DESIGN & CONSTRUCTION OF A PLASTIC MELTING POT FOR LOW DENSITY POLYETHYLENE (LDPE)

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ABSTRACT

In this project a melting pot was designed and constructed using available local materials. This pot was used to melt plastic resin without the resin-changing colour (turning brown) The project was divided into two parts: the design and construction aspect and the control aspect. A good temperature control was incorporated to achieve high quality output.

The construction was carried out using galvanized mild steel .It consists of a cylindrical enclosure that is divided into two chambers: the upper and larger one house the melting unit, the lower chamber houses sensing element of the temperature control equipment. The instrument used for the temperature control is a thermostat which has a temperature range of 0-200 °.

The dimension of the material used for the fabrication was based on the least thermal difference so that equilibrium can be achieved in a short time .Tests carried out after the construction of the prototype confirmed the relevancy of the project . The pot melted the plastic resin and flowed without change of colour.

1. INRODUCTION

Locally in the designed and constructed plastic melting pot will be useful in Nigeria. Almost all the melting pots we have in the country presently are imported from Britain or America yet the demand for plastic products is high in this country. Hence, the present effort geared towards the realisation of self-sufficiency in plastic production may save the country a huge amount of foreign exchange.

Thermal processing of plastics is the conversion of polymeric raw material into finished product by first increasing its flow property at high temperature. Polymers are available in various particulate forms: pellets, powder, and flakes. Unlike other materials with distinct phase change, polymers undergo phase change over a range of temperatures. They are generally processed at about 10-20^{0}C above the upper limit of their melting temperature range, the molten plastics are generally called polymer melt.

Before processing to produce end products, the plastics are in the form of powder, Granules, e.t.c, or in semi fabricated form such as sheets, rod, block of tube.

2. THEORETICAL BACKGROUND

2.1 ANALYSIS OF HEAT TRANSFER BY CONDUCTION

A plastic melting pot is conceived and modelled as a cylindrical enclosure with a stirrer incorporated. There is need to specify parameters for the following: (1) Heater (2) Pot (3) Mixer. The heat transfer rate per unit area is proportional to the normal temperature gradient.

Mathematically,

$$\frac{q}{A} = -k\frac{dT}{dx} \text{.................}(1)$$

Equation (1) is the Fourier law of heat conduction, k is the thermal conductivity of the material.

$$q = -kA\frac{dT}{dx} \text{.......................}(2)$$

2.2 PLANE WALL: FIXED TMPERATURES

With reference to figures (1) and (2)

$$q\int_{x_1}^{x_2} dx = -kA\int_{T_1}^{T_2} dT \text{..................................}(3)$$

Separating variables and integrating equations (1) to obtain :

$$q\int_{x_1}^{x_2} dx = -kA\int_{T_1}^{T_2} dT \text{..........................}(4)$$

$$q = \frac{-kA(T_2 - T_1)}{x_2 - x_1} \text{...............................}(5)$$

$$= -kA\frac{(T_2 - T_1)}{\Delta x} \text{.....................................}(6)$$

$$Therefore, \Rightarrow\Rightarrow\Rightarrow q = \frac{T_1 - T_2}{\frac{\Delta x}{kA}}$$

3.

$R_{th} = \Delta x / kA$ $\quad R_{th} =$ Thermal potential resistance
q= thermal potential difference / thermal resistance

$$q = \frac{T_1 - T_4}{\frac{\Delta x_1}{k_A A} + \frac{\Delta x_2}{k_B A} + \frac{\Delta x_3}{k_C A}} \text{.....}(\ 8\ )$$

For composite materials A,B,and C and thermal conductivities k_A,k_B,and k_C respectively.

$$= \frac{\Delta Toverall}{\Sigma R_{th}}$$

2.3 RADIAL SYSTEM

Refer to figures 2(a) &2(b)
Radial heat flow can be assumed for a tube with small diameter compared to the length .
Using Fourier's law of heat conduction:

$$A_r = 2\pi rL \quad \text{.....(9)}$$

$$q_r = -kA_r \frac{dT}{dt} \quad \text{.....(10)}$$

$$q_r \int_{r_i}^{r_o} dr = -kA_r \int_{T_i}^{T_o} dT \quad \text{.....(11)}$$

$$q = 2\pi kL \frac{(T_i - T_0)}{\ln(\frac{r_0}{r_i})} \quad \text{.....(12)}$$

$$R_{th} = \frac{\ln(\frac{r_0}{r_i})}{2\pi kL} \quad \text{.....(13)}$$

It is obvious here that the resistance to the flow of heat is directly proportional to the material conductivity, and inversely proportional to the area normal to the direction heat transfer.

