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RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION ON HEAT TRANSFER CHARACTERISTICS OF PARAMAGNETIC FLUID UNDER THE INFLUENCE OF AN EXTERNAL MAGNETIC FIELD

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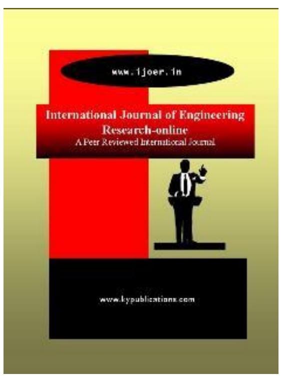

ABSTRACT

Experimentation under consideration aims at improving rate of heat transfer by employment of magnetic field in the region close to the heat transfer fluid. To produce a magnetic field single layer inductor with iron core is used which is imposed on the heated conductor such that magnetic field so produced will repel the hot air which in turn set up convection currents. As a result of which the convective heat transfer rate increases which is inferred from the increased Nusselt number whose readings are calculated from the number of experiments undertaken.

Experiments were carried out at different intensities of magnetic field reaching 1 Tesla and convective heat transfer was determined on a vertical hollow shaft over which a heater was placed. The inductor was placed close to the rod to augment the heat transfer by magnetic convection. The experimentation was conducted with two inductors, one shorter than the length of rod and other long inductor.

The length of the inductor was found to have an insignificant effect on the convetive heat transfer enhancement.

The experimental investigation shows that, the values of Nusselt numbers are higher by 18.2 and 18.8% % when external magnetic fields are present than those when there is no magnetic field for short and long inductors.

Key Words : Magnetic convection, Heat Transfer, Nusselt Number, Enhancement

Nomenclature

μ_0 - Permeability of free space = $4\pi \times 10^{-7}$ H/m
μ_r - Relative permeability of core material = 500
A – Area (m^2)
I – Current (Ampere)
B – Intensity of the Magnetic Field (Tesla)
N – Number of Turns
L – Length (m)
D- diameter of coil in meters (mm)
V – Potential Difference (Volts)
FOS – Factor of Safety

Literature review

Tomasz Bednarz et.al.[1], conducted experiments by magnetizing convection of air in a cubic enclosure with laterally shifted coil. They concluded that the character of convection strongly depends on the distribution of the magnetic field and heat transfer rate can be easily controlled by employing the present characteristics.

ToshioTagawa et.al.,2002, [2] derived simple model equations for a non-isothermal system under a magnetizing force by following the model of the Wakayama group, and the effects of gravity and the direction of magnetic field were studied numerically for air in a cubic enclosure that was heated from one wall and cooled from the opposing wall and for a cusp-shaped magnetic field applied in the X-, Y- or Z-direction. The convection of fluid was attributed to repulsion of hot fluid from the hot wall to the weak magnetic field and the attraction of cold fluid to the strong magnetic field; and these features were reflected in the mathematical model for a magnetizing force.

George S. Dulikravich and Marcelo J. Colaço 2004 [3] developed and validate MHD and EHD analysis codes in cases involving convection heat transfer without and with solidification. Authors also combined these analysis codes and an optimization algorithm in order to determine the appropriate variations of strength of the magnetic and electric fields along the boundaries of a container with a fluid that will create a desired flow-field and the solid/melt interface topology. As a by-product of the solution of this de facto inverse problem, appropriate variations of heat fluxes along the boundary of the container were found.

Experimental setup details:

Experimental setup (Fig.1) consists of rigid cylindrical rod which is 2 cm. in diameter. The length of the rod is 20cm and the material of rod is aluminum. Thermocouple are attached at a distance of 5 cm. from each other. A heater is attached at the bottom to this cylindrical rod. A knob is provided on the control panel to control voltage maintained across the inductor. By controlling the voltage heat dissipated by the cylindrical rod is regulated.

Control panel (Fig.1.) digital has a digital display to indicate Voltage, current & temperature of each thermocouple.

