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Ministry of Higher Education  
and Scientific Research  
Babylon University



***HEAT TRANSFER BY FREE CONVECTION  
BETWEEN HORIZONTAL  
CONCENTRIC PIPES***

*A Thesis*

Submitted to the College of Engineering of the University  
of Babylon in Partial Fulfillment of Requirements  
for the Degree of Master of Science in  
Mechanical Engineering

*By*

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جمهورية العراق  
وزارة التعليم العالي  
والبحث العلمي  
جامعة بابل

# انتقال الحرارة بواسطة الحمل الحر بين أنبوبين أفقين متحدي المركز

رسالة

مقدمة إلى كلية الهندسة في جامعة بابل كجزء من متطلبات نيل  
درجة ماجستير علوم في الهندسة الميكانيكية  
أعدت من قبل

مشتاق فيصل عبد السادة  
بكالوريوس هندسة ميكانيك

2006

بِسْمِ اللّٰهِ الرَّحْمٰنِ الرَّحِیْمِ  
" وَأَنْزَلَ عَلَیْكَ الْكِتَابَ وَ  
الْحِكْمَةَ وَعَلَّمَكَ مَا لَمْ تَكُن  
تَعْلَمُ وَكَانَ فَضْلُ اللّٰهِ عَلَیْكَ  
عَظِیْمًا "

صَدَقَ اللّٰهُ الْعَلِیُّ الْعَظِیْمُ

النِّسَاء - الْآیَةُ (113)

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**الإهداء**

**لو أنكرت الثمرة الورقة.....**

**فلاقد أنكرت أصلها....وظلمت نفسها**

**فعرفانا بالجميل:**

**للورقة والغصن.....أمي وأبي**

**للجذع والجذر.....الإسلام المحمدي**

**للماء والهواء.....أساتذتي**

**منكم تعلمت....أن أظأطأ رأسي نوضعا**

**وأن أرفعه باحثا منسائلا!!**

**جل احتراممي....وتقديري....والسلام.**

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"Praise be to ALLAH, Lord of the whole creations"

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Thanks to the mechanical department and college of engineering of Babylon University.

Finally, I apologize for all those whom I forget to mention their names.

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## **CERTIFICATION**

*We certify that this thesis entitled “ Heat Transfer By Free Convection Between Horizontal Concentric Pipes ” was prepared by Mushtaq Faisal Abd Al- Sadda under our supervision at the University of Babylon in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.*

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# NOTATIONS

Symbol	Meaning	Unit
$C_p$	Specific heat	J/kg.K
$D$	Diametral ratio	
$g_r$	Gravity Acceleration in $r$	m/s <sup>2</sup>
$g_\theta$	Gravity Acceleration in $\theta$	m/s <sup>2</sup>
$h_i$	Convection heat transfer coefficient of inner cylinder	W/m <sup>2</sup> .°C
$h_o$	Convection heat transfer coefficient of outer cylinder	W/m <sup>2</sup> .°C
$K$	Thermal conductivity	W/m.°C
$Nu_{ri}$	Nusselt number at inner cylinder	
$Nu_{ro}$	Nusselt number at outer cylinder	
$Nu$	Mean Nusselt number	
$Pr$	Prandtl number	
$Q_{cond}$	Conduction heat flux	W/m <sup>2</sup>
$Q_{conv}$	Convection heat flux	W/m <sup>2</sup>
$Ra$	Rayleigh Number	
$r_i$	Radius of inner cylinder	m
$r_o$	Radius of outer cylinder	m
$r$	Radial Direction	m
$T_i$	Temperature of inner cylinder	°C
$T_o$	Temperature of outer cylinder	°C
$T_m$	Mean Temperature	°C
$t$	Time	sec

<b><math>U</math></b>	Velocity in $\theta$ direction	m/s
<b><math>V</math></b>	Velocity in $r$ direction	m/s
<b><math>W</math></b>	Velocity in $z$ direction	m/s
<b><math>Z</math></b>	Longitudinal direction	m
<b><math>\beta</math></b>	Thermal coefficient of volumetric expansion	1/ C°
<b><math>\delta</math></b>	Air gap	m
<b><math>\theta</math></b>	Radian direction	degree
<b><math>\mu</math></b>	Dynamic Viscosity	kg/m.s
<b><math>\rho</math></b>	Density	kg/m <sup>3</sup>

Note: other symbols are given in their corresponding chapters.

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## ***Examination Committee Certification***

*We certify that we have read the thesis entitled “HEAT TRANSFER BY FREE CONVECTION BETWEEN HORIZONTAL CONCENTRIC PIPES ” and as examining committee, examined the student Mushtaq Faisal Abd Al-saada in its contents and what is related to it, and that in our opinion, it meets the standard of a thesis for the degree of Master of Science in Mechanical Engineering.*

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## **Theoretical Analysis.**

### **3.1 Introduction**

The study of natural convection challenges existing thermal modelling techniques. It is generally accepted that the most comprehensive modelling for natural convection systems would be Computational Fluid Dynamics (CFD). Either by using a finite volume or a finite difference method, the actual phenomena at the annular can be quantified.

Finite Element Method (FEM) can also be useful in determining performance, especially conductivity gradients, temperature distribution, velocity profile. The heat transfer coefficient can be determined by using advance (ANSYS) (Analysis Structural Systems) codes which incorporate fluid mechanics.

The difficulty of the most study resides in the theoretical modeling and finding a best numerical technique to solve the problem under consideration. In addition to reduce the time that required to solve the problem and extract the required results as a theoretical results to compared with another experimental one, packages such as ANSYS based on the finite element method is used here to create and modeling the geometry by discrete the whole structural into sub regions named as (elements).

