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Variation of Heat Transfer Coefficient for Inside and Outside Closed Space with Respect to Temperature Gradient for Three Different Metals

Abstract- *The heat transfer coefficient (h), is used in thermodynamics to calculate the heat transfer typically occurring by convection. A simple way to calculate (h) is to define it through the classical formula for convection, the present study includes correlations different natural convection can be used to calculate heat transfer coefficients theoretically for the experimental tests done inside and outside close system. All the results obtained from the experimental tests, theoretical calculations and from the literatures show that, heat transfer coefficients (h) are increasedwiththe temperature increasing. The experimental results for all the tested materials appears that there are similarity for the rules of sequence step in the change of heat transfer coefficient (h) with respect to the thermal conductivity coefficients (k) of these materials, and they are in a row from the highest value to the lowest value; Copper, Aluminum, Steel and Brick respectively for both of (k) and (h). The results show a good accuracy and compatibility of the comparison between numerical results with the present experimental work, also give a good agreement between the present experimental work and the numerical results with the experimental results obtained from literature approved in this study.*

Keywords- *Natural convection; Numerical analysis. Heat transfer coefficients(h)*

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1. Introduction

Convection heat transfer takes place whenever a fluid is in contact with a solid surface that is at a different temperature than the fluid. If the fluid is moving past the solid surface because of an external driving force, then it is called forced convection .If fluid motion is due to density differences caused by temperature variation in the fluid, then it is called natural convection [1]. The convective heat transfer coefficient h is defined according to Newton's Law of Cooling as [2]:

$$Q = h * s * (Tp - Ta) \quad (1)$$

For convection, we use the convection heat transfer coefficient h, W/(m^2.k). A different approach to define h is through the Nusselt number Nu, which is the ratio between the convective and the conductive heat transfer [3].

$$Nu = \frac{hD}{K} \quad (2)$$

Nusselt number is used directly to evaluate the convection coefficient according to (3):

$$h = Nu\frac{k}{D} \quad (3)$$

Table 1 given value (Nu) Natural convection of isothermal flat plate ,The Nesselt number relies of geometrical shape of the body heat and the air flow.

Rayleigh number defined in terms of Brandt number (Pr) and Grashof number (Gr). If Ra $<10^9$the heat flow is laminar, while if Ra $>10^9$the flow is turbulent [4]. The definition is

$$Ra = Gr*pr \quad (4)$$

Grashof number, Gr is defined as

$$Gr = \frac{g*L^3*\beta*(T_p-T_a)}{\eta^2} \quad (5)$$

Where:
- g = acceleration of gravity = 9.81, m/s^2
- L = longer side of the fin, m
- β = air thermal expansion coefficient.
-Tp = Plate temperature, °C.
- Ta = Air temperature, °C
- η = air kinematic viscosity, [5]

The Prandtl number which is the ratio of momentum and thermal diffusivities, Pr is defined as:

$$Pr = \frac{\mu * cp}{k} \quad (6)$$

Where:
- μ = air dynamic viscosity
- cp = air specific heat
- k = air thermal conductivity [6].

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Awbi [6] studied natural convection heat transfer in two-dimensional rooms by using computational fluid dynamics (CFD) technique. The room configurations included heated wall, heated floor and heated ceiling. Two kinds of CFD models were applied: a standard $k-\varepsilon$ model with "wall functions" and the low Reynolds number $k-\varepsilon$ model.

Oetelaar and Johnston [7] studied natural convection processes inside terracotta flues as a part of a larger numerical study of ancient Roman baths, The five plenum temperatures were tested (60°C, 70°C, 80°C, 90°C, 100°C) and they found , that the average convective coefficient was 7.0 (w/m^2°C).

Roncati [8] used the iterative method to calculated accurately the temperature value for heat sink and better precision of heat transfer coefficient of finite elements software for thermal analysis.

Conti et al. [9] introduced simplified model for measuring convection heat-transfer coefficient, the simplified model is valid for convective heat-transfer coefficient of about 30 W m^{-2} K^{-1} and for $\Delta T<100K$,that is when the energy exchange by radiation is negligible.

Hatton and Awbi [10] made experiments to find convective heat transfer in room building simulation on room walls or aluminum plates. They found the mean convective heat of aluminum wall to be $\mathbf{hc=1.57\Delta T^{0.31}}$. Where $\mathbf{\Delta T}$ = (T – Ta); T is the measuring temperature of air tentacles with specimen face; Ta Aluminum specimen temperature.

