted bed
 (Cone angle = 55°, Temp. of hot air = 50° C)

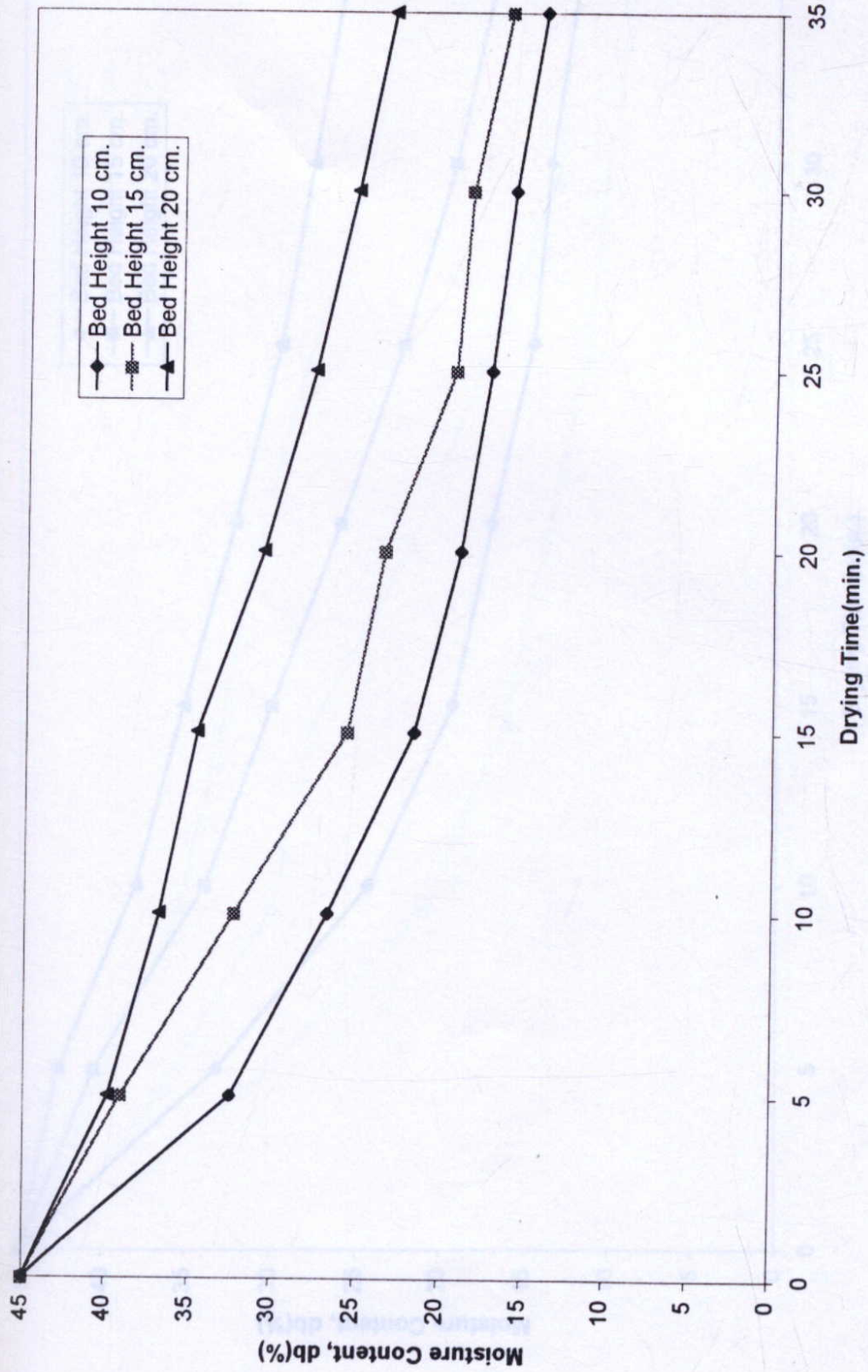


Fig. 4.12 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle = 55°, Temp. of hot air = 55° C)

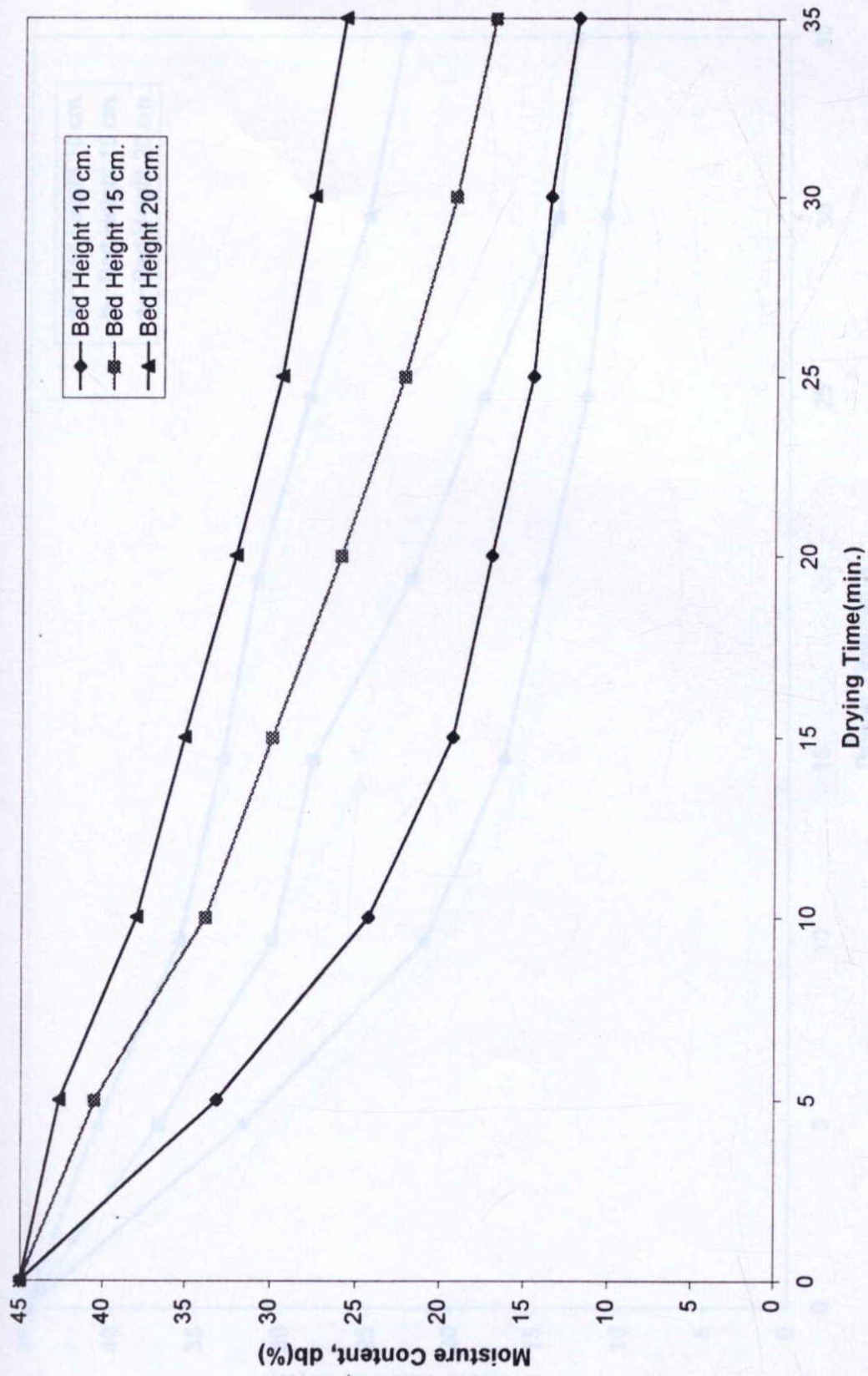


Fig. 4.13 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle = 60°, Temp. of hot air = 45°C)

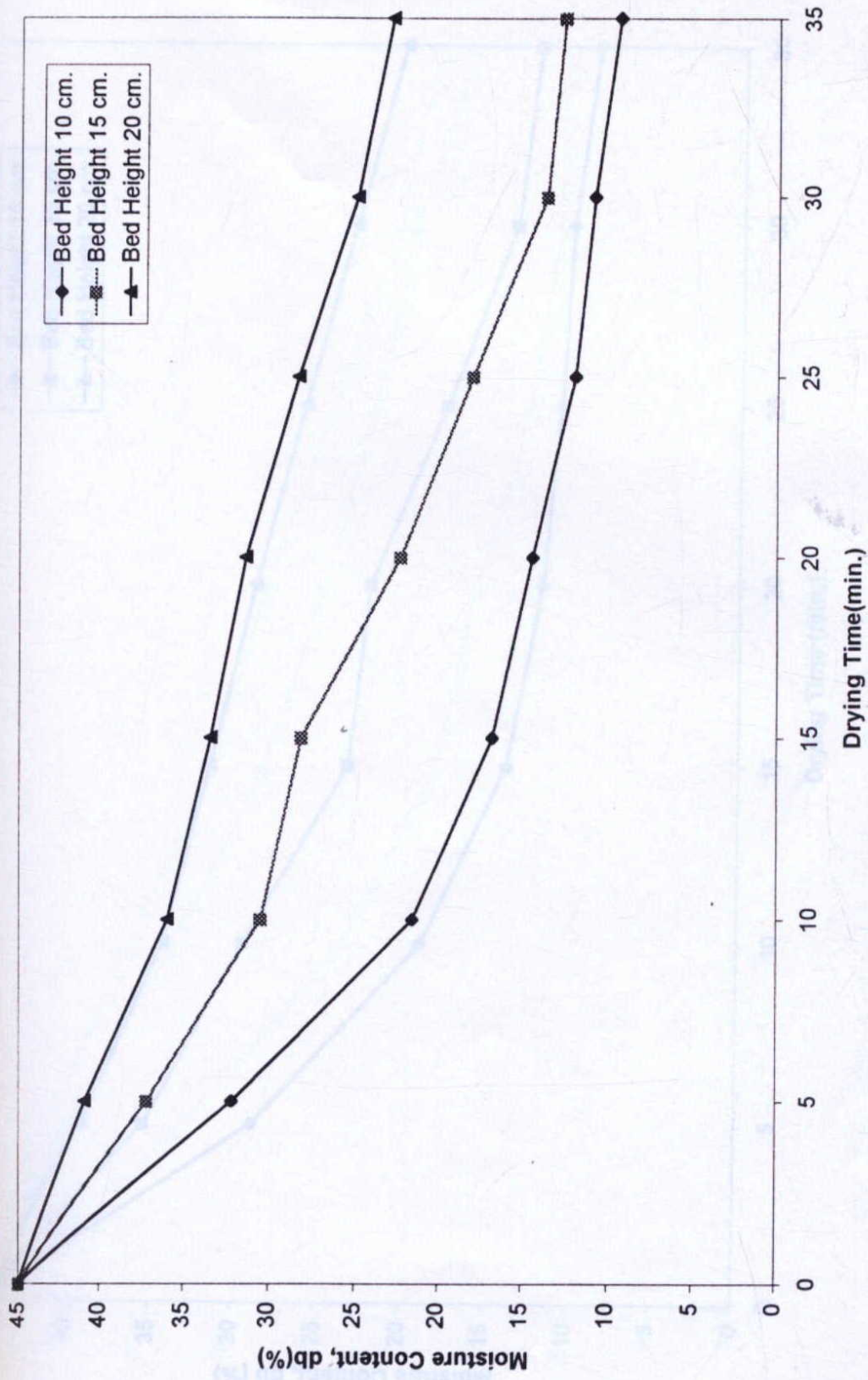


Fig. 4.14 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle = 60°, Temp. of hot air = 50°C)

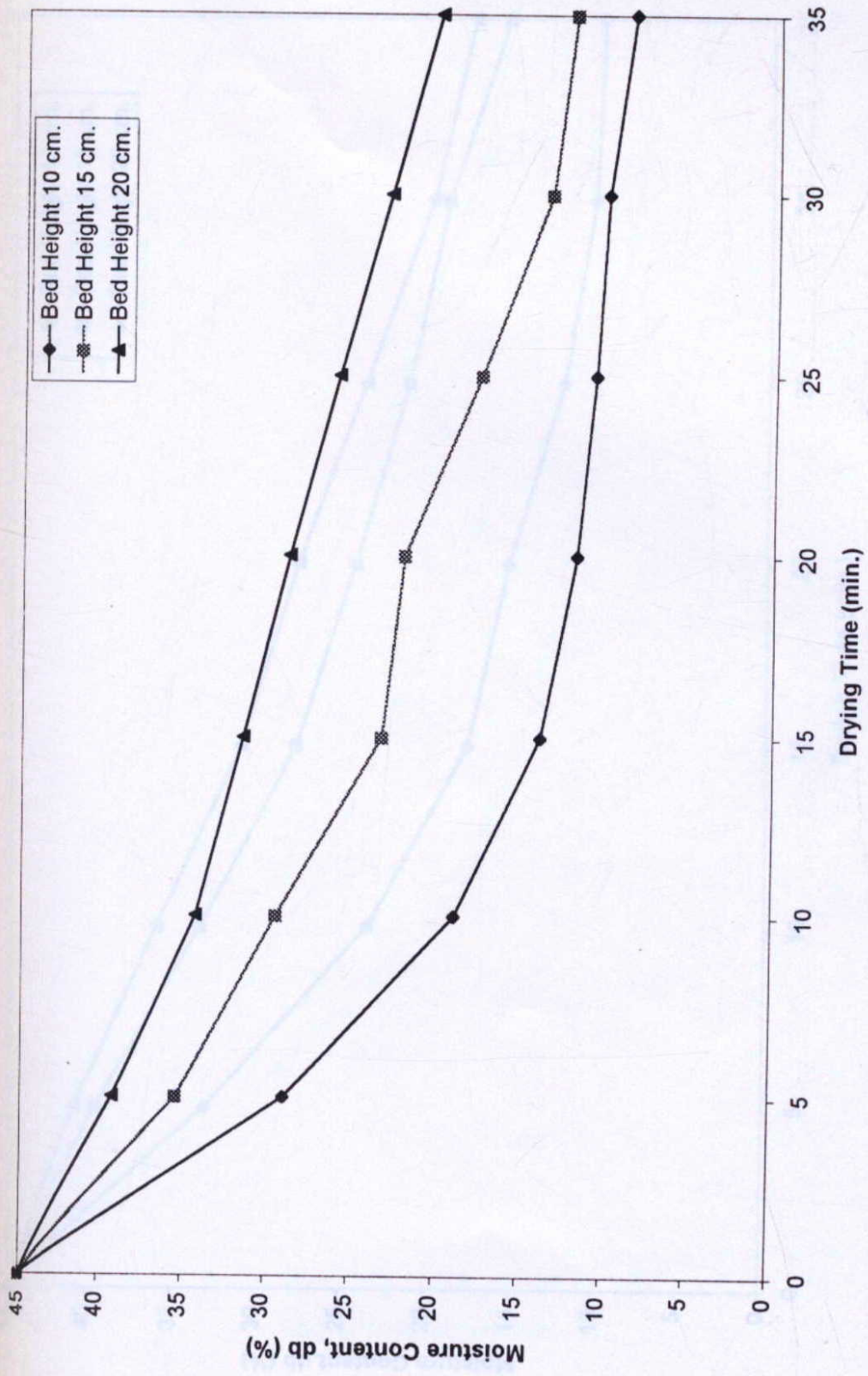


Fig. 4.15 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle=60°, Temp. of hot air =55°C)

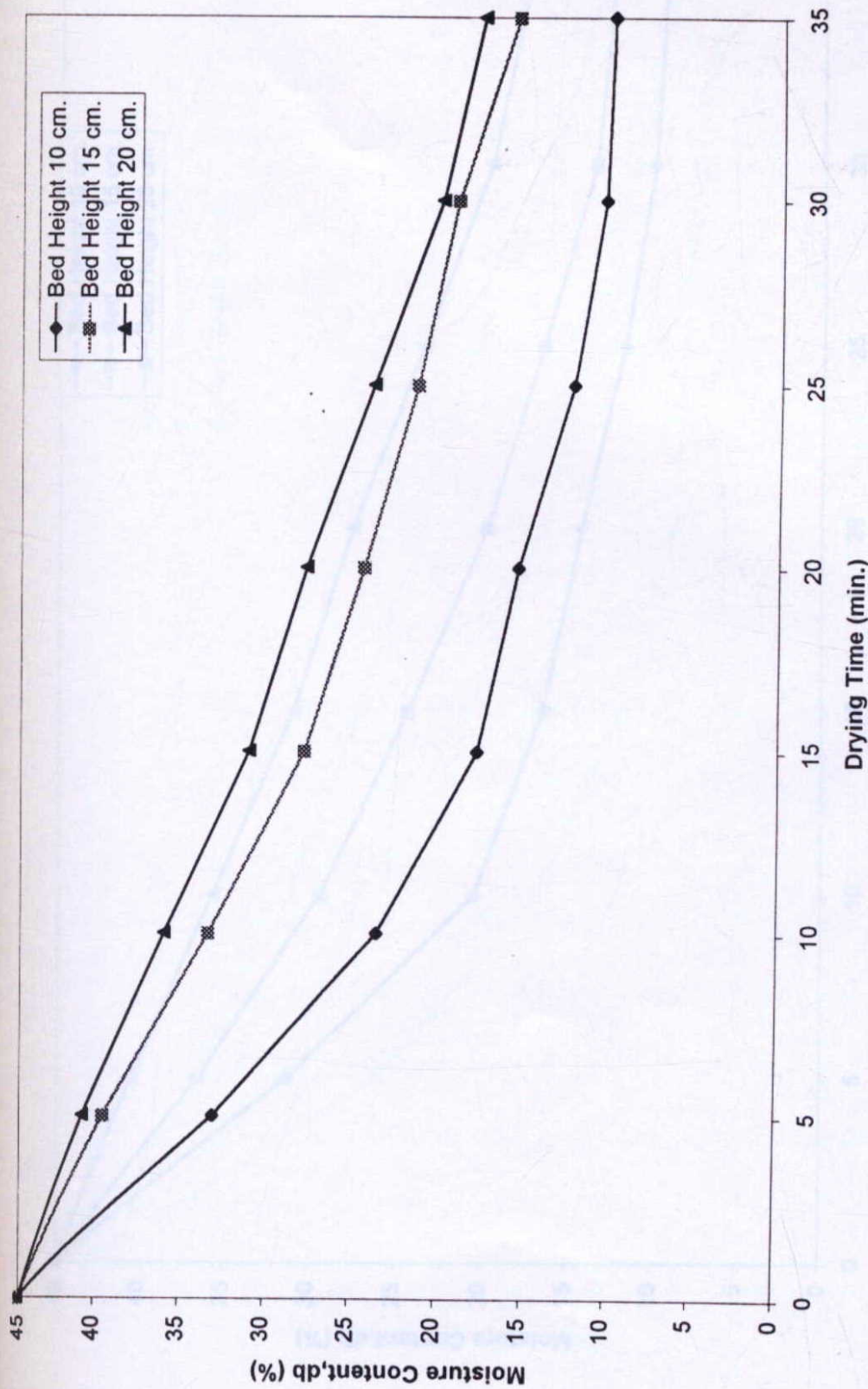


Fig. 4.16 Effect of bed height on drying time of sawdust in conical spouted bed
(Cone angle = 65°, Temp. of hot air = 45° C)

