Solar Electric Wood Seasoning Kiln

A final year project report

Presented to

SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING

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In Partial Fulfillment

Of the Requirements for the Degree of

Bachelors of Mechanical Engineering

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ABSTRACT

Wood is a highly versatile material and has a long history of use. It is used in numerous industries and is particularly famous and preferred material for furniture. In order to use wood it requires pre-processing i.e. drying of wood. In the local market green wood is relatively inexpensive where as dry wood is 25-35 % more expensive than green wood. Natural air seasoning is a very lengthy process often taking four to nine months.

The motivation behind this project is to develop a hybrid wood seasoning kiln for the local industries of Pakistan. This project is aimed at providing a cost effective and energy efficient solution to the local wood industries of Pakistan. With the help of this hybrid wood seasoning kiln wood drying process can be completed in 3-4 weeks drastically improving the time required to dry wood.

PREFACE

This report was drafted as a result of efforts made to determine the parameters required in the design of Hybrid Wood Seasoning Kiln, which we have taken up as our final year project for B.Sc. Mechanical Engineering Program.

A group of 4 students are responsible for delivering the working prototype of this project. We have made every effort to deliver this project report and we hope that it meets the expectations of our supervisor and the examination committee.

Theoretical knowledge and practical experience of the industry, gained through industry visits, make the foundations of this report.

In this report we aim to provide the theoretical aspects of manufacturing a Hybrid Wood Seasoning Kiln along with calculations for various parameters for kiln design.

ACKNOWLEDGMENTS

We would like to thank Dr. Mushtaq Khan for his guidance and supervision in for this project. His cooperation and support was valuable in the formation of this report. We would also like to appreciate the facilities and effort provided by Dr. Khalid Akhtar (HoD Mech). We would also like to thank the workshop technicians who have provided us valuable help in our project.

In the end, we are gratified to have helping friends and family members who are a constant source of support and guidance.

ORIGINALITY REPORT

We hereby confirm that this is report is solely the work of above mentioned group members under the supervision of Dr. Mushtaq Khan. The similarities however may occur in some articles which have been referenced at the end of the report.

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ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Ugwu, S.N., B.O. Ugwuishiwu, O.V. Ekechukwu, H. Njoku, and A.O. Ani. "Design, construction, and evaluation of a mixed mode solar kiln with black-painted pebble bed for timber seasoning in a tropical setting", Renewable and Sustainable Energy Reviews, 2015. Publication	3%
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NOMENCLATURE

ODW:	Oven dry weight of wood MC: moisture content
$Q_{supplied}$	Total heat supplied by the collectors and the heaters
Q_{Timber}	Heat absorbed due to Timber stack
Q_{Loss}	Heat lost through convection and conduction to the environment
I	Total rate of incident solar radiation on the solar collector (Wm^{-2})
A_c	Collector Area
Q_U	Rate of useful energy collected by air (W)
Q_{cond}	Rate of conduction losses from collector (W)
Q_{conv}	Rate of Convection losses from collector (W)
Q_R	Rate of long wave re-radiation from the collector (W)
Q_ρ	Rate of Reflection losses from the collector (W)

CHAPTER 1

INTRODUCTION

The process of wood seasoning involves removing the moisture from the wood either through artificial or natural means. The necessity of drying of wood arises from the fact that moist wood is more prone to decay. The moisture content of wood is reduced up to 6 % -8 %, so that wood is in an equilibrium state with the environment. This drying process allows wood to have a prolonged life and stable state. Drying of wood is a desired topic in the timber markets of the world.

In this report we aim to provide the theoretical aspects of manufacturing a Hybrid Wood Seasoning Kiln along with calculations for various parameters of kiln design.

Benefits of wood seasoning

- Prevention against primary decay, fungal stain and certain types of insects.
- Lighter than green wood and hence easier to transport.
- Stronger than green wood (Unseasoned wood) in most strength properties.
- Finishing, coloring and gluing is easier and better than green wood.

Industrial Scope

The industrial importance of this project in Pakistan is self-evident and can be understood by observing the current situation of the timber market. Mostly companies rely on the natural process of seasoning the wood which is time taking.

As a result, most of companies want to approach the market for wood seasoning kilns but there is no solution to this problem available in Pakistan at the moment. Unavailability of wood kilns is one issue. There is an acute power shortage in Pakistan and this forces the industrial sector to either shutdown or pay huge sums of money for electricity.

Our projects caters the needs of wood industry of Pakistan by providing them with Hybrid Wood Seasoning Kilns which will not only speed up the wood drying process but also address the problem of power shortage in wood industries.

To get to know the needs of wood industries of Pakistan we conducted a survey and visited certain furniture industries of Pakistan to get an idea of the technical problems faced by them. As a result we received a positive response from the companies such as Hazara Doors, Pak China wood Working center Peshawar, Furniture Pakistan Gujrat.

CHAPTER 2

LITERATURE REVIEW

We have reviewed numerous research articles to get the basic idea of the factors affecting the wood drying process. Listed below are the major parameters which need to be considered in kiln design

WOOD WATER RELATIONSHIPS

Fresh wood contains a large amount of water which constitutes 50% of its weight. Water is present in following three forms.

Free water:

The bulk of the water held in the Lumina is only held by the capillary forces and is not chemically bound to it. Free water is not in the same thermodynamic state as the liquid water. Energy is required to overcome the capillary forces.

Bound/Hygroscopic water

Bound water is bound to the wood via hydrogen bonds. The attraction of wood for water arises from the presence of free hydroxyl (OH) groups in the cellulose, hemicelluloses and lignin molecules in the cell wall. The hydroxyl groups are negatively charged. Because water is a polar liquid, the free hydroxyl groups in cellulose attract and hold water by hydrogen bonding. (Britannica, 2015)

Vapor

Water in Lumina is also present in the vapor form but it is mostly negligible and is not considered.

DRIVING FORCES FOR MOISTURE MOVEMENT

Capillary action

Water movement in the cells in wood is determined through capillary action. As wood dries evaporation of water from the surface sets up capillary forces that exert pull force.

Moisture content differences

Equilibrium will occur at the equilibrium moisture content of wood when the chemical potential of the wood becomes equal to that of the surrounding air. Greater the moisture difference greater will be the drying gradient. (Britannica, 2015)

FACTOR INFLUENCING WOOD SEASONING

The external conditions which are also the boundary situations help in the drying of the wood are as follows.

Temperature

While keeping relative humidity constant higher the temperature the greater the wood drying rate. Air at higher temperature has increased capacity to store moisture hence increasing the diffusion rate by quite a bit so we can say that

$$Rate\ of\ drying\ \propto Temperature$$

Relative Humidity

The partial pressure of water vapor divided by the saturated water pressure at the same temperature and pressure is called as relative humidity. Lower relative humidity will result in higher drying rates which will result in reduction of moisture content.

$$Rate\ of\ drying\ \propto \frac{1}{Relative\ Humidity}$$

Air Circulation

Drying time and timber quality depend on the air velocity and its uniform circulation. At a constant temperature and relative humidity, the highest possible drying rate is obtained by rapid circulation of air across the surface of wood, giving rapid removal of moisture evaporating from the wood.

$$Rate\ of\ Drying\ \propto Air\ Circulation$$

At very low fan speeds, less than 1 m/s, the air flow through the stack is often laminar flow, and the heat transfer between the timber surface and the moving air stream is not particularly effective. So turbulent flow is generally more desired for more proper mixing. (Britannica, 2015)

CAUTION FACTOR

We have to observe the fact that very high drying rates will result in the cracking of the wood. Different types of woods will have different types of drying rates so proper caution is necessary while fixing the drying rates.

MOISTURE CONTENT

The moisture content in the wood is our main concern for the wood seasoning so the method we will be using will be measured by using the following equation

$$Moisture\ Content = w_d - w_m \times 100\%$$

Here

$$w_m = weight\ of\ moist\ wood$$

$$w_d = weight\ of\ dry\ wood$$

CAD MODEL OF PROPOSED DESIGN

A Computer Aided Design of the proposed CAD model was made in SolidWorks to visualize the overall structure and shape of the Kiln. The model is in a trapezoidal shape. The Dimensions of the model are kept at a moderate size. The width and length are .75m x 1.5m and the height is 1.5m at the highest end whereas .75m at the lowest end.