3.1 CYLINDER WITH HEAT SOURCE

Considering temperature as a function of radius only
The relevant boundary conditions needed to solve the equation are:

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} + \frac{q}{k} = 0 \quad \text{.....(14)}$$

(1) T = T_w at r = R.....(15)
(2) Heat generated equal heat lost to the surface

Therefore,

$$q\pi R^2 L = -k2\pi RL \frac{dT}{dr} \quad \text{.....(16)}$$

$$\frac{dT}{dr} = -\frac{qR}{2k} \quad \text{.....(17)}$$

And

$$\frac{d^2T}{dr}+\frac{1}{r}\frac{dT}{dr}=-\frac{\dot{q}}{k}\text{..............................}(18)$$

Thermal resistance $R_{th} = \Delta x/kA$ ....(19)

For a composite with materials A, B , and C with thermal conductivities, k_A , k_B ,k_C respectively .

Heat flow = $\Delta T_{overall} / \sum R_{th}$ ....(20)

Refer to figures 2(a) & b

Radial heat flow can be assumed for a tube with small diameter compared to the length .

Using Fourier's law of heat conduction in radial form :

A_r = 2©rL ....(21)

$$q_r=-kA_r\frac{dT}{dt}\text{..}(22)$$

$$q_r\int_{r_i}^{r_o}dr=-kA_r\int_{T_i}^{T_o}dT\text{..}(23)$$

$$=\frac{d}{dr}(r\frac{dT}{dr})=-\dot{q}\frac{R}{k}\text{..}(24)$$

Integrating equation (24) twice to obtain:

$$r\frac{dT}{dr}=-\dot{q}\frac{r^2}{2k}+C_1\text{..}(25)$$

$$\frac{dT}{dr}=-\dot{q}\frac{R}{2k}+\frac{C}{R}\text{..}(26)$$

Combining equations 17&(22) to obtain:

$$C = 0 \quad \text{.......................................} (27)$$

Integrating equation (24) yields

$$T = -qr^2 + C\ln r + C_2 \quad \text{.......................................} (28)$$

At r = R, T = Tw

$$T_w = \frac{qR^2}{4k} + C_2 \quad \text{.......................................} (29)$$

$$C_2 = T_w + \frac{qR^2}{4k} \quad \text{.......................................} (30)$$

Therefore,

$$T = \frac{-qr^2(R^2 - r^2)}{4k} \quad \text{.......................................} (31)$$

At r = 0 , T = T₀

$$T_O = \frac{qR^2}{4k} + T_W \quad \text{.......................................} (32)$$

For a hollow cylinder with uniformly distributed heat source, the boundary conditions are :

$T = T_i$ at $r = r_i$ (inside surface)
$T = T_o$ at $r = r_o$ (outside surface)

The general solution of the differential equation is

$$T = -q\frac{r^2}{4k} + C_1 \ln r_i + C_2 \quad \text{.......................................} (33)$$

$$T_i = \frac{-qr_i^2}{4k} + C_1 \ln r_i + C_2 \quad \text{.......................................} (34)$$

Applying the boundary conditions:

$$T_o = \frac{-qr_o^{2}}{4k} + C_1 \ln r_o^{2} + C_2 \quad \text{...(35)}$$

Solving equations (19) & (20) to obtain :

$$C_1 = \frac{T_i - T_o + q\frac{(r^2_i - r_o^{2})}{4k}}{\ln(\frac{r_i}{r_o})} \quad \text{...(36)}$$

$$T - T_O = \frac{q(r_O{}^2 - r_i{}^2)}{4k} + C\ln(\frac{r_i}{r_O}) \quad \text{...(37)}$$

3 DESIGN CONSIDERATION FOR THE POT

Some factors were taken into consideration during the selection of materials for this project .The main factors are: (1) the thermal property of the material and (2) availability and cost of the material.