### **3.2 Theoretical Consideration**

The developments of suitable methods, more accurately, for analyzing various engineering structures are needed in order to investigate their behavior under different loading conditions by using ANSYS package.

ANSYS finite element analysis software enables engineers to perform the following tasks:

- 1-Building a computer model or transfer CAD model of structures, components, or systems.
- 2- Applying operating loads or other design performance conditions.
- 3- Studying physical responses such as velocity profile, temperature distributions, or flow pattern.
- 4-Optimizing a design early in the development process to reduce production costs.

ANSYS package has a comprehensive Graphical User Interface (GUI) that gives user easy, interactive access to program function commands documentation, and reference material an intuitive menu system helps users to navigate through the ANSYS program. Users can input data by using mouse, keyboard, or a combination of them.

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, non linear and transient dynamic analysis.

The analysis guide manuals in the ANSYS documentation set describe specific procedure for performing analysis for different engineering disciplines.

A mesh is generated from the node of a “grid”. The term grid is used in this work to define the set of nodal points, which puts up the respective mesh. Figure (3-1) shows proposed our finite element model (concentric double pipe), created by using two dimensional fluid elements (Fluid 141) of quadrilateral shape.

Fluid 141 can be used to model a transient or steady state fluid/thermal systems that involve fluid and / or non-fluid regions. The conservation equations for viscous fluid flow and energy are solved in the fluid region, only the energy equation will be solved in the non-fluid region.

For the FLOTRN CFD element, the velocities are obtained from the conservation of momentum principle, and the pressure is obtained from the conservation of mass principle. (The temperature, if required, is obtained from the law of energy conservation.)

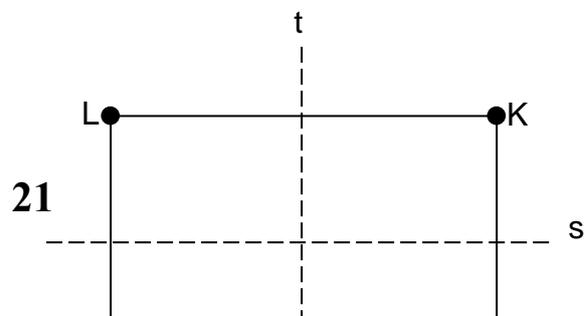
The specification of FLUD 141 according to ANSYS program can be shown as follow:

Element name	FLUID 141.
Nodes	I, J, K, L.
Degree of freedom	Vx, Vy, PRES, TEMP, ENKE, ENDS.
Surface load	HFLUX, CONV, RAD.
Body loads	HGFN, FORC.

And the shape function can defined as flow:

$$\Phi = N_1 \Phi_1 + N_2 \Phi_2 + N_3 \Phi_3 + N_4 \Phi_4$$

Where  $\Phi$  : the degree of freedom.



$$N_1 = (1 - s)(1 - t) / 4$$

$$N_2 = (1 + s)(1 - t) / 4$$

$$N_3 = (1 + s)(1 + t) / 4$$

$$N_4 = (1 - s)(1 + t) / 4$$

ANSYS finite element program is used in the theoretical analysis of this model, according to the following steps:

1. The inner diameter cylinder is 23mm.
2. The outer diameter cylinder is following values (46, 50.6, 55.2, 59.8, 64.4 and 69)mm. This made  $\delta / D_i = (0.5, 0.6, 0.7, 0.8, 0.9, \text{ and } 1)$  where  $\delta$  present annulus gap width, and  $D_i$  is the outside diameter of the inner cylinder.

The region between concentric double cylinder (inner and outer cylinders) is discredited into 384 fluid elements of quadrilateral shape. Eight elements in the radial direction, and forty eight in the angular direction as shown in Fig.(3-2).

### 3.3 Governing Equations

In general, the governing equations for laminar, incompressible fluid flow can be given as shown in  $r, \theta, z$  coordinates:-

1. Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial(rV)}{\partial r} + \frac{1}{r} \frac{\partial U}{\partial \theta} + \frac{\partial W}{\partial z} = 0 \quad \dots (3.1)$$

2. Momentum Equation:

in r-direction

$$\rho \left( \frac{\partial V}{\partial t} + V \frac{\partial V}{\partial r} + \frac{U}{r} \frac{\partial V}{\partial \theta} - \frac{U^2}{r} + W \frac{\partial V}{\partial z} \right) = -\frac{\partial p}{\partial r} + \rho g_r$$

$$+ \mu \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial V}{\partial r} \right) - \frac{V}{r^2} + \frac{1}{r^2} \frac{\partial^2 V}{\partial \theta^2} - \frac{2}{r^2} \frac{\partial U}{\partial \theta} + \frac{\partial^2 V}{\partial z^2} \right)$$
... (3.2)

in  $\theta$ -direction

$$\rho \left( \frac{\partial U}{\partial t} + V \frac{\partial U}{\partial r} + \frac{U}{r} \frac{\partial U}{\partial \theta} + \frac{VU}{r} + W \frac{\partial U}{\partial z} \right) = -\frac{1}{r} \frac{\partial p}{\partial \theta} + \rho g_\theta$$

$$+ \mu \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial U}{\partial r} \right) - \frac{U}{r^2} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \theta^2} + \frac{2}{r^2} \frac{\partial V}{\partial \theta} + \frac{\partial^2 U}{\partial z^2} \right)$$
... (3.3)

in z-direction

$$\rho \left( \frac{\partial W}{\partial t} + V \frac{\partial W}{\partial r} + \frac{U}{r} \frac{\partial W}{\partial \theta} + W \frac{\partial W}{\partial z} \right) = -\frac{\partial p}{\partial z} + \rho g_z$$

$$+ \mu \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial W}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 W}{\partial \theta^2} + \frac{\partial^2 W}{\partial z^2} \right)$$
... (3.4)

