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RESEARCH ARTICLE

Buoyancy Induced Air-Flow through a Pin Hole

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ABSTRACT

The aim of this work is to perform experimental investigations on the temperature of the surface velocity of air, heat transfer and the flow characteristics for natural convection through parabolic profile of fixed dimensions having a circular orifice of constant diameter; heat supplied, and to propose suitable correlations for the same. Establishing an experimental relationship between the dimensionless quantities in the case of buoyancy induced flow through a circular orifice in which the heat energy is incident on the surface is the main activity involved. The main parameters of interest in this study such as the values of heat flux, heat transfer coefficient and buoyancy induced flow are also made used to achieve the objectives. The work also exhibits the design and fabrication of the experimental setup and collection of experimental data. Then the graphical analysis of the results is obtained. The ultimate result is in the form of a relationship between the Reynolds number versus Grashof number for different heat fluxes. The relationship between Reynolds and Grashof number has been established and it matches with the theoretical one in the limits of experimental errors. The relationship between these two numbers is a fifth degree polynomial. The relation is independent of the dimensions of the test section and thus any test section can be analyzed given, the dimensions. Thus performance characteristics of a plant can be predicted by making a small model of the whole system which is geometrically similar and then comparisons can be drawn.

Keywords: Circular orifice, Heat transfer, Buoyancy induced flow, Reynolds number, Grashof number.

1. INTRODUCTION

Buoyancy induced flow has many applications in engineering. Solar heaters, solar dryers, solar chimney, etc. are a few to mention. One of these applications, i.e. solar chimney is discussed in detail in the following sections. In all these applications, the collector absorbs solar energy and transfers to the surrounding fluid (usually air/ water) by convection, where it gets heated up and flows upwards because of buoyancy effect. The present study attempts to develop relationship between the energy absorption by the fluid and the flow induction due to buoyancy.

Solar energy is abundantly available all over the surface of the earth. Being a tropical country, India has also the benefit of receiving the solar radiation in ample amount. One of the biggest deterrents in harnessing this naturally abundant and clean source of energy has been the cost effectiveness.

Solar chimney is the solar thermal engine of power plant which generates solar induced convective flow to drive turbines in order to produce electric energy. It consists of a solar air collector, turbine and a central updraft tube/tower called chimney that are described below.

- Collector

  Using a collector similar to glasshouse, the solar tube heats the air to drive the power station. The collector surface steadily increases up to the chimney, which directs the heated air

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towards it, and then curves up sharply at its base so that the air transition flowing up the tower is enabled. Collector is highly transparent to the solar spectrum but less transparent to the infrared rays radiated from the heated earth.

- Chimney

The warmed air from the collector is channeled to the updraft tower, where the buoyancy difference between the warmed air and the adjacent area develops a Pressure Difference (PD) in order to drive the air up to the tower.

The parameters that must be ensured while designing the tower are stated, i.e. it should reduce the frictional losses and enhance the pressure difference in the chimney. As PD is proportional to its height, increasing the height might degrade the effectiveness of the chimney.

- Turbine

By employing a turbine or multiple turbines, which function as cased pressure-staged generator or hydroelectric plant, the chimney generates electricity. Turbine is located close to the base of the chimney due to the maximum air velocity at its base which is also easy to maintain and to provide connection to the generating unit. In case of a single turbine, it is fixed on vertical axes inner to the tower, whereas an array of turbines is located inside the tower or in the transition area amidst the tower and the collector.

1.1. Drawbacks

Apart from severe effects of the dimensions of the chimney, minor losses also affect its overall efficiency. Each component has associated losses. Altogether the collector includes several associated slight losses. It also comprises of loss due to the roofing substance. Insulated glazing material is possibly a good choice for the collector, but it is costlier than single-paned glass. Friction loss is also a part of collector loss. Usually, the supports of the collector are thin and widely spaced, and the loss related with them is lower than the heat loss. Further, the tower has associated friction loss, and the loss with respect to the drag in the tower and the collector and ground are also minor. Again, turbine includes its loss and other loss that occurs because of impediment of the turbine to the flow. If the pressure drop at the turbine is two thirds of the total pressure difference, then the resulting power is higher [1]. Hence, the turbine efficiency is ideal at 67%. The turbine loss is related to cased-hydroelectric turbine loss, probably better than 90%.