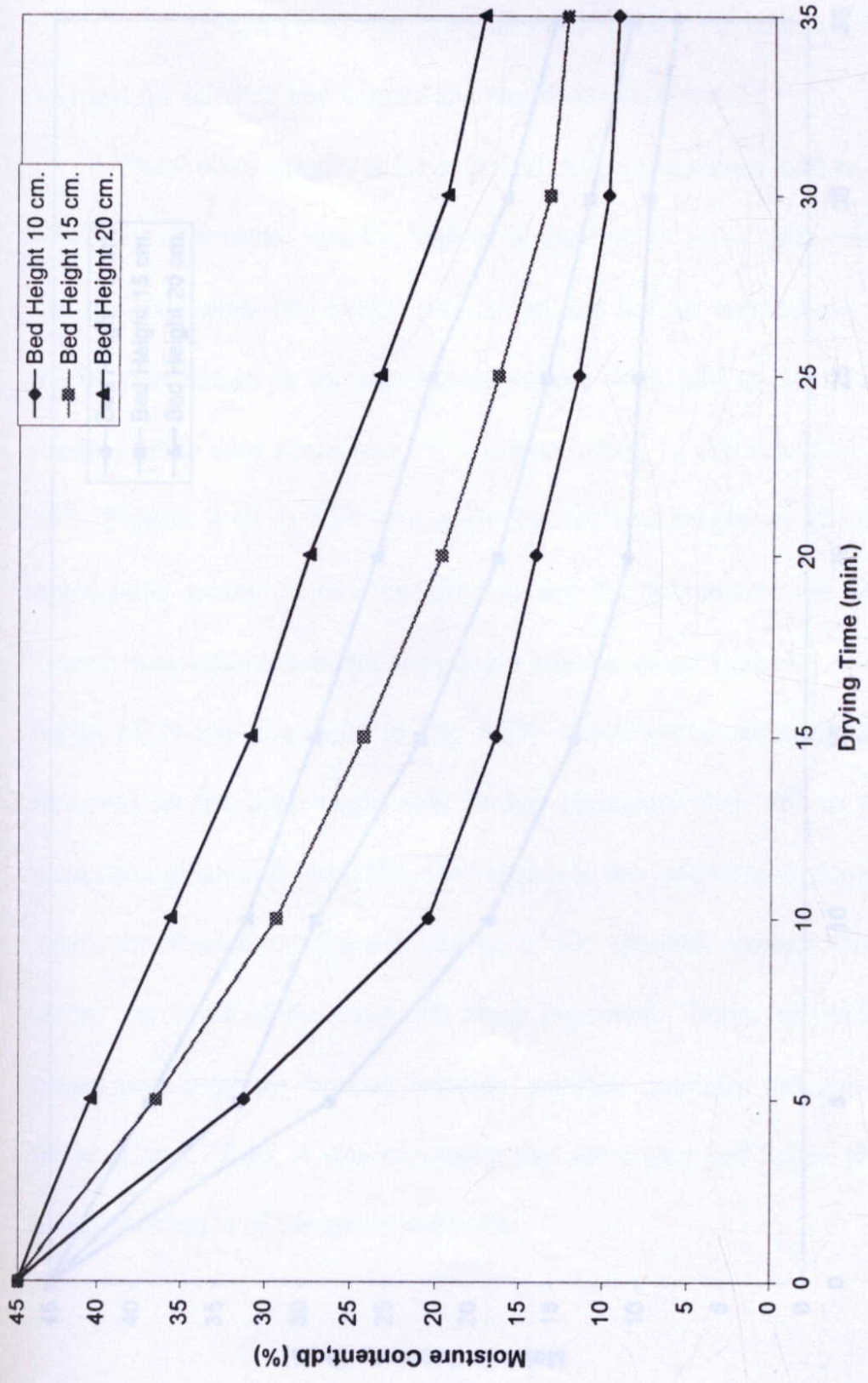


Fig. 4.17 Effect of bed height on drying time of sawdust in conical spouted bed (Cone angle = 65°, Temp. of hot air = 50°C)

4.1.3 Effect of cone angle of spout on drying of sawdust for given bed height and temperature of hot air

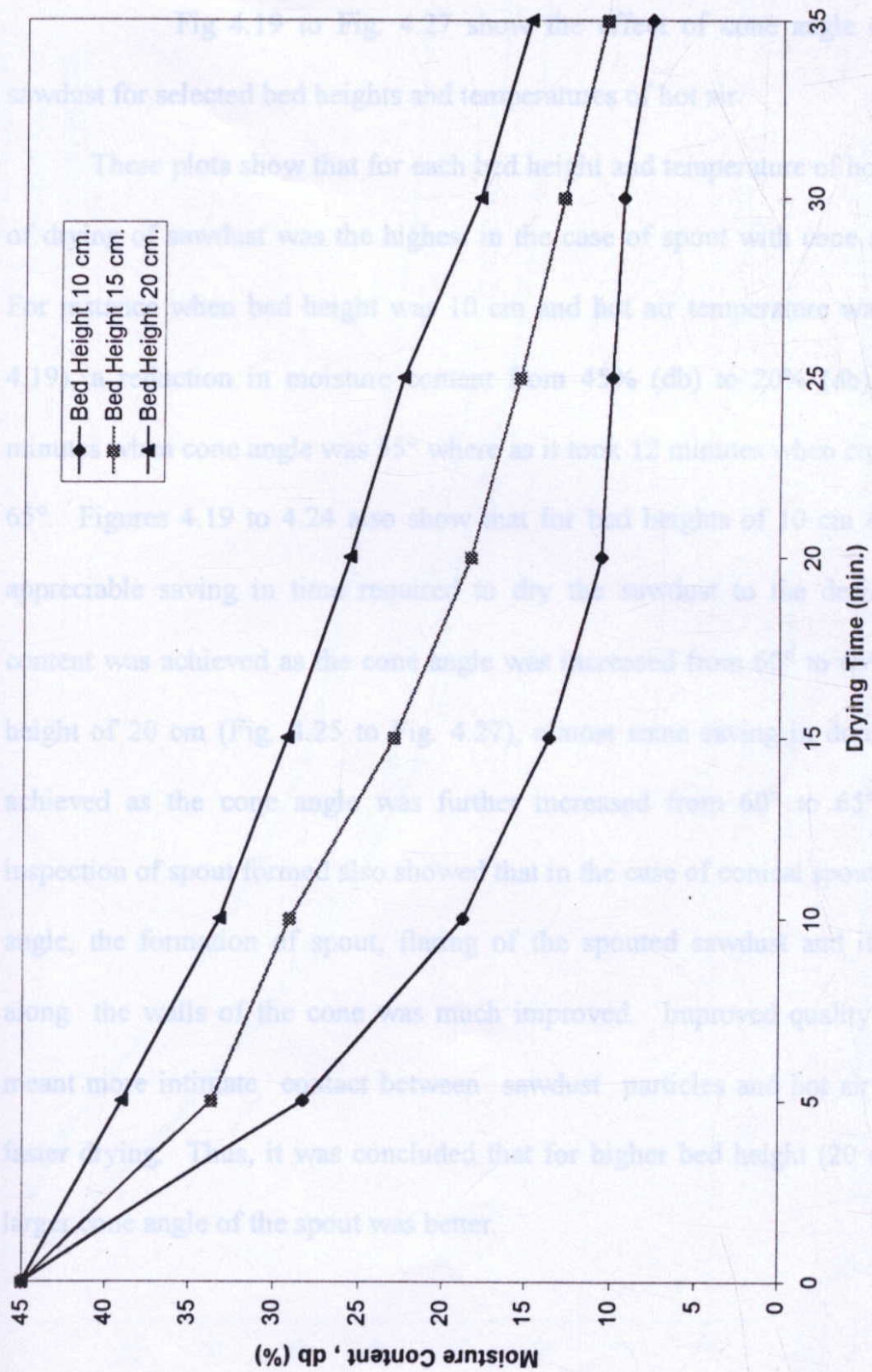


Fig. 4.18 Effect of bed height on drying time of sawdust in conical spouted bed (Cone angle = 65°, Temp. of hot air = 55°C)

4.1.3 Effect of cone angle of spout on drying of sawdust for given bed height and temperature of hot air

Fig 4.19 to Fig. 4.27 show the effect of cone angle on drying of sawdust for selected bed heights and temperatures of hot air.

These plots show that for each bed height and temperature of hot air, the rate of drying of sawdust was the highest in the case of spout with cone angle of 65° . For instance when bed height was 10 cm and hot air temperature was 45°C (Fig. 4.19), a reduction in moisture content from 45% (db) to 20% (db) required 22 minutes when cone angle was 55° where as it took 12 minutes when cone angle was 65° . Figures 4.19 to 4.24 also show that for bed heights of 10 cm & 15 cm, no appreciable saving in time required to dry the sawdust to the desired moisture content was achieved as the cone angle was increased from 60° to 65° . For bed height of 20 cm (Fig. 4.25 to Fig. 4.27), almost same saving in drying time was achieved as the cone angle was further increased from 60° to 65° . A visual inspection of spout formed also showed that in the case of conical spout of 65° cone angle, the formation of spout, flaring of the spouted sawdust and its movement along the walls of the cone was much improved. Improved quality of spouting meant more intimate contact between sawdust particles and hot air which gave faster drying. Thus, it was concluded that for higher bed height (20 cm or more) larger cone angle of the spout was better.

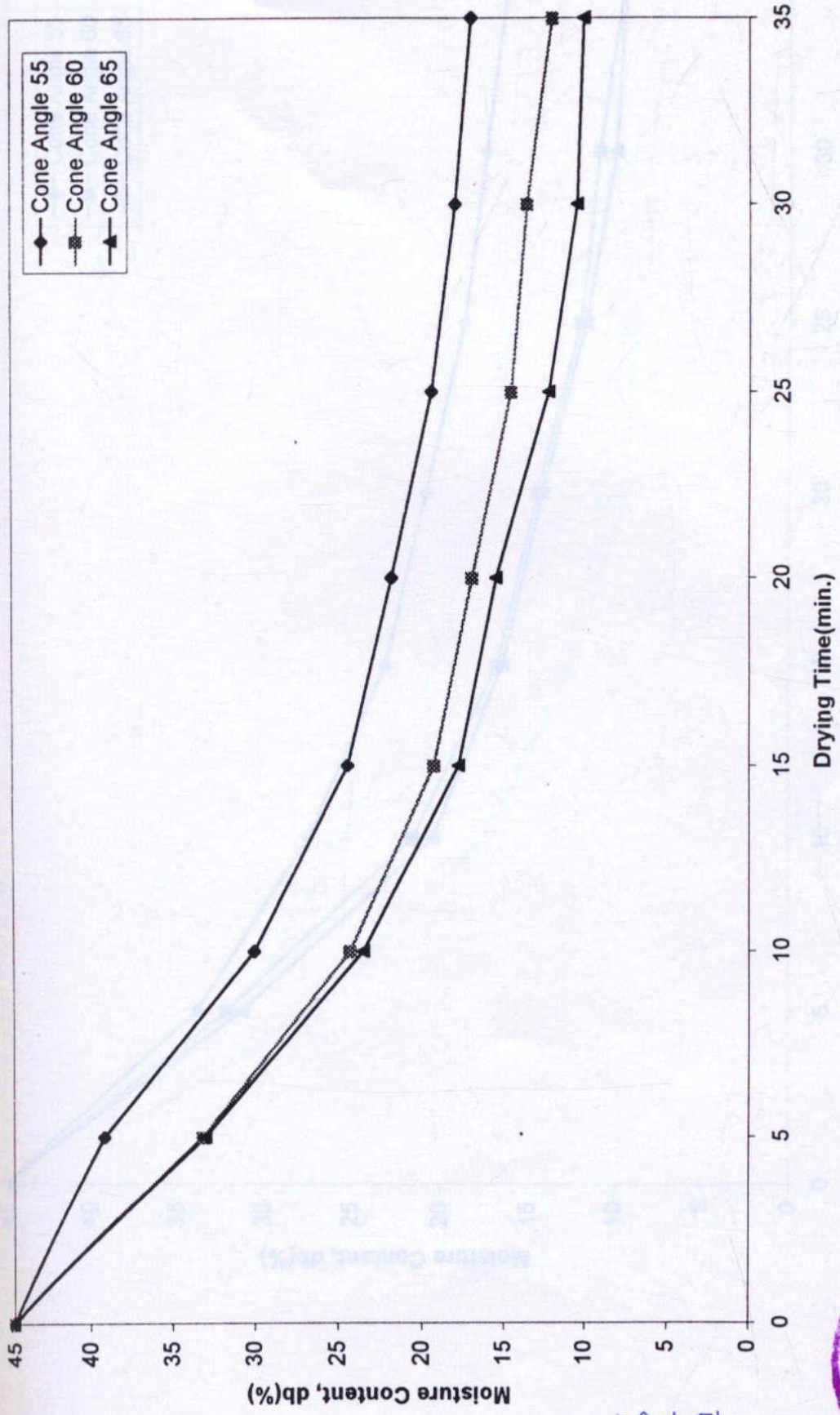


Fig. 4.19 Effect of cone angle on drying time of sawdust in conical spouted bed
 (Bed height = 10 cm., Temp. of hot air = 45°C)



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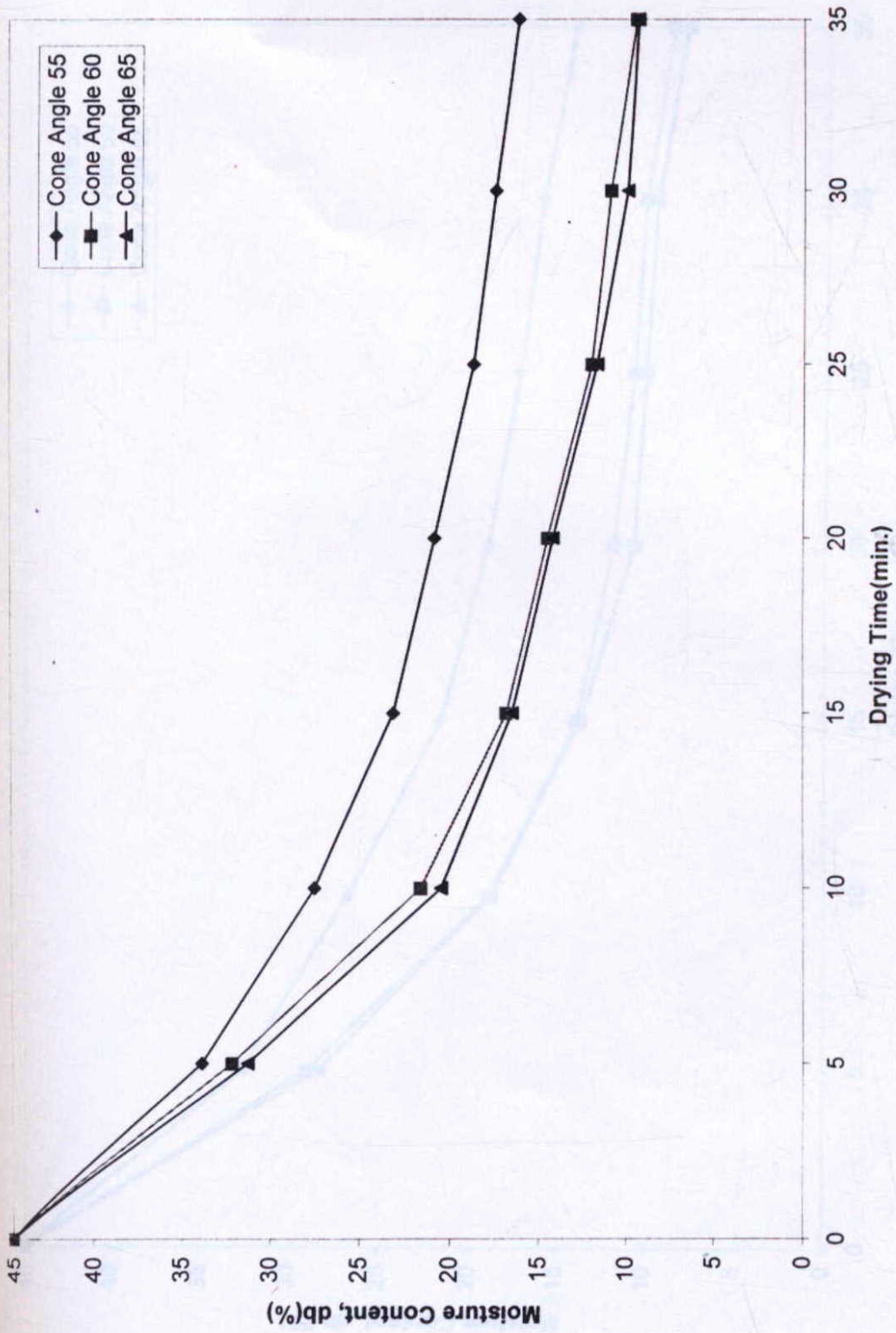