3. Energy equation:-

$$\rho \left( V \frac{\partial T}{\partial r} + \frac{U}{r} \frac{\partial T}{\partial \theta} + W \frac{\partial T}{\partial z} \right) = \frac{\mu}{p_r} \left( \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} \right)$$
... (3.5)

### 3.3.1 Assumptions

The following assumptions which assumed for the system that consists of air bounded by two concentric annular spaces are:

1. Two dimensions (2-D) steady state system.
2. Newtonian Fluid (air).
3. The fluid is viscous and incompressible.
4. Frictional heating is negligible.
5. The difference in temperature between the isothermal boundaries is small compared with the  $1/\beta$ .

The governing equations after simplification of continuity, momentum, and energy equations in two dimensions are shown as following (in  $r$  and  $\theta$  coordinates):

1. Continuity Equation:

$$\frac{\partial V}{\partial r} + \frac{V}{r} + \frac{1}{r} \frac{\partial U}{\partial \theta} = 0 \quad \dots(3.6)$$

2. Momentum Equation:- (in r-direction)

$$\rho \left[ V \frac{\partial V}{\partial r} + \frac{U}{r} \frac{\partial V}{\partial \theta} - \frac{U^2}{r} \right] = -\frac{\partial P}{\partial r} + \mu \left[ \frac{\partial^2 V}{\partial r^2} + \frac{1}{r} \frac{\partial V}{\partial r} + \frac{1}{r^2} \frac{\partial^2 V}{\partial \theta^2} - \frac{V}{r} - \frac{2}{r^2} \frac{\partial U}{\partial \theta} \right] \quad \dots(3.7)$$

$$+ g\rho\beta (T - T_o)\cos\theta$$

in  $\theta$ -direction

$$\rho \left[ V \frac{\partial U}{\partial r} + \frac{U}{r} \frac{\partial U}{\partial \theta} + \frac{VU}{r} \right] = -\frac{1}{r} \frac{\partial P}{\partial \theta} + \mu \left[ \frac{\partial^2 U}{\partial r^2} + \frac{1}{r} \frac{\partial U}{\partial r} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \theta^2} - \frac{U}{r} + \frac{2}{r^2} \frac{\partial V}{\partial \theta} \right] \quad \dots(3.8)$$

$$+ g\rho\beta (T - T_o)\sin\theta$$

3. Energy equation:-

$$\rho c_p \left[ V \frac{\partial T}{\partial r} + \frac{U}{r} \frac{\partial T}{\partial \theta} \right] = k \left[ \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \theta^2} \right] \quad \dots(3.9)$$

Where,

 $V$  and  $U$  = components of the velocity vector in  $r$  and  $\theta$  directions. $\rho$  = density $\mu$  = dynamics viscosity $c_p$  = specific heat $k$  = thermal conductivity.

$$g_r = g\beta(T_i - T_o)\cos\theta$$

$$g_\theta = g\beta(T_i - T_o)\sin\theta$$

**3.3.2 Boundary Conditions**

The elliptic equations require that the boundary conditions be specified along the entire boundary conditions which enclose the flow field. The inner and

outer cylinders are considered to be held at a uniform temperatures,  $T_i$ , and  $T_o$ , respectively such that  $T_i > T_o$ . The fluid velocity is zero on the wall of the pipes. It is assumed that at the lines of symmetry, the angular derivatives of the temperature are vanished.

### 3.3.3 Theoretical Calculation

The concentric double pipes are modeled by the tested dimensions that required in the Finite Element Method. Loads and boundary conditions are applied on the model. FLOTRN solver is used to exclude the results of temperature, velocity, and air properties in nodal coordinates system at each node. The results includes:

1-Calculation of mean temperature:

$$T_m = \frac{T_i + T_o}{2} \quad \dots(3.10)$$

2- Calculation of local heat transfer coefficient:

The local heat transfer coefficient was calculated for the inner and outer cylinders at an orientation of (0, 45, 90, 135, and 180) by the following Equations:

$$-k \frac{\partial T}{\partial r} \Big|_{r=r_i} = h_i (T_i - T_o) \quad \dots(3.11)$$

$$-k \frac{\partial T}{\partial r} \Big|_{r=r_o} = h_o (T_i - T_o) \quad \dots(3.12)$$

then,

$$h_i = \frac{-k \frac{\partial T}{\partial r} \Big|_{r=r_i}}{(T_i - T_o)} \quad \dots(3.13)$$

$$h_o = \frac{-k \left. \frac{\partial T}{\partial r} \right|_{r=r_o}}{(T_i - T_o)} \quad \dots(3.14)$$

3- Calculation of Nusselt number:

Nusselt number (Nu) presents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. The larger Nu effective the convection. A Nusselt =1 for fluid layer represents heat transfer by pure conduction.