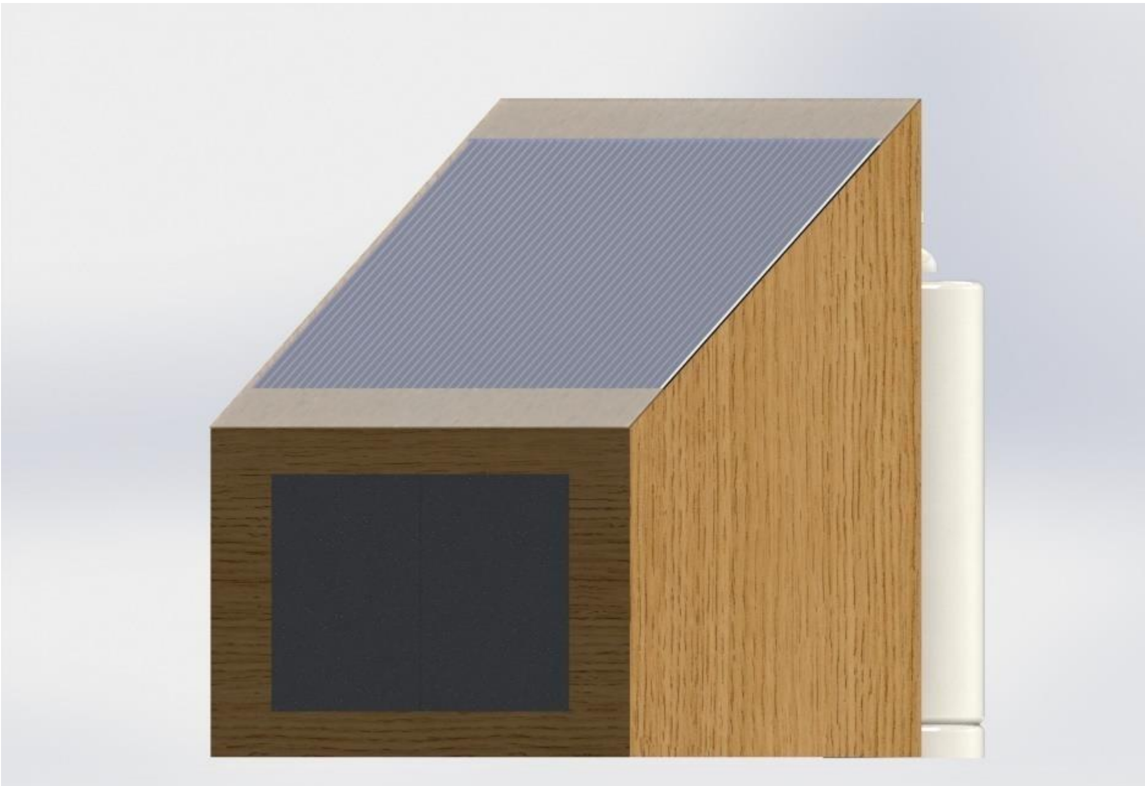

Figure 1 Proposed Kiln Design

The kiln is a Solar-Thermal hybrid design. It consists of a basic kiln with solar collectors and a water geyser for the hybrid action and heating during winters and rainy days. The solar collectors will be installed at the back of the kiln to address the size issues of the kiln and to make it easily moveable.

Figure 2 Kiln with collector

The Thermal water geyser will provide the required heating during the winter and rainy days.

A variety of fuels can be used to run the thermal water heater but we propose using Biomass or equivalent renewable sources of heat to be used.

THEORY AND CALCULATIONS

Heat balance equations are used to determine the heat transfer from the collector to the chamber. Second law of thermodynamics is utilized to calculate the thermal load of the kiln. The following Assumptions were made for the calculations:

- Steady State Conditions exist in the system
- Heat flows in one dimension only
- The thermal conductivity of materials is constant
- The kiln is a taken to a closed system

The calculations are as follows

$$\text{Thermal Load (Q)} = \text{Total Heat input } (Q_{supplied}) - \text{Total Heat Output } (Q_{Timber} - Q_{Loss}) \quad (1)$$

Where:

Q = Thermal Load

$Q_{supplied}$ = Total heat supplied by the collectors and the heaters

Q_{Timber} = Heat absorbed due to Timber stack

Q_{Loss} = Heat lost through convection and Conduction to the environment

$$\text{Total Heat Input} = Q_{Supplied} = Q_{Collector} + Q_{water\ heater} \quad (2)$$

$$\text{Total Heat Output} = Q_{loss} = Q_{Conduction} + Q_{Convection} - Q_{Wood} \quad (3)$$

Where:

$Q_{Conduction}$ = Amount of heat lost to the atmosphere by Conduction (W)

$Q_{Convection}$ = Amount of heat lost to the atmosphere by Convection (W)

Q_{Wood} = Amount of heat consumed per unit time (W)

The energy balance across the solar collector was calculated by using conservation of energy across the collector

$$I.A_c = Q_U + Q_{cond} + Q_{conv} + Q_R + Q_\rho \qquad (4)$$

Where:

I = total Rate of Incident solar radiation on the Solar Collector (Wm^{-2})

A_c = Collector Area

Q_U = Rate of useful energy collected by Air (W)

Q_{cond} = Rate of conduction losses from Collector (W) Q_{conv} = Rate of Convection losses from Collector (W)

Q_R = Rate of long wave re-radiation from the Collector (W)

Q_ρ = Rate of Reflection losses from the Collector (W)

Q_U is the quantity that we are most interested in. We can combine the three heat loss term into one Q_L Term.

$$Q_L = Q_{cond} + Q_{conv} + Q_R \qquad (5)$$

If the top glass glazing has a transmittance value of τ and the total incident solar radiation on the top surface is I_T, Then,

$$I.A_c = \tau.I_T.A_c \qquad (6)$$

The reflected energy from the collector surface is then given by applying the reflection coefficient of the absorber ρ.

$$Q_\rho = \rho.\tau.I_T.A_c \qquad (7)$$

Substituting Eq (5-7) in Eq (4), we get:

$$\tau.I_T.A_c = Q_u + Q_L + \rho.\tau.I_T.A_c$$

$$Q_U = \tau.IT.A_c.\,(1\text{-}\rho)\text{-}Q_L \qquad (8)$$

(Rearranging)

For an absorber $(1\text{-}\rho) = \alpha$ (Solar Absorbtance)

$$Q_U = (\alpha.\tau).I_T\,.A_C\,\text{-}Q_L \qquad (9)$$

The total Heat Loss Q_L is composed of a variety of heat loss including Conductive, convective and radiative heat losses. Collectively they can all written as

$$Q_L = U_L\,.A_{C.}\,(T_C - T_a)$$

Where:

U_L = Overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$)

T_C = Collector's temperature

T_a = Ambient air Temperature

Therefore, Eq (9) becomes,

$$Q_U = (\alpha.\tau).I_T.A_C - U_L.A_C.(T_C - T_a) \qquad (10)$$

The energy per unit area of the collector is therefore,

$$Q_U = (\alpha.\tau).I_T - U_L.(T_C - T_a) \qquad (11)$$

When the air is leaving the collector at temperature of the collector, then the heat gained by air will be Q_g

$$Q_g = \dot{m}_a.C_{pa}.(T_c - T_a) \qquad (12)$$

Where:

$\dot{m}_a$ = mass flowrate of air through the collector (kgs^{-1})

C_{pa} = Specific heat capacity of air ($kJ.kg^{-1}K^{-1}$)

The ratio of heat gained by air to the heat gained by the collector is known as the removal Factor (F_R)

$$F_R = \frac{Q_g}{Q_U} = \frac{\dot{m}_a.C_{pa}.(T_c - T_a)}{A_c((\alpha.\tau).I_t - U_L.(T_c - T_a))} \qquad (13)$$

The Thermal efficiency of the collector is can be written as

$$\eta_C = \frac{Q_g}{I_T.A_C} \qquad (14)$$

ENERGY BALANCE FOR THE DRYING PROCESS

According to James ES and Craig ES (James, 1974; 73), there are four basic processes that must be completed before wood can be dried in a Kiln. These processes are as follows

1. Heat the air inside the Kiln
2. Heat any material in the Kiln
3. Provide the required energy for any thermodynamic process to take place such as removing moisture from wood.

4. Compensate for all the losses in the system

Each of these processes has its own energy balance equation to it. The following Specific heat values are used throughout the following calculations

- Air = C_a = 1005.6 K/kg
- Water Vapor = C_W = 1885.5 J/kgK
- Water = C_{H2O} = 4190 K/kg

There are six different Heats involved in the drying process

1. H_1 is the heat required for raising the temperature of wood substance (kJ)

$$H_1 = ODW * C_w * \delta T \quad (kJ) \qquad (15)$$

Where ODW is the oven dry weight of Wood (kg)

2. H_2 is the heat required to overcome the hygroscopic forces (kJ)

$$H_2 = ODW * D \qquad (kJ) \qquad (16)$$

Where D is heat required in J/kg.