Fig. 4.20 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 10 cm., Temp. of hot air = 50°C)

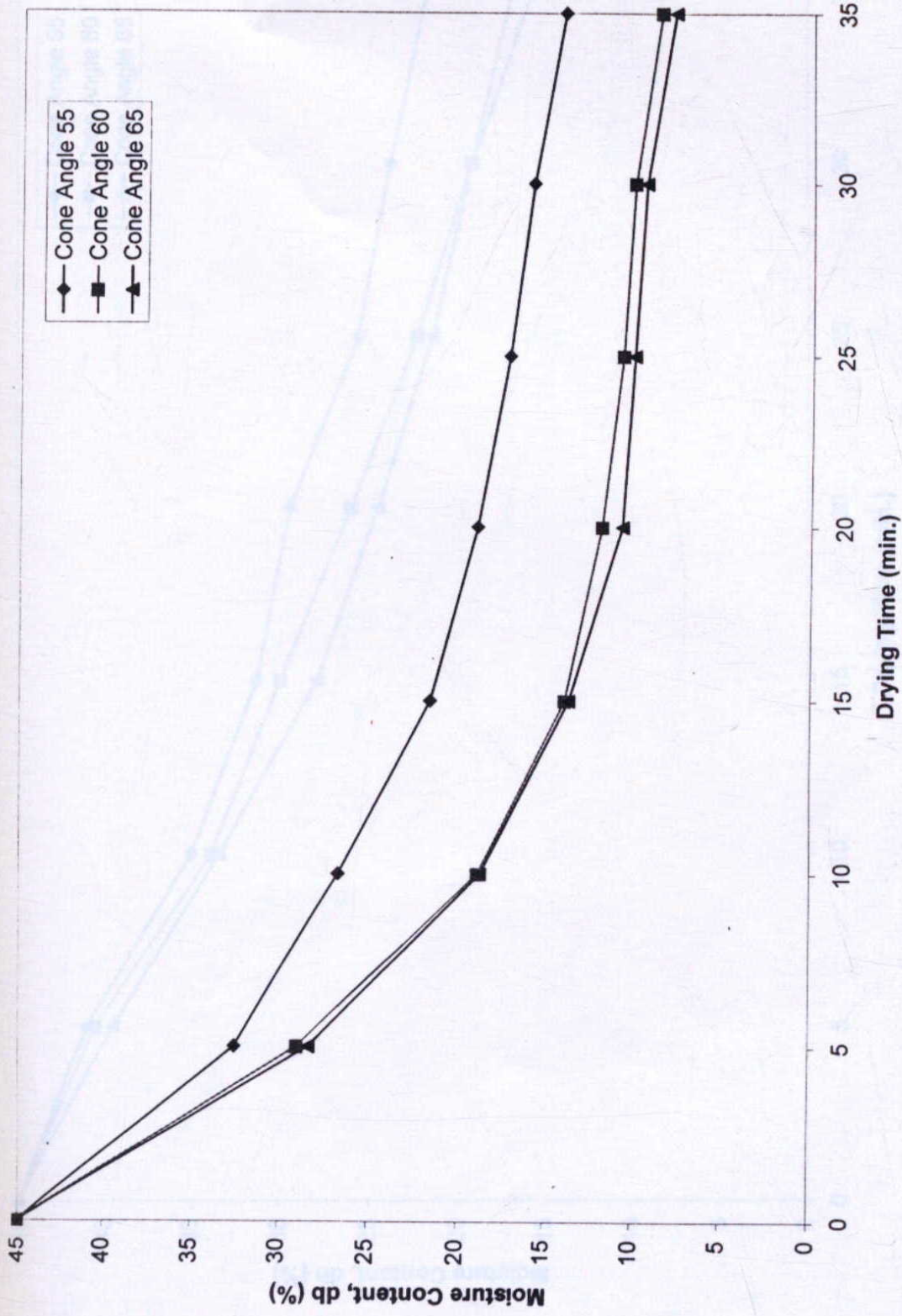


Fig. 4.21 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 10 cm., Temp. of hot air = 55°C)

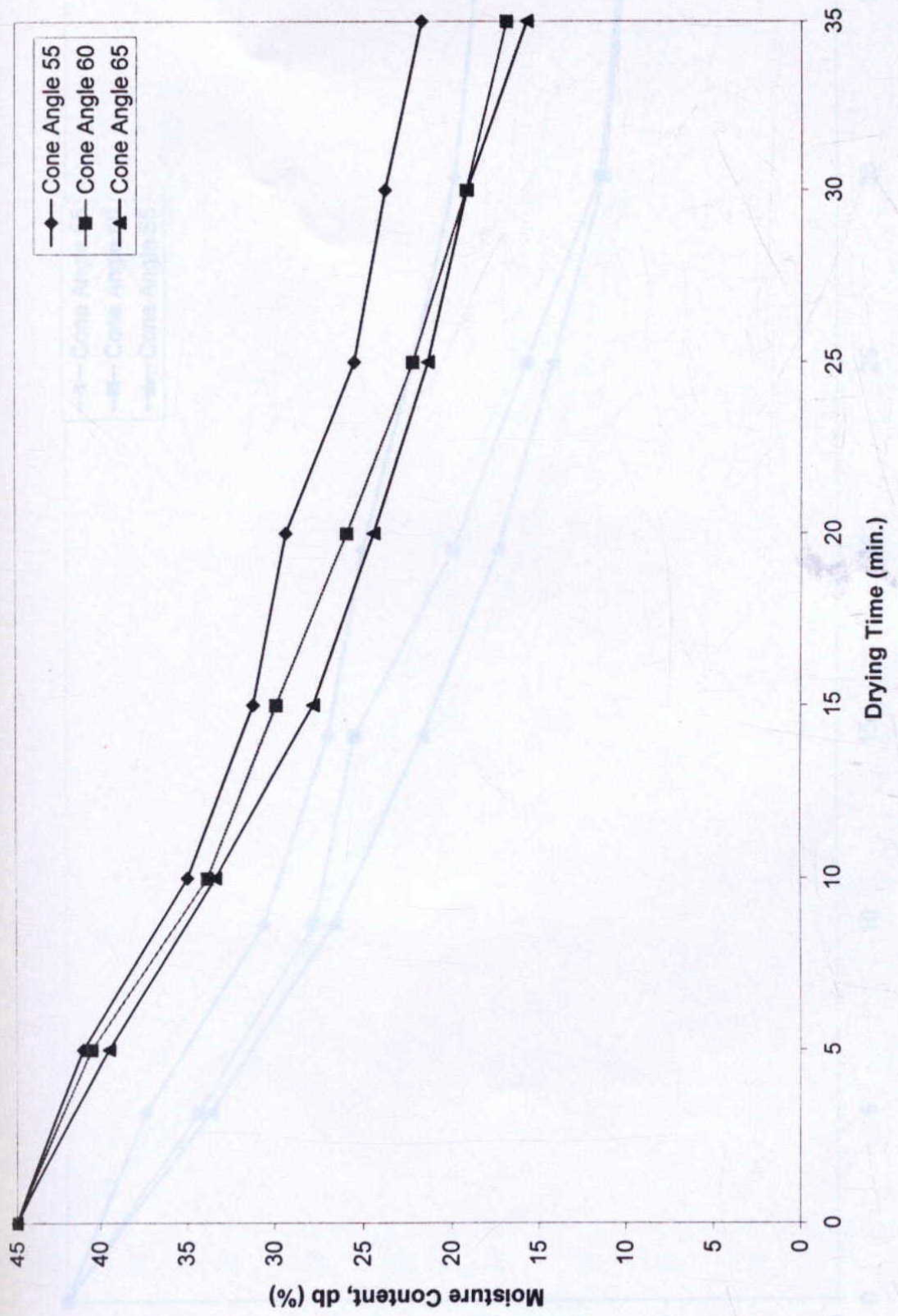


Fig. 4.22 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 15 cm., Temp. of hot air = 45°C)

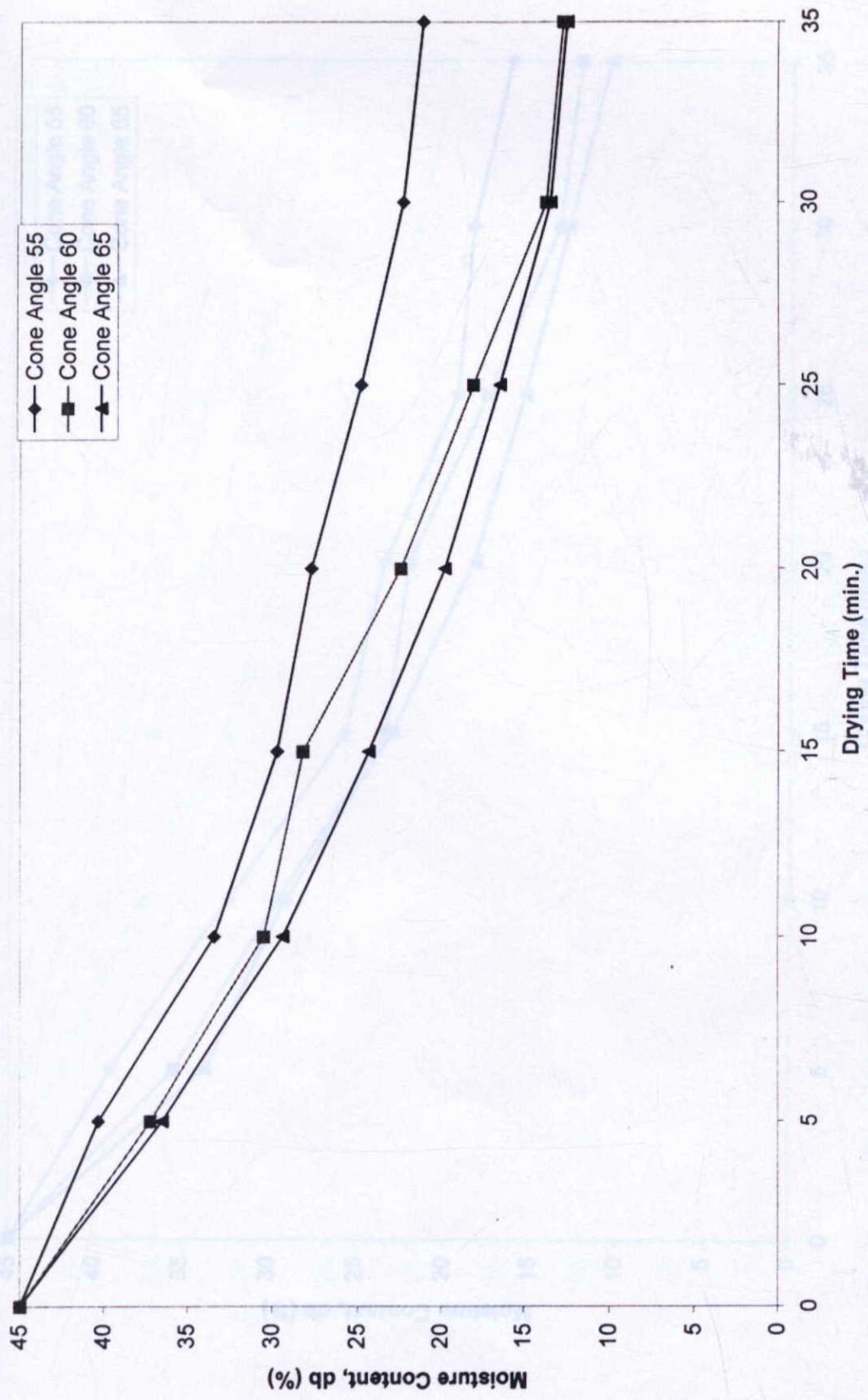


Fig. 4.23 Effect of cone angle on drying time of sawdust in conical spouted bed (Bed height =15 cm., Temp. of hot air =50°C)

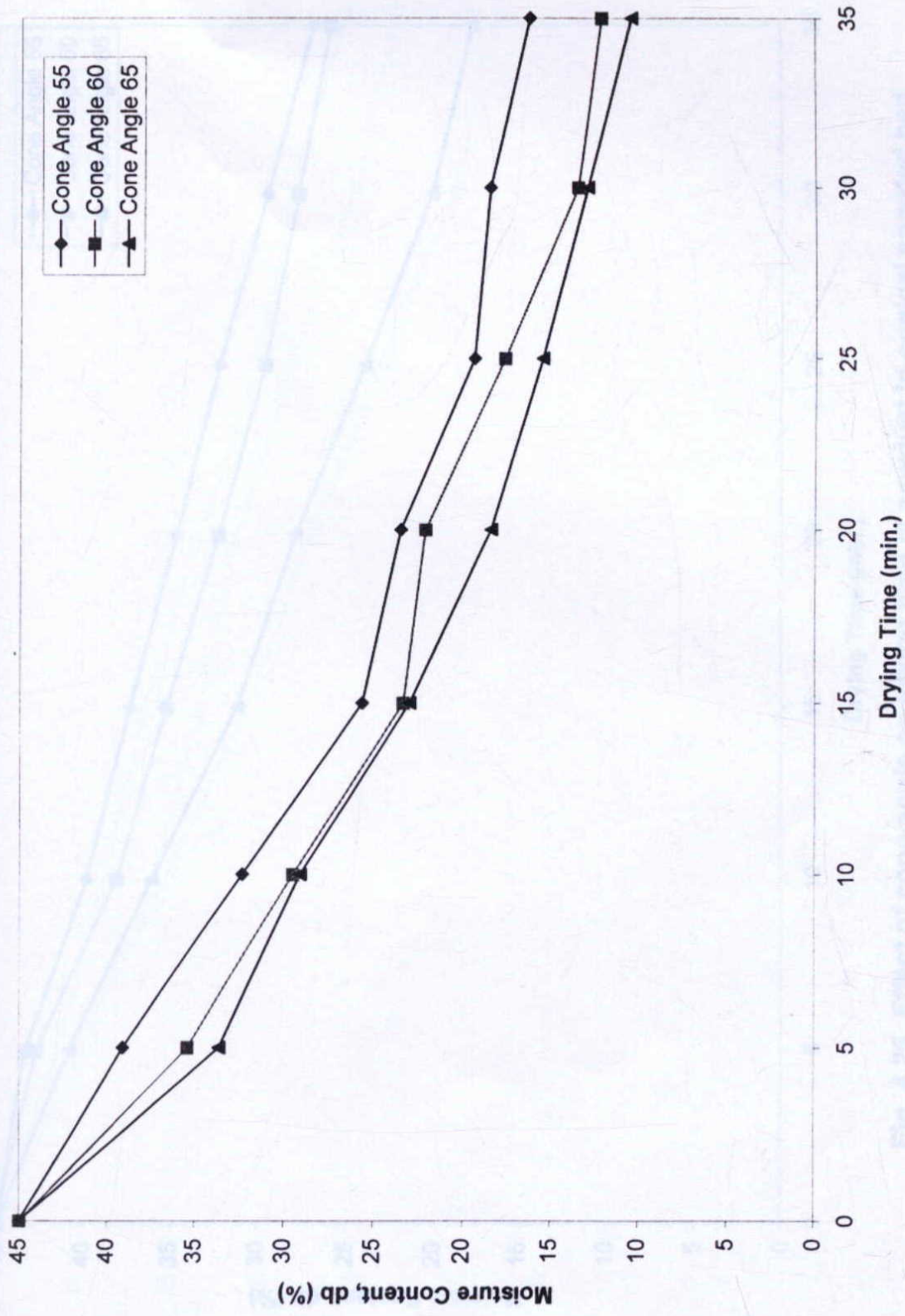


Fig. 4.24 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 15 cm., Temp. of hot air = 55°C)