Nusselt number at  $r_i$  becomes as:

$$Nu_{r_i} = \frac{h_i \cdot (r_i \ln(r_o / r_i))}{k} \quad \dots(3.15)$$

$$Nu_{r_o} = \frac{h_o \cdot (r_o \ln(r_o / r_i))}{k} \quad \dots(3.16)$$

then, the mean Nusselt number is:

$$\overline{Nu} = \frac{\overline{h_o} \cdot (r_o \cdot \ln(r_o / r_i))}{k} = \frac{\overline{h_i} \cdot (r_i \cdot \ln(r_o / r_i))}{k} \quad \dots(3.17)$$

The heat transfer rate by convection becomes:

$$Q_{conv} = \overline{h_o} \cdot 2 \cdot \pi \cdot r_o \cdot (T_o - T_i) \quad \dots(3.18)$$

which is the mean of heat transfer coefficient at  $r_2$ . Heat-transfer rate by pure conduction  $Q_{cond}$  becomes:-

$$Q_{cond} = \frac{2 \cdot \pi \cdot k \cdot (T_i - T_o)}{\ln(r_o / r_i)} \quad \dots(3.19)$$

4- Calculation of Rayleigh number:

$$Ra = \rho^2 g \beta \delta^3 (T_i - T_o) c_p / (\mu k) \quad \dots(3.20)$$

where  $\delta = (r_o - r_i)$

ANSYS program contain many options, such as laminar or turbulent, incompressible flow, etc. These options should be chosen according to the physical nature of the problem. To obtain a reliable solution, these options must be selected carefully.

The following analysis must be steady state (time independent), laminar or turbulent (depending on Rayleigh number),

Air is chosen as working fluid by using SI units for analysis and its properties are taken from the table in the program depending on nominal temperature (25 °C).

### 3.5.. Examining the Results

In the present work convergence is checked for solution of velocities, pressure, turbulent kinetic energy and its dissipation rate.

The convergence monitors are the normalized measure of the solutions rate of change from one iteration to another. By denoted the general field variable ( $\phi$ ), and any degree of freedom, the convergence monitor is defined as follows;

$$Conv.Mon. = \frac{\sum_{i=1}^N |\phi_i^n - \phi_i^{n-1}|}{\sum_{i=1}^N |\phi_i^n|} \quad \dots(3.21)$$

Where;

$N$  = Total number of finite element node.

$n$  = Current global iteration number.

$\phi$  = Degree of freedom.

From the observing of the change rate of the solution and the behavior of the relevant dependent variable, one can monitor the solution convergence of the analysis.

### **3.6 Checking Results of Computer Model**

To verify the results, the procedure that listed below should be taken into consideration:

1. Checking the mass balancing that printed a part of the result summary.
2. Checking the validity of the used boundary conditions within ANSYS to ensure that they are accurate.
3. Checking if the properties are specified correctly.

If the unexpected results diverge the solution, the finite element mesh may not have sufficient resolution or significant gradients may not be suitable.

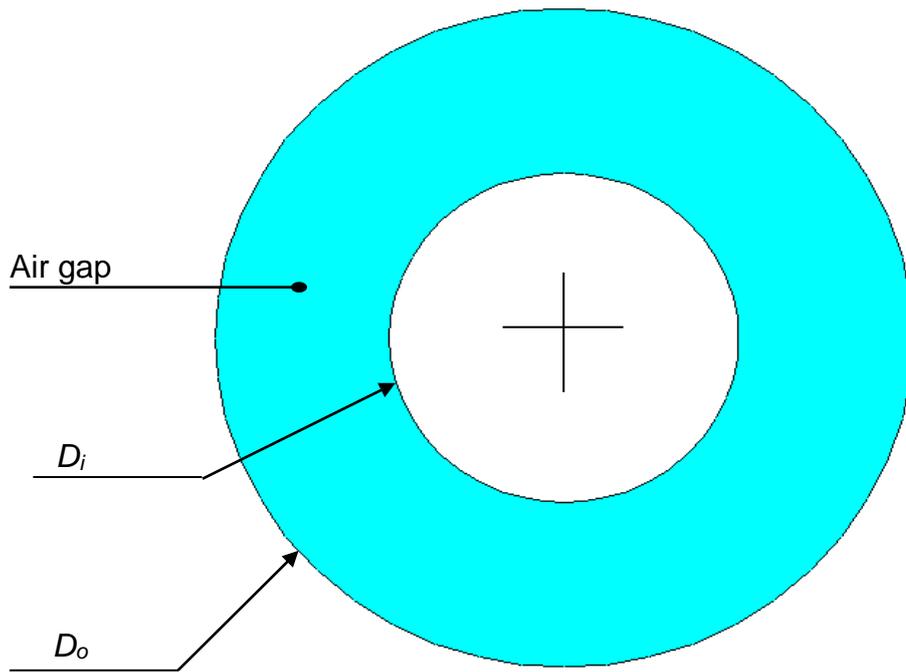
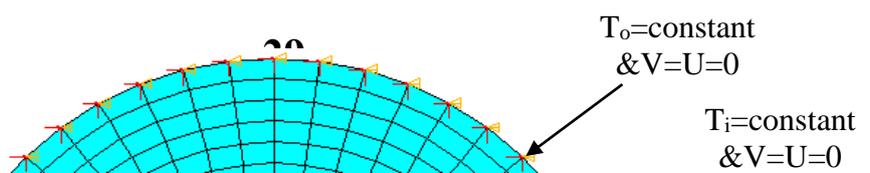


Fig.(3.1): Finite element modeling.



## **EXPERIMENTAL WORK**

### **4.1 Introduction**

The main purpose of the experimental work that achieved in the present work is to validate the investigation of the accordance between the experimental and theoretical results, to support the numerical (theoretical) results by the experimental one, to check the theoretical case with the real experimental case. In addition, the experimental work gives a clear idea and the whole information about the thermal behavior and flow pattern, temperature distribution between concentric pipes when the inner cylinder of a high temperature and the outer is of a low temperature.

