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DESIGN, CONSTRUCTION AND EVALUATION OF A LOW COST TRAY DRYER.

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ABSTRACT

A low cost food processing tray dryer was designed and constructed using locally available material.The dryer design temperature was such that various types of solid food material can be dried. The maximum temperature specified was 80^{0}C. For better design and operational performance, a survey and design appreciation exercises were carried out on the available tray dryers in the Faculty of Technology, University of Ibadan, and Ibadan. The performance of the dryer was tested using (Dioscorea genus) slices at different thickness and various temperatures and it was found that at higher temperatures and smaller thicknesses the product being dried lose their moisture content at a faster rate. The dryer was able to dry the sample product weighing approximately 24g initially to 8.86g at different time for different temperature as outlined below. For 70^{0}C it dried at 19.5hr, for 60^0 C it dried at 32hr, and for 50^{0}C it dried at 38hr In order to show the effect of temperature, thickness of product to be dried and velocity a computer program was written using visual basic (software) to simulate the performance characteristics.

Key Words: Tray, Evaluation, Design, Dryers, Slices

INTRODUCTION

Drying is one of the oldest preservation processes available to the mankind, one we can track since prehistoric times. In today's food market, dried foods play an important role in the food supply chain. The main feature of this process consists of reducing the water content in order to avoid or slow down food spoilage by micro-organism. At this point some understanding can be derived from the vocabulary employed. Common words found are: drying" or "dehydration" or even "dewatering", Dewatering is usually employed for the process of reducing the water content without phase change by using physical means. However, drying and dehydration are used commonly in the literature. hen considering transferring water from a solid/liquid to a gas, a phase change occurs, thus high energy consumption is involved. Energy consumption is one of the major concerns in drying not only for its cost but for the associated environmental effect.

RESEARCH METHODOLOGY

MECHANICAL DESIGN: Different theories of mechanical dryer designs were compiled and analyzed in order to arrive at the optimum method for design of dryers. User friendly computer software was developed to automatically generate performance characteristics parameters based on the specification of input data.

DESIGN PROCEDURE

The basic principles governing Dryer design are:

i. Principle of conservation of energy
ii. Heat transfer

Heat is transferred by: (i) Conduction (i) Convection (iii) Radiation

The rate of heat transfer by conduction is governed by Fourier's law, which is written as:

$$Q = -kA\ DT/DX \qquad (1)$$

Where Q = heat transfer rate (Watts)
K = thermal conductivity of conducting material (W/m °C)
A = Area of surface in the perpendicular direction to the heat flow (m^2)
$\underline{DT}$= temperature gradient DX

The rate of convective heat transfer is governed by Newton's law of cooling.

$$Q = hA\ dT \qquad (2)$$

Q = rate of heat transfer (w)

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h = Convective heat transfer co-efficient ($w/m^2 k$)
A = Surface area (measured normal to the direction of flow) (m^2)

The rate of heat transfer by radiation by a perfect radiator or black body is governed by Stefan-Boltzmann law for black body radiation.

$$E_b = \sigma T^4 \quad \text{.......................} \quad (3)$$

σ = Stefan Boltzman constant = 5.669×10^{-8} $W/m^2 \cdot k^4$
E_b = Energy radiated per unit time and per unit area (W/m^2)
T = absolute temperature of radiation (°K)

HEAT INSULATORS

Insulators are materials which conduct heat at a very low rate, that is poor conductors of heat, in the Dryer, the material used as insulators and the size of the dryer usually determines the thickness of the insulators required, after specifying the temperature, the thickness of insulator required is calculated from the equation below:

$$q = \frac{Q}{A} = UDT \quad \text{.......................} \quad (4)$$

Where U = the overall heat transfer co-efficient (W/m^2k) q = heat flux (w/m^2)
Other parameters have the usual meaning

$$U = \frac{1}{\frac{dx_1}{k_1} + \frac{dx_2}{k_2} + \ldots \frac{dx_n}{k_n} + \frac{1}{h_i} + \frac{1}{h_o}} \quad \text{.......................} \quad (5)$$

$dx_1, dx_2 \ldots dx_n$ = thickness of plate, wall or insulator (for composite walls) (m)
k1, k2 ...... kn = Thermal Conductivities of material (w/m. K)
h_i = convective heat transfer coefficient, inner wall ($W/m^2.K$)
ho = convective heat transfer coefficient, outer wall ($W/m^2.K$)