3.1 · DESIGN SPECIFICATION:

A plastic melting pot is a container (hollow cylinder) with a stirrer incorporated.

3.2 HEATER SPECIFICATIONS:

SUPPLY SOURCE	220/240 Volts
POWER RATING	450 Watts
OUSIDE DIAMETER	108 mm
INSIDE DIAMETER	100 mm
WIDTH	50 mm

3.3 POT SPECIFICATION:

MATERIAL	1 mm Thick galvanized mild steel
THERMAL CONDUCTIVITY	43 W/m °C
DIAMETER OF CYLINDER	120 mm
HEIGHT OF CYLINDER	250 mm
HEIGHT OF UPPER CHAMBER	230 mm
HEIGHT OF LOWER CHAMBER	20 mm
INCLINATION OF POT	14^0

3.0 MIXER SPECIFICATIONS:

LENGTH OF MAIN SHAFT	220 mm
LENGTH OF TORQUE ARM	75 mm
DIAMETER OF MAIN SHAFT	25 mm
DIAMETER OF TORQUE ARM	30 mm
LENGTH OF PADDLE	20 mm

8.0 DESIGN ANALYSIS FOR THE POT

The governing equation for the design of the melting pot is the Fourier's equation for the cylindrical radial system.

$$q = 2\pi kL\frac{(T_0 - T_i)}{\ln(\frac{r_0}{r_i})} \quad \text{...(38)}$$

Data:

$q = 450 w/m^0C$

$k = 43 W/m^0C$

$L = 250mm$

$T_I = 128^0C$

$r_0 = 60mm$

$r_I = 59mm$

The outer surface temperature (T_0) is obtained from the equation above to be:

$$T_0 = T_i + q\frac{\ln(\frac{r_0}{r_i})}{2\pi Lk} \quad \text{...(39)}$$

$$= 128 + 450\frac{\ln(\frac{60}{59})}{2\pi x 43 x 0.25} = 128.11^{\circ}C$$

3.3 DESIGN ANALYSIS FOR THE MIXER

In designing the mixer, some assumptions were made, for example the mass moment of inertia of the paddles is negligible.

3.3.1 DESIGN PARAMETERS FOR THE MIXER

e_r = Unit weight of resin
e = Unit weight of mild steel
F = Force required to turn resin during heating
W = Total weight of pot and resin
I_r = Mass moment of inertia of resin
I_s = Mass moment of hollow shaft
I_f = Mass moment of inertia of flange
I_{total} = Total mass moment of inertia
L = Length of pot
d_{op} = outer diameter of pot
d_{ip} = inner diameter of pot
L_s = Length of main shaft
L_t = Length of torque arm
D_{osi} = outer diameter of main shaft

$$= \pi x 0.075 x 77 x 10^3 \frac{(0.03^4 - 0.026^4)}{32 x 9.81} = 2.04 x 10^{-5} kgm^2$$

D_{isi} = inner diameter of main shaft
D_{of} = outer diameter of torque arm
D_{if} = inner diameter of torque arm
E_a = Energy required to rotate shaft
T = Torque required to rotate shaft
⓿ = Torsional shear stress on shaft
n = No of revolutions per minute
g = Acceleration due to gravity

$$I_S = \frac{\pi L_S e({D_{osi}}^2 - {D_{isi}}^2)({D_{osi}}^2 + {D_{isi}}^2)}{32g} \quad \text{...(40)}$$

$$= \pi x 0.22 x 77 x 10^3 \frac{(0.025^2 - 0.02^2)(0.025^2 + 0.02^2)}{32 x 9.81} = 3.325 x 10^{-5} kgm^2$$

$$I_r = \frac{1}{32} x L x e_r x \frac{{d_{op}}^4}{9.81} = \frac{1}{32} x 0.23 x 6 x 10^3 x \cdot \frac{0.12^4}{9.81} = 1.189 x 10^{-3} kgm^2 \text{..................(41)}$$

$$I_{TOTAL} = (3.325 x 10^{-5} + 1.189 x 10^{-3} + 2.04 x 10^{-5}) kgm^2$$

$$\underline{= 1.243 x 10^{-3} kgm^2}$$

$$E_a = \tfrac{1}{2} I_{TOTAL} w^2 \quad \text{..............................(42)}$$