3. H_3 is the heat required to raise the temperature of any remainder water in the wood

$$H_3 = W * C_{H2O} * \delta T \qquad (kJ) \qquad (17)$$

4. H_4 is the heat required to evaporate the water from wood

$$H_4 = ODW * \delta MC * t (C_{H2O} * \delta T) + h$$

Where:

- MC = Moisture content in wood (%)
- t = Temperature of water
- h = quantity of water vapor absorbed by the flowing air (kg/kg of air)

5. H_5 is the required heat to humidify the incoming air (J)

6. H6 is the heat required to compensate all the different losses from the system (kJ)

$$H_{6_i} = U_i * Area * \delta T_L$$

$$H_6 = \sum H_{6i} * Total\ Drying\ time\ (hr)$$

With these six heats, the total heat consumed in the Kiln will be

$$H \quad = \quad \sum (H_1 + \quad H_2 + \quad H_3 + \quad H_4 + \quad H_5 + \quad H_6)\ (kJ)$$

Therefore, the quantity of heat consumed per unit time for drying the wood is given by

$$Q_{Wood} = H/\text{drying time (hr.)} \qquad (18)$$

Substituting Eq 16 in Eq 3, we get the total heat loss

$$Q_{Loss} = Q_{cond} + Q_{conv} - Q_{Wood}\ (W) \qquad (19)$$

Moisture content of wood is found by weighing a fresh piece of wood and comparing it the weight of an oven dried similar sample. The difference is recorded and the MC is calculated as follows

$$MC = (\frac{Weight\ of\ wet\ section}{Weight\ of\ oven\ dried\ section} - 1) * 100$$

$$Estimated\ Oven\ Dried\ Temperature\ (g) = \frac{Weight\ of\ wet\ sample}{100 + MC\%}$$

CFD ANALYSIS

CFD analysis of an air heating channel was done initially to model the heating of air in the solar collector channels. The analysis was done using the ANSYS FLUENT software. (Manish Sharma1, 2013)

Governing Equations

Energy Equation

$$\frac{\partial \rho E}{\partial T} + \nabla\big(\upsilon(\rho E + P)\big) = \nabla\big(k_{eff}\nabla T - \textstyle\sum_j h_j J_j + \big(\overline{\overline{\tau_{eff}.\upsilon}}\big)\big) + S_h \qquad (20)$$

$$E = h - \frac{P}{\rho} + \frac{\upsilon^2}{2}$$

$$k_{eff} = k + k_t$$

$$Ji = Diffusion\ Flux$$

$$Sh = Heat\ of\ chemical\ Reaction$$

$$k_t = Turbulent\ conductivity$$

Momentum Equation

$$\frac{\partial(\rho\nu)}{\partial t} + \nabla(\rho\upsilon\upsilon) = -\nabla P + \nabla\bar{\bar{\tau}} + \rho g + F \qquad (21)$$

$$\bar{\bar{\tau}} = Stress\ Tensor$$

$$\bar{\bar{\tau}} = \mu[(\nabla\nu + \nabla\nu^T) - \frac{2}{3}\nabla\upsilon I]$$

$$P = static\ pressure$$

$$F = external\ forces$$

$$\rho g = Gravitational\ forces$$

$$I = unit\ Tensor$$

$$\mu = molecular\ viscosity$$

Continuity Equation

$$\frac{\partial(\rho)}{\partial t} + \nabla(\rho v) = S_m \tag{22}$$

$$S_m = Source\ Mass$$

K-epsilon Model

K

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b - \rho\epsilon - Y_m + S_t \tag{23}$$

e

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial k}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}(P_k + C_{3\epsilon}P_b) - \rho C_{2\epsilon}\frac{\epsilon^2}{k} + S_e \tag{24}$$

CFD ANALYSIS OF COLLECTOR

Geometry

The Geometry for the problem was made using the ANSYS Design Modeler for easy editing and modification later on.

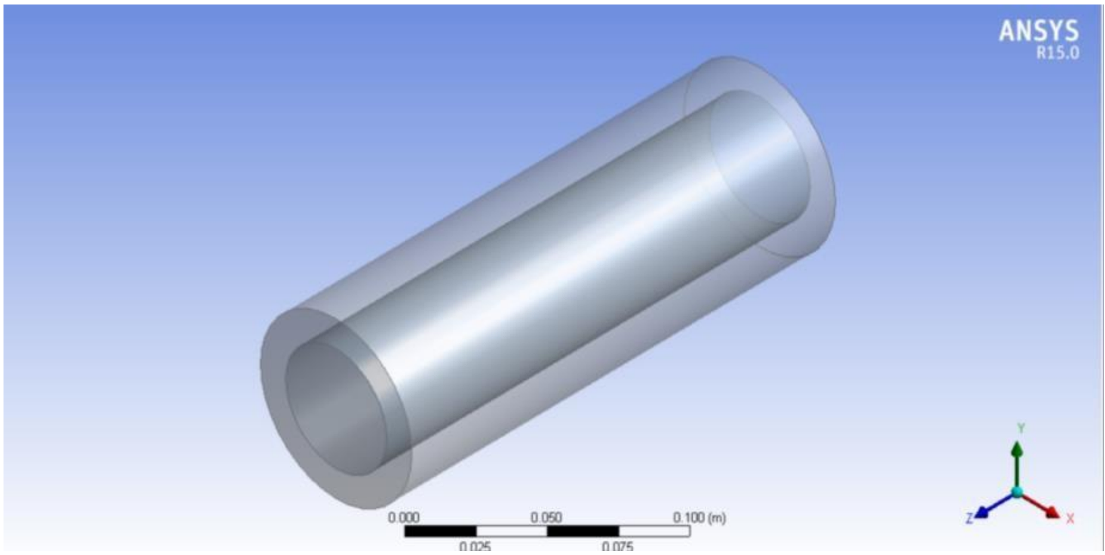

Figure 3 Geometry

There are two distinct zones in the geometry. A central cylindrical geometry is used as the channel for the airflow. The outer cylindrical jacket is used at the heating element to generate the heat.

Mesh

The mesh was made using the ANSYS Mesher. According to the rule of thumb; The LOOKED good to the eye.

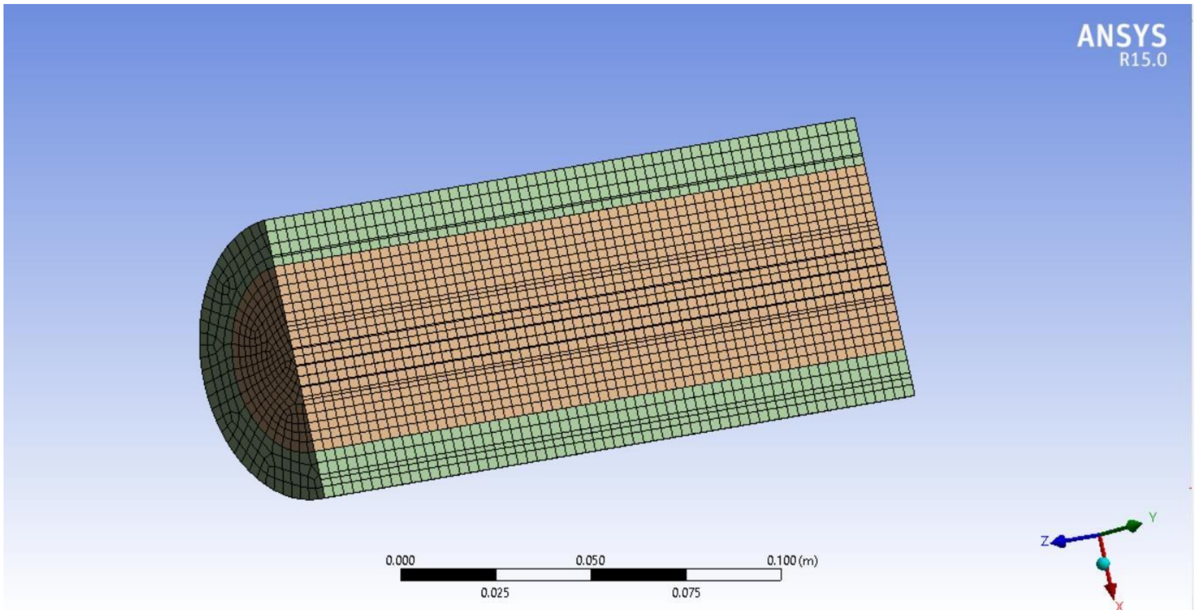

Figure 4 Sectioned Mesh

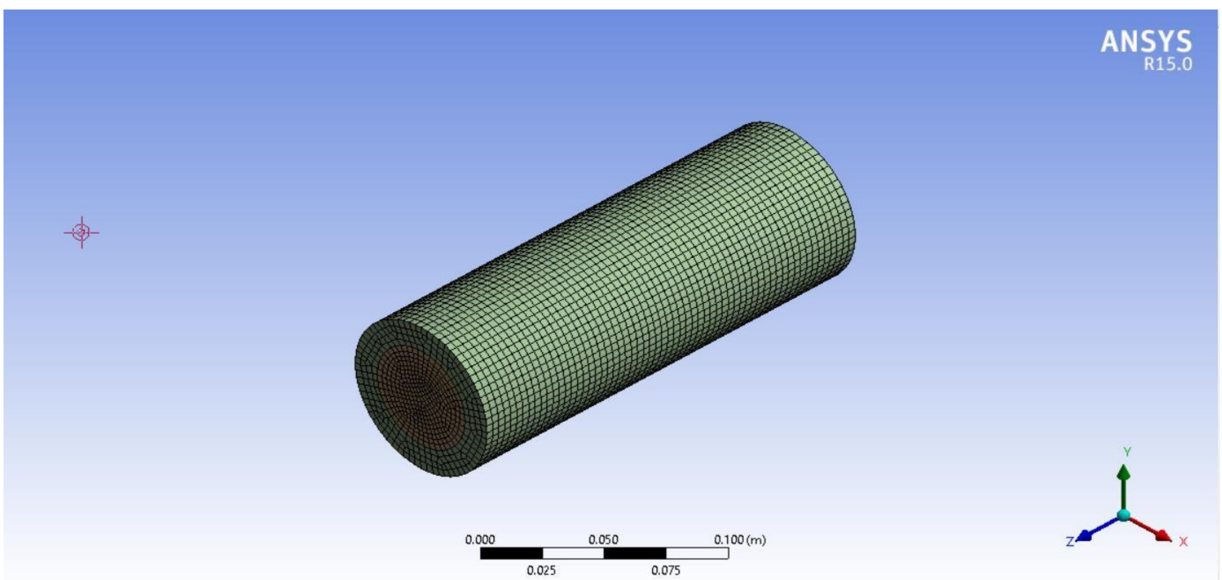

Figure 5 Mesh

As we can see the mesh is mostly in a structured form. This means it is very efficient for handling CPU requirements and will be faster to process. A total of 42,227 nodes and 36,648 elements are present in the mesh.