DRYING RATE/DRYING TIME

$$Rc = \frac{hA\,(Ta-Tw)}{\Lambda_w} \quad \text{.......................} \quad (6)$$

Where R_c = Constant rate of drying kg s^{-1}
A = surface are of solid m^2
h = heat transfer co-efficient $W/m^2. K^{-1}$
T_a = drying air temperature 0C
T_w = wet solid temperature ^0C
Λ_w = latent heat of vaporization of water (KJ/Kg^{-1})

Substituting the above values into the equation we have.
Rc = 1.12 kg water m^{-2} S^{-1}
As the drying rate is constant, the drying time tc may be expressed as

$$tc = \frac{Ms\,(x_1-x_2)}{Rc} \quad \text{.......................} \quad (7)$$

Where X_1, X_2 = initial and final moisture content respectively M_s = mass of bone dry solid

HEAT LOAD CALCULATION AND DETERMINATION OF INSULATION THICKNESS

To raise the temperature of air in the drying chamber from ambient temperature of 30^0C to 80^0C.

$$Q = M_aC_{pa}(T_2 - T_1) \quad \text{.......................} \quad (8)$$

$$Ma = \rho_aV_a \quad \text{.......................} \quad (9)$$

Where Q = the heat required (J)
M_a = mass of air in drying chamber (kg)
ρ_a = density of air in chamber(kg/m^3)
V_a = volume of air in drying chamber (m^3)

HEAT LOSS THROUGH THE WALL

In order to maintain the air mass temperature when heating, the rate of heat loss through the walls of the dryer has to be evaluated and compensated for. In the steady state the heat transfer rate entering the left face is the same as that leaving the right face (see figure 7) thus,

$$q = \frac{T_1 - T_2}{X_{12}/K_{12}A}, \quad q = \frac{T_2 - T_3}{X_{23}/K_{23}A} \quad \text{and} \quad q = \frac{T_3 - T_4}{X_{34}/K_{34}A} \quad \text{.......................} \quad (10)$$

Together this gives

$$q = \frac{T_4 - T_1}{\frac{X_{12}}{K_{12}A} + \frac{X_{23}}{K_{23}A} + \frac{X_{34}}{K_{34}A}} \qquad (11)$$

$$\frac{q}{A} = \frac{T_4 - T_1}{\frac{X_{12}}{K_{12}} + \frac{X_{23}}{K_{23}} + \frac{X_{34}}{K_{34}}} \qquad (12)$$

This equation is known as Fourier's law for composite wall (metal-insulator-metal) as in the case of the dryer design. Wall thickness

Vertical wall

For inner surface

$$\frac{q}{A} = hi\,(T_4 - T_5) \qquad (13)$$

$$T_4 - T_5 = (T_o - T_1) \qquad (14)$$

Knowing T_o, T_1 and T_5 we can easily obtain T_4 and this will be used when calculating the thickness of the insulating wall using the Fourier's law for composite wall.

$$\frac{q}{A} = \frac{T_4 - T_1}{\frac{X_{12}}{K_{12}} + \frac{X_{23}}{K_{23}} + \frac{X_{34}}{K_{34}}} \qquad (15)$$

X_{12}, X_{23}, X_{34} and q can be calculated, k_{12}, k_{23}, k_{34}, k_o and T_5 are known. For vertical plate:

$$h = h_0 = 0.95\,(DT)^{1/3} \qquad (16)$$

Where DT = Temperature difference

(ii) Horizontal wall (top) heat surface facing downward from

We have

$$h = 0.61\,\frac{(DT)^{1/5}}{L^2} \qquad (17)$$

L = vertical or horizontal dimension, (m)

RESULTS AND DISCISSION

In order to characterize the design dryer, some tests were carried out. The working drawings for the construction of the dryer are shown in figures 1-5 while figure 6 shows the drying characteristic for yam at 70° C for different thickness (treated and untreated).

(i) Yam Slices (Dioscorea genus) were dried in the dryer at various thicknesses

There were six samples of yam slices as shown in table below. From the above, we are able to see how the thickness of the product dried affects the performance of the dryer. It was observed that product with small thickness dries faster than those with higher thicknesses. All samples had the same dimension, length (20mm), breadth (80mm) Tests were also carried out on the dryer using yam (Doscoreagenus) as the test sample but at different temperature namely 50°C & 60°C and the following result were obtained and compared with that of 70° using the same sample size and weight.