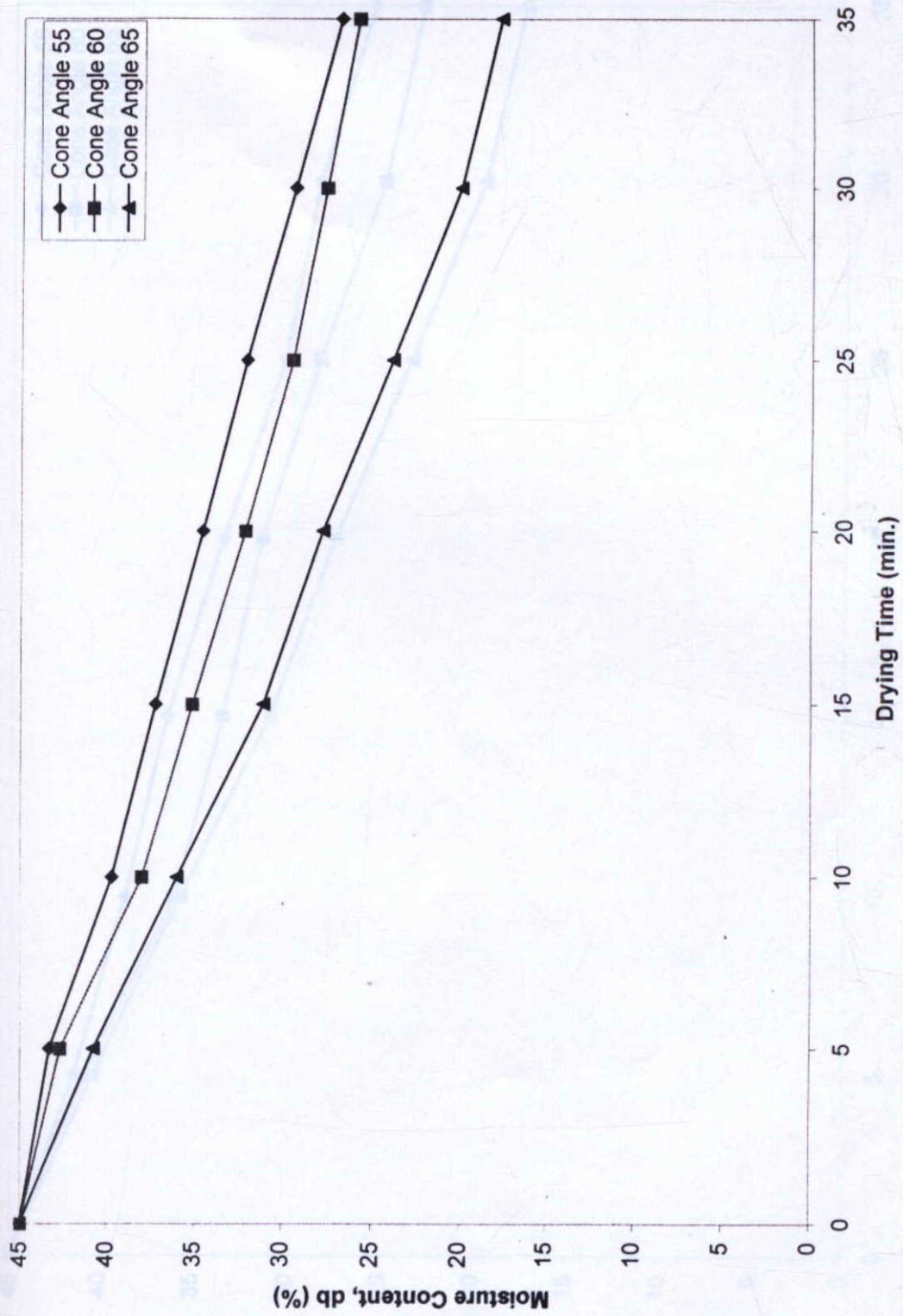


Fig. 4.25 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 20 cm., Temp. of hot air = 45°C)

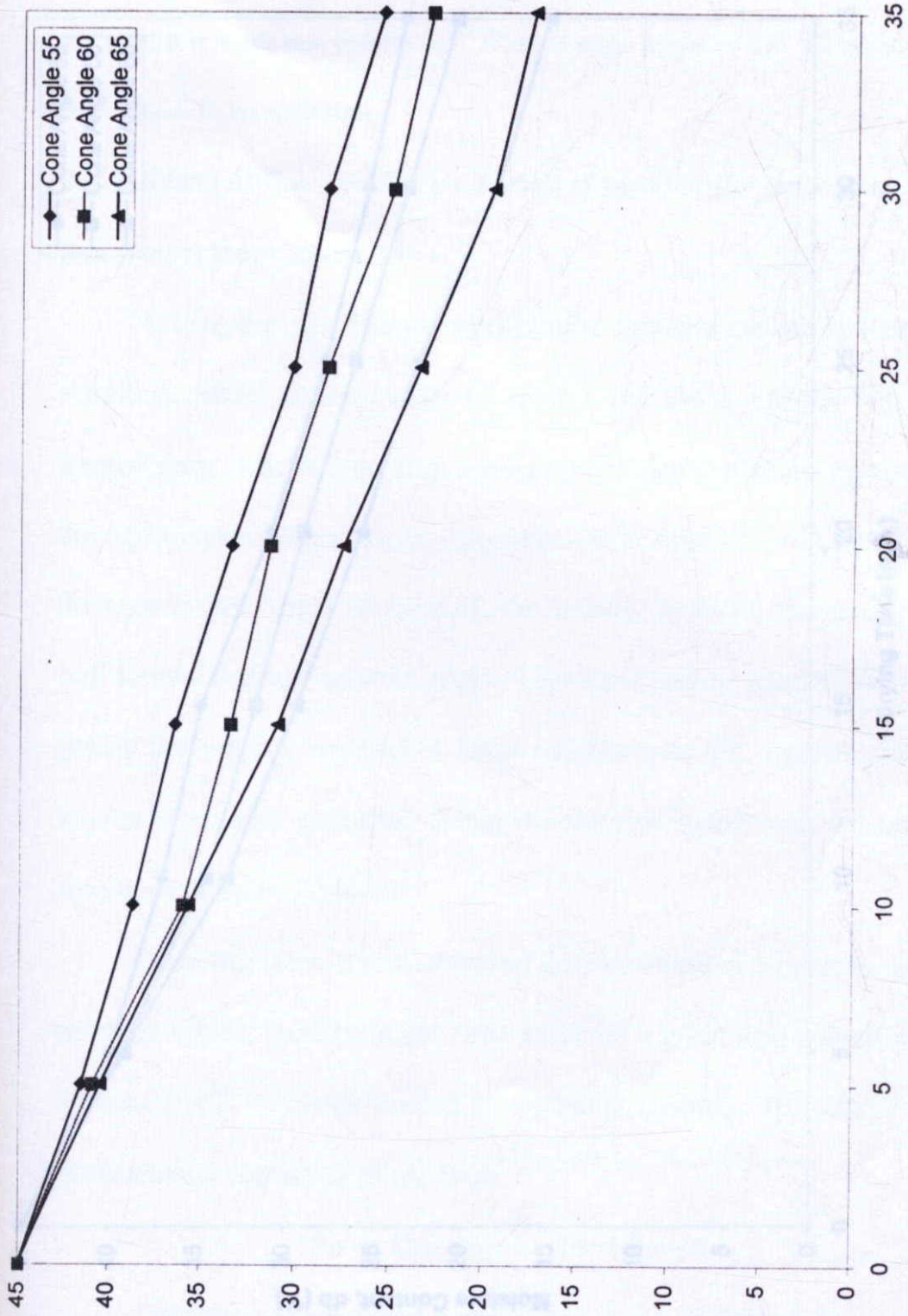


Fig. 4.26 Effect of cone angle on drying time of sawdust in conical spouted bed
(Bed height = 20 cm., Temp. of hot air = 50°C)

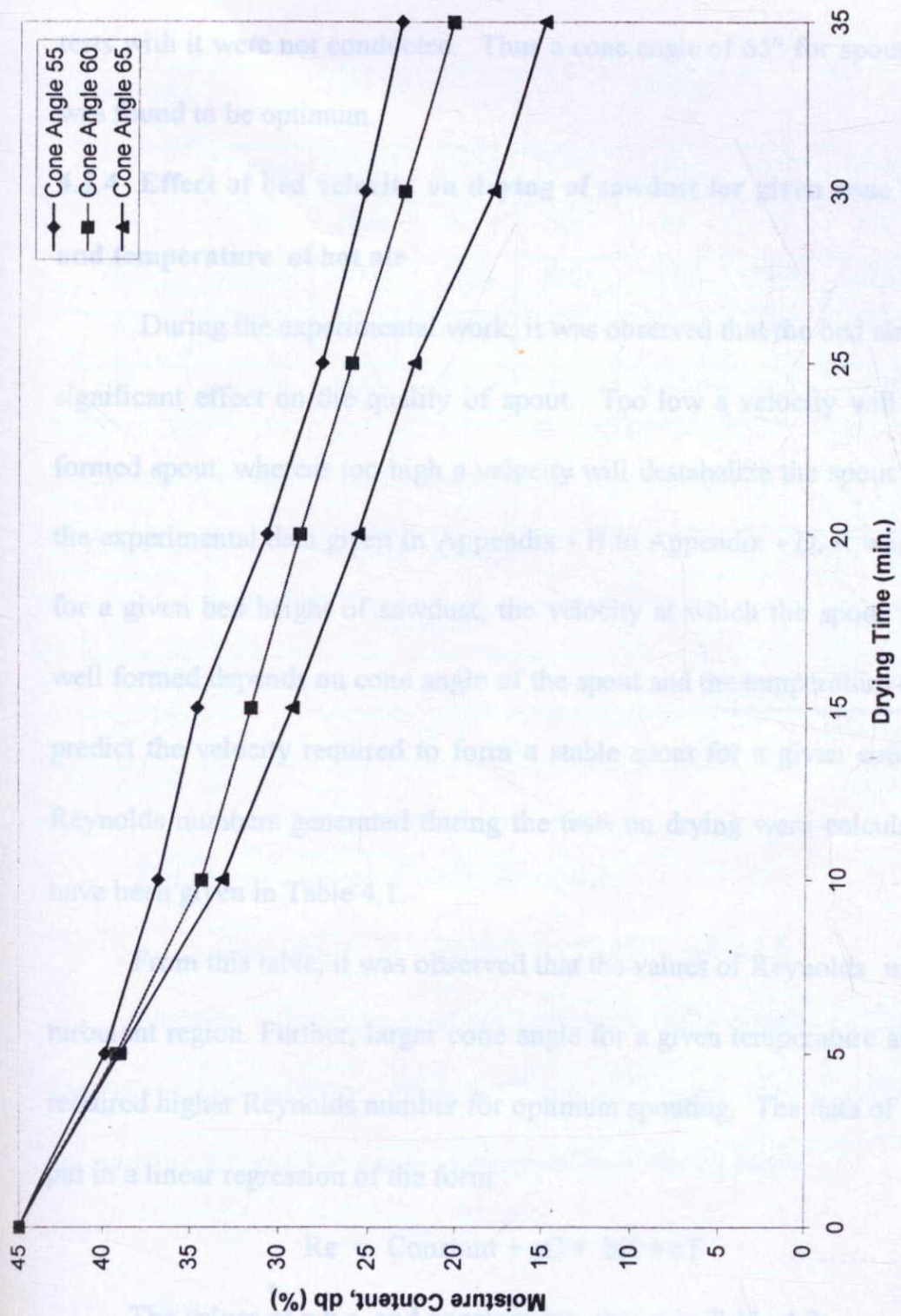


Fig. 4.27 Effect of cone angle on drying time of sawdust in conical spouted bed (Bed height = 20 cm., Temp. of hot air = 55°C)

Keeping this in mind, a spout with cone angle of 70° was fabricated. It was observed that the quality of spout formed was the poorest of all and hence further tests with it were not conducted. Thus a cone angle of 65° for spouting of sawdust was found to be optimum.

4.1.4 Effect of bed velocity on drying of sawdust for given cone angle of spout and temperature of hot air

During the experimental work, it was observed that the bed air velocity had a significant effect on the quality of spout. Too low a velocity will not form well formed spout, whereas too high a velocity will destabilize the spout formed. From the experimental data given in Appendix - B to Appendix - D, it was observed that for a given bed height of sawdust, the velocity at which the spout was stable and well formed depends on cone angle of the spout and the temperature of hot air. To predict the velocity required to form a stable spout for a given conical spout, the Reynolds numbers generated during the tests on drying were calculated and these have been given in Table 4.1.

From this table, it was observed that the values of Reynolds number were in turbulent region. Further, larger cone angle for a given temperature and bed height, required higher Reynolds number for optimum spouting. The data of Table 4.1 was put in a linear regression of the form.

$$Re = \text{Constant} + aC + bH + cT \quad \dots\dots\dots 4.1$$

The values of a,b,c and constant are shown in Table 4.2

Table 4.1 Values of Reynolds numbers at different bed heights, temperatures and cone angles

Cone Angle	T=45C			T=50C			T=55C		
	H=10	H=15	H=20	H=10	H=15	H=20	H=10	H=15	H=20
	Re	Re	Re	Re	Re	Re	Re	Re	Re
55	5094	6914	8734	4951	6721	8490	4820	6543	8265
60	5456	7276	9096	5304	7073	8842	5163	6885	8607
65	7276	9096	10916	7073	8842	10612	6885	8607	10330

Table 4.2 Unweighed least squares linear regression of Re

S.No.	Predictor Variables	Coefficient
1	Constant	-8412.6
2	a	212.28
3	b	354.11
4	c	-41.7

Thus linear regression yields the relation.

$$Re = 354.11 H - 41.70 T + 212.28 C - 8412.6 \quad \dots\dots\dots 4.2$$

Equation 4.2 can be used for estimating the Reynolds number for a given conical spouted bed dryer. From the Reynolds number, the velocity of air required for spouting the sawdust can be determined from the equation :

$$Re = VD \rho / \mu$$

Where,

$$V = \text{Velocity of hot air entering the spout}$$

- D = Inlet diameter of spout
 ρ = Mass density of hot air
 μ = Coefficient of viscosity

4.2 Drying of sawdust in a linear spouted bed dryer

Linear spouted bed is a combination of conical spouts in series. Since a cone angle of 65° was found optimum, the included angle between the sloping sides of a linear spouted bed (Fig.3.2) was kept at 65° . Therefore, only bed height and temperature of hot air were considered as the variables. The studies have been conducted taking bed height of sawdust as 10 cm, 15 cm and 20 cm and hot air temperature of 45°C , 50°C and 55°C . The initial moisture content of sawdust for each test run was 45% (db). The moisture content of sawdust was measured after every 5 minutes. The experimental data has been given in Appendix - E and the results discussed below :

4.2.1 Effect of temperature of hot air on drying of sawdust at a given bed height

Figures 4.28 - 4.30 show the effect of hot air temperature on drying of sawdust at a given bed height. It was observed that as in the case of a simple conical spout for a given bed height of sawdust ,the moisture reduction was faster when temperature of hot air was more.

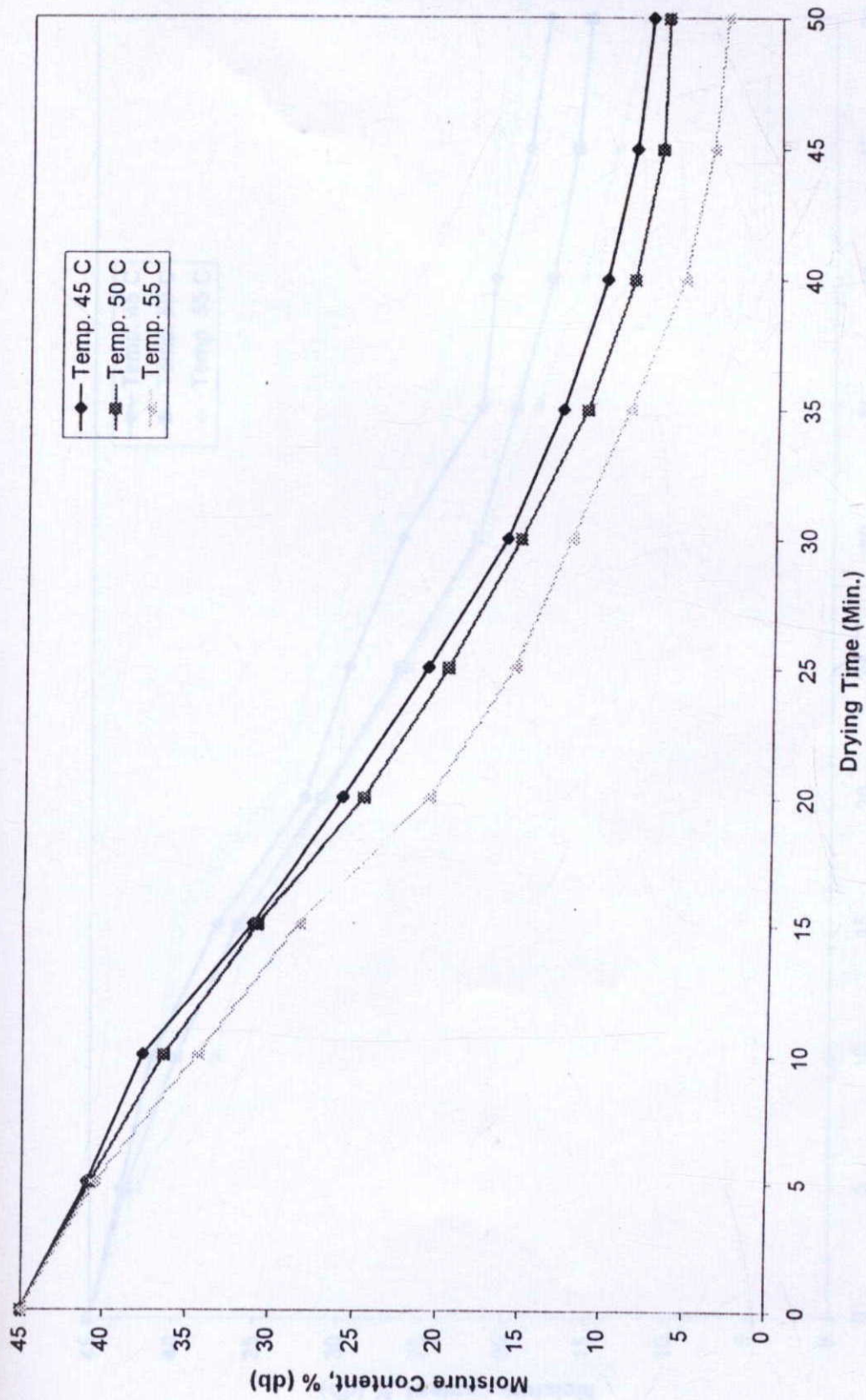


Fig. 4.28 Effect of temperature of hot air on drying time of sawdust in linear spouted bed
(Cone angle = 65°, Bed height = 10 cm)