The examination is relatively easy when it comes to forced convention. Here, the rate of flow is regulated to an unchanged value. The heat transfer coefficient [2-4] is estimated simply by the help of the data from the literature.

But, in the case of natural convention, it becomes hard to find out the exact associations for estimating the heat transfer coefficient's value, where the total flow rate is also not found. The first objective of the current study is to fabricate a test apparatus for buoyancy induced flow of air in an inclined circular duct. The second aim is to perform experimental investigations on the surface and air temperature, heat transfer and the flow characteristics for natural convection through vertical tube of fixed length and diameter (for constant L/D ratio), heat supplied and the tube and also to create correlations in the case of transfer of heat for the flow induced by means of buoyancy which takes place over inclined tubes with air as the working fluid.

Convection heat transfer is a process of transferring heat that has been produced due to the huge amount of motion of the fluid. This type of heat transfer can only be caused in liquids, gases and mixtures that have many phases. This type of heat transfer is classified into two broad divisions such as natural convection, or free convection and forced or adjective convection. When the fluid moves in the phase of forced convection, it is easy to be noted, whereas, the movement of the fluid in natural convection is difficult to notice as the fluid exhibits lower velocities.

The situation of natural convention is hard to find out as the exact correlation for estimating the rate of the induced mass flow because of the thermo siphon effect and the correlated coefficient of heat transfer is not present. The designing of thermo siphon system depends on the application needs. In some situations higher fluid temperatures are required, while in some cases more heat collection is required. To create a thermo siphon arrangement to the specific needs, knowledge of the flow induced by means of buoyancy and the correlated transfer of heat are very important.

The purpose of the current work is to perform experimental investigations on the surface temperature, velocity of air, transfer of heat and the flow characteristics for natural convection through parabolic profile of fixed dimensions and to have a circular orifice of constant diameter at the apex, heat supplied, standard heater etc. and to propose suitable correlations for the same.

2. STUDIES PERFORMED

Many approaches were utilized in augmenting the activity of SAHs (Solar Air Heaters) like,

- Enhancing the magnitudes of heater construction elements.
- Using lengthy surfaces, shapes and sizes together.
- Using practical storage medium or latent storage medium.
- Using concentrators to enhance the present solar radiation.
- Fitting the heaters with the photovoltaic elements.

Apart from this, certain advantages of making use of the SAHs were deliberated [5]. Enhancement of the thermal functioning of SAH was achieved by augmenting the heat transfer level [6]. Artificial roughness corresponding to continuous ribs would be an operative method to augment the functioning of SAH [7].

Numerous investigations were also performed to find out the consequence of a variety of artificial roughness dimensions on friction and heat transfer properties of SAH ducts [8]. Results were gained related to the enhancement of the functional operations like, roughness measurements and examination procedures employed in the artificial SAH [9]. The thermal efficiency of the SAH which are made rough through artificial means was deliberated [10]. The thermal transfer and the thermal performance of SAH possessing rough nature through artificial means were studied [11]. CFD (Computational Fluid Dynamics) approach was used to calculate the thermal transmission and the examination of the fluid's movement in SAH [12] CFD is the study which involves fluid transmission's thermal motion that makes use of the computer based simulation. [13]. This CFD technique has made a shift in analyzing the fluid flow. Analyzing the thermal transmission and flow of fluid in several roughness was performed on SAH's absorber plate [14]. Nusselt number and associations of friction value for SAH with projections were examined [15]. Studies on the effect of various controlled arrangements at the entry of the thermal tube had also been reported in the literature [16].

Investigational arrangement was done for defining the consequence of various configurations of constraints kept in the lower part at the entrance of the hot pipe on the surface temperature circulation, the indigenous and normal thermal transfer coefficients. Empirical correlations were proposed for all the cases that were examined and a common association was yielded. This exposed the consequence of the controlled scenario on the natural convection's thermal transmission process through a vertical circular pipe [17]. An experimental study was performed on the convection by natural means through horizontal passages having constant thermal flux on its upper wall [18].