This chapter contains two parts: in the first, a detailed description of the experimental model (concentric pipes) and the devices that used are presented. In the second, a presentation to procedure of experimental case in addition to related results is showed.

### **4.2 Experimental Apparatus**

The main aim of the research is to specifying a better case of temperature distribution, convection heat transfer coefficient and thermal conductivity of models (concentric pipes). Therefore, all these properties are required to build a suitable and main experimental rig.

The assembled apparatus and the devices that used in the experimental work for wholly testing case are consist of concentric pipes models, cooling system, test section, control system for power supply to heat source, portable

ammeter, data acquisition system to be used with PC to control the test section, and all measurement. All these devices and requirements are shown in the Figures (4.1) and (4.2).

### 4.2.1 Experimental Model

The experimental models are mainly consisting of two cylinders, inner and outer. The inner is machined from solid stainless steel bar stocking into a tube 203mm long with an outside diameter of 23mm and a wall thickness of 3mm. This is heated by passing direct current through a 190 $\Omega$  tubular resistor approximately 180mm long held in the centre of the cylinder. 15 thermocouples distributed in the test section, 13 in the mid-plane spaced 45 $^{\circ}$  apart and one at each end of the test section (on the inner and outer cylinders surfers), were positioned within (3, 6 and 9) mm of the inner cylinder surface as shown in Fig.(4.6). Expanded solid cylinder of fire brick (17mm diameter and 11.5mm thickens) mounted on each end of the heater to reduce the conduction losses in the ends of inner cylinder. The inner cylinder is held concentrically within the outer cylinder by three wood disks with thickness 0.4cm and (23, 46) mm inner and outer diameter.

The outer cylinder, also of stainless steel, is machined into a tube 20.35cm long with an inside diameter of 46mm and a wall thickness of 7.5mm. This made  $\frac{\delta}{D_i} = 0.5$ , where  $\delta$  is the annulus gap width and  $D_i$  is the outside diameter of the inner cylinder.

## 4.2.2 Cooling System

In order to attain constant temperature for the inner surface of outer cylinder ( $T_o = \text{constant}$ ), the outer surface of this cylinder is cooled by circulated water of quasi-constant temperature.

A simple cooling system is manufactured by using a third cylinder of radius of 75mm and 4mm in thickness, this cylinder is surrounded to the experimental model. This cylinder is provided with an input and output orifices to circulate the cooling fluid (water). Two orifices (upper and lower) are mounted at the third cylinder in order to ensure that the cooling system is good feature and efficiency. The constancy of outer cylinder temperature gives an approximation with the theoretical assumptions, thereby, an accordance to the experiments the results will be attained.

## 4.2.3 Electrical Power Supply

To change and control the temperature for the inner cylinder, a heater is connected with a transformer (Variac 12Amp, max). The transformer is received the electrical current from the main power supply. The power is supplied with a values started from 1 to 6 step 1 watt and from 10 to 50 step 5 watt in addition to another two values of 0.5 and 8 respectively.

The supplied power can be measured by using of multimeter (ROBIN, TAUT multimeter) with an error of  $\pm 0.01\%$  so that the voltage across the heater is read by voltmeters and the current that passed through the same heater is indicated by ohmmeter. The heater resistance is recorded by using an ohmmeter. Finally, the supplied power is calculated.

#### 4.2.4 Monitoring Device

The Interphase device is connected with the computer that used to present the experimental results in connection with visual BASIC program (V 6.0) on certain digital panel as shown in Fig. (4.4). This panel contains fifteen channels to read and record the magnitude of temperature values for each thermocouples set. In addition to these channels, there are two more digital screens to record and read the saved data and work time (exposure time). The attained results are saved in the personal computer.

The properties of the computer are PIII of 735 MB and 128 in RAM and 20GB in capacity. It is important to refer that these properties are very acceptable for the measuring devices that are used.

#### 4.2.5 Thermocouple Sets

Thermocouple sets type **K** (0.27) mm Chromel-Alumel thermocouple wires are used. The thermocouple wire was cut into two pieces, each piece of the wire was skinned from both ends and one of the ends was spot-welded forming a spherical bead. In all experiments (15) thermocouples were distributed uniformly as shown in Fig. (4.6) in the air gap between the two cylinders and through their surfaces to determine the temperature distribution through these regions.

### 4.2.6 Interface Cart and Software Driver

So as to convert all the data from the test section to the PC computer the Interface board was used, where this Interface board activated on the PC by using the visual BASIC package (V. 6.0). This software control converting data to PC. The software driver consists of several forms and some function.

## 4.3 Experimental Work

Two aspects must be satisfied before starting the experimental work. The first is the calibration process for thermocouples to ensure the accuracy of them in addition to the device that required in the measuring itself. The calibration process is satisfied by using four types of experimental metals: die ionized water, Heptan, Acetone and Putanon. The boiling and freezing temperatures for these metals must be known previously. The measured temperature must be taken at an instance of transformation conditions from solid to liquid phase. Then, the four metals are subjected to heater so that these metals have been found in boiling case. In this instant the temperature must be recorded again and considered as a boiling temperature. These processes are repeated for the four metals so that the results are five points: (four for boiling and one for freezing). Finally, two curves are extracted: one for the experimental measuring and the other for the theoretical values that must be available previously. These curves are shown in Fig. (4.5).

In the second aspect, a Precision Balancing Water Bubbles is used to sustain the horizontal level of the models, so that more accurate temperature measurements are resulted.