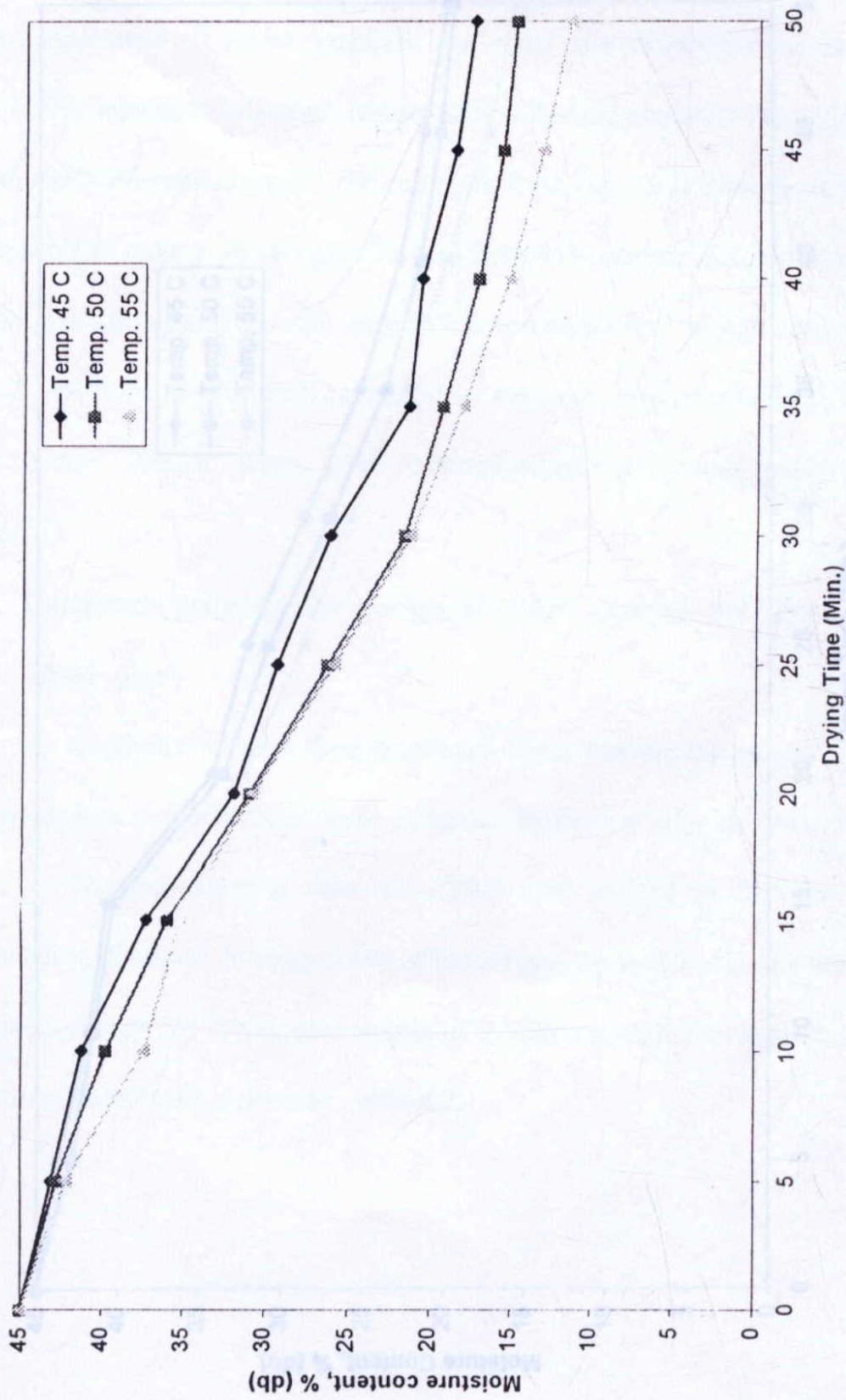


Fig. 4.29 Effect of temperature of hot air on drying time of sawdust in linear spouted bed
(Cone angle = 65°, Bed height = 15 cm)

4.2.2 Effect of bed height on drying of sawdust at a given temperature of hot air

Figures 4.31 - 4.33 show the effect of bed height on drying of sawdust at each temperature of hot air supplied. In the case of single component spouted bed, it was seen that for a given temperature of hot air supplied, the drying time when the bed height is small. For example, from Fig. 4.31 it was seen that 35 minutes to reduce the moisture content from 45% (db) to 25% (db) when the bed height was 20 cm. Similar results were obtained when hot air was supplied at 45°C and 55°C.

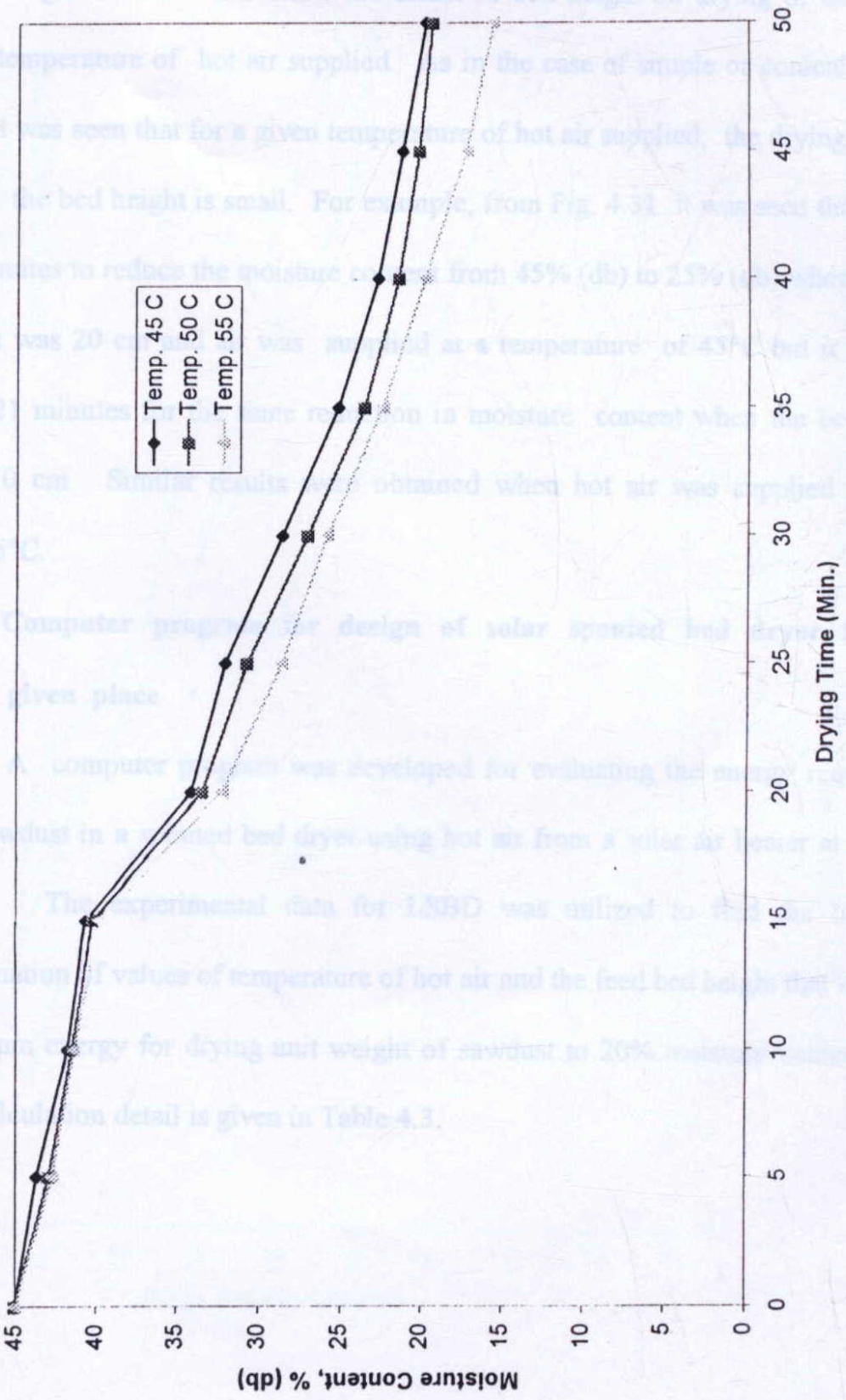


Fig. 4.30 Effect of temperature of hot air on drying time of sawdust in linear spouted bed (Cone angle = 65°, Bed height = 20 cm)

4.3 Computer program for design of solar spouted bed

A computer program was developed for evaluating the minimum energy for drying unit weight of sawdust to 20% moisture content. The experimental data for LSSD was utilized to find the combination of values of temperature of hot air and the feed bed height that would require minimum energy for drying unit weight of sawdust to 20% moisture content. The calculation detail is given in Table 4.3.

4.2.2 Effect of bed height on drying of sawdust at a given temperature of hot air

Figures 4.31 - 4.33 show the effect of bed height on drying of sawdust at each temperature of hot air supplied. As in the case of simple or conical spouted bed, it was seen that for a given temperature of hot air supplied, the drying is faster when the bed height is small. For example, from Fig. 4.31 it was seen that it took 35 minutes to reduce the moisture content from 45% (db) to 25% (db) when the bed height was 20 cm and air was supplied at a temperature of 45°C but it required only 21 minutes for the same reduction in moisture content when the bed height was 10 cm. Similar results were obtained when hot air was supplied at 50°C and 55°C.

4.3 Computer program for design of solar spouted bed dryer for any given place

A computer program was developed for evaluating the energy required to dry sawdust in a spouted bed dryer using hot air from a solar air heater at a given place. The experimental data for LSBD was utilized to find the optimum combination of values of temperature of hot air and the feed bed height that required minimum energy for drying unit weight of sawdust to 20% moisture content (db). The calculation detail is given in Table 4.3.

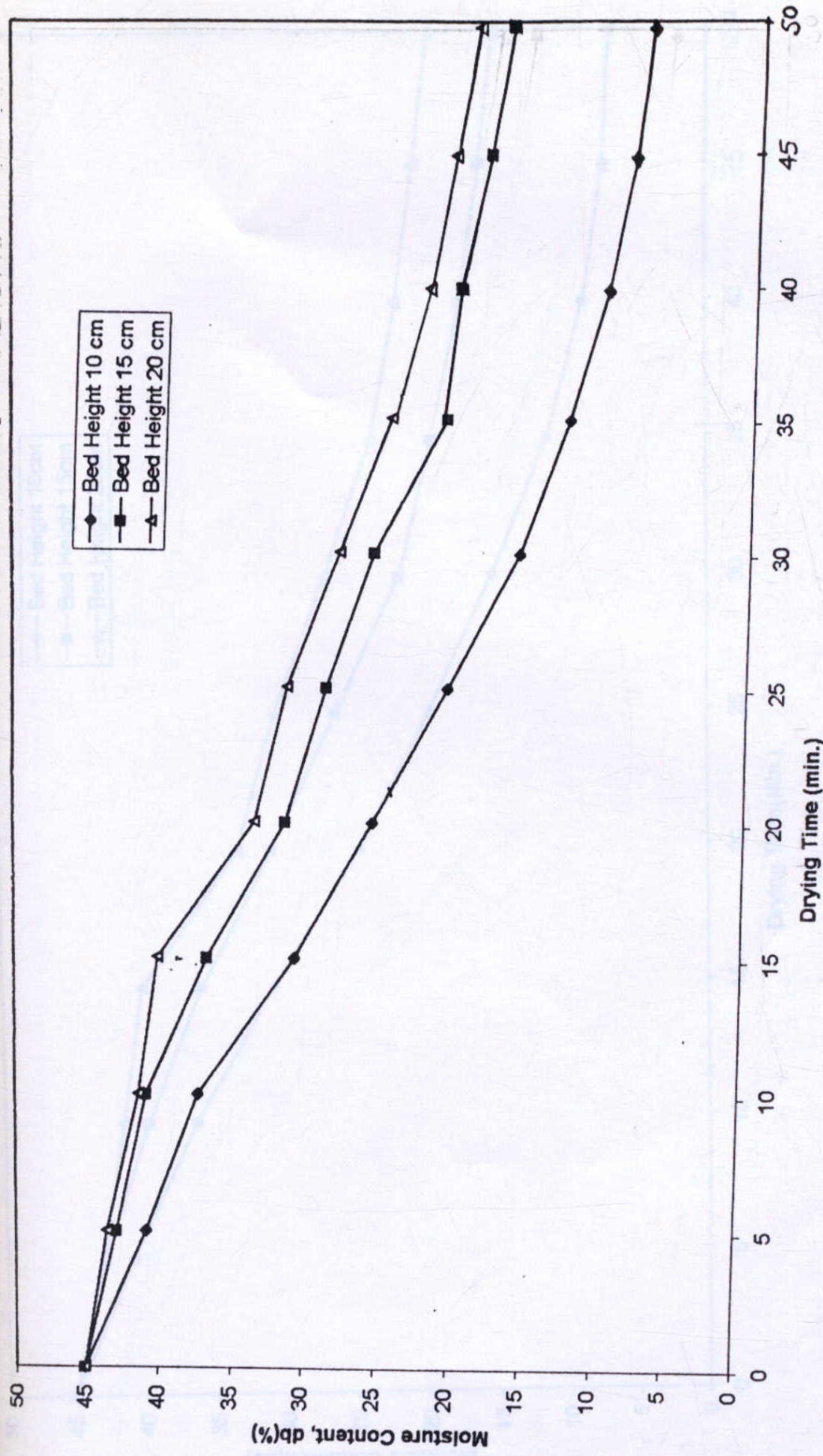


Fig. 4.31 Effect of bed height on drying of sawdust in linear spouted bed
(Cone angle = 65°, Temp. of hot air = 45°C)

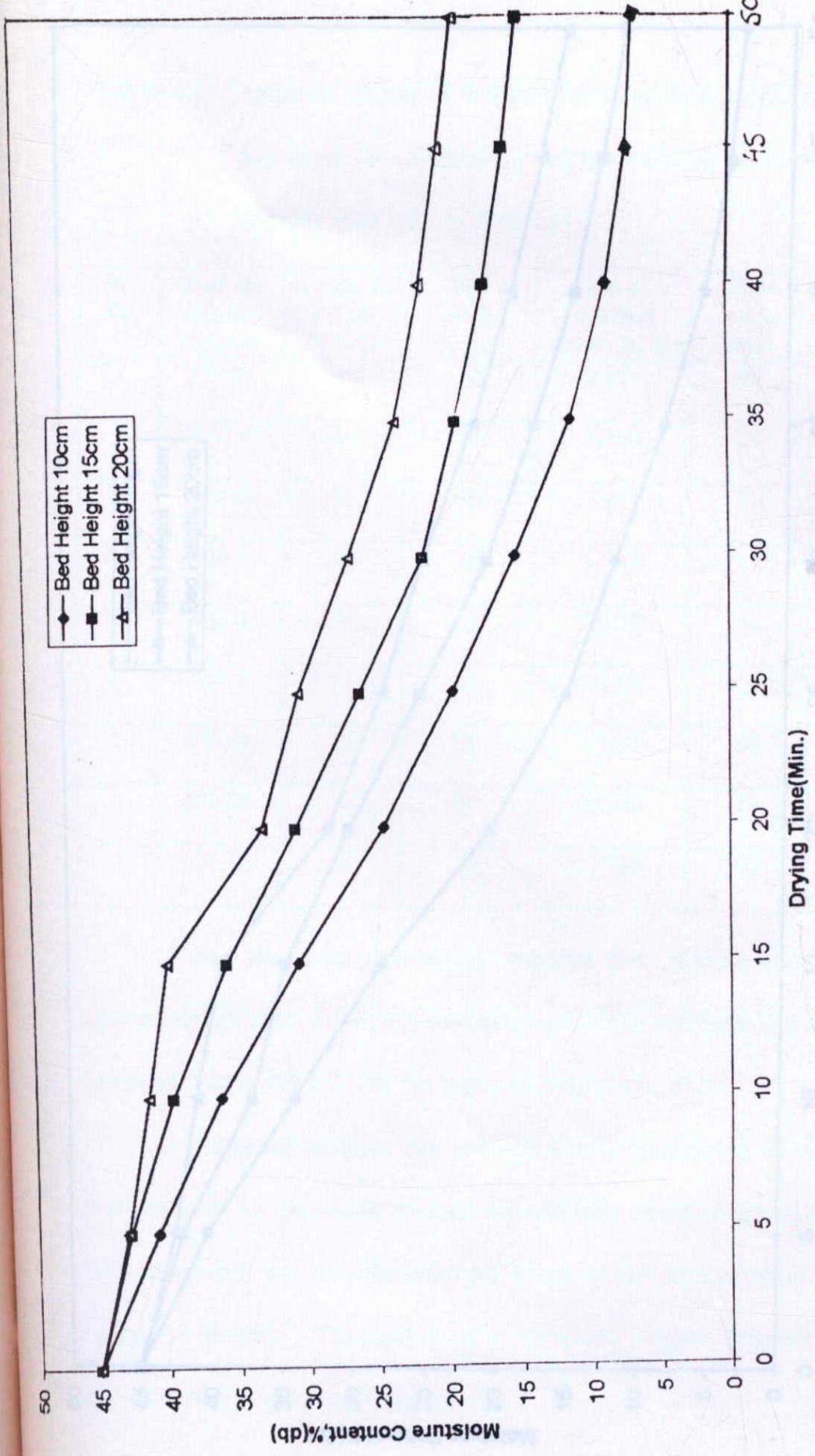


Fig. 4.32 Effect of bed height on drying of sawdust in linear spouted bed
(Cone angle = 65°, Temp. of hot air = 50°C)