Mathematical examination of heat transfer taking place by convectional means in nanofluid was performed [19, 20].

Air temperature within the open ended cavity shows that the heat inclinations together with the gap cavity are feeble for lower heat fluxes. Here, the Control Volume based Finite Element Method (CVFEM) was utilized to induce Cu-water nanofluid's convectional heat transmission by natural means [21]. The models like Brinkman and Maxwell–Garnetts (MG) were engaged to calculate the consequence of heat conductance and the viscidness of Nano fluid. Laminar, forced convection thermal transmission of the power-law fluid's movement was numerically investigated [22].

The dependence of heat transfer on Reynolds number, power-law index and cavity aspect ratio for single and double cavity configuration has also been studied. It was found that for small value of aspect ratio, the effects of power-law index and the effects of Reynolds number on heat transfer are more pronounced. The results also reveal that when Reynolds number increases, after a slight deviation, the heat transfer abruptly tends to rise for all fluid types. The solar heat pipe was analyzed using volumetric fluid [23].

2.1. The present work

The methodology adopted was as follows,

1. Fabrication and testing of the section under test and experimentation set-up.
2. The input parameters will be varied during experimentation by introducing the heat flux from the range 400W/m^2 to 1400W/m^2.
3. Data collection during experimentation and sample calculation.
4. Propose heat transfer correlations in terms of dimensionless quantities.

3. EXPERIMENTATIONS

This section deals with the details of all parts used for the fabrication of the experimental set-up, their size, shape and specifications so that we can find out the transfer of heat and the features of fluid flow for natural convection inside the parabolic shape for different parameters.

3.1. Experimental set-up

The representation of the investigational arrangement used for the present investigation is revealed under section 3.2.1. Table 1 shows the details of experimental set-up and varied parameters.

The set-up consists of following components. They are,

1. Metallic paraboloid with a circular orifice (test section)
2. Ni-Cr wire (heating element)
3. Adiabatic insulation (Silicon sand)
4. Electrical insulation (Porcelain)
5. Digital temperature indicator
6. Dimmerstat

The measuring instruments are, voltmeter (potential difference between heater terminals), venometer (velocity of air at the outlet of circular orifice, ambient temperature and the stream of air), multimeter (resistance of the heating point).

- Metallic paraboloid: Metallic paraboloid was selected as the test section. The considerations are,
  - Availability: It is easily available.
  - Cost: It is an important factor and it is cheap compared to other materials.
  - Heat loss to the atmosphere: As the column of air is driven by the pressure gradient upwards, the air loses some of its heat to the atmosphere through paraboloid. This loss of heat to the atmosphere will also be minimized as the material is a bad conductor of heat. As the collector will be heated to a high temperature (in the range of 200°C), the paraboloid and the collector will also get heated up. But there was no need of providing a ring or cardboard between paraboloid and collector as there was no problem of melting when we actually conducted the experiment.

Table 1.Details of experimental set-up and parameters varied

S. No.	Parameter	Range
1.	Perimeter of the paraboloid	
2.	Diameter of the circular orifice	5mm
3.	Heating Element	1.5Kw
4.	Heat flux supplied	400W/m^2 to 1400 W/m^2
5.	Type of insulation	Silicon sand
6.	Diameter of the heating element	200mm
7.	Diameter of the guide-way	210mm
8.	Venometer	
9.	Cross section	Circular
10.	Multimeter	

- Collector material: GI sheet of 0.3mm thickness (other materials which were considered had to be rejected due to greater thickness in addition to the difficulty in forming to give the desired shape to it). Following factors were considered in the selection of materials,
  - Availability: It is easily available.

- Formability: Any shape can be given easily.
- Thickness: There is no requirement of much thickness, thus resulting in requirement of less heat input as the heat absorbed by the collector will be less. Imparting any shape to this material will also be easier because of its thickness.
- Ease of welding: Gas welding can be easily done over GI sheet even though welding is not suitable.

3.1.1. Test section

The test section is shown in figure 1. It consists of GI paraboloid and Ni-Cr wire wounded in the porcelain heating element.

Figure 1.Test section

The set-up was fully insulated to diminish the thermal loss. The terminals of the heater were connected to A.C. power supply.