Ahmed and Chaichan [11] study of Free Convection in A solar Chimney Model. Shows Maximum heat transfer coefficient h was 31.83 W/m2 K. A maximum air temperature difference attained was 22 º C at mid-day through the solar chimney and Empirical equation that relates Nusselt and Rayleigh numbers was obtained.

Mohammed [12] study experimental and numerical simulation for natural convection heat transfer formed by uniformly heated inclined elliptical cylinder concentrically located in an enclosed square cylinder subjected to the ambient have been investigated. Experiments have been carried out for Rayliegh number ranges from 0.9 $\times10^6$to3.3$\times10^6$ while a numerical simulation was conducted by using commercial Fluent CFD code to investigate the steady laminar natural convective heat transfer. The experimental results explained the heat transfer process improves with increases in Rayliegh number . In this paper, description of experiment and theoretical methods to measure and to calculate the convective heat-transfer coefficient, which is a characteristic constant of convection systems.

2. Experimental Apparatus and Results of Measurements

I. Experimental apparatus

Electrical france explains in Figure 1 utilized to calculate the transfer coefficient of the convection heat. The heater room is intended to hole the round and hollow samples sleeve of (140mm) length in gap in the rear mass of the heater, the samples are penetrated to embed the thermocouples so as to gauge the heat via the sample materials. To acquire sensible temperature consistency along the sample, an aluminum tube is used to place the sample holder in it. The experimental variables are different specimen materials and specification such as Aluminum, Copper and Steel, each specimen has outside diameter of (30mm) and length (40mm). In order to measure the temperature the heating process, we have inserted thermocouple type (k) inside specimen and measured the temperature of the specimen when temperatures furnace from 50°C to 500°C. Once the heat degree of the thermocouple is settled by switching on the heater that becomes in state of balance, accordingly, the reading is begun to show up. Figure 2 and 3 shows scheme of measuring temperature through the tested specimen and scheme of furnace.

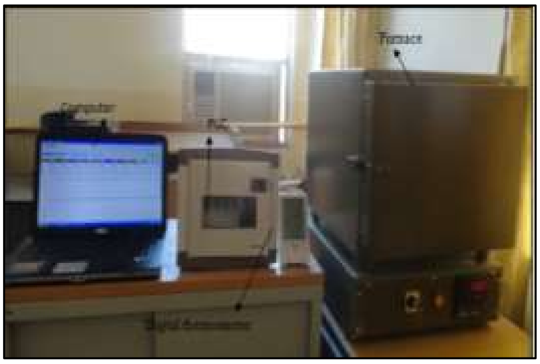

Figure 1: Experimental apparatus set up

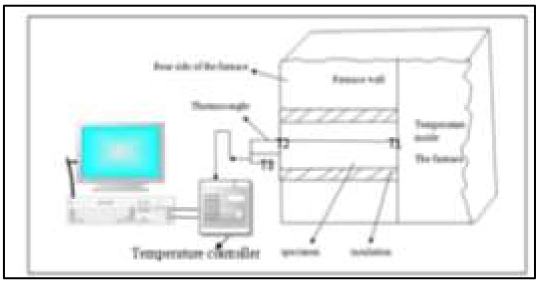

Figure 2: The scheme of measuring temperature through tested specimen

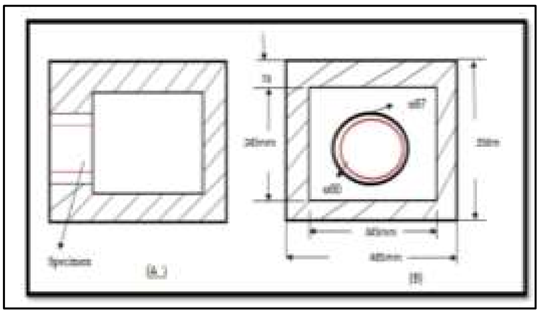

Figure 3: The scheme of furnace
A-side view section of furnace
B- Front view section of furnace

II. Temperature Measurement

The temperature values have been automatically acquired by the software (PLC). The first temperature measured (T1) for the face of the specimen located in side furnace, the second temperature (T2) represented second face of specimen is located in outer side of furnace wall, the third temperature (T3) represented temperature near of furnace wall as shown in Figure 2.