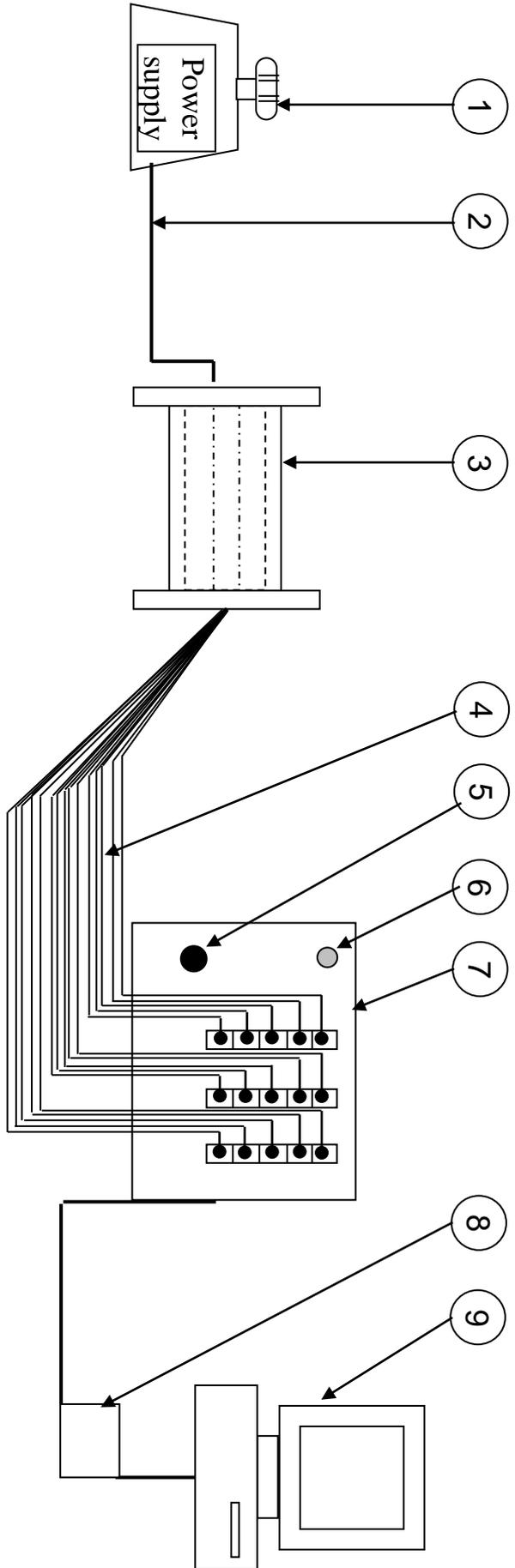
The value of the power that supplied to the heater is obtained by using a transformer to change the voltage value. The temperature of the heater is largely depending on the power that supplied. Therefore, the temperature value of the inner cylinder changes due to the changing in the power itself. For each iterative value of the power, the temperature of thermocouple will change also. The temperatures of thermocouples will be record by using an Interphase device which transforms the temperature signals to a digital signals which can be read easily from the monitor of the computer. After reaching the steady state case (usually from 2-3 hours), the temperature of each set of thermocouples is recorded and may saved in any text file by using a VB (Visual Basic) program which prepared for this purpose.

At last, the above procedure is repeated again for all iterative power values (temperatures values) that required attaining the test.

### **4.3.1 Temperature Measurement**

The temperatures are measured at the testing part that located in the middle section of the model as shown in the Fig.(4.6), so that the locations of the test are distributed in uniform manner to attain an wholly information about the temperature distribution through the section. Fig.(4.6) presents the distribution of thermocouples sets. There are 15 sets of these thermocouples, one insulated from the other through the experimental model. Two of them are located at the outer surface of the inner cylinder and the inner surface of the outer cylinder of the models and the other is distributed on a three circular paths around the inner cylinder of equally distance of 3mm from the inner cylinder of the model. At the first and the second circular paths, there are 5 sets of each set

inclines from the other by  $45^\circ$ . But for the third path, there are 3 sets distributed in a  $45^\circ$ ,  $90^\circ$ , and  $180^\circ$ .