Problem setup

In this section, we will discuss the problem setup in detail.

Time

Time was taken as Transient. This was mainly done to get control of the flow time of air by using the appropriate time steps.

Models

The Energy equation and a k-epsilon (with RNG, Enhanced wall function) turbulence models were used to model the flow.

Cell zone conditions

The heat generation was modelled in the cell zone condition be adding a source term to the heater cell zone. A value of $30x10^5$ W/m^3 was used a starting point.

Boundary Conditions

The boundary conditions were setup were setup. Inlet air conditions were setup as Velocity-Inlet with air inlet velocity of .14m/s. Outlet was chosen as a Pressure-Outlet. The wall between the heating element and the airflow was set to be in connection with a convection coefficient of 1.5 W/m^2-K. The wall temperature was set at 500k as shown from our calculations.

Initialization

The solution was initialized from the values at inlet.

Monitoring the Solution

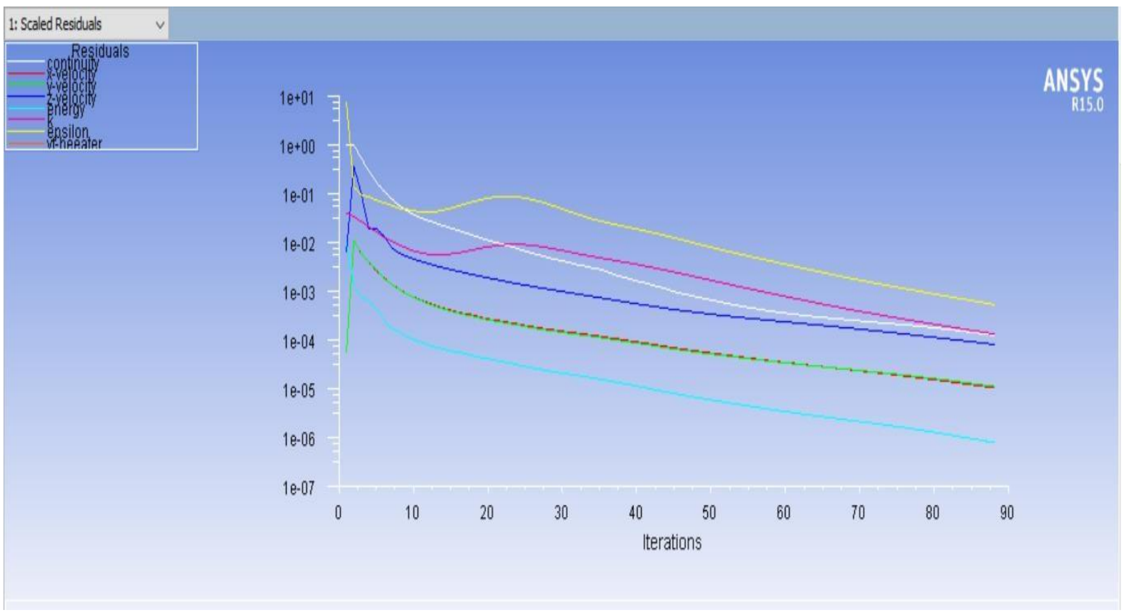

Figure 6 Residuals Contour

The scaled residue graph show that the solution has converged to fairly great degree. Almost all the values have converged to about 10^{-3}.

Solution Setup

We used an implicit scheme of solution. That meant a larger time step could be used. Because of computational and long simulation time, we used a fairly large time step size of 100s to simulate a higher flow time quicker. The accuracy was maintained by having 20 iterations/time step.

RESULTS

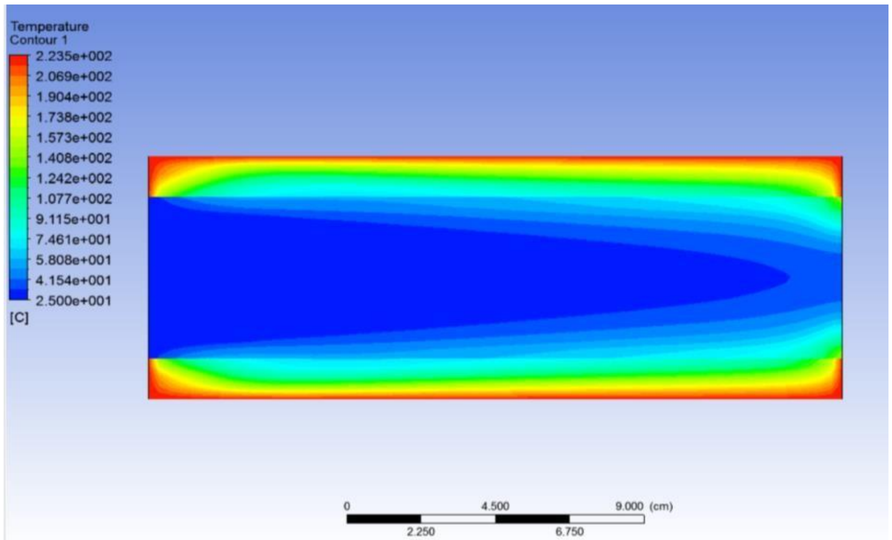

Figure 7 Temperature Contour

The above result is quite satisfactory albeit not the final one. The above result shows the temperate of the air increasing as it passes along the channel in the positive z. direction. More heating could be achieved by using a higher flowtime that will need more computational power and time.

Data results

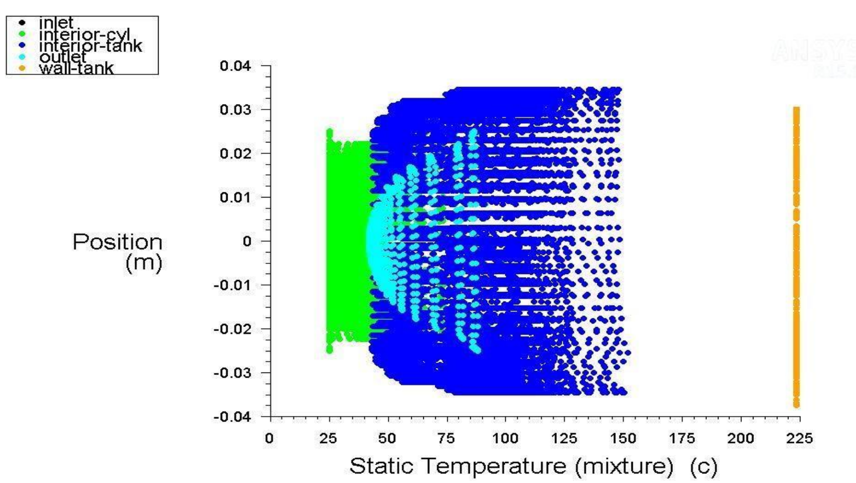

Figure 8 Static Temperature

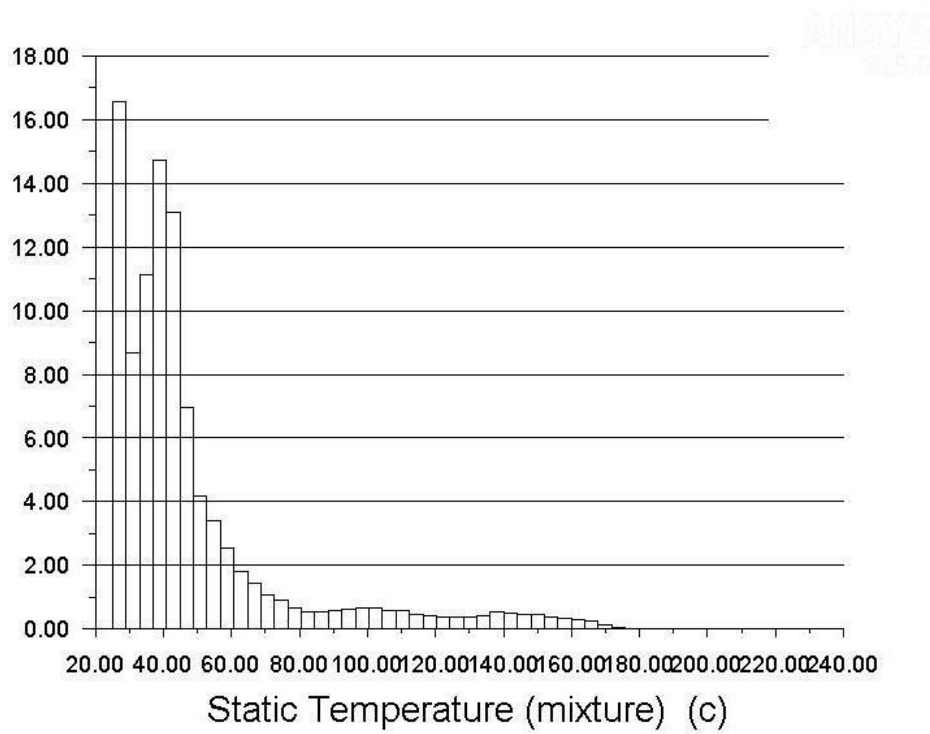

Figure 9 Static Temperature Curve

From above histogram we can observe that most of the temperature of the collector lies in the range of 50-55 degree centigrade. This is our desired range for the seasoning of the wood. So we can observe that our design is going to the desirable direction.