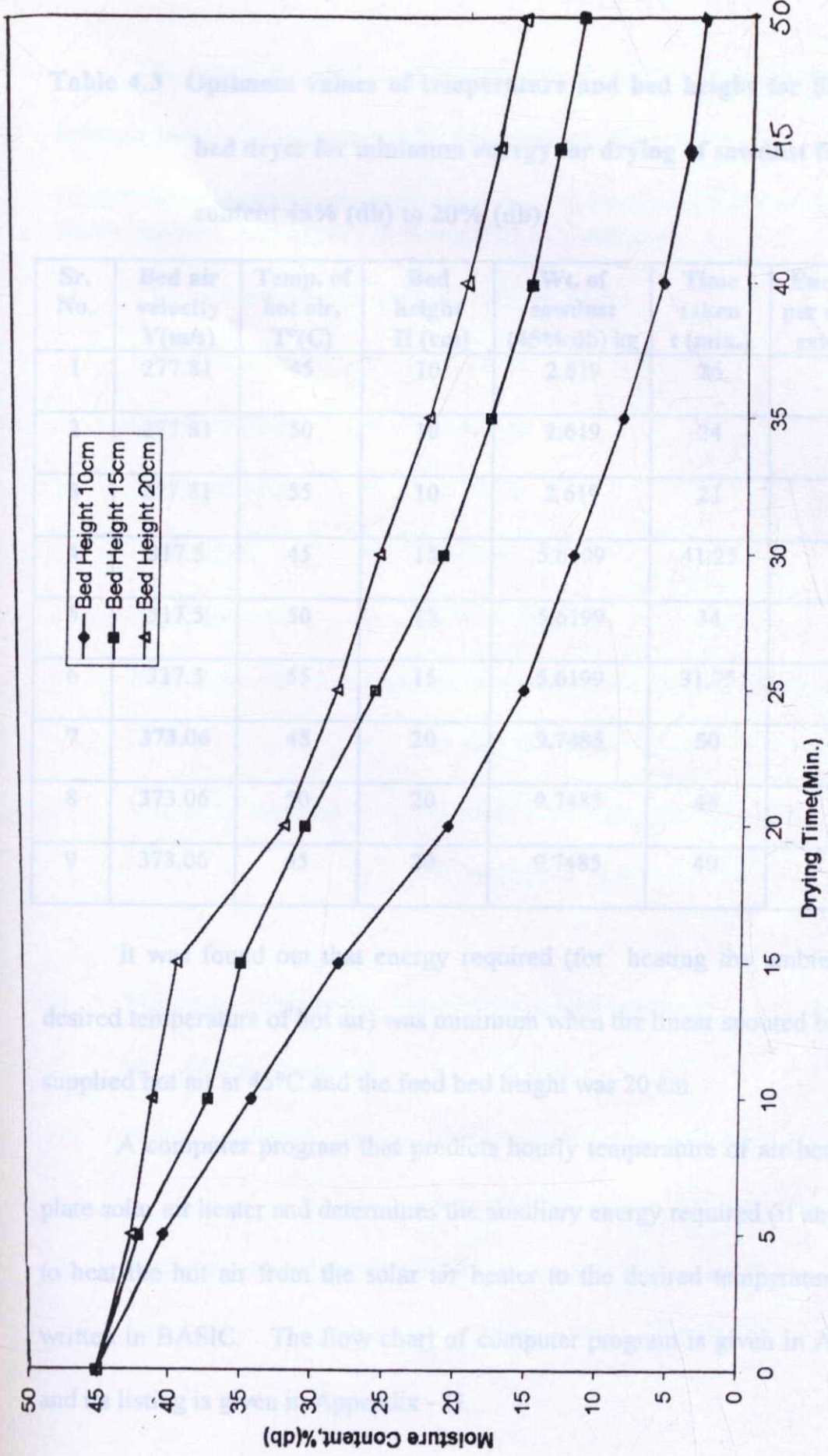


Fig. 4.33 Effect of bed height on drying of sawdust in linear spouted bed
(Cone angle = 65°, Temp. of hot air = 55°C)

Table 4.3 Optimum values of temperature and bed height for linear spouted bed dryer for minimum energy for drying of sawdust from moisture content 45% (db) to 20% (db)

Sr. No.	Bed air velocity V(m/s)	Temp. of hot air, T°(C)	Bed height H (cm)	Wt. of sawdust (45% db) kg	Time taken t (min.)	Energy required per unit weight of sawdust (kWh)
1	277.81	45	10	2.619	26	0.326
2	277.81	50	10	2.619	24	0.355
3	277.81	55	10	2.619	21	0.357
4	317.5	45	15	5.6199	41.25	0.274
5	317.5	50	15	5.6199	34	0.266
6	317.5	55	15	5.6199	31.75	0.286
7	373.06	45	20	9.7485	50	0.225
8	373.06	50	20	9.7485	46	0.246
9	373.06	55	20	9.7485	40	0.245

It was found out that energy required (for heating the ambient air to the desired temperature of hot air) was minimum when the linear spouted bed dryer was supplied hot air at 45°C and the feed bed height was 20 cm.

A computer program that predicts hourly temperature of air heated in a flat plate solar air heater and determines the auxiliary energy required (if any) each hour to heat the hot air from the solar air heater to the desired temperature (45°C) was written in BASIC. The flow chart of computer program is given in Appendix - F and its listing is given in Appendix - G.

The sum of the auxiliary energy required and the energy required for running solar air heater was calculated and the results are given below :

Results of total energy consumed in drying sawdust in a solar air heater assisted linear spouted bed dryer (in November at Ludhiana)

a) Energy consumed for running solar air heater

1) Collector area = 1. sq. m.

2) Collector length = 1.414 m

3) Collector width = 0.707 m

4) Duct depth = 0.03 m

5) Mass flow rate = 0.0115 kg/s

6) Mass flow rate of air required in solar assisted spouted bed dryer

= 0.1053747 kg/s

7) Vol. of air required = 0.1053747 x (1/ρ at 20°C) m³/s

= 0.1053747 x (1/1.21) = 0.087 m³/sec

= 5.22 m³/min.

8) Maximum capacity of commercially available blower = 2.3 m³/min

9) No. of blower required = 5.22/2.3 ≅ 3

10) Power consumed = 3 x power input for each blower

= 3 x .335 kW = 1.005 kW ≅ 1 kW

11) Energy consumed by electric blower used for air heaters (EBA)

= 1 x 10 = 10 kW - hr

b) Energy consumed for heating air to desired temperature (45°C)

Time (I)	Temp. of hot air from air heater TFO (I)	Delta T = 45-TFO (I)	EH
9-10	30.16	14.83	1.57
10-11	37.58	7.41	0.784
11-12	42.53	2.46	.261
12-13	45.33	00	00
13-14	45.74	00	00
14-15	43.99	1.003	0.106
15-16	40.22	4.77	.505
16-17	34.35	10.64	1.127
17-18	27.50	17.49	1.85
Total EH =			6.20 kW-hr

c) Total energy consumed per day for solar assisted linear spouted bed dryer (EH + EBA))

$$= 10 + 6.2 = 16.2 \text{ kW - hr}$$

d) Sawdust dried in each batch = 9.7485 kg

e) No of batches per day = 9

f) Total wt. of sawdust dried per day = 9.7485 x 9

$$= 87.73 \text{ kg}$$

g) Energy required per kg of sawdust = 16.2 / 87.73 = 0.18 kW- hr

Thus a solar air heater (working at Ludhiana) assisted linear spouted bed dryer requires 0.18 kW-hr energy for drying 1 Kg of sawdust from initial moisture content of 45% (db) to 20% (db).

SUMMARY AND CONCLUSIONS

The wide spread use of coal and other fossil fuels have resulted in their sharp depletion, due to which there has been renewed interest in the use of biomass fuels. Most biomass fuels are cheap at the source but are relatively expensive to collect, process and haul. Materials like sawdust, rice husk, rice straw etc. can be used as inexpensive alternative source of energy.

Sawdust is low cost, low utility byproduct of the lumber industry and can be converted into useful fuel by making briquettes. The moisture content of sawdust varies from 35% to 55% (wb) which causes fungal growth and reduction in energy content. Therefore, sawdust needs to be dried before briquetting

A spouted bed dryer is a vessel open at the top and filled partially with the sawdust. When hot air is injected vertically through a centrally located small opening at the base of the vessel, it causes a stream of particles to rise rapidly in a hollowed central core within the bed of solids. As the particles reach somewhat above peripheral bed level, some particles fall back on to the annular region and slowly travel downward as a loosely packed bed.

The present work deals with the design, development and performance evaluation of solar spouted bed dryer. The specific objectives of investigation are :

- a) To design and fabricate conical and linear spouted bed dryer.
- b) To study the effect of cone angle, bed depth, bed air velocity and air

temperature on drying.

c) To develop a computer programme for design of solar spouted bed dryer for any place.

Two types of spouted bed dryers viz. conical and linear were designed, fabricated and tested. The effect of bed height, temperature of hot air and cone angle on drying of sawdust were studied. The optimum operating point in terms of temperature and bed height of sawdust that required minimum energy to dry was found for drying sawdust in linear spouted bed dryer.

The auxiliary (additional) energy required for heating air to the optimum operating temperature in case of solar air heater assisted linear spouted bed dryer was calculated using a computer program that predicted the temperature of hot air. Based on the experimental results, the main conclusions drawn were as :

- 1) A spout of cone angle of 65° having column diameter 80 mm and air inlet diameter 8 mm gives best performance for spouting sawdust.
- 2) The drying rate increased with increase in temperature of hot air for drying sawdust in a conical spouted bed dryer for all cone angles and bed heights.
- 3) The velocity of hot air necessary for producing stable spout can be determined from the correlation :

$$Re = 354.11 H - 41.70 T + 212.28 C - 8412.6$$

- 4) The energy required for drying a unit weight of sawdust was minimum in linear spouted bed dryer of cone angle of 65° when the bed height of sawdust was

20 cm and temperature of hot air was 45°C.

5) The energy required per unit weight of sawdust when dried in a solar assisted linear spouted bed dryer at the optimum operating point (bed height 20 cm and temperature of hot air 45°C) was found to be 0.18 kw-hr for reducing the moisture content from 45% (db) to 20% (db).

Scope for future work :

The study on drying of sawdust using other types of spouted bed dryers should be conducted to optimize the choice of a spouted bed dryer.

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* Original reference not seen.

APPENDIX-A

Material preparation and moisture content determination on dry basis

The sawdust was procured from the saw mills. For making it 45%(db) moisture content, the following procedure was adopted:

- 1) Initial weight of sawdust sample procured from the saw mill = W_1
- 2) Final weight of sawdust sample after placing in oven for 2.30 hrs = W_2
- 3) Net weight (W) = $W_1 - W_2$
- 4) For making the procured sawdust sample 45% (db) moisture content, the calculation for amount of water added

$$\frac{W_2 * 45\% - W}{W_1} * W_t$$

Here W_t = Total weight of sawdust

The above calculated amount of water added was sprinkled over the sawdust and was thoroughly shaken for about 15 to 20 minutes. The sawdust thus prepared was kept in polythene bag to avoid moisture evaporation for 24 hours.

The moisture content determination on the dry basis as under:

$$\text{m.c \% (db)} = \frac{W_1 - W_2}{W_2} * 100$$

Sample of calculation for material preparation and m.c. on dry basis :

- 1) Initial weight of sawdust sample (W_1) = 1.5982 g
- 2) Final weight of sawdust sample after keeping in oven (W_2) = 1.5102 g

3) Net weight (W) = $W_1 - W_2 = 1.5982 - 1.5102 = .088$ g of water

Suppose total weight of sawdust $W_t = 200$ g

4) Now, amount of water added in total weight of sawdust to make it 45%(db)

m.c. was as under :

$$= \frac{1.5102 * 45\% - .088}{1.5982} * 200$$

$$= 74.03 \text{ g of water}$$

APPENDIX - B

Experimental data on drying of sawdust in conical spouted bed [Cone angle = 55°, Initial moisture content = 45% (db)]

Drying Time (minutes)	T = 45°C			T = 50°C		
	H = 10 cm V = 11.1 ml Re = 0.54	H = 15 cm V = 15.9 ml Re = 0.81	H = 20 cm V = 20.6 ml Re = 1.08	H = 10 cm V = 11.1 ml Re = 0.51	H = 15 cm V = 15.9 ml Re = 0.73	H = 20 cm V = 20.6 ml Re = 0.95
	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)
05	37.19	41.60	43.28	40.31	41.90	41.90
10	30.06	35.00	39.73	33.39	36.32	36.32
15	26.97	31.25	37.26	29.72	34.48	34.48
20	21.83	26.40	34.39	27.13	33.50	33.50
25	19.43	25.51	32.11	24.86	32.10	32.10
30	18.07	24.25	29.41	23.31	28.50	28.50
35	15.07	21.02	26.27	21.12	25.01	25.01

APPENDIX - B

Experimental data on drying of sawdust in conical spouted bed [Cone angle = 55°, Initial moisture content of sawdust = 45% (db)]

Drying Time (minutes)	T = 45°C			T = 50°C			T = 55°C		
	H = 10 cm V = 11.11 m/s Re = 5094	H = 15 cm V = 15.08 m/s Re = 6914	H = 20 cm V = 19.05 m/s Re = 8734	H = 10 cm V = 11.11 m/s Re = 4951	H = 15 cm V = 15.08 m/s Re = 6721	H = 20 cm V = 19.05 m/s Re = 8490	H = 10 cm V = 11.11 m/s Re = 4820	H = 15 cm V = 15.08 m/s Re = 6543	H = 20 cm V = 19.05 m/s Re = 8265
	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)
05	39.19	41.00	43.28	33.85	40.31	41.50	32.50	39.09	39.86
10	30.08	35.00	39.73	27.50	33.39	38.72	26.72	32.32	36.85
15	24.47	31.25	37.26	23.15	29.72	36.48	21.70	25.65	34.65
20	21.85	29.40	34.59	20.85	27.73	33.50	19.03	23.50	30.73
25	19.43	25.55	32.11	18.70	24.83	30.30	17.26	19.39	27.73
30	18.07	23.85	29.41	17.50	22.35	28.50	15.97	18.55	25.36
35	17.07	21.80	26.87	16.25	21.12	25.64	14.20	16.30	23.29

APPENDIX - C

Experimental data on drying of sawdust in conical spouted bed [Cone angle = 60°, Initial moisture content of sawdust = 45% (db)]

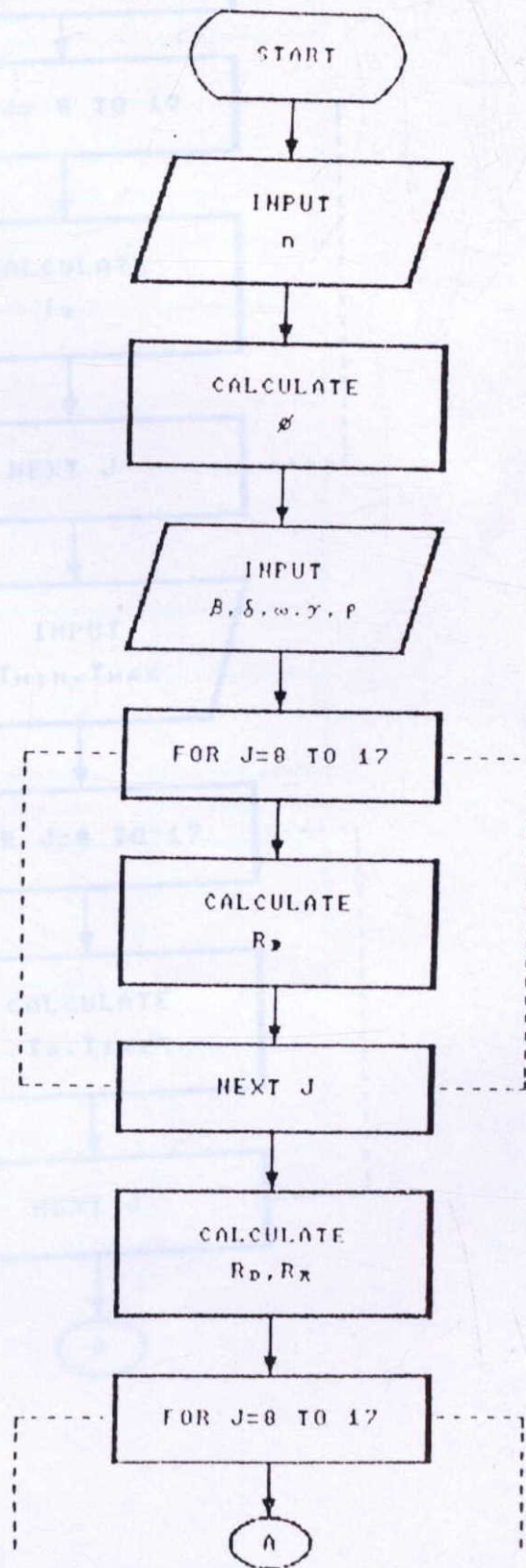
Drying Time (minutes)	T = 45°C				T = 50°C				T = 55°C									
	H = 10 cm		H = 15 cm		H = 10 cm		H = 15 cm		H = 10 cm		H = 15 cm		H = 20 cm					
	V = 11.90 m/s Re = 5456	Moisture content % (db)	V = 15.87 m/s Re = 7276	Moisture content % (db)	V = 11.90 m/s Re = 5304	Moisture content % (db)	V = 15.87 m/s Re = 7073	Moisture content % (db)	V = 11.90 m/s Re = 5163	Moisture content % (db)	V = 15.87 m/s Re = 6885	Moisture content % (db)	V = 19.84 m/s Re = 8607	Moisture content % (db)				
05	33.15	40.50	42.65	32.15	37.19	40.90	28.95	35.40	39.20	33.15	40.50	42.65	32.15	37.19	40.90	28.95	35.40	39.20
10	24.30	33.85	38.00	21.60	30.50	36.00	18.95	29.50	34.35	24.30	33.85	38.00	21.60	30.50	36.00	18.95	29.50	34.35
15	19.30	29.95	35.15	16.85	28.22	33.50	13.95	23.35	31.60	19.30	29.95	35.15	16.85	28.22	33.50	13.95	23.35	31.60
20	17.00	25.96	32.15	14.50	22.45	31.45	11.85	22.10	28.90	17.00	25.96	32.15	14.50	22.45	31.45	11.85	22.10	28.90
25	14.55	22.25	29.50	12.00	18.10	28.45	10.75	17.65	26.05	14.55	22.25	29.50	12.00	18.10	28.45	10.75	17.65	26.05
30	13.60	19.25	27.65	10.95	13.75	25.05	10.15	13.55	23.10	13.60	19.25	27.65	10.95	13.75	25.05	10.15	13.55	23.10
35	12.00	16.95	25.90	9.50	12.70	23.00	8.65	12.20	20.30	12.00	16.95	25.90	9.50	12.70	23.00	8.65	12.20	20.30