3.1.2. Nichrome wire 26 G (1.5kW)

The diameter of the heating element is 0.46mm. The resistance per meter length is 8.76Ω; total length of heating element is 20m. Material property of nichrome wire 26 G at standard ambient temperature and pressure is shown in table 2. A wire heater is a device which is mounted radially on a surface and used to heat the surface or air (gasses), nichrome wire 26 G is one grade among them. Chemical content %: 80.00 nickel, 20.00 chrome. Nickel-chromium alloy possesses,

- Elevated and steady resistivity
- Good corrosivity
- Surface oxidation resistivity
- Enhanced functioning within elevated temperature
- Seismic power
- Good ductility
- Good workability
- Good weld capability

Table 2.Material properties of nichrome wire 26 G at standard ambient temperature and pressure

Physical property	Range
Modulus of elasticity	$2.2x10^{11}$pa
Specific Gravity	8.4
Density	8400 kg/m^3
Melting point	$1400^{\circ}C$
Specific heat	450 J/kg^oC
Electrical resistivity at room temperature	$1.0x10^{-6}$ to $1.5x10^{-6}$Ω/m
Thermal conductivity	11.3 $W/m^o/C$
Thermal expansion	$14x10^{-6}/C$

3.1.3. Thermal insulation

Sand is used in heat insulation to avoid the thermal loss from the tube's surface. The thickness of insulation is 14.38mm.

3.1.4. Electrical insulation

Silicon sand is used as an electrical insulation. It has thermal conductivity of 1.5 W/m℃ at room temperature. Its high resistance to the passage of electricity makes silicon an excellent insulator. Figure 2 shows the electrical insulation.

Figure 2.Electrical insulation

3.1.5. Wattmeter

Figure 3 given below shows the diagrammatic representation of Wattmeter.

Figure 3.Wattmeter

The Wattmeter is a tool to calculate the electric power in watts. With the help of Wattmeter we can vary the heat input parameters. Figure 4 shows the Wattmeter circuit.

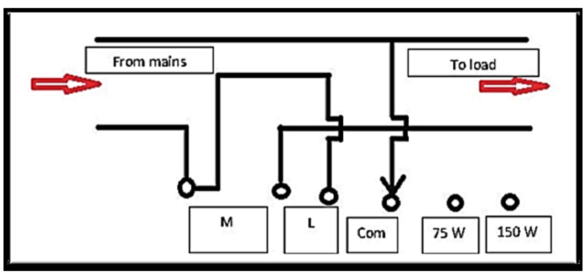

Figure 4.Wattmeter circuit

3.1.6. Dimmerstat

Dimmerstat is a very useful and an efficient tool for uninterrupted regulation of A.C. voltage and so, for the control of numerous other constraints reliant on A.C. voltage. Figure 5 given below shows the photographic image of dimmerstat. Table 3 given below shows the specifications of dimmerstat.


Figure 5.Dimmerstat

Table 3.Specifications of dimmerstat

S. No.	Parameters	Capacity
1	Max. Load	4 Amp
2	Max. KVA	1.08
3	Input	240 V
4	Frequency	50/60 Hz at C-B
5	Output	0-270 V at C-E

With the help of this auto transfer, we can change the value of voltage and because of this we can change the heat input (power). Power (Watt) is measured by multiplying voltage with current.

3.1.7. Venometer

Figure 6 and table 4 represent the pictorial image of venometer and its specifications respectively.

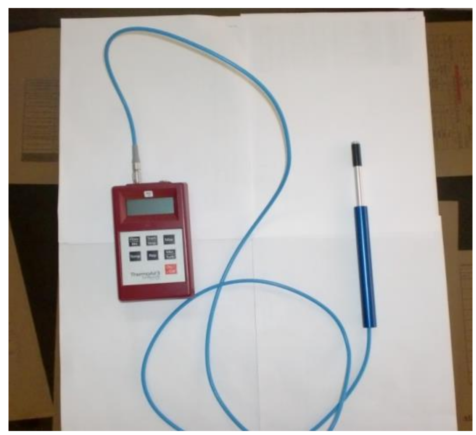
Figure 6.Venometer

Table 4.Specifications of venometer

S. No.	Parameter	Specification
1.	Make	SWISS Make Thermoelectric Anemometer
2.	Model	ThermoAir 3 Indication Unit
3.	Velocity probe	TA3(0.015 to 1m/s) Unidirectional

3.2. Fabrication and testing

This section deals with the fabrication of the experimental set-up and related testing, which is used to generate the sufficient data for development of the thermal transfer, temperature and the fluid flow characteristics for free convection inside the set-up.