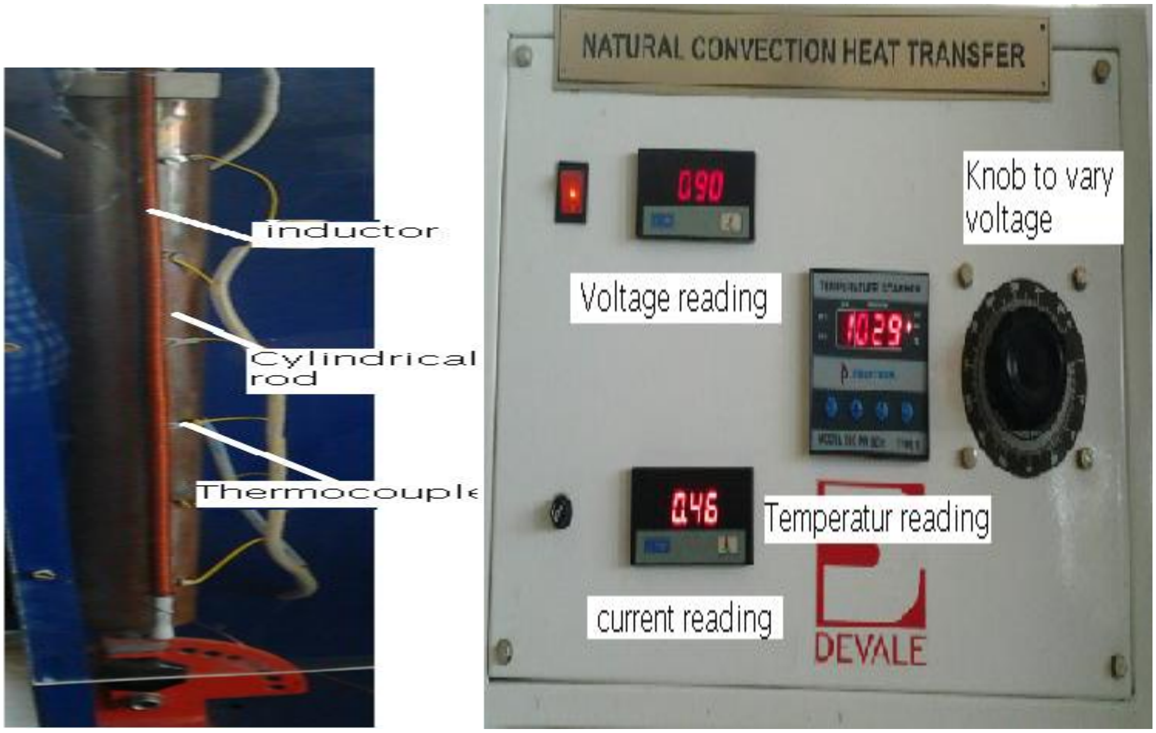

Fig 1. Inductor set up and Control Panel

CONTROL PANEL: PANEL WITH METERS: COMMON PANEL

01. Mains switch : Rocker type, DPST, with illumination, 16 A
02. Fuse : Glass type, 2A
03. Voltmeter : Digital, 0-750 V AC
04. Ammeter : 0-5 A, Digital, AC
05. Temperature : Digital, 0-999 o C
06. Selector : temperature, 12 channel
07. Variac : 0-2 A, 0-230 V, heavy duty
08. Connector : Johnson Bakelite connector to each test Section
09. Diameter of Copper Pipe D = 50 mm
10. Length of Copper pipe L = 500 mm

Design of the Inductor: The objective of design is to create a magnetic field of minimum 1 Tesla strength. The same can be reduced as required by changing the amount of current flowing through the inductor. The inductor is designed in such way, so as to produce a magnetic field of 1Tesla, when 1 ampere current flows through the inductor.

The Experiment is carried on two inductors, one is short inductor and other is long inductor.

(A) Based on above decision following specification of short inductor are decided, which are as follows

N = number of turns (N) =180

D= diameter of coil in meters (mm) =1mm

$A = 7.85 \times 10^{-7}\ m^2$

L=length of the inductor in meter (m) =0.15 m

D_1=diameter of the inductor in meters (m) =0.015 m

A_1= 1.766525 x10^{-4}

I = 1

V= 30 volt

FOS= 2

Consider the equation of the amount of magnetic field produced for a long inductor [5]

$$B = \mu_0 \mu_r N i / l \quad (1)$$

Substituting value in the above equation we get,

B= 0.30144 Tesla

(B) Based on above decision following specification of long inductor are decided, which are as follows

N = 800

D= 1mm

A = 7.85x10^{-7} m^2

L= 0.5m

D1= 0.05m

A1= 9.8125x10^{-4}

I= 1 ampere

V= 30 volt

FOS= 2

Value of B=0.3215 Tesla

EXPERIMENTAL PROCEDURE

Experimental was carried out in two stages. First stages comprised of performing experiments on cylindrical rod and to find out the Nusselt number without applying a magnetic field. The second stages comprised of performing experiments on cylindrical rod, to find out the Nusselt number with the application of magnetic field.