Conclusion

Although the results need more refinement and experimentation. The above set up proves to be working along the expected lines and we hope that it will provide a good starting point for adding more complexities as we incorporate the humidity and porous media into the problem

CFD ANALYSIS OF THE KILN

Geometry and Domain Definition

A Fluid Domain Geometry Was made for CFD study of the air circulation around the Kiln.

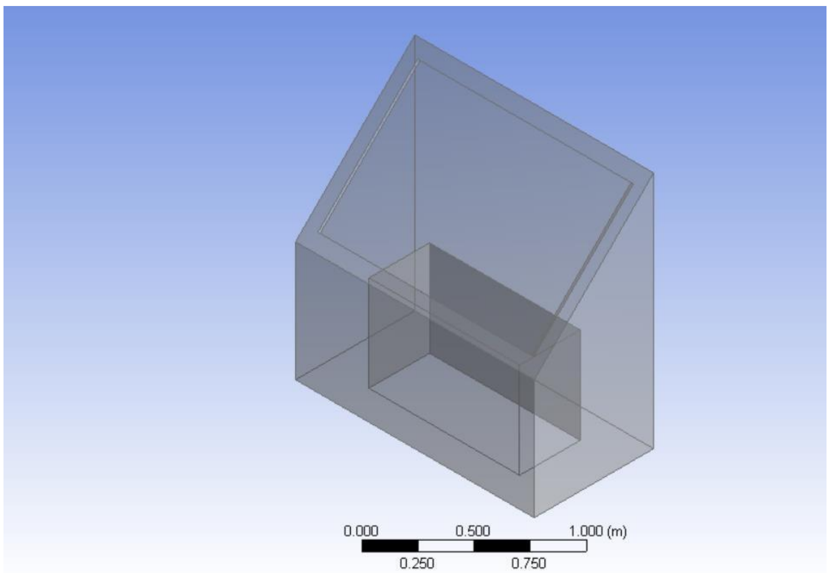

Figure 10 Kiln Geometry

Mesh

The geometry was meshed using the ANSYS Mesher. It’s an unstructured mesh. It has 9141 nodes and 44648 elements.

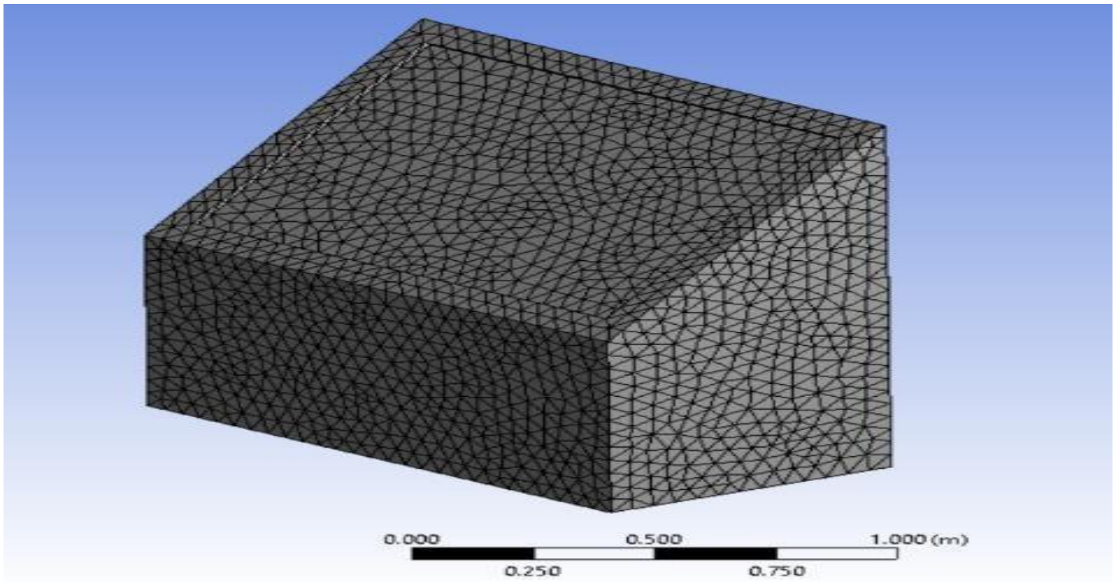

Figure 11 Kiln Mesh

Problem Setup

Problem setup was almost the same as that of the air channel since both analysis was done to study het exchange.