This is shown below in table 1-3.It could be seen from the above figures that the higher the temperatures the faster the drying time of the product. But lower temperature yields better final moisture content.

Table 1: Samples of yam slices dried at 70°C

S/N	Sample	Thicknes(mm)	Mass (g)	Treated/Untreated
1	202	10	11.86	Treated
2	301	20	21.1	Untreated
3	328	10	12.08	Treated
4	433	20	22.25	Treated
5	103	20	23.73	Treated
6	213	10	13.16	Treated

Table2: Yam slices dried at 70° C, 60 °C & 50 °C

Temperature °C	Initial moisture content kg	Final moisture content kg	Time taken to dry (hr)
70	23.73	8.86	19.5
60	23.1	8.08	32
50	23.6	7.86	38

Table 3: Yam slices dried at different temperatures

Sample	**Initial weight (g)**	**Final weight (g)**	**Time taken to get to final weight (mins)**
202	11.86g	4.04	690
301	21.18	7.39	930
328	12.08	3.71	750
433	22.25	7.4	930
103	23.73	8.86	1170
213	13.16	4.53	930

Table 4: BILL OF QUANTITIES

Item No	Item Description	Quality	Dimension	Unit Price N	Total price N	Location on Dryer
1.	Stainless steel sheet	3 plate	8ft X 4ft	N18,500	55,500	Outer & inner plates
2.	1.5" X 1.5" sq pipe	2 length	19.5ft	N500	1,000	Frame
3.	Fibre glass	3 bags	-	2500	7,500	Inside Dryer
4.	Fan blade	1	Φ0.14	800	800	Inside year of Dryer
5.	Thermocouple	1	-	700	700	Temp reader
6.	Temperature control	1	-	2,500	2,500	Temp control
7.	Heating element	1	-	2,000	2,000	Rear of Dryer
8.	Electric motor $^{1}/_{10}$hp	1	-	1,800	1,800	Rear of Dryer
9.	Fan control	1	-	700	700	
10.	Heat resistance capble	2		100	200	
11.	Door Hinges	1		250	250	
12.	Labour cost			15,000	15,000	
13.	Transport Cost	2,500	2,500			
	Total					N90,450

CONCLUSION AND RECOMMENDATION

The constructed Dryer is neat, efficient, fast and relatively simple in design. It has been tested and found to be very silent in operation. It is capable of meeting the tough demand expected of it in the laboratories and food industries. The dryer is recommended for use in our Industries, Laboratories in the Universities and Private organizations where drying forms the major parts of their operations as this will improve their productivities.

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'Computer proram Using Visual Basic to show how  temerature
'Velocity and Thickness Of material being
'being Dried Could affect the drying Time when
'the parameters mensioned above are varied
Private Sub Command1_Click()
On Error GoTo kunle1
v = CDbl(txtkv.Text)
den = CDbl(txtden.Text)
k = CDbl(txttc.Text)
pr = CDbl(txtpn.Text)
le = CSng(txtlen.Text)
u = CDbl(txtvel.Text)
re = (u * le) / v
txtrn.Text = CDbl(re)
nu = 0.0332 * ((pr) ^ (1 / 3)) * ((re) ^ 0.5)
txtnn.Text = CDbl(nu)
h = (nu * k) / le
txthtc.Text = CDbl(h)
Exit Sub
kunle1:
MsgBox ("please you have left a text box empty please try again")
End Sub
Private Sub Command2_Click()
On Error GoTo kunle2
area = CSng(txtarea.Text)
lhv = CDbl(txtlhv.Text)
dwdm = (h * area * (at - vt)) / lhv
txtdmdt.Text = CDbl(dwdm)
Exit Sub
kunle2:
MsgBox ("please you have left a text box empty please try again")
End Sub
Private Sub Command3_Click()
On Error GoTo kunle3
mc1 = CDbl(txtmc1.Text)
emc = CDbl(txtemc.Text)
da = CDbl(txtemc.Text)
tp = CDbl(txttp.Text)
dmdt = (((0.3142 ^ 2) * da) / (4 * (tp ^ 2))) * (mc1 - emc)
txtfr.Text = CDbl(dmdt)
Exit Sub
kunle3:
MsgBox ("please you have left a text box empty please try again")
End Sub
```