Inductor was placed parallel to the cylindrical rod to produce a magnetic field. Precaution was taken that the inductor did not touch cylindrical rod at any point , if this care is not taken, then this will affect the final reading as there will be some transfer of heat from cylindrical rod to inductor by conduction.

The inductor was then connected to power supply, and with the help of the variac, amount of dc current flowing through the inductor was controlled.

In the first phase of experiment inductor is not energized , resulting in no magnetic field. The intention of placing of the inductor without operating was, however, to take into account the effect of air dynamics due to the presence of an inductor. The inductor acts as a placebo in the first phase of experimentation.

The power supply was switched on to the heater attached to cylindrical rod and by using dimmerstat control a fixed voltage was applied and the corresponding current value was noted.

The values of temperature from T1 to T8 were noted by enabling manual mode. After a regular interval of five minutes reading were taken. This procedure was repeated till steady state is attained. The same procedure was followed at different values of voltages and currents and reading were taken.

DATA REDUCTION

The temperature readings (Table 1) for each thermocouple were averaged. For example, for finding average T1 temperature,

$$T_{1avg} = (t_1+t_2+t_3+\ldots\ldots\ldots\ldots t_n)/n \quad (2)$$

Where, t_1, t_2 ,t_3....t_n are the temperature at point 1 at intervals of five minutes stating from first reading t1 and t_n is steady state temperature at that point after five multiplied by n times minutes.
Similarly, average reading of temperature at point 2 ,3 , 4 …till 8 can be obtained as stated above.
Once these average temperatures are obtained, then T_{avg} is obtained which is given by,

$$T_{avg}=(T_{1avg}+T_{2avg}+T_{3avg}+T_{4avg}+T_{5avg}+T_{6avg}+T_{7avg})/7 \quad (3)$$

Now amount of heat supplied to cylindrical rod is give as

$$Q=V*I \quad (4)$$

Where,

V= amount of voltage supplied to heater
I=amount of current flowing through heater

Being a case of pure resistive heating for the heater, the power factor was assumed to be unity.
Thus, heat produced, by the heater is equal to heat transfer by convection, neglecting heat loss by radiation.
Heat transfer by convection is given by Newton's law of cooling as,

$$Q = h*A_2*(T_{avg}-t_8) \quad (5)$$

Where,
Q= heat transfer by convection
H= convective heat transfer coefficient
A2=area normal to direction of heat flow

Thus, heat produced by heater = heat transfer by convection

$$V*I = = h*A_2*(T_{avg}-t_8) \quad (6)$$

Thus h= (V*I) / (A_2*(T_{avg}-t_8))
Where Nusselt number is given as

$$N_U=(h*L)/ K \quad (7)$$

Where,
h= convective heat transfer coefficient
L= effective length or characteristic length
K=thermal conductivity at mean temperature (T_{mean})
Where,
T_{mean} is given as ,

$$T_{mean} = (T_{avg}+t_8) / 2 \quad (8)$$

Thus the value of thermal conductivity at temperature T_{mean} is found out from standard temperature, as the value of thermal conductivity changes with change in temperature.Thus value of Nusselt number can be found out by substituting values of convective heat transfer coefficient in equation of Nusselt number.

OBSERVATIONS

Voltage supplied (v) =90v ,
Current flowing through heater (i) =0.47 ampere

Table 1 : Temperature Reading

Sr. no.	Time (Hr:Min)	Temperature(ºC)							
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1	00:00	22	23	23	23	23	23	23	23
2	00:05	27	27	28	28	28	28	28	23
3	00:10	33	34	35	35	35	35	36	24
4	00:15	41	41	44	44	44	44	44	24
5	00:20	47	47	51	51	51	51	52	24
6	00:25	53	53	57	57	57	57	57	24
7	00:30	57	57	62	63	63	63	63	24
8	00:35	62	68	67	69	69	69	69	24
9	00:40	66	69	72	72	73	73	73	24
10	00:45	69	69	75	76	76	76	76	24
11	00:50	72	72	78	80	80	80	80	24
12	00:55	75	75	80	83	83	83	82	24
13	01:00	76	76	83	84	84	84	84	24
14	01:05	77	77	84	86	86	86	85	24
15	01:10	78	78	85	88	88	88	87	24
16	01:15	80	80	86	90	90	90	88	24
17	01:20	80	80	87	91	91	91	89	24
18	01:25	81	81	88	92	92	92	90	24
19	01:30	82	82	89	93	93	93	91	24