III. Metal Selection

The composition of the used alloy are shown in Table 1, 2 and 3 its chemical analysis of sample Equipped by company inspection engineering (S.I.E.R) as it was given in Appendix

3. Experimental Results and Calculation

I .Calculation samples of convective heat transfer coefficient (h) of materials

An initial determine value for Tp then is set in Eq. 5 to define Garshof number. Once calculated the parameters Gr, Pr, Ra and Nu, then calculated value of (h) from is the equation (Eq.3) for estimation convection coefficient of copper inside furnace at temperature 100°C, the air properties at the mean temperature are evaluated as followed:

$$T_F = \frac{T_1 + T_2}{2} = \frac{100 + 63.5}{2} = 81.75°C$$

According to average mean temperature (T_F), the physical properties of Air (k,pr and μ) got assessed.

K= 0.03003 w/m °C, pr=0.697, μ =2.075x10^{-5}kg/m.s

Define air thermal expansion coefficient.

$\beta = \frac{1}{TF} = 2.8x10^{-3}$

The Rayleigh number can be calculated from Garshof-Prantdal number according the following equation:

$$Re = \frac{g\beta(T_1 - T_2)\delta}{\mu^2}Pr$$

$$Re = \frac{9.8X2.8X10^{-3}X(100-63.5)X6.4X10^{-5}}{(2.075x10-5)^2}x0.697 = 103765.6286$$

For laminar flow, horizontal fins and the heat of upward flow, Table 1 represented value of (Nu) Nusselt number can be calculated by using the equation :

$Nu=0.54(Re)^{0.25}$

$Nu=0.54(103765.6286)^{0.25}=9.69$

Heat transfer coefficient determine according the following equation:

$h=Nu\frac{k}{D}$

$h=\frac{9.69x0.03003}{0.04}=7.2w/m^2°C$

The results of calculated values of convicted heat transfer coefficient (h) from the experimental measurement are given in table [5,6].

The results of calculated values of convicted heat transfer coefficient (h) from the experimental measurement are given in table [5,6].

II. Numerical model to evaluation of convective heat transfer coefficient (h) of materials

Heat transfer coefficients for the samples Copper, Aluminum, Steel and Brick which were calculated from the measurement results in the inside closed system. The results calculated from the derived numerical expressions are given in Table 7. These numerical formulas were derived by using the general polynomial, Taylor series and least square methods which give accurate results are closed on each other for all the three methods of solutions. The value of h for all the samples are expressed as follows which were derived from the general polynomial and solved by Gaussian eliminations:

The general polynomial used was:

$$f(x) = a1 + a2x + a3x2 \quad (7)$$

Which can be written as follows:

$$h = a1 + a2 + a3T2 \quad (8)$$

Then after were finding the values of a1, a2 and a3 get the following empirical equations:
Samples of Copper formula:

$$h = 3.53 + 0.034T - 3.125x10^{-5}T^2 \quad (9)$$

Samples of Aluminum formula:

$$h = 3.46 + 0.0324T - 3.2x10^{-5}T^2 \quad (10)$$

Samples of Steel formula:

$$h = 2.1 + 0.038T - 4x10^{-5}T^2 \quad (11)$$

Samples of Brick formula:

$$h = 2.87 + 6.42x10^{-3}T + 2.85x10^{-6}T^2 \quad (12)$$

Then the heat transfer coefficients(h) of the thin layers of air at the surface of the samples Copper, Aluminum, Steel and Brick were calculated from measurements in the outside closed system,. The expressions given in Table 8 represent these values. These numerical formulas derived by using the general polynomial of infinite degree, taylor series and least square methods which give accurate results closed on each other for all the three methods of solutions. The value of h for all the samples are expressed as follows which were derived from the general polynomial of infinite degree and solved by Gaussian eliminations:
The general polynomial used was:

$$f(x) = a1 + a2x + a3x^2 \quad (13)$$

Which can be written as follows:

$$h = a1 + a2 + a3T^2 \quad (14)$$

Then after were finding the values of a1, a2 and a3 get the following empirical equations:
Samples of Copper formula:

$$h = 3.07 + 0.05T - 9.9X10^{-5}T^2 \quad (15)$$

Samples of Aluminum formula:

$$h = 3.6 + 0.034T - 5.5X10^{-5}T^2 \quad (16)$$

Samples of Steel formula:

$$h = 2.65 + 0.056T - 1.33X10 - 4T^2 \quad (17)$$

Samples of Brick formula:

$$h = 2.07 + 0.059T - 1.32X10^{-4}T^2 \quad (18)$$

4. Results and Discussion

I. Heat transfer coefficients (h) for the inside closed space, which were calculated from the results of experimental temperature measuring for the thin layers of air at the surface of the inside wall of the furnace and at the face of specimen inside the furnace under natural convection ,are shown in Figures 4, 5, 6 and 7. It can be observed that increase in air temperature inside the furnace results in corresponding increase in coefficient that measures convection heat of thin layer in contact with all material surface of Aluminum, Copper, Steel and Brick. Also, it could be observed that there was a good agreement found between the results calculated from the derived numerical equation (9, 10, 11 and 12) and the values of the experimental study .It can be said that any little dissimilarity happened within the values of aforementioned results (out comes) may come as a result of the dissimilarity in the precision of temperature measured by different types of sensor (thermocouples).

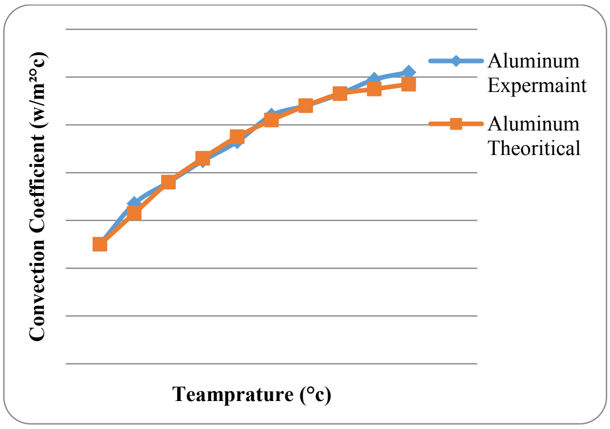

Figure 4: Measured convective heat transfer coefficient inside closed space

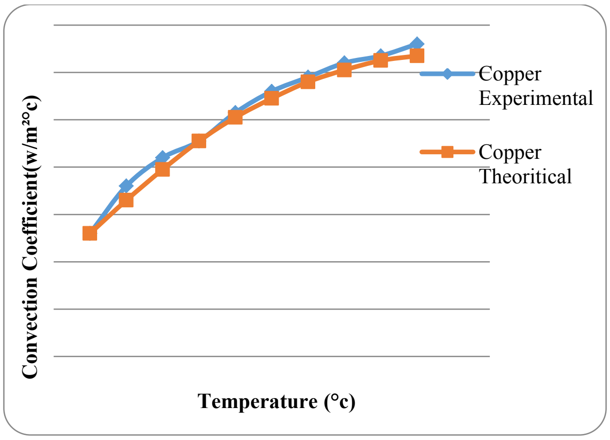

Figure 5: Measured convective heat transfer coefficient inside closed space

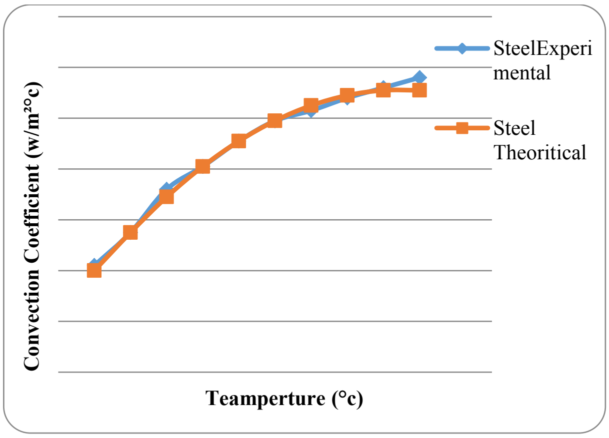

Figure 6: Measured convective heat transfer coefficient inside closed space