3.2.1. Fabrication of complete experimental set-up

The complete investigational arrangement is expressed in figure 7. It depicts steps from step 1 to step 3. The nichrome wire was put into the ceramic frame and supplied with electric current. This is shown in step 1. The hot nichrome wire was covered with the inverted tawa as shown in step 2 of the same figure. The paraboloid was put over the tawa assembly as shown in step 3 and was fully insulated with sand. Electric connections were made as necessary.

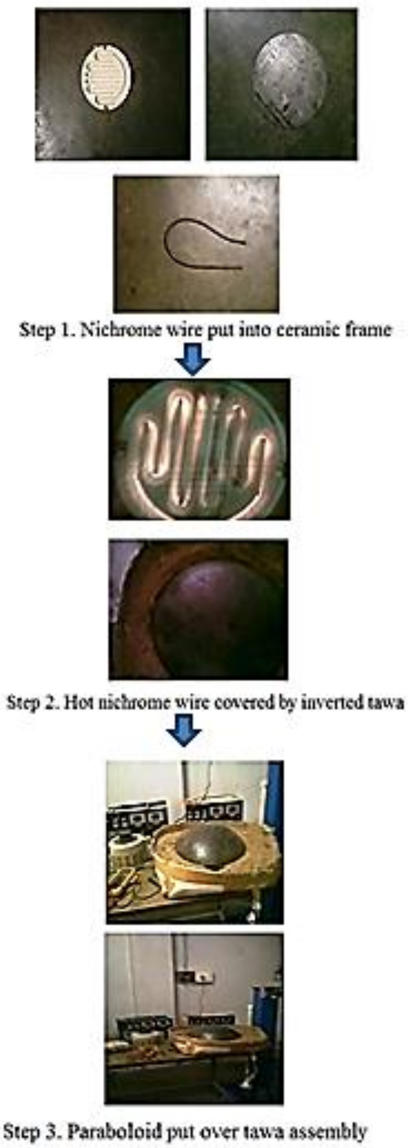

Figure 7.Fabrication of complete experimental set-up

3.2.2. Shock-proof test

After the fabrication of complete experimental set-up, shock proof test was carried out. In this test, power supply was given to the experimental set-up for 30 minutes by the dimmerstat through wattmeter. During this time, the whole set-up was checked by the tester and found that there is no current in the set-up.

3.3. Methodology and data reduction

This section deals with the experimental methodology to establish the effect of heat input on the buoyancy induced flow through the orifice.

3.3.1. Experimental methodology

After completing the fabrication work and different types of testing, we go for experimentation.

1. Before starting the set-up (power supply) first of all check, whether all the parts are properly working.
2. Ensure that the test section is away from air disturbances.
3. Connect the current coils in parallel (2A) on wattmeter.
4. Switch on the heating element.
5. Set the wattmeter reading at the corresponding value, by rotating the knob of dimmerstat (changing the voltage).
6. Note down the time of giving the input power to the test section.
7. Wait for reaching the steady state of the test section.
8. After reaching the steady state, i.e. there is no variation in the temperature, note down the reading of temperature by digital temperature indicator.
9. Repeat the above process for different heat fluxes (400, 500, 600, 700W/m^2).

3.3.2. Instrumentation

The quantities measured during the tests were,

- Velocity: The velocity was measured with the help of a venometer when the working fluid (air) achieves a steady state.
- Heat flux: The heat input was directly measured with the help of an analog

type precalibrated wattmeter (0-150 Watt) for 2A current.

- Temperature: The air temperatures were measured by means of thermocouples available in the laboratory.

3.3.3. Data reduction

The main parameters of interest in this study are the values of heat flux, heat transfer coefficient and buoyancy induced flow. The present work aims at determining the experimental correlation between Grashof number and Reynolds number for different heat fluxes.