```
Private Sub Command4_Click()
On Error GoTo kunle4
mc2 = CDbl(txtfmc.Text)
mbds = CDbl(txtmbds.Text)
tc = (mbds * (mc1 - mc2)) / dwdm
txttc.Text = CDbl(tc)
Exit Sub
kunle4:
MsgBox ("please you have left a text box empty please try again")
End Sub
Private Sub Command5_Click()
On Error GoTo kunle5
cmc = CDbl(txtcmc.Text)
dtfr = (((mbds * (cmc - emc)) / dmdt) * (Exp((mc1 - emc) / (mc2 - emc) ^ -1)))
txtdtfrc.Text = CDbl(dtfr)
Exit Sub
kunle5:
MsgBox ("please you have left a text box empty please try again")
End Sub
Private Sub Command6_Click()
On Error GoTo kunle6
tdt = (tc + dtfr)
txttdt.Text = CDbl(tdt)
Exit Sub
kunle6:
MsgBox ("please you have left a text box empty please try again")
End Sub

Private Sub txtvt_Change()
at = CSng(txtat.Text)
vt = CSng(txtvt.Text)
ft = (vt + at) / 2
txtft.Text = CSng(ft)
End Sub
```

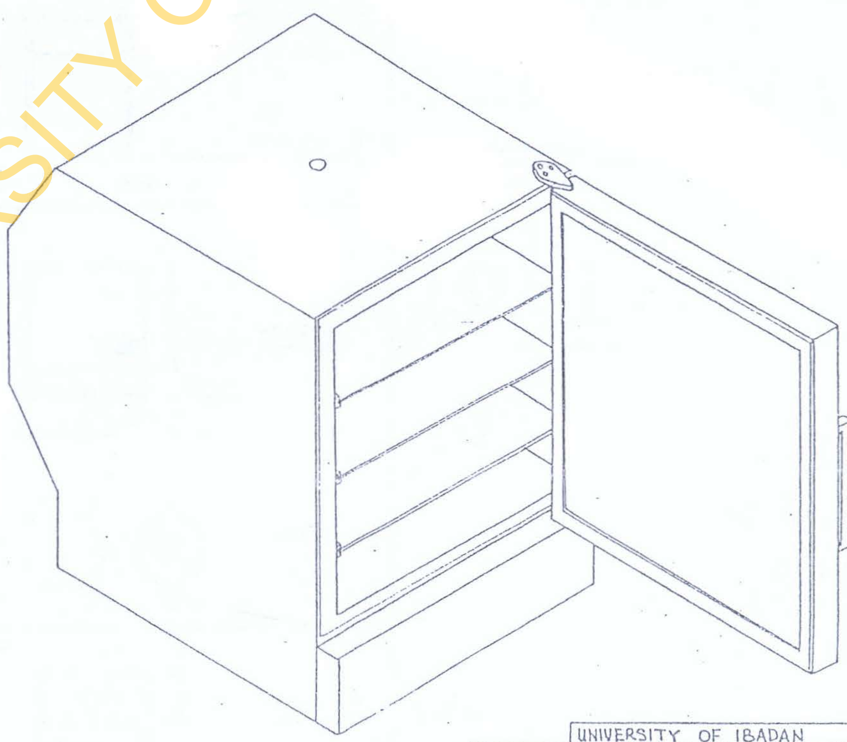


Fig1 A. ISOMETRIC VIEW

	UNIVERSITY OF IBADAN			
SCALE	DEPT.	MECHANICAL ENGINEERING		
1:100	DRWN. BY	OKORO C. CHARLES	MAT. NO	94727
DATE	PROJECT	[illegible] OF LOW COST DRYER		