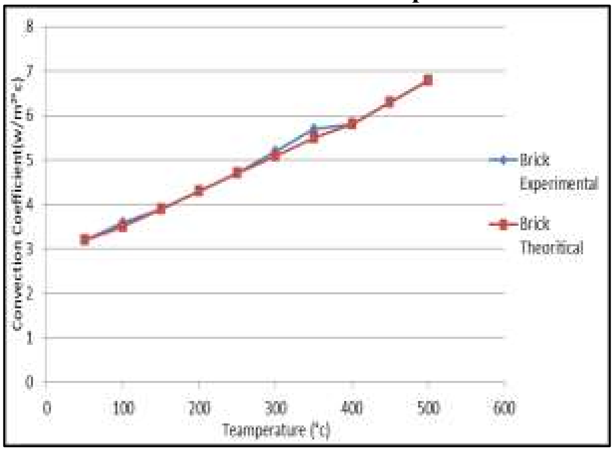

Figure 7: Measured convective heat transfer coefficient inside closed space

II. The second study was to focuses on the behavior of coefficient heat transfer (h) at the outside of closed space with respected to variable temperature. The results show that when there is an increase in the temperature of all specimen faces (Copper, Aluminum, Steel and Brick) which located at outside the furnace leads to an increase in convective heat transfer coefficient of thin layers in contact with all materials, as displayed in the Figures 8, 9, 10 and 11. These figures also show a comparison between the experimental results and the results which were calculated from the derived empirical equation (15, 16, 17and 18), it was clear that the theoretical results are nearly close each other

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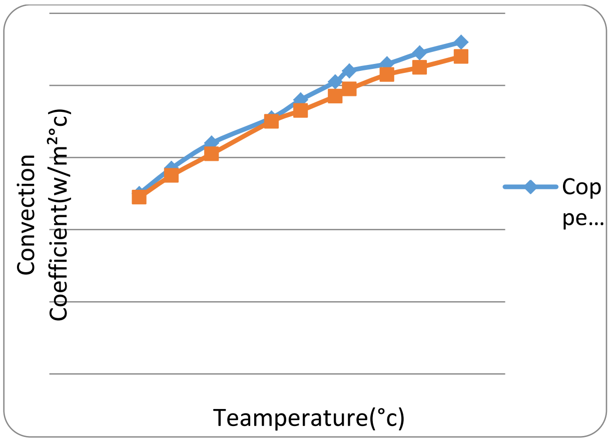

Figure 8: Measured convective heat transfer coefficient outside closed space

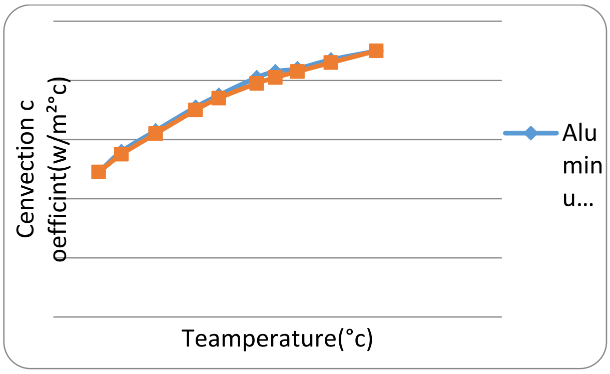

Figure 9: Measured convective heat transfer coefficient outside closed space

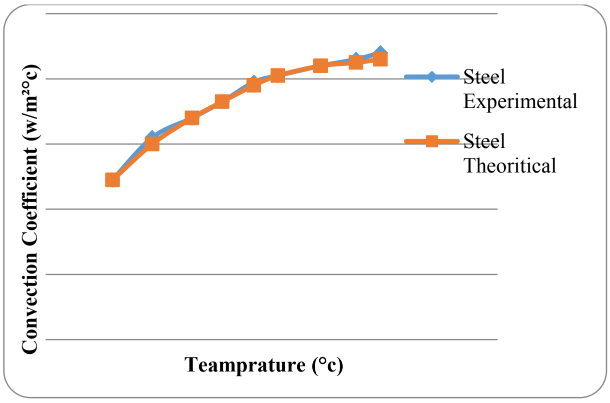

Figure 10: **Measured convective heat transfer coefficient outside closed space**

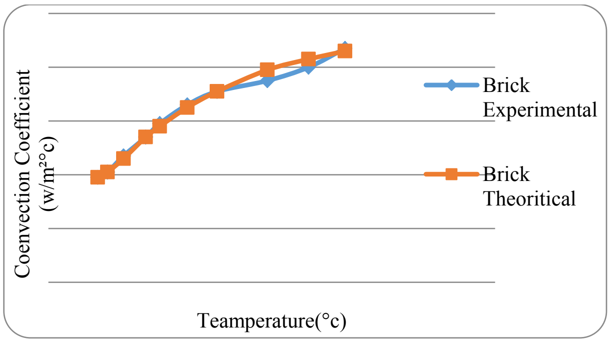

Figure 11: Measured convective heat transfer coefficient outside closed space.