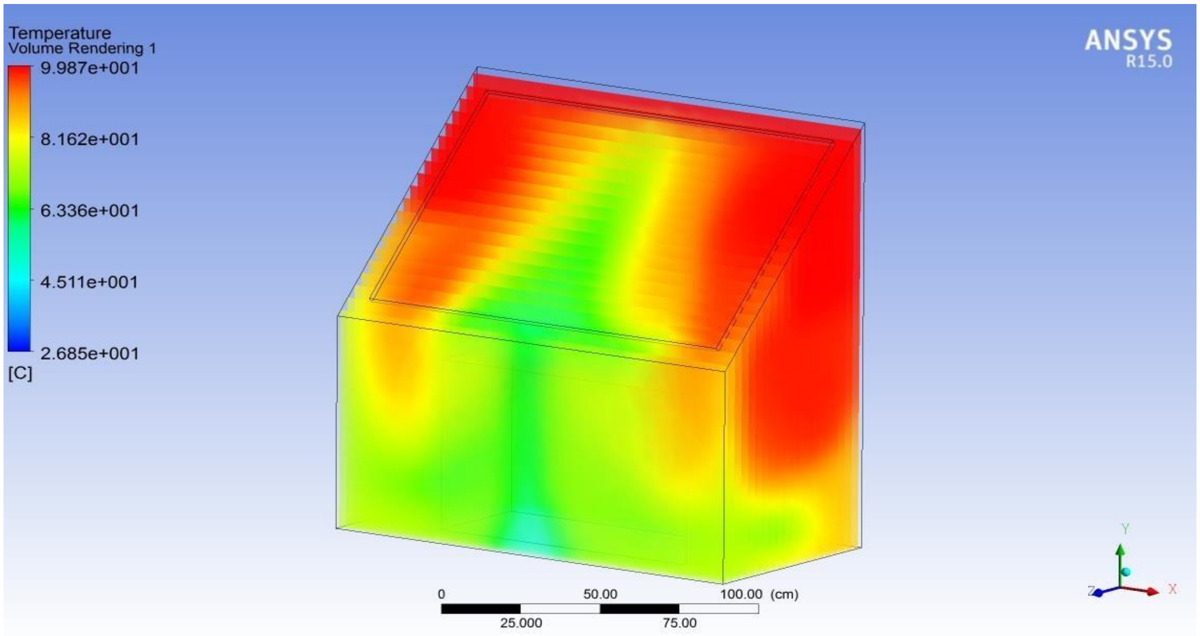

Figure 12 Kiln Temperature contour

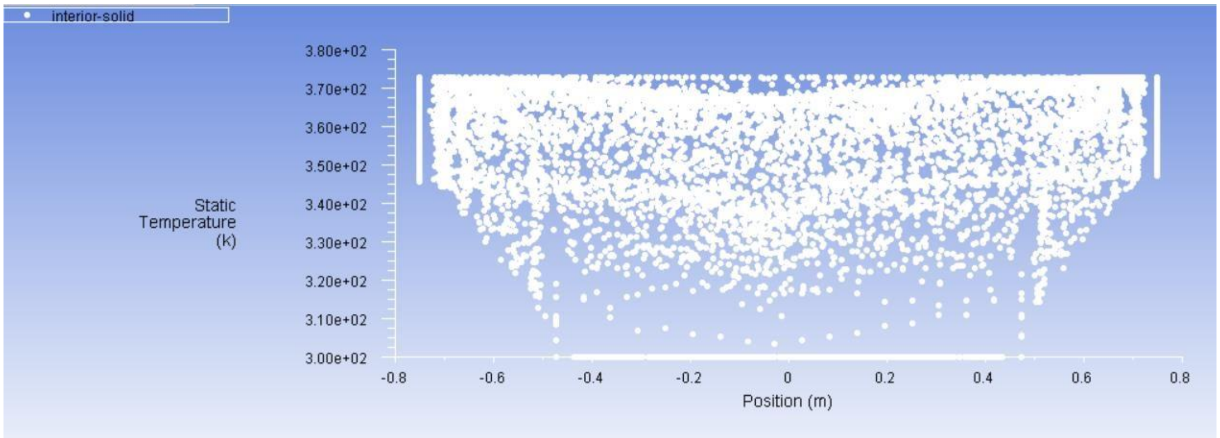

Figure 13 Static Temperature Contour

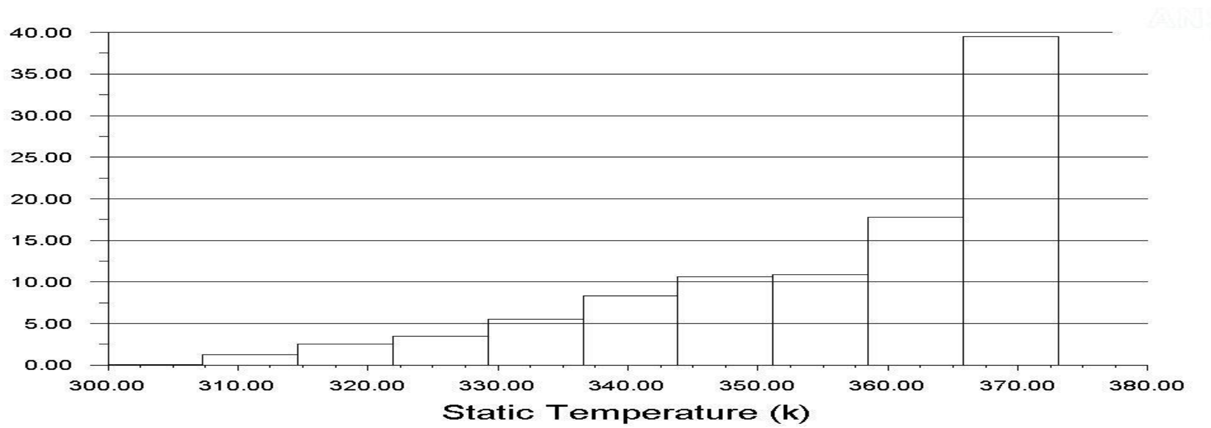

Figure 14 Static Temperature

Result

We can see that we can in the kiln the maximum temperature we get from the solar collector is 90 degree centigrade and the average temperature after the dissipation through the kiln is 50-55 degree centigrade. Through this we observe that we are close to our desired objective in this model analysis.

CHAPTER 3

KILN COMPONENTS

The kiln will consist of following components

- Fan
- Solar Collectors
- Glazing
- Moisture/temperature meters
- The control circuit

DEHUMIDIFIER

Wood seasoning process requires the wood to be dried up to 8% moisture to protect it from decay. Since air has a relative moisture content of approximately 16% therefore it is impossible to dry wood using atmospheric air. Wood moisture varies from 100%-16% and calls for a need to install de-humidifier in wood seasoning kiln for efficient drying of wood.

Various de-humidifiers have been considered for this purpose however due to financial constraints a simple de-humidifier with silica gel has been used for drying of air.

The de-humidifier will consist of the following components.

- Silica gel
- Fans
- Foam
- A plastic box

Construction

The four compartments of a plastic box are used as a de humidifier box for ease of use, financial constraints and to protect silica from extreme temperatures.

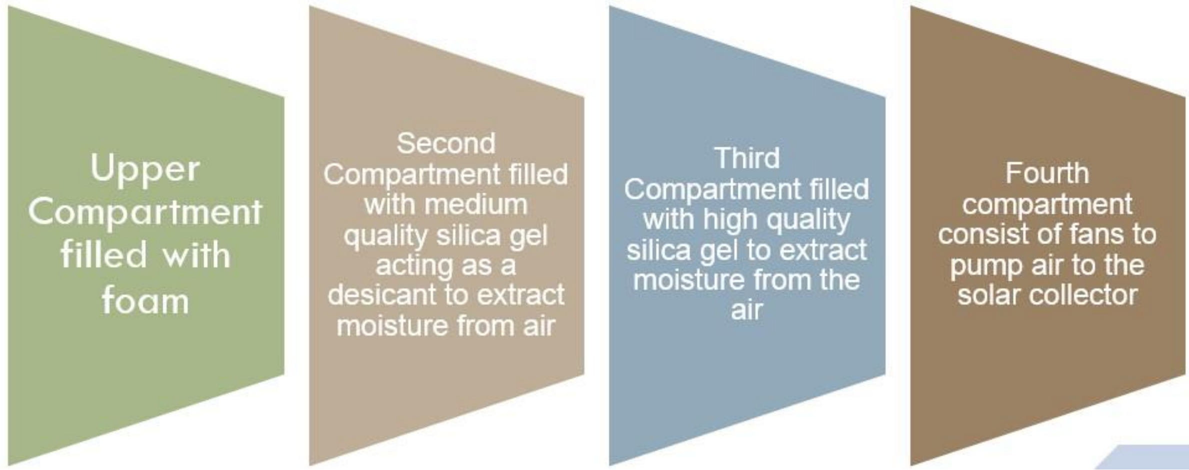

Figure 15 Dehumidifier Construction

SOLAR COLLECTOR

Solar collectors have been designed to heat the air before it enters the kiln. Various designs for solar collectors have been studied and the final design is chosen for its efficiency ease of use and space constraints.

For heating the air in the kiln the required area of solar collectors needs to be approximately 4 square meters. An area of 4 square meters was quite large and requires a lot of space with installation difficulties. In order to address this issue we have designed our solar collectors to be installed in series. Two collectors are deemed enough for use in summers when there is ample sunlight and long hours for which sunlight is available for use to achieve a temperature of approximately 60 degrees. However, in winters when there is not enough sunlight and temperatures are low, three solar collectors installed in series will be enough to achieve a temperature of 60 degrees to heat air for the kiln.

The calculations for solar collectors have been done using reference form the Book "Solar Engineering of Thermal Processes, 4th Edition – Gear Team". The results for collector calculations are as follows:

Table 1 Collector Temperatures

Serial Number	Summer Temperature (C)	Winter Temperature (C)
Collector 1	41.65	38.00
Collector 2	52.09	45.16
Collector 3	61.49	51.57

Calculations:

Collector 1:

Following are the calculations performed for the size of the collector. The Solar intensity value is taken as average of summer and winter values for the collector.

Solar intensity = S =500 W/m^2

Input temperature = Ti = 30 degree Centigrade

Ambient Temperature = Ta = 25 degree Centigrade

Length of plate = L = 1.2 meter

Width of plate = W = 1 meter

Height of air duct = H = 0.3 meter

Boltzmann Constant = σ = 5.67*10^-8 W/m^2.K^4

Height of Cover = Hc = 0.04 meter

Emittance of the duct = ε = 0.63

Mass flow rate = $\dot{m}$ = 0.05 kg/s

Fluid Viscosity for air = μ = 2.04*10^-5 Pa/s

Area of Flow = Af = L*H = 0.036 meter^2

Specific heat at constant pressure = Cp = 1.003 kj/kg.K

Hydraulic Diameter = Dh = $\frac{2(L*H)}{L+H}$ = 0.585 meter

The absorber plate for the collector was selected to be steel. The main reason for this selection is its resistance to corrosion and durable nature. The air passing in the collector has moisture content and other particles which might be harmful to the plates so resistance to corrosion is necessary.

Thermal conductivity of steel = k = 54 W/m.C

Area of Plate = Ac = 1.2 m^2

The mean fluid temperature Tm will be an assumed value based on the collector plate and inlet temperature of air. In summers we achieved a plate temperature up to 80 degree centigrade. So the fluid temperature will be assumed up to 60 degree centigrade

Mean fluid temperature = Tm = 60 degree centigrade

The linearized heat transfer coefficient "hr." will be then calculated by following formula. Emittance of the duct ε1 and ε2 will be same as duct is made of steel.

$$hr = \frac{4\sigma(\mathrm{Tm})^4}{\frac{1}{\varepsilon}+\frac{1}{\varepsilon}-1} = 3.85\ \mathrm{W/m\text{^}2.C}$$

Now the heat transfer coefficient of the fluid will be calculated. For this we will be calculating Reynolds number "Re" and Nusselt number "Nu"

$$Re \quad = \frac{\dot{m}Dh}{Af\mu} = 3985.33W/m\text{^}2.C$$

From the Re value we can see that it is greater than 2100. The flow will be turbulent which we require as it allows for better heat exchange. So the Nusselt number will be

$$Nu = 0.0158\ (\mathrm{Re})^{0.8} = 11.99$$

The heat transfer coefficient inside the duct will be given by formula

$$h = Nu\ (\frac{k}{Dh}) = 11066.116\ w/m\text{^}2.C$$

We will take back loss coefficient Ub as 1 W/m^2.K and top loss coefficient Ut as 1 W/m^2.K.The total loss coefficient will be given as

Ul=Ut+Ub= (3.3+1) W/m^2.C = 4.3 W/m^2.C

Now we will calculate the collector heat removal factor from flow factor.

$$F' = \left[1 + \frac{Ul}{h + \left[\frac{1}{h} + \frac{1}{hr}\right]^{-1}}\right]^{-1} = 0.998$$

The expressionless factor for flow factor will be

$$x = \frac{\dot{m}cp}{AcUlF'}, = 9.78$$

$$F'' = x\left[1 - e^{-\frac{1}{x}}\right] = 0.950$$

So the heat removal factor will be

Fr=F’*F’’= 0.9502

Now the heat gain will be calculated as

$$Qu = AcFr[S - Ul(Ti - Ta)] = 545.68\,W$$

And outlet temperature will be given as

$$To = Ti + \frac{Qu}{\dot{m}cp} = 40.814\,degree\ Centigrade$$

Collector 2

The only input factor changing would be Ti which will be 40.814 degree centigrade and the output temperature will be 50.75 degree centigrade.