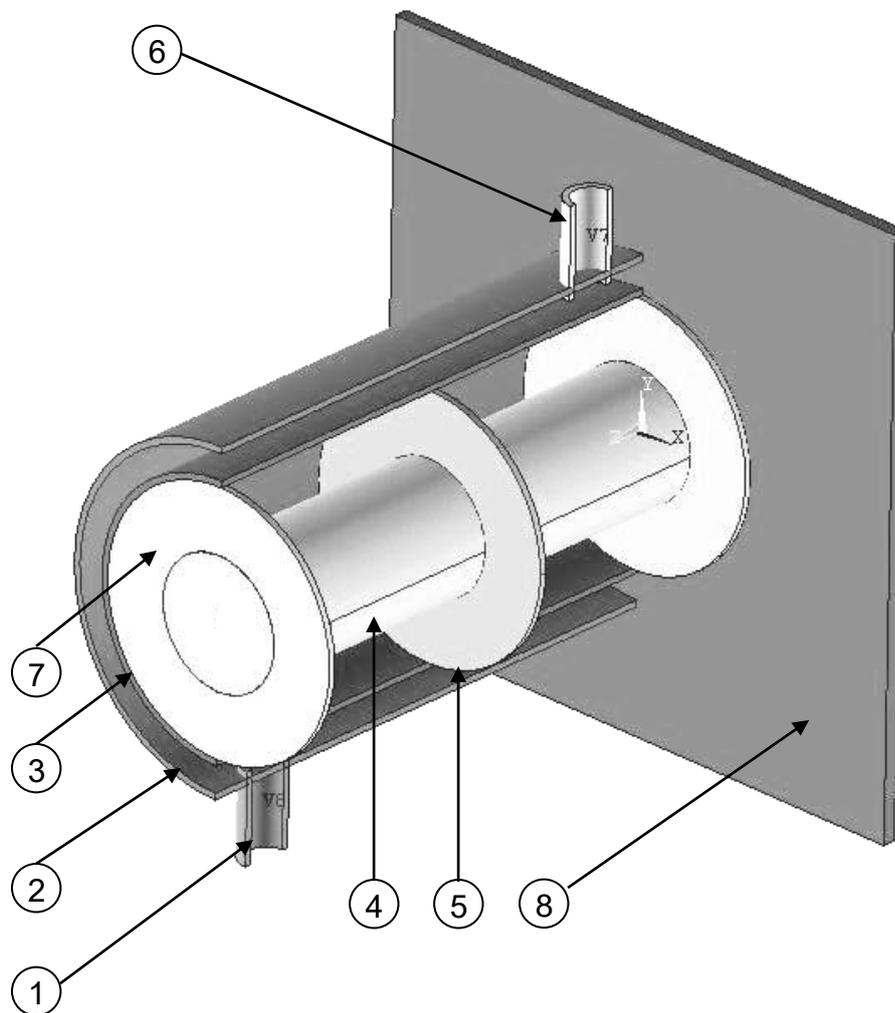


**Fig.(4-1)** Schematic arrangement of experimental rig.

1- Power Supply.	2- Cables.	3- Experimental rig.
4- Thermocouples.	5- On/Off Switch.	6- Power On.
7- Interface.	8- Data Cables.	9- PC.



**Fig. (4-2)** Photograph of test rig.



**Fig.(4. 3):** Full geometrical consideration of the concentric pipes , 1- water inlet, 2- outer cooling cylinder, 3- outer pipe, 4- Inner pipe, 5- test section, 6- water outlet, 7-insulated discs, 8-handle

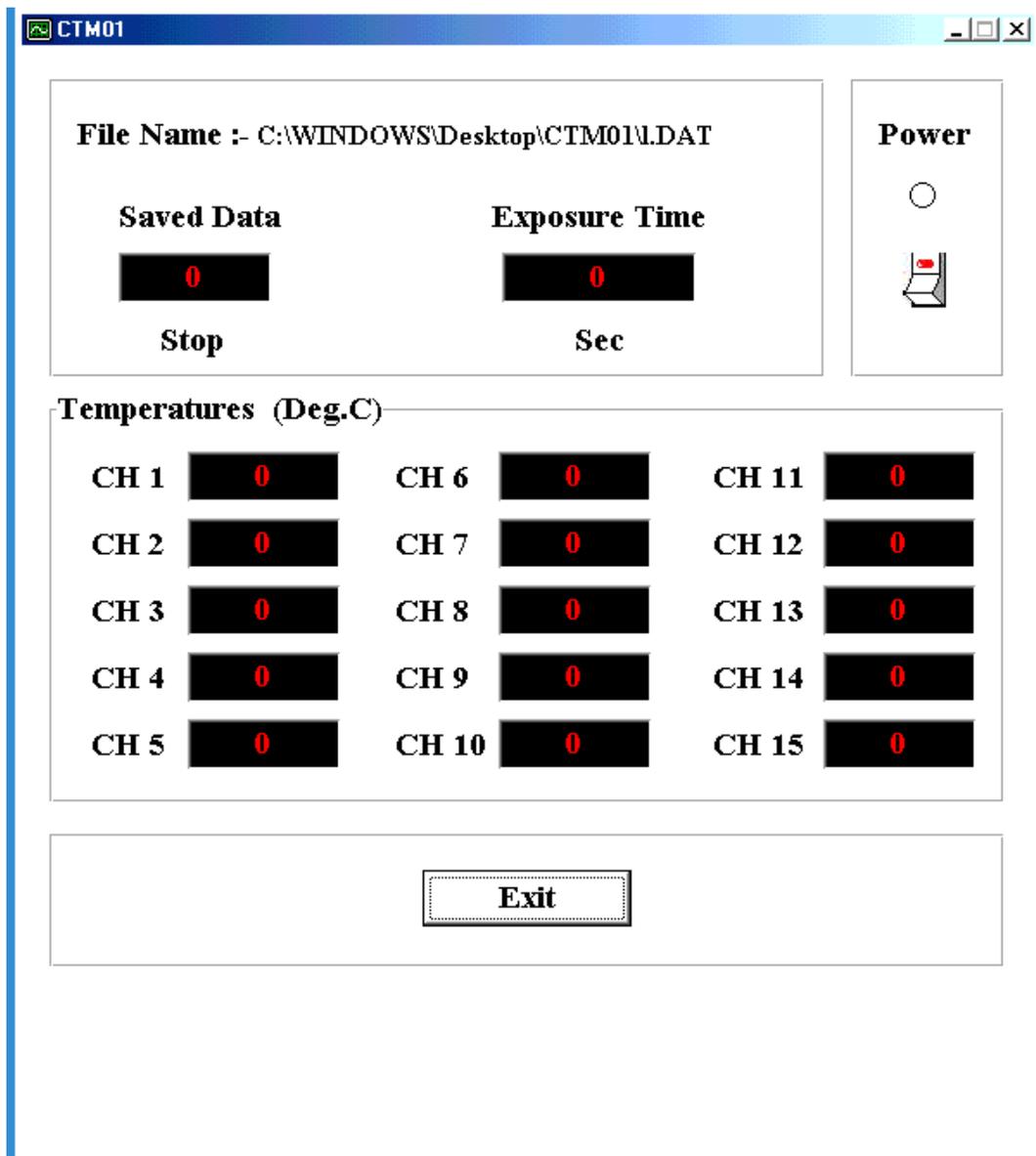


Fig. (4.4) : Windows data.