Refer to figure 3

$$= \frac{1.243 x 10^{-3}}{2} \frac{(2 x 30)^2}{60} = 6.134 x 10^{-3} kJ$$

Toque required to rotate shaft T = Force x Distance = 160x0.06 = 9.6Nm
Using the ASME code to determine the shear stress developed in the shaft.

$$\tau = \frac{16T}{d_0{}^2T} = \frac{16x9.6}{(0.035^3 - 0.026^3)} = 519kN/m^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(43)$$

The choice of mild steel with a yield strength of 145MN/m^2 shows that the design is safe.
F + mgsin(angle)

Volume of pot

$$= \frac{(d_{op}{}^2 - d_{ip2}{}^2)}{4} = 3.44x10^{-4}m^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(44)$$

Density of material = 611.62kg/m^3
Mass = density x volume

F_{TOTAL} = F + 611.62x3.44x10^{-4}sin14x9.81
= 160 + 2.04N
= 162.04N

3.4 BEARING SELECTION

The basic load rating of a bearing assumes pure radial load.
The needed bearing will only be subjected to thrust loading with inner ring rotating.
Applied thrust load F_{TOTAL}= 162N

Equivalent radial load:

R_e= 1x1x162 = 162N

The bearing with the following specification was used

Bore = 25mm
Width = 15mm

4.0 Results AND Conclusions

The material used for testing was low density polyethylene which has a glass transition temperature of 700 C and a melting point ranging between 8.^{0} C--111^0 C, processing temperature of 20^0 C above upper limit of melting temperature. Results from the test showed that by maintaining the temperature of the hottest portion of the pot at the processing temperature of the material, melting was achieved without any change of colour. Being the first phase of the project the aim of the exercise was achieved. During the test, areas where improvements are needed were noted. One such observation is that the heating process can be made more effective by increasing power output of the outer heater. Some factors that were identified which affected specifications are: (i) material used for the inside and outside surfaces (ii) ambient temperature (iii) quality of the fuel being used and (iv) type and thickness of insulation in use .

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13.0 APPENDIX 1

BILL OF MATERIALS

ITEM	PART NAME	QUANTITY	MATERIAL TYPE	QUANTITY	MAKE / BUY	COST (NAIRA)
1	Cylindrical pot	1	Galvanized mild steel	Ø120x250	Make	160
2	Cover lid	1	"	Ø120	"	24
3	Cover rim	1	"	375x30	"	20
4	Partitioning	1	"	Ø118	"	24
5	Base cover	1	"	Ø120	"	24
6	Paddles	4	"	335x20	"	10
7	Flow piece	1	"	9x30	"	10
8	Flow guide	1	"	9x30	"	10
9	Front stand	2	Mild steel	40x18x3	"	20
10	Handle flange	1	"	60x18x3	"	20
11	Rear stand	1	"	68x18x3	"	20
12	Bearing Housing	1	"	200x18x3	"	100
13	Main hollow shaft	1	Gal.mild steel	Ø25x225	Buy	100
14	Torque arm	1	"	Ø30x75	"	20
15	Handle	1	Wood	Ø20x100	"	20
16	Bearing	1	02 series	Ø25	"	80
17	Bolts and nuts	5	Steel Ø10x20	5	"	30
18	Bolts and nuts	3	Steel Ø10x60	3	"	40
19	Cable	2	Twin copper	2m	"	40
20	Two pin plug	1	Polyethylene	1	"	20
21	2-Point-terminal	1	Steel	1	"	20
22	Heater band	1	450watts, 220volts	450watts, 220volts	"	1000
23	Thermostat	1	0-250^{0} C	1	"	700
24	Base support	1	Wood	270x250 x50	"	60

Estimated cost = Total cost + Labour cost= N2572.00 + 643 = N3215

14.0 APENDIX 2

NOTATIONS

A	Area (m^2)
C	Specific heat capacity (J/ kg-K)
C_1 , C_2	**Arbitrary constant**
D , d	diameter (m)
F	Force (N)
I	mass moment of inertia (kgm^2)
k	thermal conductivity (W / m °C)
L	length (m)
m	mass (kg)
Q , q	Quantity of heat (kJ)
R , r	radius (m)
R_{th}	thermal resistance (°C/ W)
T	temperature (°C)
V	Volume (m^3)
dT	temperature difference (°C)
ρ	density (kg / m^3)
r , z , ϕ	Cylindrical co-ordinate axis