[illegible]	SUPERVISOR	ENGINEER ODESOLA I.F.		

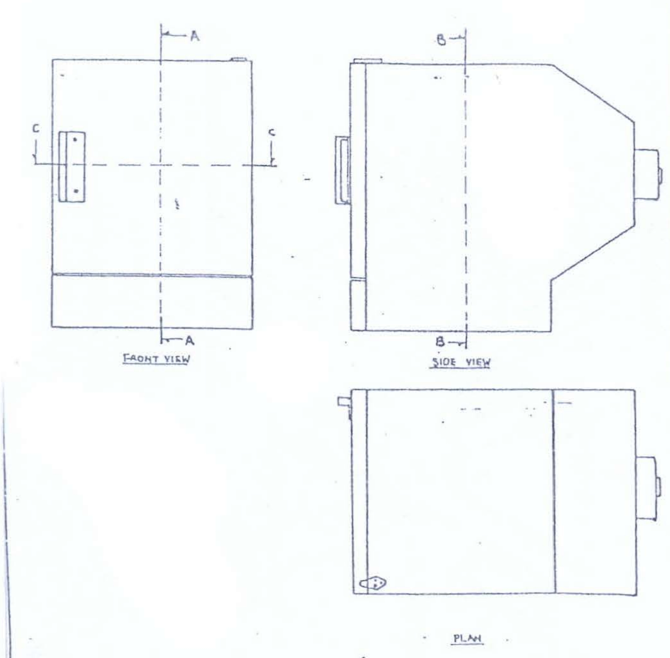


Fig 2 B. PROJECTION DRAWING

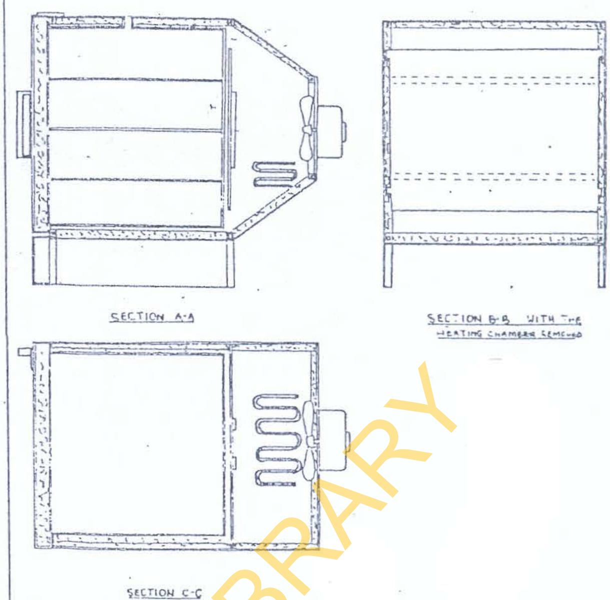
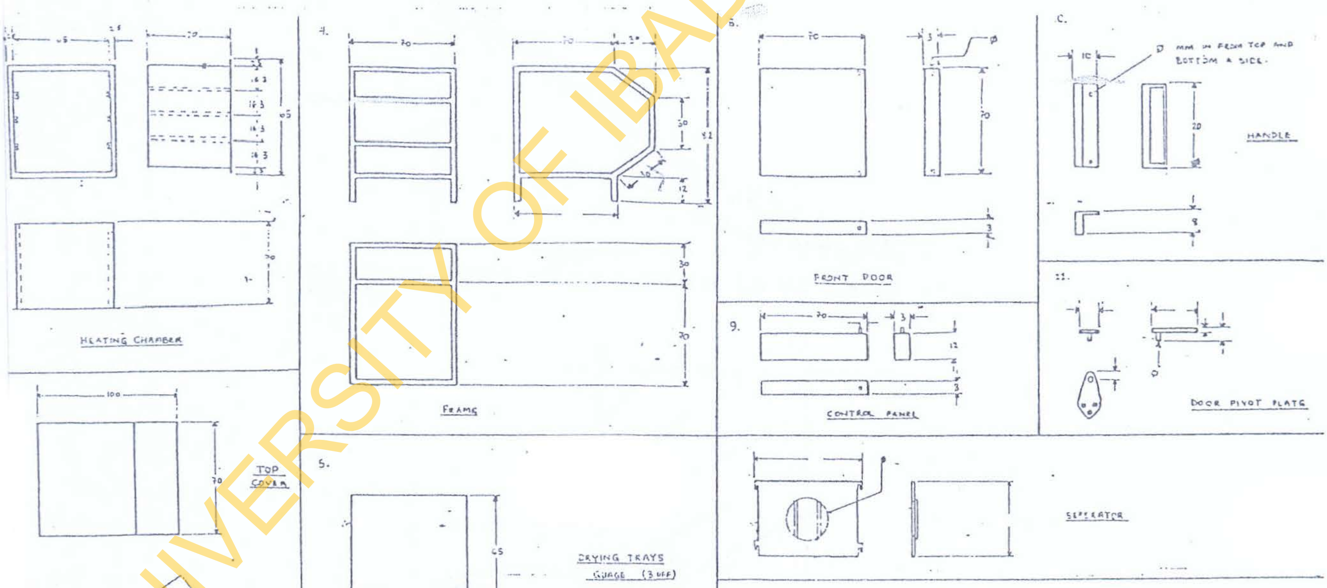
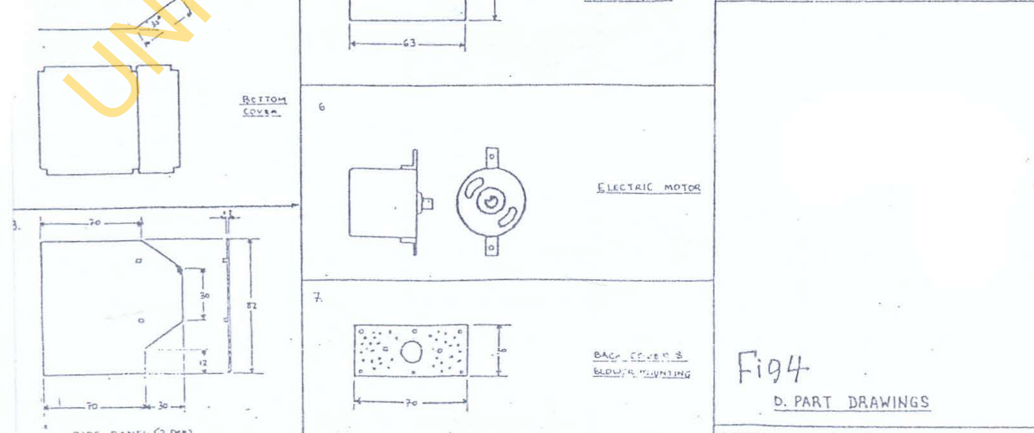


Fig 3 C. SECTION DRAWING

DATE	UNIVERSITY OF IBADAN			
	DEPT.	MECHANICAL ENGINEERING		
MARCH 2004	DRWN. BY	OKORO C. CHARLES	MAT. No	94727
	PROJECT	DESIGN & FABRICATION OF A LOW COST DRYER		
	SUPERVSR	ENGINEER ODESOLA I.F.		





PART LIST

S/No	DESCRIPTION	MATERIAL	SPECIFICATION	QTY.