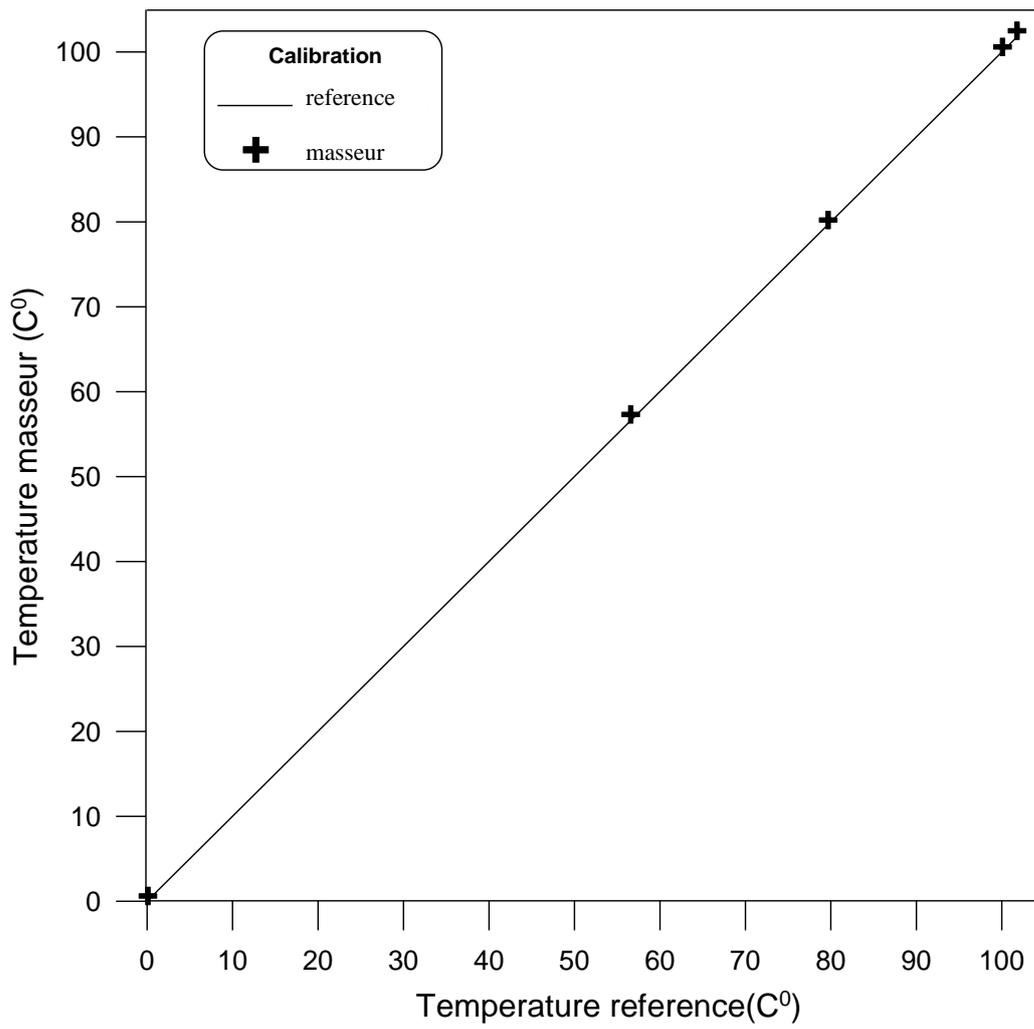
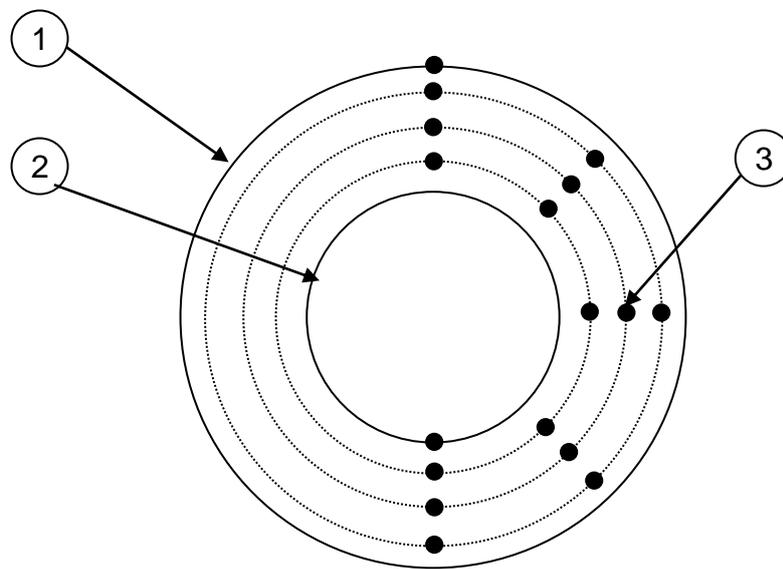


Fig. (4.5) :calibration curve for thermocouple.



**Fig.(4.6):** Presents test section.  
1-outer cylinder, 2-inner cylinder, 3- thermocouples