Experimental Analysis of Temperature Variation in an Air Medium Radiation Field

Sudarshan B, Vishwesh Prasad, Mohammed Ismail Zabi, Prashanth M

Abstract— ***In Turbo jet engines, Gas turbines, High pressure boilers and IC engine applications the heat distribution after combustion is a combined phenomenon of convection and radiation heat transfer. Interpreting the role of each mode of heat transfer in the perspective of increasing the efficiency and reducing the heat loss is one of the prime necessities for thermal power plant, aerospace and automobile industries. Here we analyzed the characteristics of the radiation field by temperature profiles through their variation at different planes of the domain, using an experimental approach. The testing domain, which replicates the size of the IC engine cylinder, is heated to a high temperature using a coil heater and is insulated to avoid external influence. Using 'K' type thermocouples arranged in series, the temperatures at various points and at various sections are determined. Correspondingly the Temperature profiles for different section planes are plotted. The propagation of radiation from the source as a function of distance and the effect of wall has been analyzed using the temperature profiles.***

Index Terms— ***air medium, radiation, temperature variation, thermocouple.***

I. INTRODUCTION

The electromagnetic radiation emitted by bodies due to its temperature is called thermal radiation. It is continuously emitted by all matter whose temperature is above absolute zero due to the motion in atoms and molecules at the microscopic level, increasing with temperature. The radiative heat transfer equation for an air medium within an enclosure is given by

$$Q_{net\ radiation} = \sigma\epsilon A\,[T^4 - T_a^{\ 4} - T_e^{\ 4}] \qquad \text{(i)}$$

Equation (i) shows that the net radiation heat transfer is dependent on temperature of air medium and the enclosure surrounding the medium.

II. LITERATURE REVIEW

1. E.D. DOS Santos [3] and M. M. Galarca [3] studied the fluctuations in temperature profile in a thermal field due to radiant heat flux divergence in a cylindrical cavity. In their Numerical study, Radiation heat transfer equation (RTE) was solved using Discrete Ordinates Method (DOM) by assuming the participating medium as a gray gas which is non-scattering in nature.

They imposed four temperature profiles considering 0%, 10%, 20%, 30% turbulence intensity to evaluate the behavior of radiant heat flux divergence in the cavity.

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Results obtained by them showed that the fluctuation in temperature profiles increase significantly with the mean divergence radiant flux.

2. I. Zahmatkesh [4], studied the influence of thermal radiation on the development of free convective flow inside an enclosure filled with a porous medium saturated with fluid. Laminar flow and heat transfer is calculated by solving governing equations such as mass, momentum and energy equations. Incorporating approximations for absorbing, emitting and non-scattering medium, the author illustrated that due to the presence of thermal radiation, temperature distribution is nearly uniform in the vertical sections inside the enclosure causing the streamlines to be nearly parallel with the vertical walls. The author also demonstrated that nearly uniform adiabatic wall temperature is maintained in the enclosure.
3. Severino P.C [5], in his work, studied the temperature fields and heat flux distributions of conduction-radiation transfer in an absorbing and emitting non-gray enclosure. The author also formulated the computationally efficient model to evaluate combined conduction-radiation problems under a steady-state condition on the basis of the iterative approach, considering finite strip discretization of the medium. The results obtained through numerical study clearly indicated that the formulated model was accurate and efficient even for pure steady-state radiation problems. It was also found by the author that convergence to such problems is achieved in minimal number of iterations. The author claimed that the model can be used to evaluate and design materials for thermal insulation for radiation dominant mechanisms.
4. A. Tremante [1] and F. Malpica [1], in their work, illustrated the thermal characteristics of semitransparent materials exposed to simultaneous conduction and radiation between concentric cylinders. Using gray model and the two-flux method, governing equations were reduced into a system of non-linear ordinary differential equations. By adopting an iterative approach, solutions to systems of ODE were obtained and were numerically compared with theoretical solutions. It was found that solutions were in good agreement with theoretical solutions.
5. M. Y. Abdollahzadeh [2] and M. H. Halmedi [2], studied convection heat transfer and its conjugation with thermal radiation on the thermal and flow characteristics of the system in their work.