- Velocity: The velocity of hot air coming from the circular orifice is very less. There was slight difficulty in measuring this small velocity. However, with the help of venometer, it was achieved.
- Average heat transfer coefficient: This is deliberated from the equations (3.1, 3.2, 3.3 and 3.4). Qact=Q–Qloss (estimated to be around 50%) and ΔT is the average temperature difference between surface of test section and outside air.

$$\mathrm{Qact} = \mathrm{havg.\,A}\,\Delta\mathrm{T} \quad (3.1)$$

$$\text{i.e. } \mathrm{q} = \mathrm{havg.}\,\Delta\mathrm{T} \quad (3.2)$$

$$\mathrm{havg} = \mathrm{q}/\Delta\mathrm{T} \quad (3.3)$$

where,

$$\Delta\mathrm{T} = (\mathrm{T_s} - \mathrm{T_a})\mathrm{avg} \quad (3.4)$$

T_s is the surface temperature along the test section at different locations, T_a is hot air's temperature flowing inside the test section.

- Dimensionless parameters:
  - Reynolds number (Re): It is a dimensionless number that provides a calculation of the ratio of inertial forces to viscous forces. This is used to calculate the comparative significance of the two types of forces for particular flow circumstances. Equation (3.5) depicts the formula for Reynolds number.

$$\mathrm{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} \quad (3.5)$$

  - Grashof number (Gr): It is a dimensionless number which estimates the ratio of the buoyancy to viscous force performing on a fluid. It repeatedly occurs in the examination of conditions comprising natural convection. Equation (3.6) depicts the formula for Grashof number.

$$\mathrm{Gr_D} = \frac{g\beta(\mathrm{T_s} - \mathrm{T_\infty})\mathrm{D}^3}{\nu^2} \quad (3.6)$$

Here, L and D specifies the length scale for the Gr, g is the acceleration due to Earth's gravity, β is the volumetric thermal expansion coefficient, T_s is the surface temperature, T_∞ is the bulk temperature, L is the length, D is the diameter and ν is the kinematic viscosity.

4. RESULTS AND DISCUSSSIONS

This part is broadly categorized into three sections. The heat loss results are discussed in the first part whereas the results related to discharge and flow characteristics are discussed in the second and third parts respectively.

The steady state data was generated on the experimental set-up and the results obtained for heat flux supplied at $400 W/m^2$ is expressed in table A1.

Table A1 shows the experimental observation got after 18 different trials after the steady state with no variation in temperature being reached. This experimentation result reveals the ambient temperature, temperature inside the test section, velocity of air in the circular orifice, Reynolds number, Grashof number and the air flow in the circular orifice. Both the temperatures, i.e. (T_A) the ambient temperature, which is the temperature of the air around, and the temperature denoted as T, which is the temperature inside the duct were measured using thermocouple and are displayed in table A1. It was perceived that though, the velocity of hot air coming from the circular orifice was very less which is usually difficult to measure; venometer was found helpful to measure this small value. The values under the velocity in table A1 clearly indicate that the values of velocities are very less.

To evaluate the flow of air in cubic feet per minute, we first define the velocity of the flow in feet per minute and later multiply the value got with the cross sectional area of the duct. The circular orifice is of constant diameter at the apex. The air flow values are thus expressed in table A1.

The values of temperatures and velocity are taken as basic parameters for the work, which are used in section 4.2.

Two major cases are needed to be given prime importance, when the convection is taken into account. The first case is that, the natural convection is to be analyzed by Grashof number and the second case is that, when it comes to the forced convection, the Reynolds number is to be analyzed. Both these numbers are dimensionless numbers, which gives the boundary of the flow. These are used to find the flow characteristics which are explained under section 4.3.

4.1. Heat loss calculation

The first part is related to the heat loss. The heat loss also means the heat transfer. Here the convectional heat transfer coefficient was obtained by the equations (3.1 to 3.4) as expressed earlier.

Thus the heat transfer coefficient was calculated by utilizing the values of the temperatures that were calculated with thermocouple. It is very well clear that the formula relies on the surface temperature and the air which is hot, that makes its way into the test section. This makes it helpful to find the heat loss.