Sample Calculations:

i. Area:

$A_s = D * L$

= 0.05 * 0.5

= 0.025 m^2

ii. Heat Transferred by heater

Q = V * I

= 90 * 0.46

= 41.4

iii. Average temperature:

$T_s = (T_1 + T_2 + T_3 + T_4 + T_5 + T_6) / 6$

= 64 + 64.52 + 69.23 + 71 + 71.04 + 71.04 + 7.52

= 68.47 ^oC

iv. dT = Ts- T_7

= 68.47 – 23

= 45.47 ^oC

Table 2 : Observation Table

Temperature t_1 when inductor is not placed (ºC)	Temperature t_1 when inductor is placed but not working(ºC)	Temperature t_1 when short inductor is placed and working. (ºC)	Temperature t_1 when long inductor is placed and working. (ºC)
22	22	21	24
27	27	26	28
33	35	33	34
41	41	40	36
47	47	47	46
53	53	53	51
57	57	57	56
62	61	61	60
66	65	68	65
69	68	71	68
72	71	74	70
75	73	75	74
76	75	76	76
77	75	78	77
78	76	79	79
80	77	79	81
80	79	-steady state reached	81
81	79	-	-steady state reached
82	79	-	-
- steady state reached	80	-	-
-	80	-	-

v. Convective heat transfer coefficient

h= Q/(A*dT)

=11.59 N/m^2K

vi. Nusselt number is given as,

N_U=(h*L)/ K

Where h= Convective heat transfer coefficient

L= characteristic length, in this case it is length of cylindrical rod

K= thermal conductivity

Where value of thermal conductivity depend on mean temperature, which is given as

$$K=(1.5207*10^{-11}*T_{mean}^{3})-(4.8574x10^{-8}*T_{mean}^{2})+(1.0184x10^{-4}*T_{mean})-(3.9333x10^{-4}) \quad (9)$$

Where in this case value of T_{mean}= 45.735 ^{o}C

Thus substituting value of T_{mean} in above equation (9)

K=0.0275 W/mK

Thus value of Nu=210.727

Depending upon the condition of the inductor the value of temperature at a give point on cylindrical rod changes, since the depending upon the condition of magnetic field the rate of heat transfer changes and as a result the temperature of rod will also change.

Graphically, it is represented as follows for temperature t1 for various condition of the inductor.

Result table:

Experiment was carried out at different voltages and following result table was obtained,

Table 3 : Result Table

Status of the inductor	Value of Convective heat transfer coefficient (w/m^2k)	Nusselt number
When inductor is not employed.	11.59	210.727
When short inductor is placed without operating.	11.46	203.08
When short inductor is placed and under working condition.	12.83	234.6
When short inductor is placed and under working condition.	13.13	240.388
When long inductor is placed and under working condition.	13.21	241.32
When long inductor is placed and under working condition.	13.46	246.7
When long inductor is placed and under working condition.	13.68	250.36

The results are plotted against time for various combinations..