The authors also performed a parametric study illustrating the influence of the heating number (dimensionless quantity), aspect ratio, thermal loading characteristics and other parameters which were conceived during the course of study. Investigation of Nusselt number and the maximum stream function rate was also studied. Results obtained by them suggested that the thermal radiation has an important effect on loading characteristics of the system even at low heating numbers.

As discussed above, E.D. Dos Santos [3], Severino [5] numerically studied the heat distributions and its fluctuation in an enclosure and formulated the mathematical model. Zahmatkesh [4], A. Tremante [1] and F. Malpica [1] numerically studied the influence of thermal radiation in the combined phenomenon of conduction-radiation and convection-radiation respectively. After referring, we felt that the radiation analysis under air medium using experimental technique will enhance radiation studies.

III. METHODOLOGY

The experimental setup consists of a cylinder sleeve which is made up of cast iron (Melting Point – 1200^{o}C). The cylinder sleeve is completely insulated by fiber blanket and sealed inside a steel container. This is done to prevent any heat exchange between the system and surroundings. Heating device (Coil Heater) which is made up of Kanthal A1 resistance wire is installed in the bottom portion of the cylinder such that there is no air gap/clearance between them. A long metal rod consisting of metal strip is introduced from the top of the cylinder. With the help of bolt and nut arrangement, metal rod can be raised or lowered inside the cylinder during the experiment. Five K-type thermocouples which are highly sensitive at higher temperatures are mounted on the metal strip at distances of 1.5, 2.75, 3.75, 4.5 and 5 centimeters from the center line. This is done to ensure that the thermocouples are closer to the cylinder sleeve and the characteristics of heat emitted from the wall can be observed clearly. The ends of thermocouples are connected to a digital multipoint controller through the hollow metal rod and the corresponding temperatures reading are noted. Dimmer stat is used to vary load (voltage) that is supplied to the heater. Voltage is maintained at 60Volts constantly for first set of readings. Digital multi meter which is connected in series with the dimmer stat and heater is used to note down current (I) at every instant. Free space filled with air inside the cylinder is divided into five equal planes. Now metal strip is placed in plane 1 (nearer to the heater). Voltage is adjusted to 60Volts and corresponding current is noted down. Room temperature is noted down. The timer / stop watch is started immediately after power is switched on. After every 5 minutes, thermocouple temperatures t_1, t_2, t_3, t_4 and t_5 are tabulated and the corresponding current readings are noted down from the digital multimeter. This procedure is repeated until steady state is obtained. Readings are tabulated and various temperature profiles are plotted. The procedure is repeated for all the planes and respective temperature profiles are plotted for 80Volts and 100Volts input conditions.