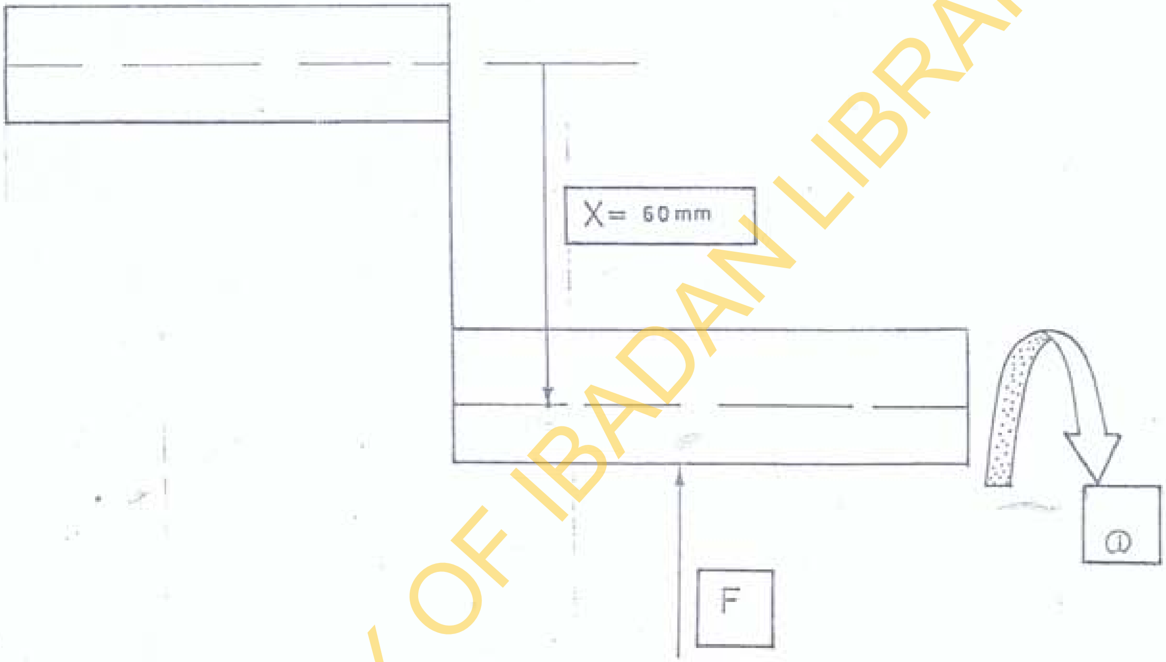

Fig. 3·0: Torque required to rotate shaft

Item	Name
1	HANDLE
2	HANDLE FLANGE
3	TORQUE TRANSMITER
4	COVER LEAD
5	MAIN CYLINDER
6	HEATER BAND
7	ELECTRICAL TERMINAL
8	THERMOSTAT KNAB
9	THERMOSTAT RESET
10	FLOW OUTLET