It is noted that T_s is a function of heat dissipation from the circular duct. Thus the first aim of calculating the heat loss in convection flow is achieved.

4.2. Discharge related to heat transfer

The fluid flow which exhibits laminar or turbulent nature makes an impact on the process of swapping of heat among the walls of the object and the fluid (in our case, it is air). As a consequence, to differentiate the hydrodynamic feature of the flow, it becomes important to select appropriate formula to estimate the coefficients that are involved in convection. As the process of convection is highly reliant equally on the pattern of air flow and on the temperature that is partitioned in the surrounding area of the wall's circular duct, the ambient temperature and velocity are related together and this is expressed in the graph below in figure 8.

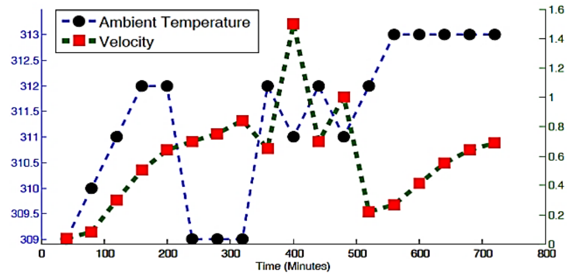

Figure 8.Variation of velocity and T_A with respect to time

Figure 8 shows the functional relationship of free convection between velocity of air flowing out of the circular orifice and the air temperature around the surface, at varying time intervals calculated in minutes.

During this state, an energy swap among the fluid (air) and the object takes place. On seeing through the physical point of view, this swap of heat is because of the buoyant force that is created by the rise in density that is induced in the fluid (air). This causes the current of natural convection to be created and this assists the swapping of heat. Natural convection starts from an unsteady temperature, where the air that is warm goes up and the cold air which is heavy comes down.

It is clear that, owing to the fluid's viscosity, an extremely thin layer does not make its motion towards the wall. This raises the wall's velocity from zero to a range that is of a maximum value, and again diminishing to zero. This is the point at which the air's consistent temperature is achieved. The temperature makes a fall from the wall's temperature T_w to T_∞, which is the temperature of the room. This fall in temperature occurs within the similar wall's remoteness.

This makes it obvious that the temperature and the velocity that has been spread are very associated.

It is also obvious that the velocity will increase with the increase in temperature and the same is confirmed by the graph shown in figure 8.

4.3. Flow characteristics of air

From table A1, the values of the Reynolds and Grashof number are used to determine the flow of air or the boundary layer of air in the duct, which are flow characteristics of air.

As shown in table A1, with the increase in the temperature the velocity also increases, and also the viscosity of air increases as well. To determine the flow characteristics of the air both in case of the free and forced convection, viscosity is needed.

It is this viscosity that will help the calculation of flow characteristics in both the convections. Depending upon the values they occupy while they are applied to the two dimensionless numbers, it is found whether the flow is laminar or turbulent or transitional. This gives the boundary layer of the air flow.

4.3.1. Effect of Reynolds number

The experimentation table A1 was obtained by the application of the formula to find the flow characteristics, with variations in temperature. It is clear from the table that as the temperature increases, the velocities increase and less value of viscosities pave way to an increased Reynolds numbers. And as the temperature decreases and the velocity decreases, higher viscosity causes Reynolds number to be low. Thus from the experimentation, it is clear that the boundary layer in the forced convection shows a transition between laminar and turbulent flow and vice versa.

Thus the boundary layer of air exhibits a shift from laminar to turbulent flow, when the range of the flow related by means of the Reynolds number surrounding the body is sufficiently great.

And as the temperature decreases, the decrease in velocities make the viscosity high and thereby Reynolds number will become low, causing the flow surrounding the object not to reveal a shift to turbulent flow but remains laminar. This is also easily seen in the table A1 that shows that, when velocities are low, viscosity is high which makes the Reynolds number to be low.

4.3.2. Effect of Grashof number

The application of the appropriate values in the formula, gives the Grashof number. From the table A1 it is clear that, as the temperature increases, the density of air decreases and therefore air rises. This movement is induced by buoyancy force, which plays a main role in resisting the force of viscosity. Also as the temperature decreases, the density of air increases and therefore air goes down. This action causes the boundary of the air to make transitions from laminar to turbulent and vice versa.