III. A comparison between both experimental and theoretical results compared with the results get from the formula given in reference [10] Hatton and Awbi are illustrated in Figures 12 and 13.The results are approximately close to each other.

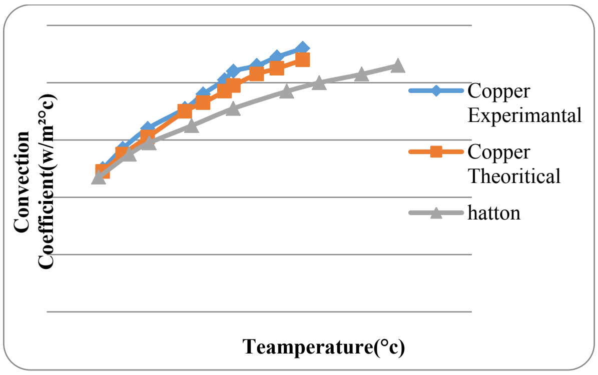

Figure 12: A comparison between convective heat transfer coefficients in this research with the results given in literature for copper materials

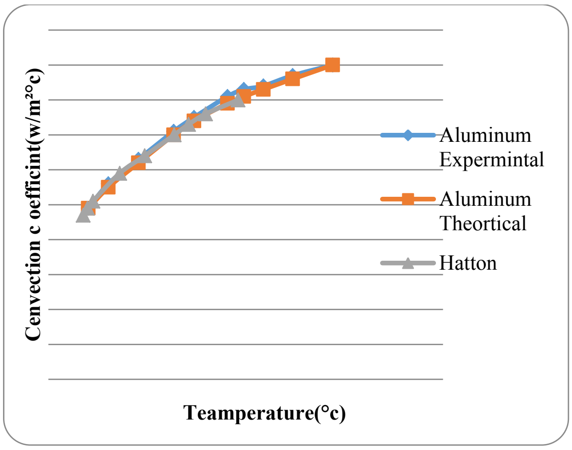

Figure 13: A comparison between convective heat transfer coefficients in this research with the value given in literature for aluminum materials

5. Conclusion

1)The new experiment design made by a hole through the wall of a a furnace and the new technique of measurement give a good rules to find heat transfer convicted coefficient (h) inside and outside a furnace or any closed spaces or system

2) The result show that ,heat transfer convicted coefficients (h) of the thin layers in contact with all tested materials increased with temperature increasing in both cases ,inside and outside closed space.

3) All the empirical equations derived to find the values of heat transfer convicted coefficient give good approximation between experimental and theoretical results.

4) A good compatibility of the results in this research is compared with other research results.

5) Sequence steps value of heat transfer coefficient are similar to the conduction heat transfer coefficient**.**

Nomenclature

- G gravity
- H convective heat transfer coefficient
- K thermal conductivity
- Nu Nusselt number
- Ra Rayleigh number
- Tc temperature of Copper (°C)
- H convective coefficient of Copper
- Temperature of Aluminum (°C)
- H a convective coefficient of Aluminum
- Temperature of Steel (°C)
- H s convective coefficient of Steel
- Temperature of Brick (°C)
- H b convective coefficient of Brick
- β thermal expansion coefficient
- Tp air thin layer temperature contact with specimen surface (°C)

Appendix-A

Table 1: Nusselt number formula [8]

	Vertical fins		Horizontal fins
Laminar flow	$Nu = 0.59*Ra^{0.25}$	Upward laminar flow	$Nu = 0.45*Ra^{0.25}$
Turbulent flow	$Nu = 0.14*Ra^{0.33}$	Downward Laminar flow	$Nu = 0.27 * Ra^{0.25}$
	Turbulent flow		$Nu = 0.14 * Ra^{0.33}$

Table 2: Chemical composition of Steel specimen

Material	C%	Si%	Mn%	p%	S%	Cr%	M o%	Ni%	Cu%	V%	Al%	Fe%
Weight %	0.974	0.0270	0.307	0.006	0.019	1.49	0.02	0.121	0.229	0.059	0.0	Balance

Table 3: Chemical composition of Aluminum specimen.

Material	C%	Si%	Mn%	Pb%	Ti %	Cr%	Mg%	Ni%	Cu%	Zn%	Fe %	Al%
Weight%	0.0	0.291	0.480	0.007	0.022	0.09	1.29	0.014	3.81	0.525	0.453	Balance

Table (4): Chemical composition of Copper specimen.