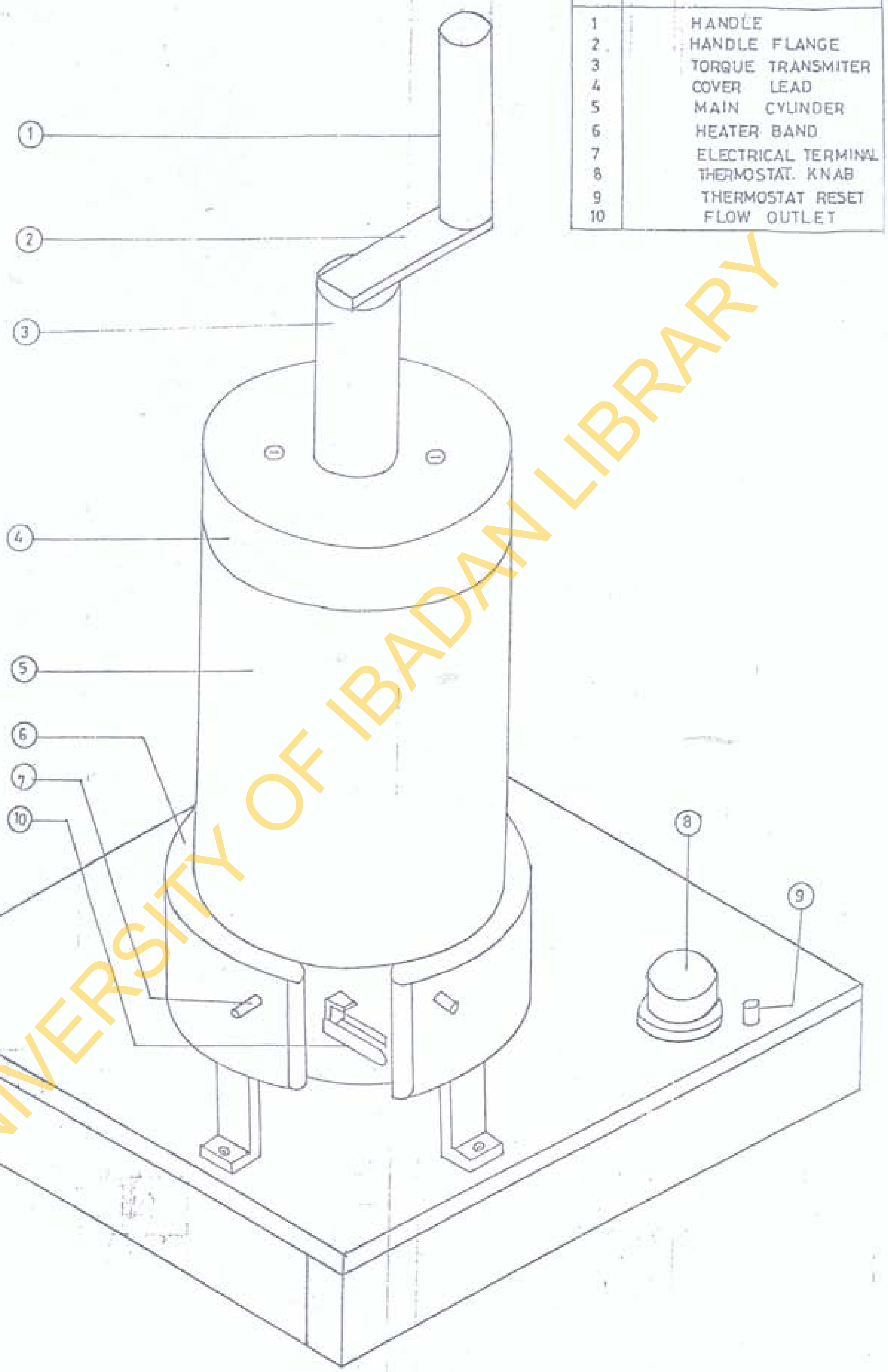

Fig. 4·0· Isometric drawing

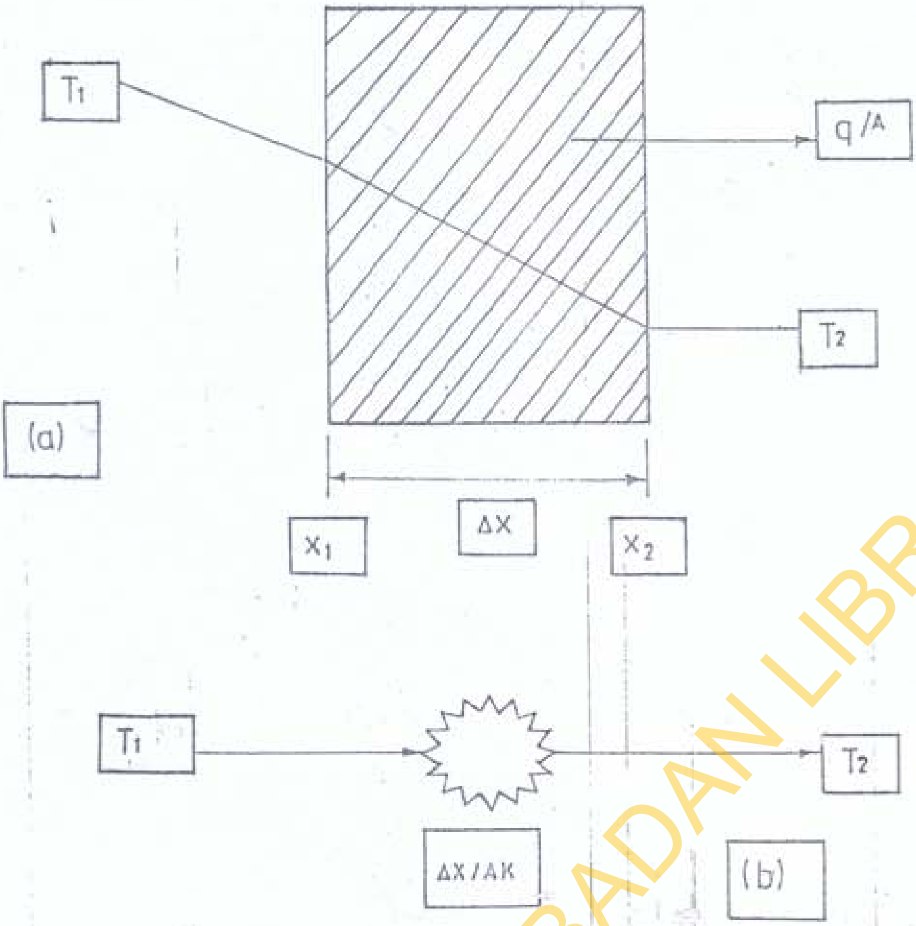