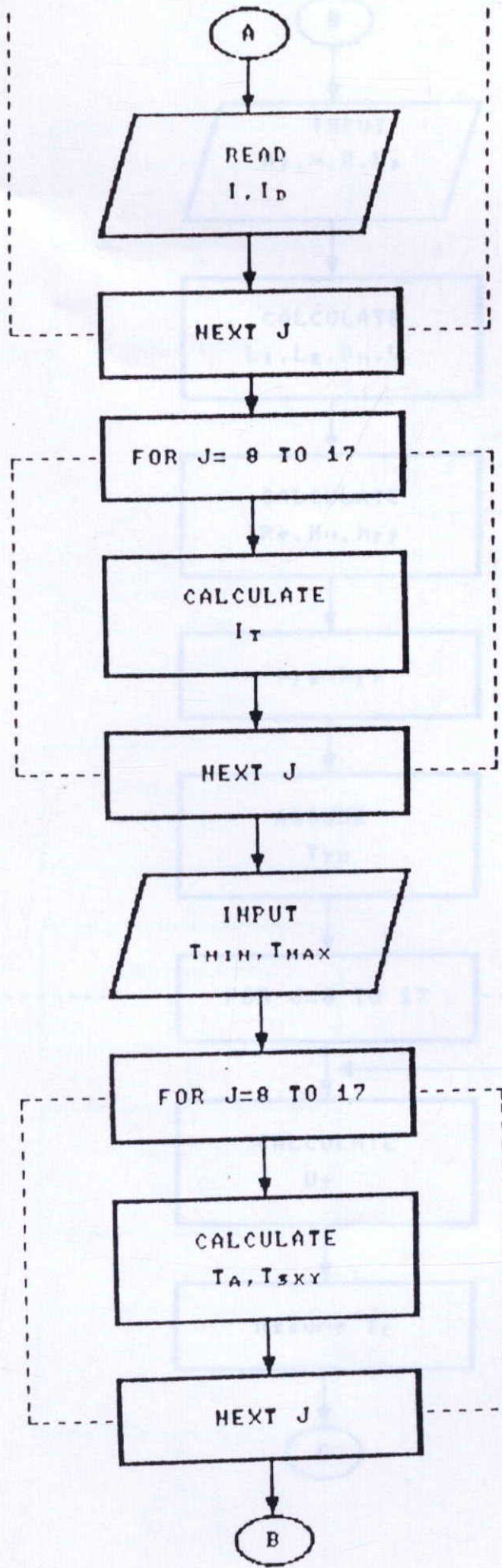
APPENDIX - D

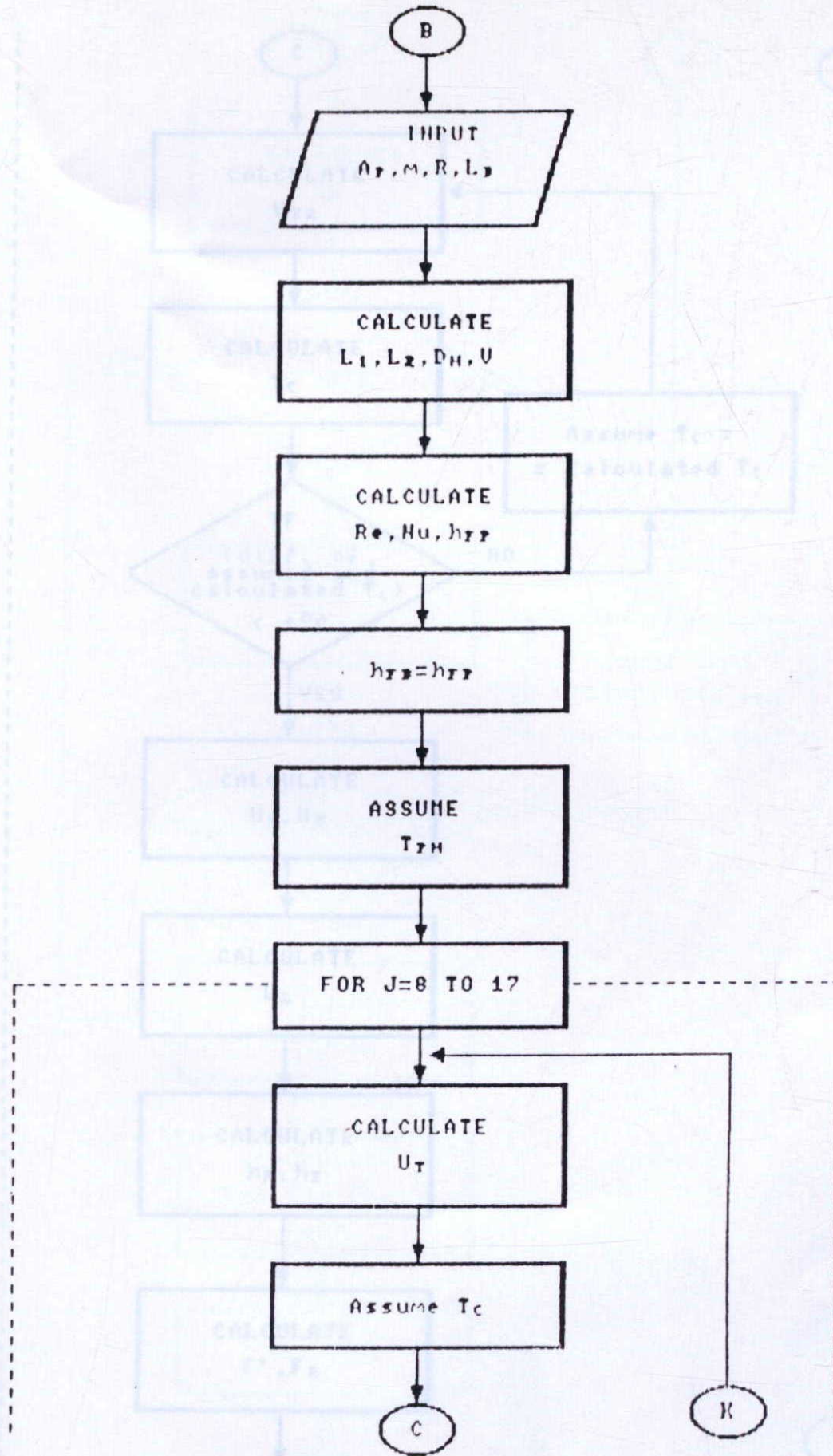
Experimental data on drying of sawdust in conical spouted bed [Cone angle = 65°, Initial moisture content of sawdust = 45% (db)]

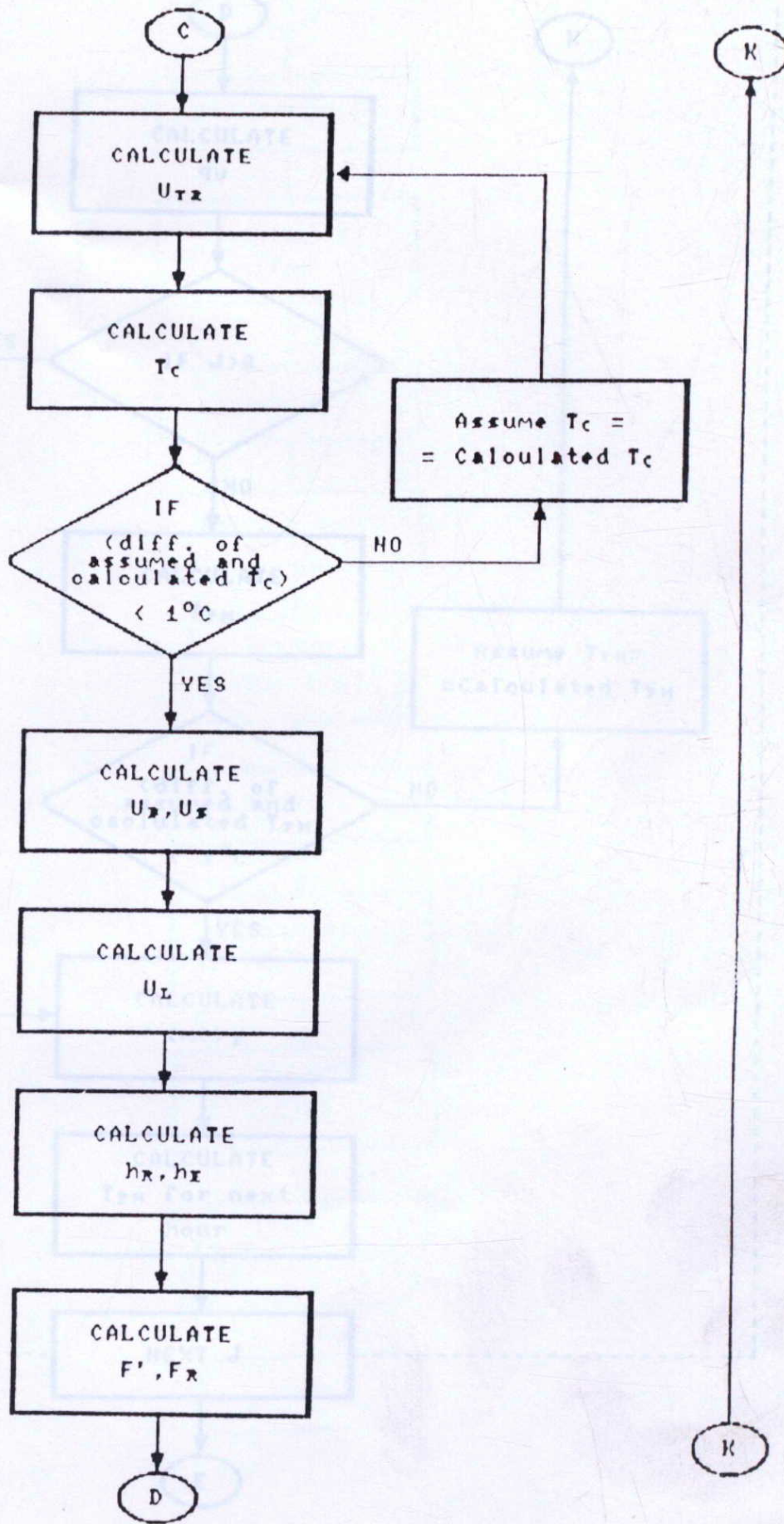
Drying Time (minutes)	T = 45°C			T = 50°C			T = 55°C		
	H = 10 cm V = 15.87 m/s Re = 7276	H = 15 cm V = 19.84 m/s Re = 9096	H = 20 cm V = 23.81 m/s Re = 10916	H = 10 cm V = 15.87 m/s Re = 7073	H = 15 cm V = 19.84 m/s Re = 8842	H = 20 cm V = 23.81 m/s Re = 10612	H = 10 cm V = 15.87 m/s Re = 6885	H = 15 cm V = 19.84 m/s Re = 8607	H = 20 cm V = 23.81 m/s Re = 10330
	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)	Moisture content % (db)
05	33.02	39.50	40.75	31.25	36.50	40.45	28.30	33.62	39.00
10	23.52	33.40	36.00	20.48	29.40	35.70	18.79	29.10	33.19
15	17.82	27.85	31.10	16.54	24.35	31.00	13.71	23.00	29.29
20	15.50	24.45	27.80	14.20	19.80	27.60	10.68	18.40	25.67
25	12.22	21.40	23.92	11.70	16.50	23.53	10.10	15.50	22.52
30	10.47	19.20	20.10	10.00	13.50	19.67	9.50	13.00	17.99
35	10.04	15.78	17.79	9.40	12.47	17.50	7.85	10.50	14.99