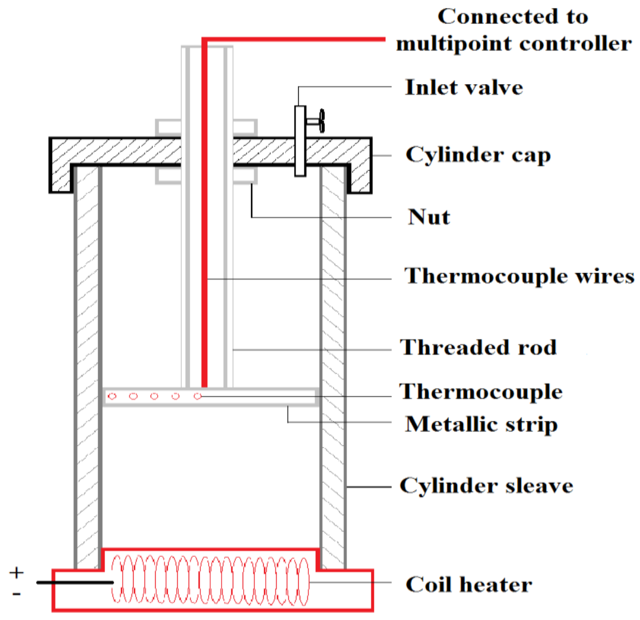

Fig. 1. Experimental setup

IV. RESULTS AND DISCUSSION

A. Temperature variation with respect to time:

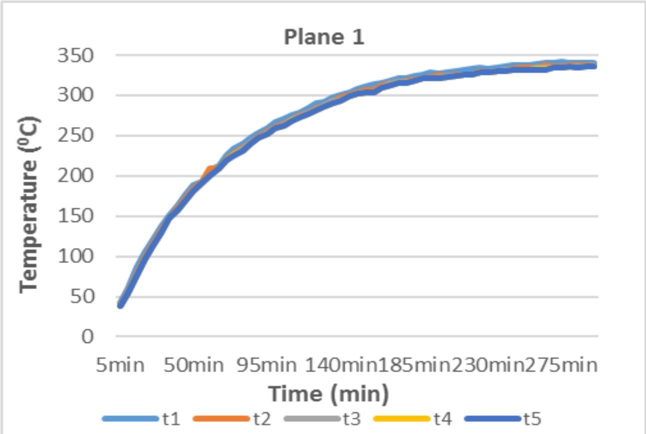

Fig. 2. Variation of temperature in plane-1 for 60 volts

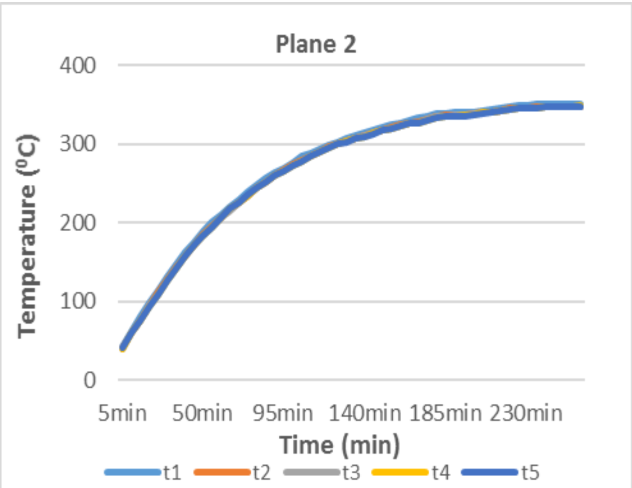

Fig. 3. Variation of temperature in plane-2 for 60 volts

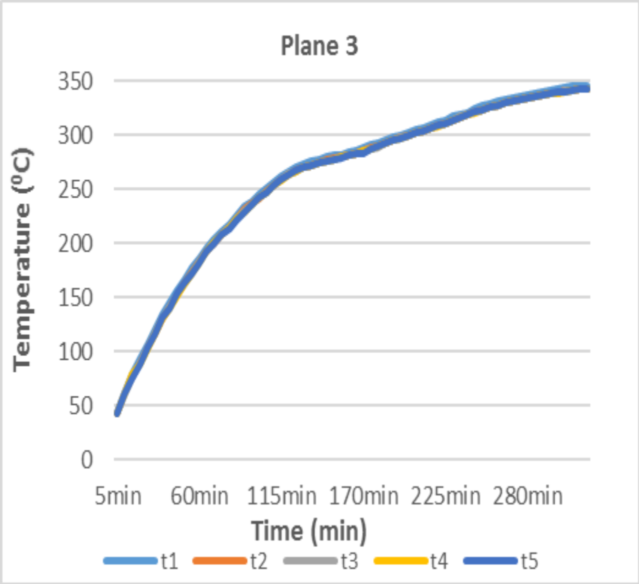

Fig. 4. Variation of temperature in plane-3 for 60 volts

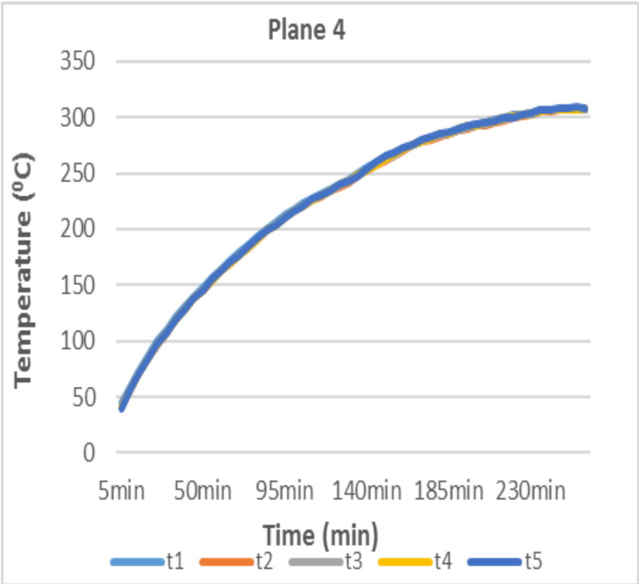

Fig. 5. Variation of temperature in plane-4 for 60 volts

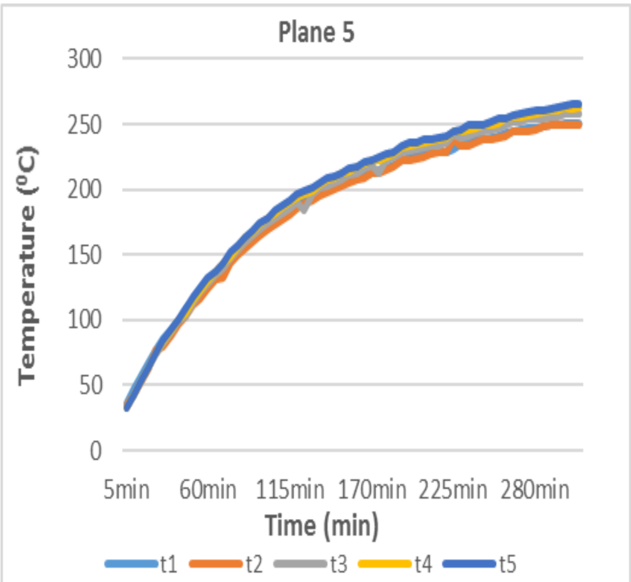

Fig. 6. Variation of temperature in plane-5 for 60 volts

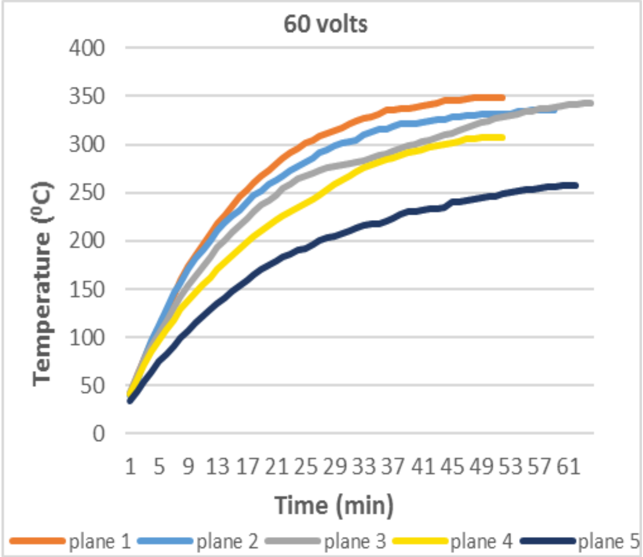

Fig. 7. Variation of temperature in different planes for 60 volts

Figures 1 to 5 show the variation of temperature at different time intervals for different planes at 60 volts. The trend with an exponential temperature rise at initial condition and gradual decrement leading to a constant value over time has been observed. This same trend is followed in all the planes. The fig.7. shows that the temperature rise decreases from plane 1 to plane 5 with the same trend. The temperature rise is maximum at plane 1 which is nearer to the source and is minimum at plane 5 which is far away from the source. The intensity of radiation gradually decreases with respect to the distance.