Material	Co%	Si%	Mn%	P%	S%	Cr%	pb%	Ni%	Sb%	Fe%	Sn%	cu%
Weight%	0.002	0.001	0.005	0.008	0.004	0.0007	3.58	0.082	0.015	0.321	0.287	Balance

Table 5: The experimental values coefficient of heat transfer (h) for the thin layers of air at the surface different materials inside closed system at different temperature

No	Temperature (°c)	Convection coefficient of Copper	Convection coefficient ofAluminum	Convection coefficient of Steel	Convection coefficient of Brick
1	50	5.2	5	4.2	3.2
2	100	7.2	6.7	5.5	3.6
3	150	8.4	7.6	7.2	3.9
4	200	9.1	8.5	8.1	4.3
5	250	10.3	9.3	9.1	4.7
6	300	11.2	10.4	9.9	5.2
7	350	11.8	10.8	10.3	5.7
8	400	12.4	11.3	10.8	5.8
9	450	12.7	11.9	11.2	6.3
10	500	13.2	12.2	11.6	6.8

Table(6) The experimental values coefficient of heat transfer (h) for the thin layers of air at the surface different materials outside closed system at different temperature .

No	Temperature (°c)	Convection coefficient of Copper		Convection coefficient of Aluminum		Convection coefficient of Steel		Convection of coefficient of Brick	
		TC(°c)	hc(w/m²°c)	TA(°c)	ha(w/m²°c)	TS(°c)	hs(w/m²°c)	TB(°c)	hb(w/m²°c)
1	50	39.5	4.9	40.5	4.9	44.5	4.9	33.2	3.9
2	100	53.6	5.5	60.8	5.5	67.7	5.7	39.8	4.1
3	150	71.2	6.1	91.3	6.2	70.8	6	50.0	4.7
4	200	97.5	7	127	7.1	97.2	6.8	65.4	5.2
5	250	110.3	7.3	147.6	7.4	117.2	7.3	74.8	5.8
6	300	125.7	7.7	181.5	8	138.4	7.8	93.3	6.5
7	350	131.7	7.9	198.1	8.2	154.2	8.1	113.4	7.1
8	400	148.2	8.3	217.8	8.4	182.6	8.4	147.1	7.9
9	450	162.5	8.5	247.6	8.6	206.1	8.5	174.8	8.3
10	500	180.7	8.8	288.1	9	222.2	8.6	199.3	8.6

Table(7)) The calculated values of heat transfer coefficient (h) from the derived empirical equations for the thin layers of air at surface of different materials inside closed system at different temperature.

No	Temperature (°c)	Convection coefficient of Copper	Convection coefficient ofAluminum	Convection coefficient of Steel	Convection coefficient of Brick
1	50	5.2	5	4	3.2
2	100	6.6	6.3	5.5	3.5
3	150	7.9	7.6	6.9	3.9
4	200	9.1	8.6	8.1	4.3
5	250	10.1	9.5	9.1	4.7
6	300	10.9	10.3	9.9	5.2
7	350	11.6	10.8	10.5	5.5
8	400	12.1	11.3	10.9	5.8
9	450	12.5	11.5	11.1	6.3
10	500	12.7	11.7	11.1	6.8

Table(8) The calculated values coefficient of heat transfer (h) from derived empirical equations for the thin layers of air at surface of different materials outside closed system at different temperature.

No	Temperature(°c)	Convection coefficient of Copper		Convection coefficient ofAluminum		Convection coefficient of Steel		Convection coefficient of Brick	
		TC(°c)	hc(w/m²°c)	TA(°c)	ha(w/m²°c)	TS(°c)	hs(w/m²°c)	TB(°c)	hb(w/m²°c)
1	50	39.5	5	40.5	4.9	44.5	4.9	33.2	3.9
2	100	53.6	5.7	60.8	5.6	67.7	5.7	39.8	4.1
3	150	71.2	6.4	91.3	6.3	70.8	6.2	50.0	4.7
4	200	97.5	7 .1	127	7.1	97.2	6.8	65.4	5.4
5	250	110.3	7.6	147.6	7.5	117.2	7.3	74.8	5.9
6	300	125.7	8.1	181.5	8.1	138.4	7.9	93.3	6.6
7	350	131.7	8.4	198.1	8.3	154.2	8.1	113.4	7.1
8	400	148.2	8.6	217.8	8.4	182.6	8.4	147.1	7.4
9	450	162.5	8.9	247.6	8.7	206.1	8.6	174.8	7.9
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