Figure 9 graphically depicts how Re varies with the variation in Gr. Basically Gr represents the input parameters and Re represents the output of the system which consists of velocity of the air in the test section. The direct relationship between Re and Gr is shown in the below graph. This graph clearly shows that the experimentation values come near to the fifth order polynomial. And thus the experimentation exhibits a fifth degree polynomial relationship.

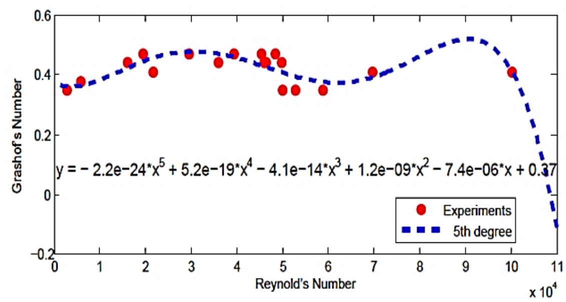

Figure 9.Variation of Re with Gr (fifth degree polynomial)

5. CONCLUSION

The main conclusions of the present experimental study are,

- Heat flux powerfully induces the heat transfer coefficient and the mass flow rate.
- The tube length and the tube inclination have a combined effect influence on the flow rate given by a function L sin 0 i.e. 'H', the vertical distance between the entrance and the exit of the tube's end.

The relationship between Reynolds number and Grashof number has been established and it matches with the theoretical one in the limits of experimental errors.

The relationship between these two numbers exhibits a fifth degree polynomial. The relation is independent of the dimensions of the test section and thus any test section can be analyzed given the dimensions. Thus performance characteristics of a plant can be predicted by making a small model of the whole system which is geometrically similar and then comparisons can be drawn.

Other functions that fit into the data obtained from the experimental investigations are smoothing spline function and Gaussian function. But these functions are valid only for particular parameter values of the test section. We need more universal relationship between the two numbers viz., Reynolds number and Grashof number. Hence other functions were rejected and the power-law is selected as the correct relationship function.

6. FUTURE ENHANCEMENT

The limitations of the experiments performed are, the number of data points are less and more data points can be obtained if the number of variables is increased. This can be done in following ways,

- Size of the collector was constant and could be made variable.
- Height and the diameter of chimney was constant and could have been variable.
- The head loss that takes place due to friction between the pipe material and air stream can be estimated and an optimum pipe diameter can be selected for minimizing the losses.
- Analysis of the solar radiation incident on a transparent cover could have been done and the air temperature achieved due to solar radiation could be estimated.
- Heat input was not distributed uniformly because the plate temperature was not uniform throughout, which could be addressed in the future.

The experimental set-up should approach real situation in every possible way so that the results obtained can be extrapolated and the same can be applied to a geometrically similar set-up.

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APPENDIX A

Table A1.Experimental observations

S. No.	T(amb)	T	Velocity	Re	Gr	Air flow
1	309	331	0.04	2955.283	0.347219	0.189313
2	310	336	0.08	5874.182	0.378161	0.375065
3	311	352	0.3	21694.33	0.409002	1.384789
4	312	357	0.5	36047.94	0.439741	2.293822
5	312	361.5	0.64	46002.35	0.439741	2.91819
6	309	382.5	0.7	50163.93	0.347219	3.182068
7	309	385	0.75	52951.77	0.347219	3.388759
8	309	390	0.84	58957.02	0.347219	3.772615
9	312	393	0.65	46441.29	0.439741	2.97285
10	311	423	1.5	100265.7	0.409002	6.355123
11	312	408	0.7	49804.87	0.439741	3.168585
12	311	423	1	69776.37	0.409002	4.42477
13	312	343.5	0.22	16069.92	0.439741	1.022772
14	313	350.5	0.27	19524.89	0.470380	1.238664
15	313	355.1	0.41	29559.31	0.470380	1.869465
16	313	358.25	0.55	39414.52	0.470380	2.4962
17	313	370	0.64	45454.55	0.470380	2.874373
18	313	376.2	0.69	48571.88	0.470380	3.071264