Collector 3

The only input factor changing would be Ti which will be 50.75 degree centigrade and the output temperature will be 59.37 degree centigrade.

Given below is the figure of the collector and its flow schematic.

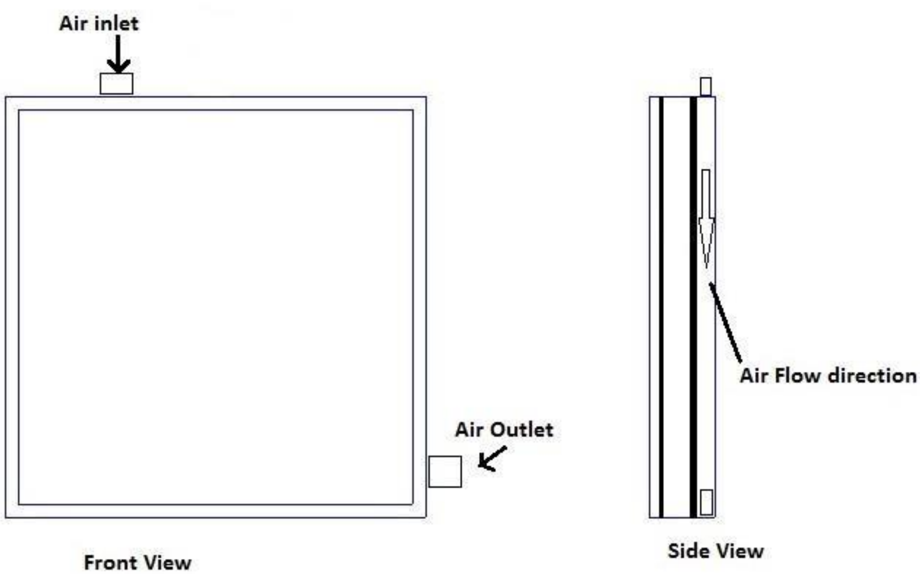

Figure 16 Collector Figures

AUXILIARY POWER SOURCE

An electric heater might be used if there is insufficient heating in the kiln. Wood industries have a lot of waste wood which can be used to heat the air in case of insufficient heating through the solar collectors. An inlet for thermal heat source has been installed in the control circuit to control the heat input to the kiln.
In the thermal and solar heating fails to provide the optimum temperature of 65 degrees to the kiln an electric heater is also installed in the kiln.

WOOD SELECTION

Deodar is one of the most commonly used woods for constructional purposes in Pakistan. The wood is derived from the Cedrus deodara tree that is native to the Northern region of Pakistan. It is durable, strong and most importantly rot-resistant. Its grains are fine and closely knitted due to which it can withstand high polishing. As a construction material, most Architects in Pakistan preferably select Deodar. (Amer Adnan, n.d.)

CHAPTER 4

RESULTS

LAB TESTING

Various wood samples of pine wood and ash wood have been procured from Dir and local wood industries in Islamabad and nearby areas. These wood samples have been tested in controlled environment to study the behavior of wood and the wood drying process overall.

Percentage weight reduction

Samples of pine wood have been prepared and tested in controlled laboratory conditions in CASEN lab and samples have been taken after regular intervals for inspection and the data for percentage weight reductions against time as been collected.

Procedure:

Following procedure is being employed to check the wood water relationships and the behavior of different types of wood under controlled environmental conditions:

- Samples of 2.25 square inch weighed
- Heated at 60 degrees centigrade in an oven
- Analyzed after every 60 minutes for moisture left and weight reduced.
- The data has been recorded in the form of tables and graphs are obtained to study the relationship of wood and water

For Sample A:

Table 2 Lab Testing Results Sample A

Sample A		
Time	Weight	% Moisture
Fresh sample	51.4	92.47
After 2 hours	43.47	62.7
after 5 hours	35.95	34.59
after 7 hours	31.49	17.89
after 8 hours	30.59	14.52
after 10 hours	29.95	12.13
after 11 hours	29.76	11.41
after 15 hours	28.93	8.31

Graphs for percentage weight reduction and percentage moisture content have been plotted against time for both samples. The graphs show the relationship of moisture removal with the passage of time if the temperature is kept constant at 60 degrees.

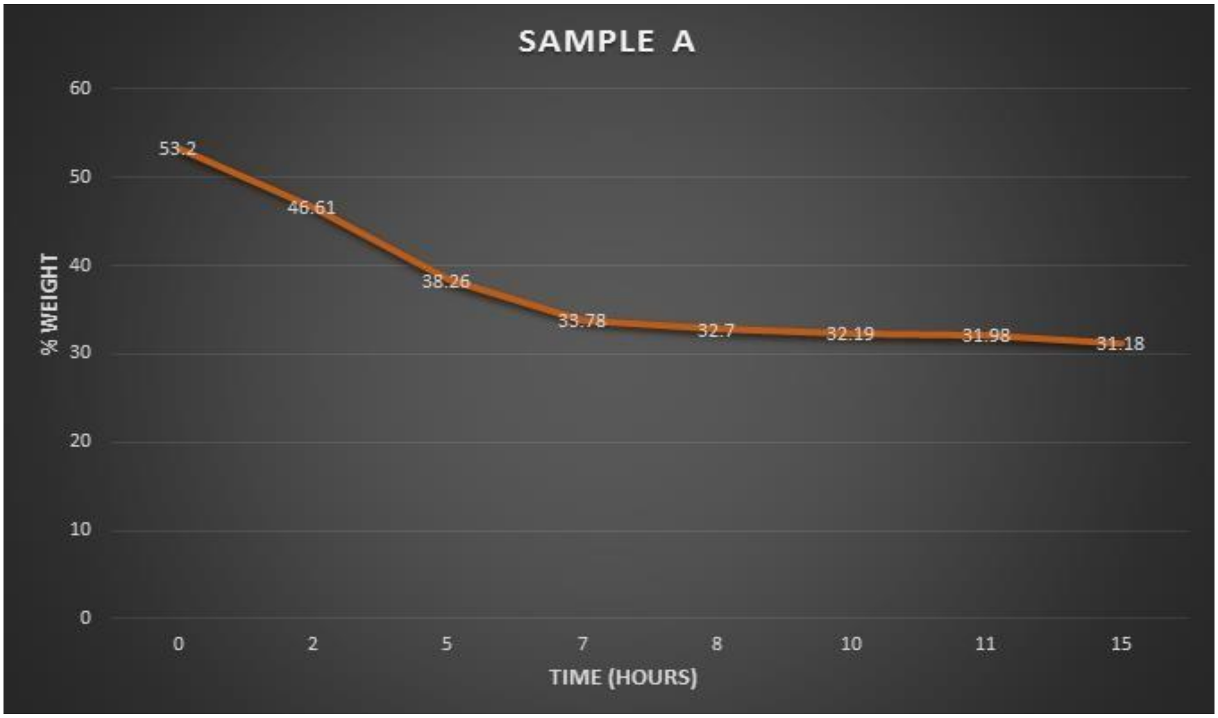

Figure 17 Percentage Weight Reduction for Sample A

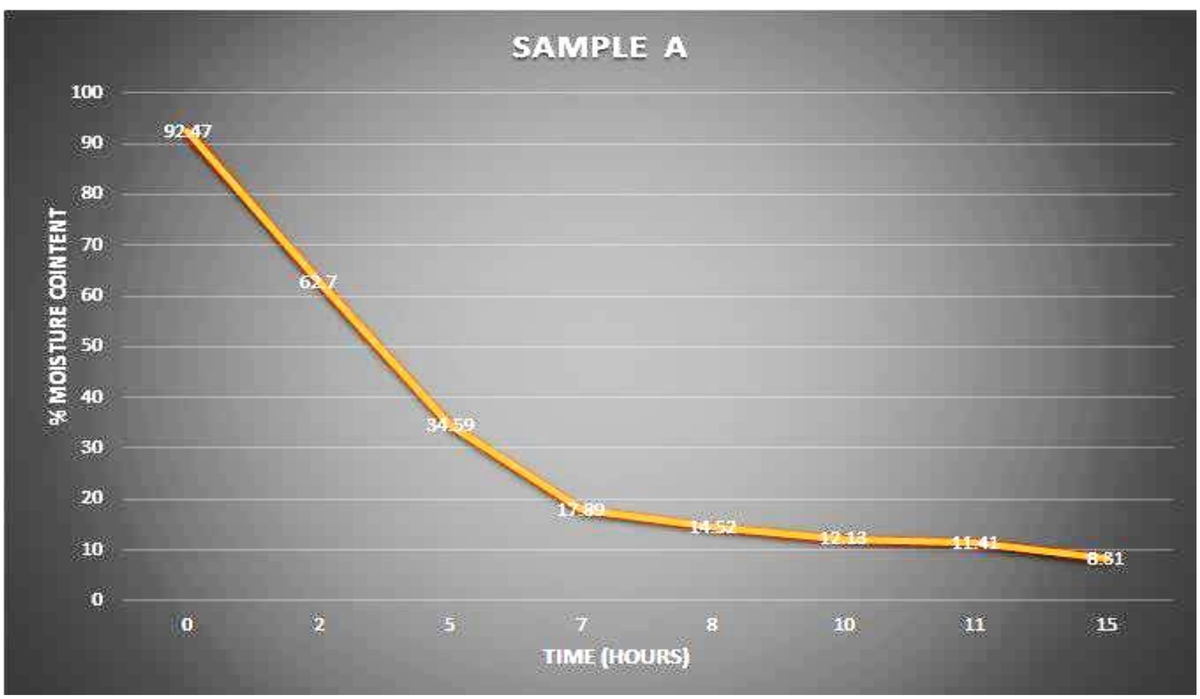

Figure 18 Percentage Moisture Content for Sample A

For Sample B

Data collected for sample B is as follows:

Table 3 Lab Testing Results for Sample B

Sample B		
Time	Weight	% Moisture
Fresh sample	53.2	99.17
After 2 hours	46.61	74.5
after 5 hours	38.26	43.24
after 7 hours	33.78	26.46
after 8 hours	32.7	22.42
after 10 hours	32.19	20.51
after 11 hours	31.98	18.73
after 15 hours	31.18	16.73

Same graphs for sample B are plotted. Moisture content against time relationships of sample B are as follows

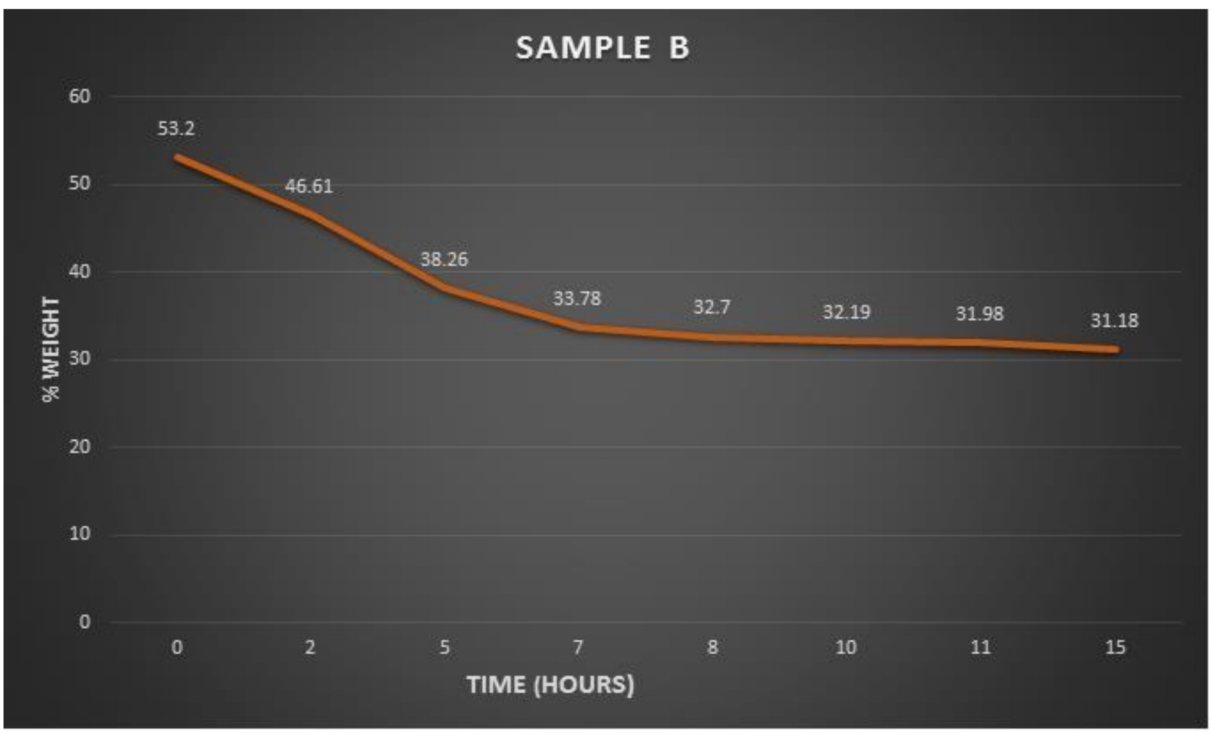

Figure 19Percentage Weight Reduction Sample B

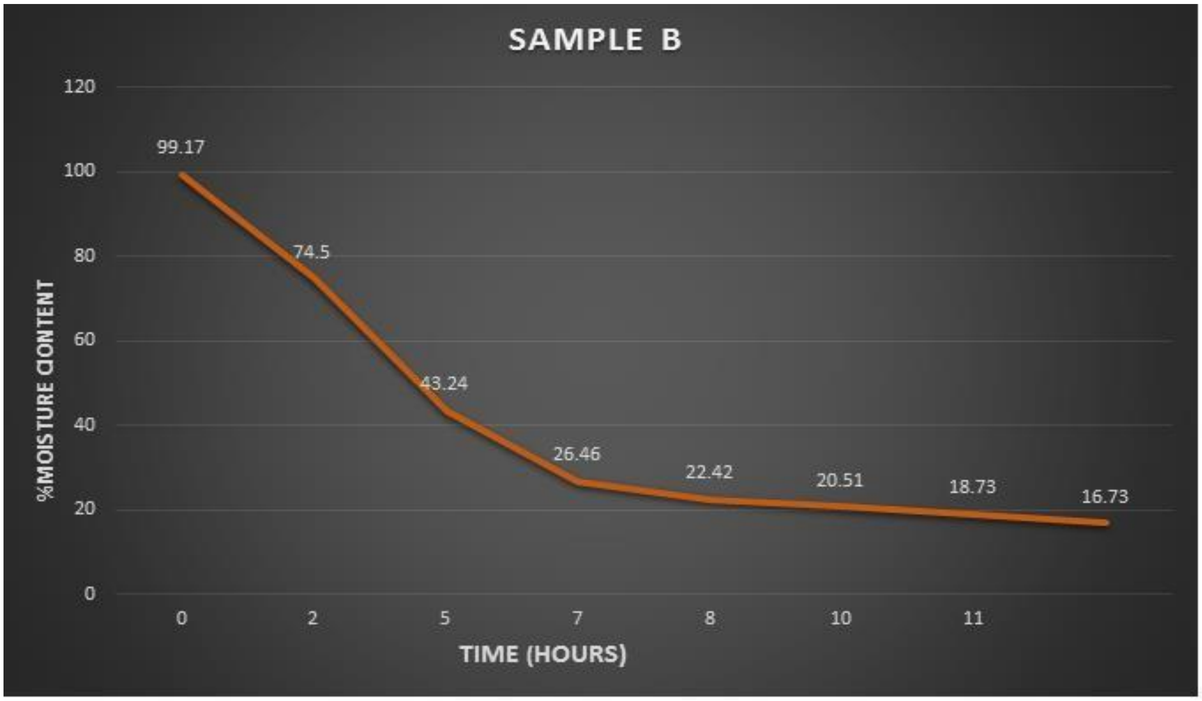

Figure 20 Percentage Moisture Content Sample B

CHAPTER 4

CONCLUSION

The kiln design allows wood to be dried at optimum temperature of 60 degrees. In order to achieve moisture content of almost 18% wood requires 21 days approximately.

Following recommendations are made on this project and can pave way for further research on this topic.

RECOMMENDATION

Moisture control

To decrease moisture in wood we need an efficient dehumidifier design. Dried wood can have moisture as low as 8%.Currently our kiln has a maximum moisture removal content of up to 18% because we cannot extract the moisture from the air. Our current prototype works on the principle of creating a moisture gradient to extract moisture out of wood. There is no mechanism to control the moisture content in the kiln.

Recommended dehumidifiers are costly but efficient therefore dehumidifier should be installed in the prototype having the ability to extract all the moisture from air. However, further research can be done on this aspect of wood kiln to make the dehumidifier cost effective and efficient while controlling the size of the kiln to ensure its portability.

Material of Wood Kiln

Wood kiln for use in industries needs to be rugged and resistant to temperature variations. We have used wood as our kiln material due to cost constraints and to ensure easy handling of the prototype. However, in wood industries the prototype needs to be made of Stainless steel to ensure that the kiln is resistant to environmental changes and efficient in its function.

Cooling equipment for controls Circuit

The temperature in the collectors and the kiln rises up to 80 degrees in summers. The controls circuit cannot withstand such high temperatures and result in short circuit. Arduinos and certain other electronics are expensive components, sensitive to high temperature and calls for the need to install cooling equipment for trouble free and continuous operation.

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