Fig. 1·0· (a) & (b)

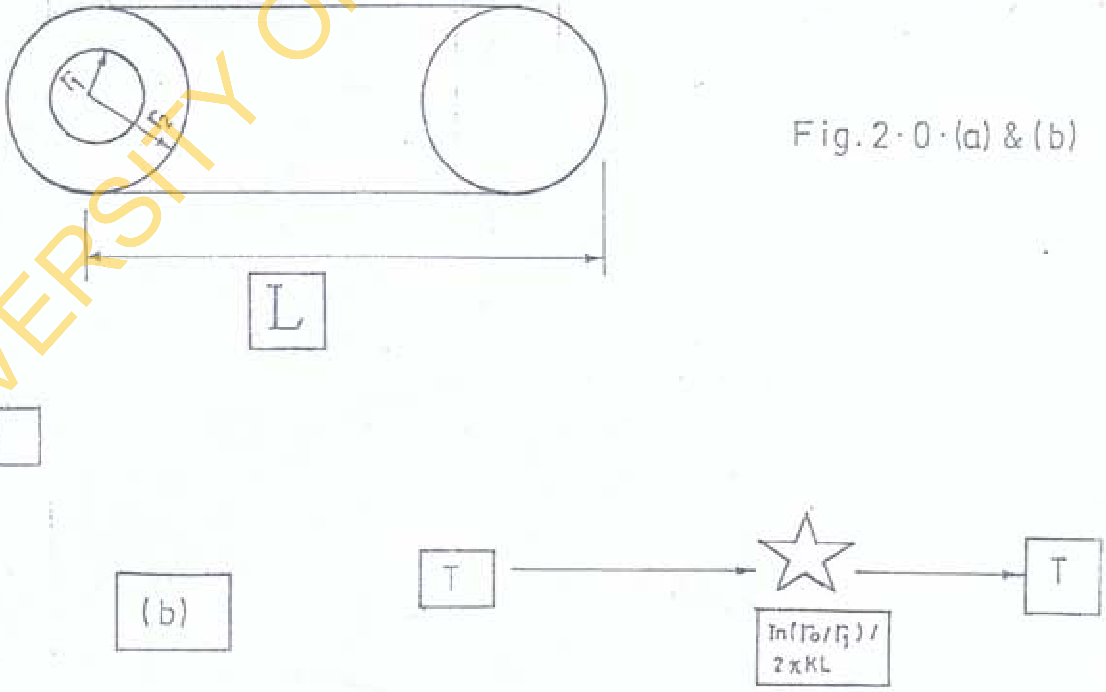

Fig. 2·0·(a) & (b)