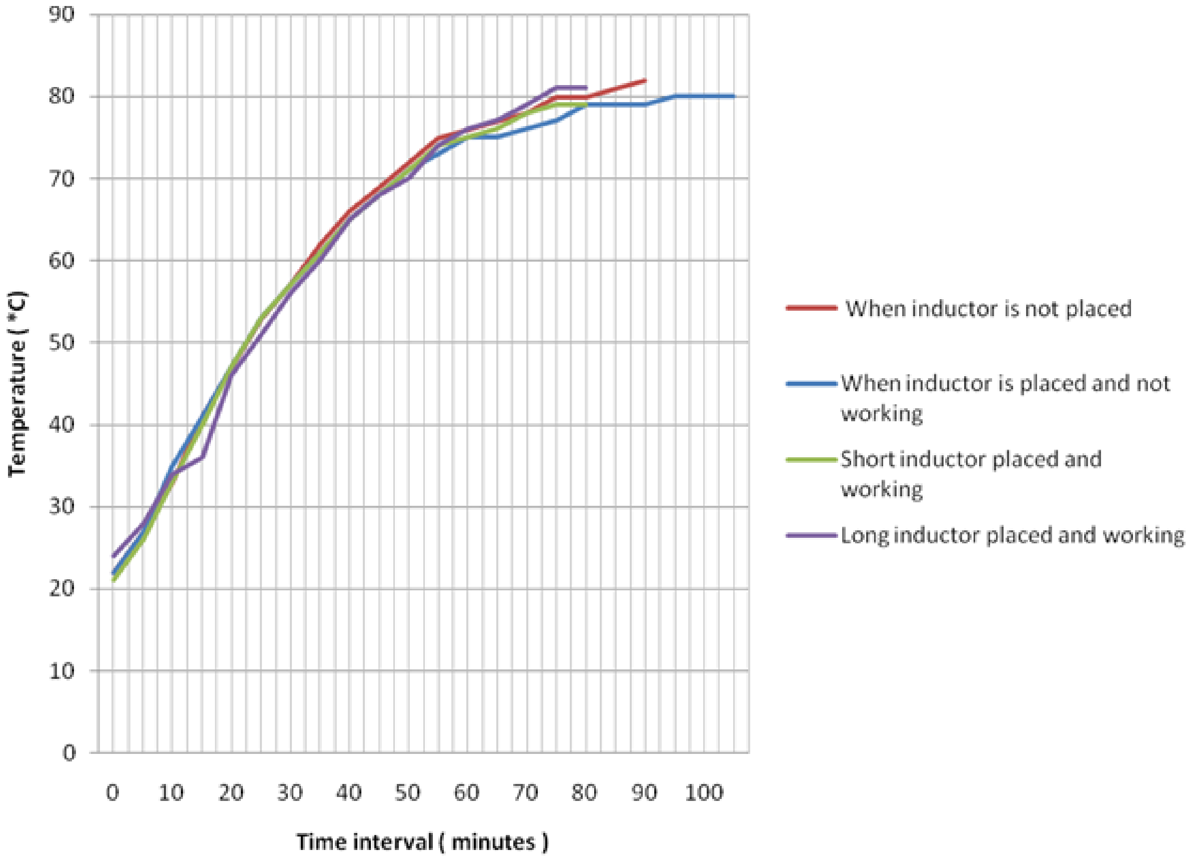

Fig. 2. Temperature versus time

RESULT AND DISCUSSION

Convective heat transfer coefficient and Nusselt number were determined for different values of input power. The values of convective heat transfer coefficient obtained when the inductor was energized were compared with the values of convective heat transfer coefficient when the inductor was not energized.

It was observed that, the values of Nusselt number for trial with an energized inductor were higher than those obtained when the inductor was not energized. The indicates that the convective hear transfer rate increases with application of magnetic field. The length of the inductor was found to have very negligible effect on the enhancement. The highest increase with short and long inductors were found to be 18.2 and 18.8 % respectively.

This method of enhancement may be employed in heat exchanger where it's not possible to employ passive methods. A typical case may be due to higher weight of elements used passive methods.

CONCLUSION

Magnetic field of high intensity have tendency to repel hot air. When this principle is employed to natural convection it can be seen that value of Convective heat transfer coefficient increases. Since value of Convective heat transfer coefficient increases, which means that value of Nusselt number also increases. Since Nusselt number increase the rate of heat transfer also increases. Amount by which the rate of heat transfer increases depends on amount of magnetic field created. Higher amount of magnetic field will lead to high rate of heat transfer. In the experimentation, it has been found that the value of Convective heat transfer coefficient increases from 11.59 W/m^2K when inductor is not used to 13.68 W/m^2K when long inductor is placed near heated rod and under working conduction. In this way the percentage increase in Convective heat transfer coefficient is **18.02%.** Also, it is seen that the value of Nusselt number increases from 210.727 when inductor is not used to 250.36 when long inductor is placed near heated rod and under working conduction. In this way the percentage increase in Nusselt number is **18.8%.**

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