1	INNER CHAMBER	S. STEEL	1.2 MM	4
2	TOP & BOTTOM COVER		"	2
3	BODY SHEET		"	2
4	MAIN FRAME	1"x1" ANGLE		15
5	DRYING TRAYS	S. STEEL	1.2 MM	3
6	ELECTRIC MOTOR		1HP	1
7	REAR COVER	S. STEEL	1.2 MM	1
8	DOOR	"	"	2
9	DOOR SUPPORT	"	"	1
10	HANDLE	"	"	1
11	DOOR PIVOT PLATE		"	1
12				

Fig 4 D. PART DRAWINGS

OKORO C.C. → DESIGN OF LOW COST DRYER

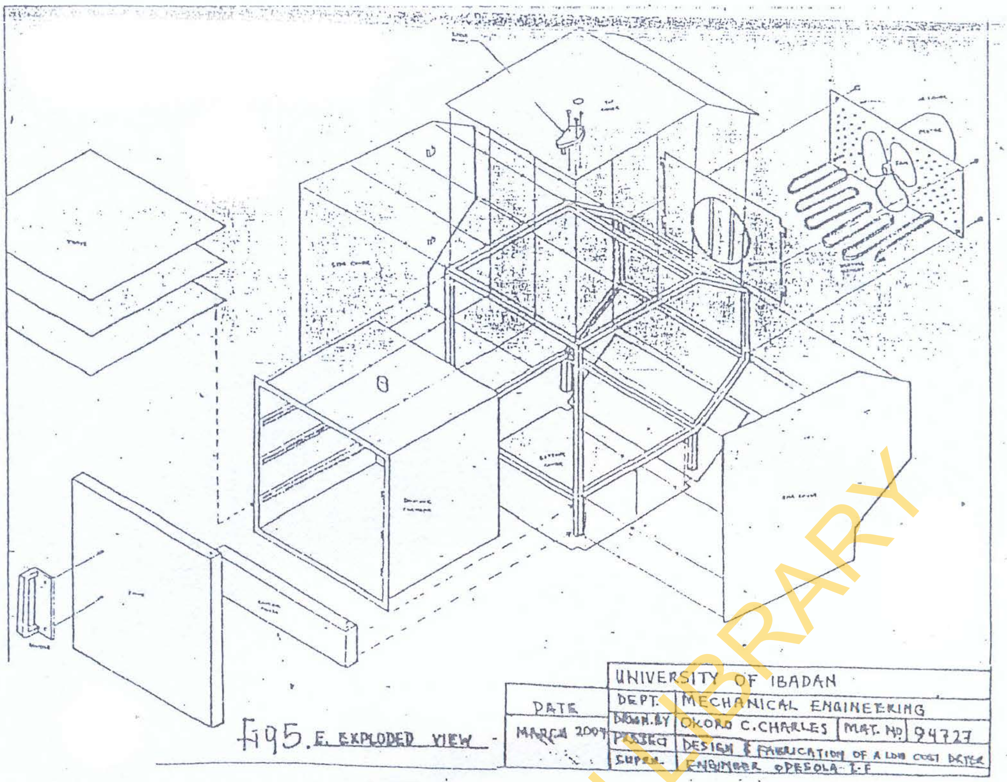


Fig5. E. EXPLODED VIEW

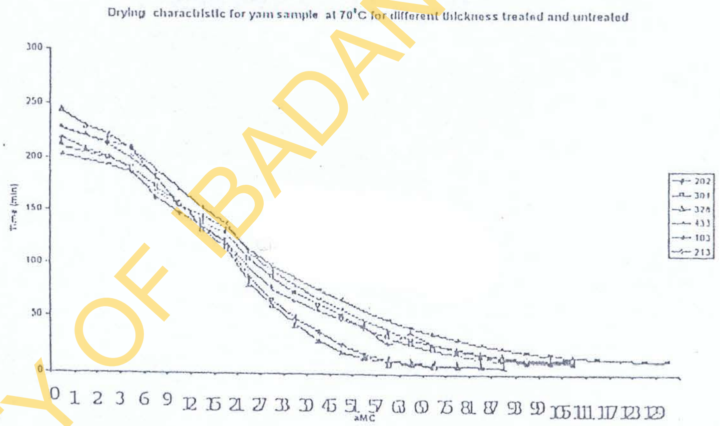


Fig.6

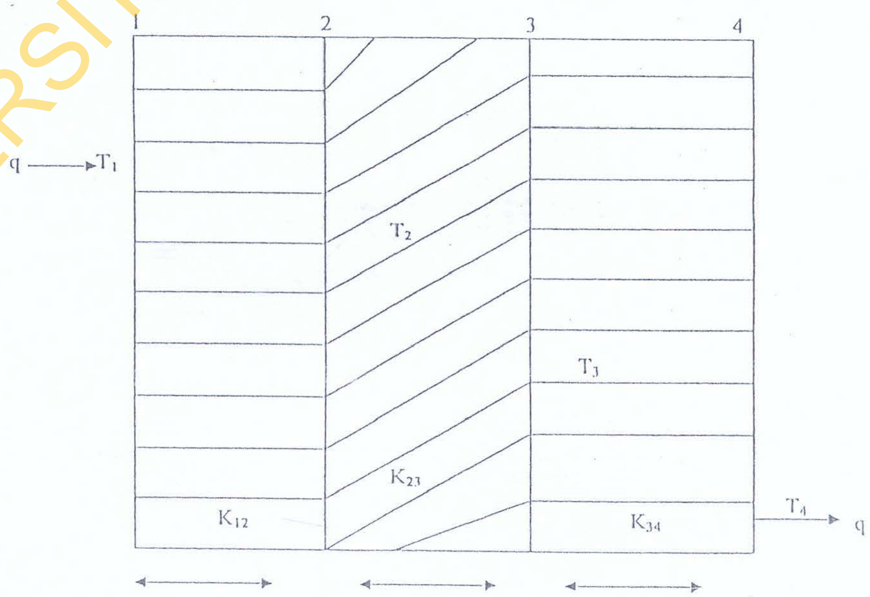


Fig.7: Composite wall