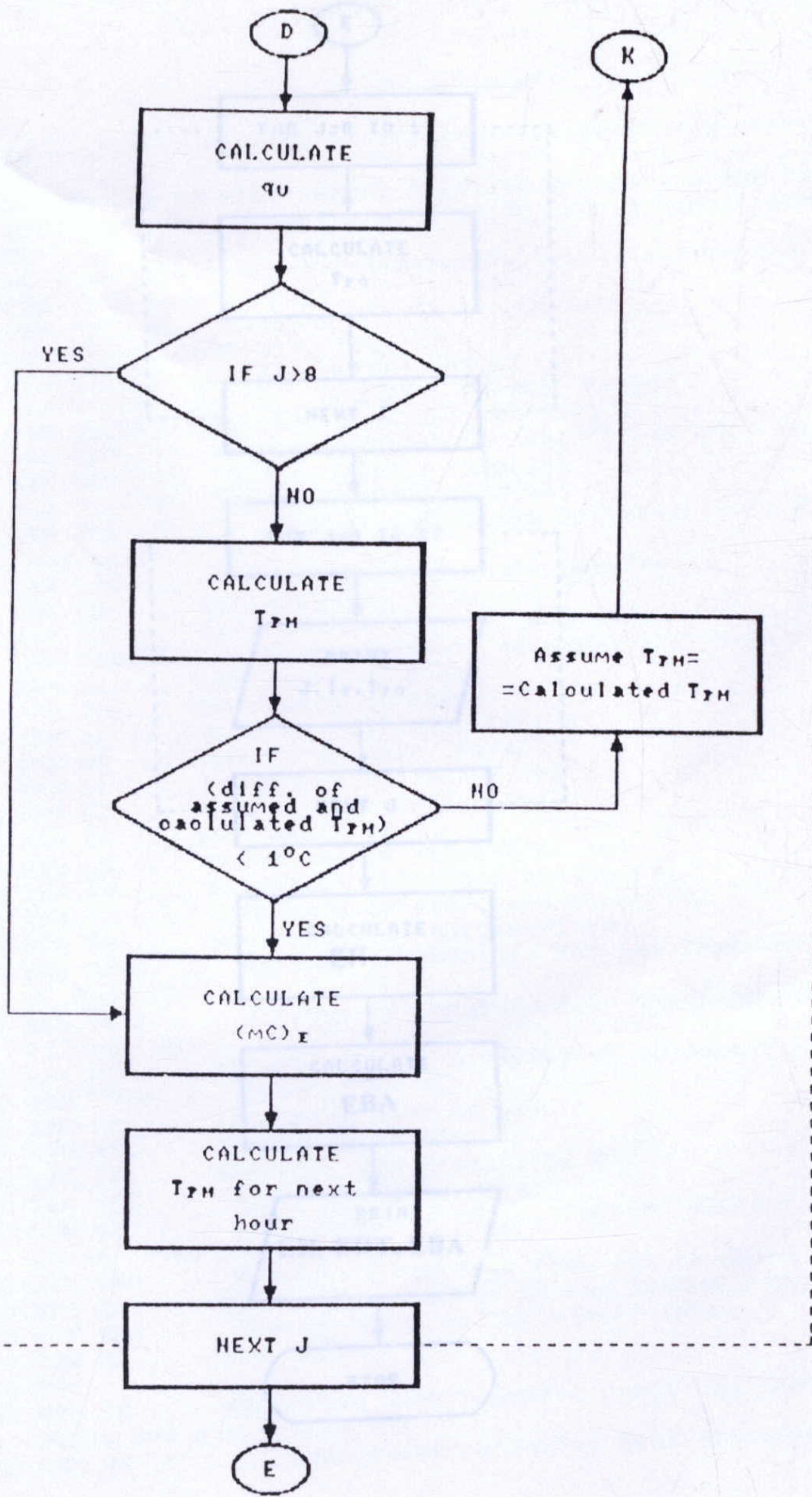
FLOWCHART OF COMPUTER PROGRAM

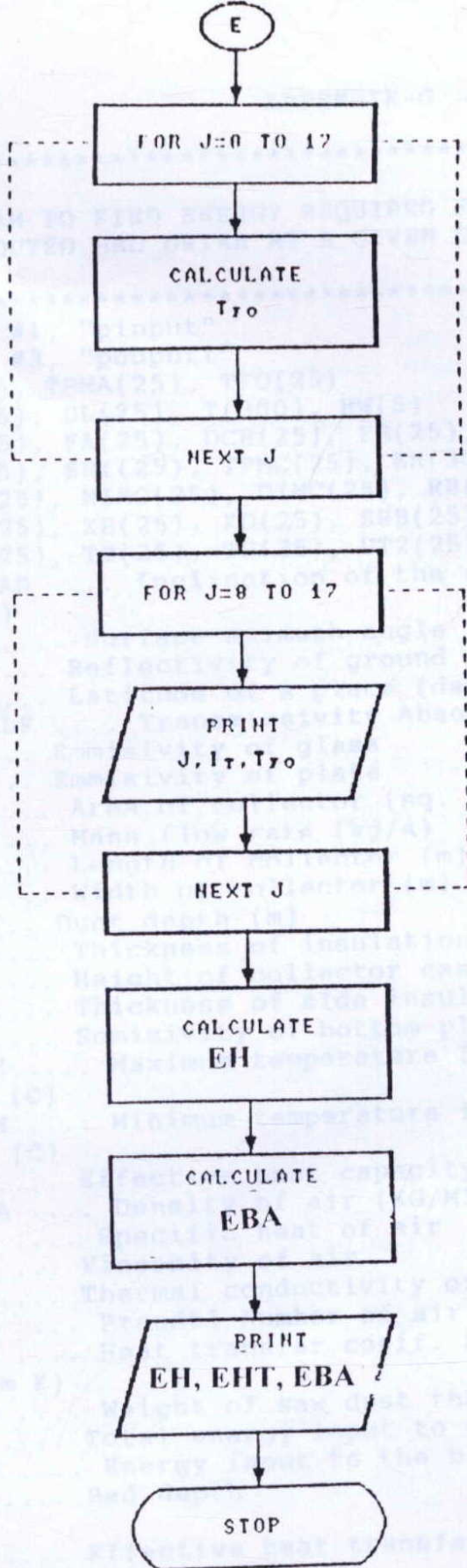












APPENDIX-G

```

10 REM *****
20 REM
30 REM PROGRAM TO FIND ENERGY REQUIRED FOR DRYING THE SAWDUST IN
   LINEAR SPOUTED BED DRIER AT A GIVEN GEOGRAPHICAL LOCATION
50 REM
60 REM *****
70 OPEN "I", #1, "pinput"
80 OPEN "O", #3, "pouputt"
90 DIM TA(25), TPMA(25), TFO(25)
100 DIM UT(25), UL(25), T(300), HW(5)
110 DIM hr(25), FA(25), DCR(25), FB(25), FR(25)
120 DIM QU(25), SRI(25), TPMC(25), EH(300)
130 DIM DEC(25), NINC(25), DINC(25), RB(25), SR(25), R(25)
140 DIM SRD(25), XB(25), XD(25), SRB(25)
150 DIM TCA(25), TC(25), TS(25), UT2(25)
160 REM BEETAD .... Inclination of the collector with horizontal
   (degrees)
170 REM AZS .... Surface azimuth angle (degrees)
180 REM RO .... Reflectivity of ground
190 REM LD .... Latitude of a place (degrees)
200 REM TAUALF .... Transmissivity Absorptivity Product
210 REM EG.... Emmisivity of glass
220 REM EP.... Emmisivity of plate
230 REM AP .... Area of collector (sq. m)
240 REM MR .... Mass flow rate (kg/s)
250 REM L1 .... Length of collector (m)
260 REM L2 .... Width of collector (m)
270 REM L3 ... Duct depth (m)
280 REM L4 .... Thickness of insulation (m)
290 REM L6 .... Height of collector casing (m)
300 REM L7 .... Thickness of side insulation (m)
310 REM EB .... Emmisivity of bottom plate
320 REM TMAX .... Maximum temperature for the representative day
   of Nov. (C)
330 REM TMIN .... Minimum temperature for the representative day
   of Nov. (C)
340 REM MC .... Effective heat capacity of collector (J/C)
350 REM DTYA .... Density of air (KG/M3)
360 REM CPA .... Specific heat of air
370 REM MUA ... Viscosity of air
380 REM KA .... Thermal conductivity of air
390 REM PRA .... Prandtl Number of air
400 REM HFP .... Heat transfer coeff. between fluid & plate
   (W/sq. m K)
410 REM WSD .... Weight of saw dust that can be dried (kg)
420 REM EH .... Total energy input to the system (Whr)
430 REM EBA .... Energy input to the blower (Whr)
440 REM BD .... Bed depth
470 REM
480 REM HE .... Effective heat transfer coeff. between absorber
   plate and air stream
500 REM HR (I) .... Equivalent radiative heat transfer coeff.

```

500 REM HR (I) Equivalent radiative heat transfer coeff.
 510 REM SIGMA Stephan -Boltzmann constant
 520 REM K Thermal conductivity of insulation (W/m-K)
 530 REM L4 Thickness of insulation (m)
 540 REM UB Bottom loss coeff. (W/sq. m. K)
 550 REM US Side loss coeff. (W/sq. m. K)
 560 REM Subscript I Time during the day
 570 REM FA (I) ... Collector efficiency factor
 580 REM DCR (I) Dimensionless capacitance rate
 590 REM FB (I) Collector flow factor
 600 REM FR(I) Collector heat removal factor
 610 REM QU (I) Useful Energy gain (W/sq. m)
 620 REM HFB Heat transfer coeff. between fluid and bottom
 plate (W/sq. m K)
 630 REM DH Hydraulic diameter (m)
 640 REM VI Velocity of air in duct (M/s)
 650 REM RE Reynolds number
 660 REM NU Nusselt Number
 670 REM UT (I) Top loss coeff. (W/sq. m K)
 680 REM HW Convective heat transfer coeff. due to wind
 (W/sq. m K)
 690 REM N Number of covers
 700 REM TPMA (I) Mean plate temperature (C)
 710 REM TCA (I) Assumed cover temperature (C)
 720 REM TC (I) Calculated cover temperature (C)
 730 REM XB (I) Ratio of hourly beam rad. to total rad. on
 horizontal
 740 REM XD (I) Ration of hourly diffuse rad. to total rad.
 on horizontal
 750 REM TS (I) Sky temperature (C)
 760 REM SRI (I) ... Solar radiation intensity on inclined surface
 (W/sq. m)
 770 REM TA (I) Ambient temperature
 780 REM M (N) Drying time (minute)
 790 REM UT2 (I) Top loss coeff. of cover (W/sq. m K)
 800 REM TFO (I) Fluid outlet temperature (C)
 810 REM R1 Density of glass (kg/m3)
 820 REM K1 Thermal conductivity of glass (J/kg/K)
 830 REM T1 Thickness of glass (m)
 840 REM R2 Density of glass wool (kg/m3)
 850 REM K2 Thermal conductivity of glass wool (J/kg/K)
 860 REM R3 Density of G.I. Sheet (kg/m3)
 870 REM K3 Thermal conductivity of G.I. sheet (J/kg K)
 880 REM T3 Thickness of G.I. Shett (m)
 890 REM T4 Thickness of angle iron (m)
 900 REM L5 Total length of angle iron (m)
 910 REM C1 Heat capacity of glass (J/C)
 920 REM C2 Heat capacity of galsss wool (J/C)
 930 REM C3 Heat capacity of iron (J/C)
 940 CLS
 950 SIGMA = 5.67E-08
 960 REM *****
 970 REM

980 REM Input variables

990 REM

1000 REM *****

1010 BEETA = 45

1020 LD = 31

1030 AZS = 0

1040 RO = .2

1050 TAUALF = .85

1060 EG = .95

1070 EP = .95

1080 HW = 10

1090 N = 1

1100 K = .04

1110 L4 = .065

1120 L6 = .15

1130 L7 = .05

1140 EB = .95

1150 TMAX = 26.2

1160 TMIN = 10.1

1170 DTYA = 1.094

1180 CPA = 1005

1190 MUA = .0000196

1200 KA = .0283

1210 PRA = .698

1220 RI = 2700

1230 K1 = 840

1240 T1 = .004

1250 R2 = 24

1260 K2 = 700

1270 R3 = 7849

1280 K3 = 452

1290 T3 = .001

1300 T4 = .003

1310 L5 = 9

1320 INPUT "Area of collector (sq.m)="; AP

1330 INPUT "Mass flow rate (kg/s)="; MR

1340 INPUT "Ratio of length to width="; R

1350 INPUT "Duct depth (m) ="; L3

1360 REM *****

1370 REM

1380 REM End of input variables

1390 REM

1400 REM *****

1410 REM

1420 REM *****

1430 REM

1440 REM TO FIND TOTAL RADIATION INCIDENT ON INCLINED PLANE

1450 REM

1460 REM *****

1470 REM

1480 REM To find declination angle for representative day

1490 REM

1500 DR = 3.1415927# / 180

1510 DN = 318

```

1520 XX = (360 / 365) * (284 + DN)
1530 XX1 = XX * DR
1540 YY = SIN(XXI)
1550 DEC = 23.45 * YY
1560 REM
1570 REM To find factor to convert beam radiation on horizontal
      surface
1580 REM To beam radiation on inclined plane
1590 REM
1600 LR = LD * DR
1610 AZSR = AZS * DR
1620 BEETAR = BEETAD * DR
1630 FOR I = 6 TO 12
1640 HD = (I - 12) * 15
1650 hr = HD * DR
1660 A1 = DEC * DR
1670 DINC(I) = SIN(A1) * SIN(LR) + COS(A1) * COS(LR) * COS(hr)
1680 A2 = SIN(A1) * SIN(LR) * COS(BEETAR)
1690 A3 = SIN(A1) * COS(LR) * SIN(BEETAR) * COS(AZSR)
1700 A5 = COS(A1) * SIN(LR) * SIN(BEETAR) * COS(AZSR) * COS(hr)
1710 A4 = COS(A1) * COS(LR) * COS(BEETAR) * COS(hr)
1720 A6 = COS(A1) * SIN(BEETAR) * SIN(AZSR) * SIN(hr)
1730 NINC(I) = A2 - A3 + A4 + A5 + A6
1740 RB(I) = NINC(I) / DINC(I)
1750 NEXT I
1760 REM
1770 RB(13) = RB(11)
1780 RB(14) = RB(10)
1790 RB(15) = RB(9)
1800 RB(16) = RB(8)
1810 RB(17) = RB(7)
1820 RB(18) = RB(6)
1830 RB(19) = 0
1840 REM
1850 REM To read data from data set for hourly total radiation on
      horizontal surface
1870 REM
1880 FOR I = 6 TO 19
1890 INPUT #1, SR(I)
1900 NEXT I
1910 REM
1920 REM To read data for hourly diffuse radiation on horizontal
      surface
1940 FOR I = 6 TO 19
1950 INPUT #1, SRD(I)
1960 NEXT I
1970 REM
1980 REM To find value of XB and XD
1990 REM
2000 FOR I = 6 TO 19
2010 SRB(I) = SR(I) - SRD(I)
2020 IF SR(I) = 0 THEN XB(I) = 0
2030 IF SR(I) = 0 THEN XD(I) = 0
2040 IF SR(I) = 0 THEN GOTO 2070

```

```

2050 XB(I) = SRB(I) / SR(I)
2060 XD(I) = SRD(I) / SR(I)
2070 RR = (1 - COS(BEETAR)) / 2
2080 RR = RR * RO
2090 RD = (1 + COS(BEETAR)) / 2
2100 R(I) = XB(I) * RB(I) + XD(I) * RD + RR
2110 SRI(I) = R(I) * SR(I)
2120 SRI(I) = SRI(I) * 1000
2130 PRINT SRI(I)
2140 NEXT I
2150 PRINT "REACHED 2150"
2160 REM *****
2170 REM
2180 REM           To calculate ambient temperature
2190 REM
2200 REM *****
2210 AA = (TMAX - TMIN) / 2
2220 TMEAN = TMAX - AA
2230 THETA = 0
2240 FOR J = 8 TO 19
2250 THETAR = THETA * 3.14159 / 180
2260 TA(I) = TMEAN + AA * SIN(THETAR)
2270 THETA = THETA + 15
2280 NEXT J
2290 REM
2300 REM *****
2310 REM
2320 REM Assuming cover temperature TCA(I) 1 C above ambient
    temperature for first iteration
2340 REM
2350 REM *****
2360 FOR I = 9 TO 17
2370 TCA(I) = TA(I) + 273 + 1
2380 TS(I) = TA(I) - 6 + 273
2390 NEXT I
2400 REM
2410 REM *****
2420 REM
2430 REM Assuming cover temperature TPMA(I) I C above ambient
    temperature for 8.00 a.m. for first iteration
2450 REM
2460 REM *****
2470 I = 9
2480 TPMA(I) = TA(I) + 273 + 1
2490 L2 = SQR(AP / R)
2500 L1 = R * L2
2510 C1 = AP * T1 * R1 * K1
2520 C2 = AP * L4 * R2 * K2 / 2
2530 C3 = R3 * (2 * AP * T3 + L5 * .04 * T4) * K3
2540 REM
2550 REM           T find HFP & HFB
2560 REM
2570 DH = 4 * L2 * L3 / (2 * (L2 + L3))
2580 VI = MR / (DTYA * L2 * L3)

```

```

2590 RE = DTYA * VI * DH / MUA
2600 IF RE > 2300 THEN 2640
2610 AA = RE * PRA * DH / L1
2620 NU = 5.4 + ((.0019 * (AA) ^ 1.71) / (1 + .00563 * (AA) ^ 1.17))
2630 GOTO 2650
2640 NU = .0158 * ((RE) ^ .8)
2650 HFP = NU * KA / DH
2660 HFB = HFP
2670 REM *****
2680 REM
2690 REM          TO FIND USEFUL HEAT GAIN (W/sq. m)
2700 REM
2710 REM *****
2720 REM
2730 C = 520 * (1 - .000051 * (BEETAD) ^ 2)
2740 F = (1 + .089 * HW - .1166 * HW * EP) * (1 + .07866 * N)
2750 FOR I = 9 TO 17
2760 E = .43 * (1 - (100 / TPMA(I)))
2770 hr(I) = 4 * SIGMA * (TPMA(I) ^ 3) / ((1 / EP) + (1 / EB) - 1)
2780 U1 = (C / TPMA(I)) * (((TPMA(I) - 273 - TA(I)) / (N + F)) ^ R)
2790 U2 = SIGMA * (TPMA(I) + TA(I) + 273) * ((TPMA(I)) ^ 2 +
      (TA(I) + 273) ^ 2)
2800 U3 = EP + .00591 * N * HW
2810 U4 = (2 * N + F - 1 + .133 * EP) / EG
2820 UT(I) = (1 / ((N/U1) + (1/HW))) + (U2 / ((1/U3) + U4 - N))
2830 UT2(I) = (HW * (TCA(I) - (TA(I) + 273)) + (SIGMA * EG *
      (TCA(I) ^ 4 - TS(I) ^ 4))) / (TCA(I) - TA(I) - 273)
2840 TC(I) = (TA(I) + 273) + (UT(I) * (TPMA(I) - (TA(I) + 273))
      / UT2(I))
2850 ZZ = ABS(TC(I) - TCA(I))
2860 IF ZZ < 1 THEN 2890
2870 TCA(I) = TC(I)
2880 GOTO 2830
2890 MC = C2 + C3 + (C1 * UT(I) / UT2(I))
2900 UB = K / L4
2910 US = (L1 + L2) * L6 * K / (L1 * L2 * L7)
2920 UL(I) = UT(I) + UB + US
2930 HE = HFP + (hr(I) * HFB / (hr(I) + HFB))
2940 FA(I) = 1 / (1 + (UL(I) / HE))
2950 DCR(I) = MR * CPA / (AP * UL(I) * FA(I))
2960 FB(I) = DCR(I) * (1 - EXP(-1 / DCR(I)))
2970 FR(I) = FA(I) * FB(I)
2980 QU(I) = FR(I) * SRI(I) * TAUALF
2990 IF I > 9 THEN 3040
3000 TPMC(I) = (273 + TA(I)) + QU(I) * (1 - FR(I)) / (UL(I) * FR(I))
3010 IF (ABS(TPMC(I) - TPMA(I))) < 1 THEN 3040
3020 TPMA(I) = TPMC(I)
3030 GOTO 2760
3040 A = SRI(I) - QU(I)
3050 TPMA(I + 1) = (TA(I) + 273) + (1 / UL(I)) * (A - (A - UL(I)
      * (TPMA(I) - (TA(I) + 273))) * EXP(-AP * UL(I) * 3600 / MC))
3060 NEXT I
3070 REM
3080 REM *****

```

```

3090 REM

3100 REM                               To find air outlet temperature
3110 REM
3120 REM *****
3130 FOR I = 9 TO 17
3140 TFO(I) = TA(I) + (QU(I) * AP / (MR * CPA))
3150 NEXT I
3160 TFO = TFO(9)
3170 FOR I = 10 TO 17
3180 IF TFO > TFO(I) THEN 3210
3190 TFO = TFO(I)
3200 NEXT I
3210 IF (ABS(TFO - 52)) < 1 THEN 3300
3220 MR = MR - .0005
3230 PRINT MR
3240 GOTO 2570
3250 REM *****
3260 REM
3270 REM                               RESULTS
3280 REM
3290 REM *****
3300 PRINT #3, "Collector area ="; AP; "sq.m"
3310 PRINT #3, "Collector length ="; L1; "m"
3320 PRINT #3, "Collector width ="; L2; "m"
3330 PRINT #3, "Duct depth ="; L3; "m"
3340 PRINT #3, "Mass flow rate ="; MR; "kg/s"
3342 PRINT #3, "Mass flow rate of air required in solar assisted
spouted bed dryer ="; MRRS; "kg/s"
3344 PRINT #3, "No. of air heaters required ="; nah;
3346 PRINT #3, "Energy consumed by electric blower for all air
heaters = "; EBA;"
3350 PRINT #3, "I          "; "SRI(I)          "; "TFO(I)          ",
"DELTA T", "EH"
3354 MRRS = 3.1415927 * .25 * .018 * .018 * 373.06 * 1.11
3356 nah = MRRS / MR
3360 FOR I = 9 TO 17
3362 DELTA = 45 - TFO(I)
3364 ENER = (3.1415927 * 0.018 * 0.018 * 373.06 * 1.11 * .25 *
1005 * DELTA) / 1000
3366 IF (DELTA) < 0 THEN DELT = 0!
3368 IF ENER < 0 THEN ENER = 0!
3370 PRINT #3, I, SRI(I), TFO(I), DELT, ENER
3380 NEXT I
3390 REM
3400 REM *****
3410 REM
3420 REM       Calculation of total energy input to the system
3430 REM
3440 REM *****
3450 REM
3460 BH = 20
3470 M(BH) = 50
3480 FOR I = 1 TO 60
3490 T(I) = TFO(9)

```

linear spouted bed dryers ="; EHT;" kW-hr"

5040 PRINT #3, "Energy required per kg of saw dust ="; ERPS;
" kW-hr"

5050 END

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