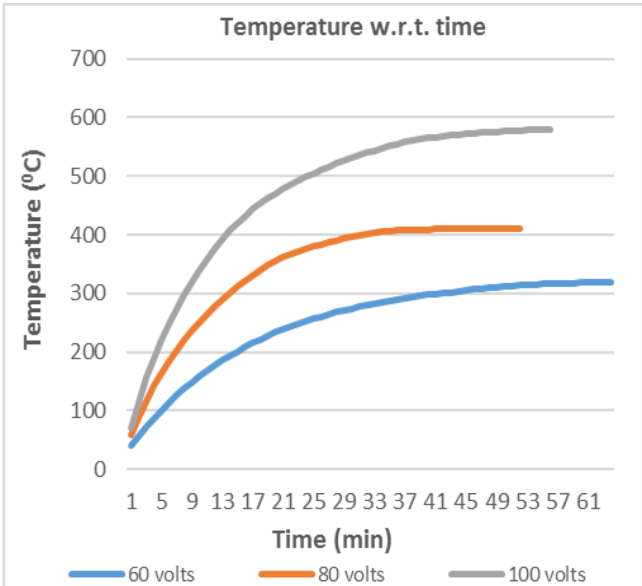

Fig. 8. Variation of temperature for different voltages

Similarly we plotted a graph for different input sources. Fig 8 shows the variation of temperature under different heat input sources for the plane 1. The temperature variation trend with respect to time is almost the same. The temperature attained is maximum at 100 volts and minimum at 60 volts.

Therefore the exponential trend initially and an almost constant trend later remains the same for different input conditions.

B. Variation of temperature over the length of the cylinder:

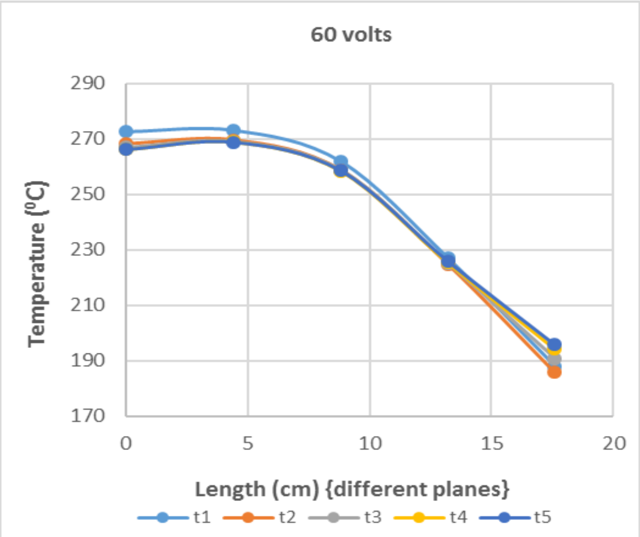

Fig. 9. Variation of temperature over the length for 60 volts

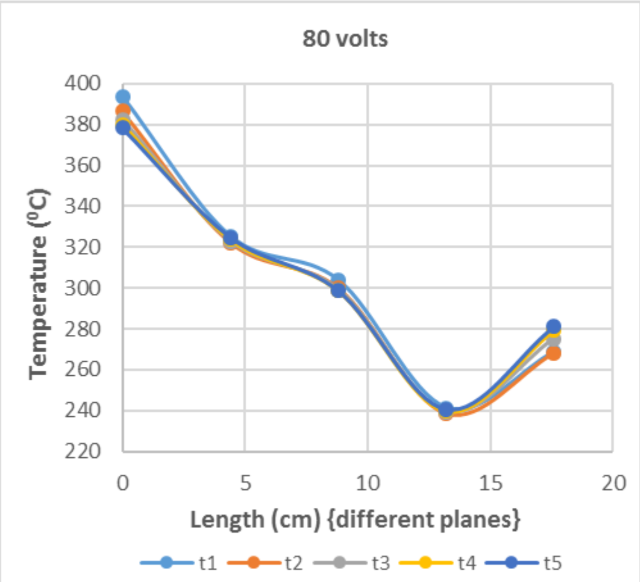

Fig. 10. Variation of temperature over the length for 80 volts

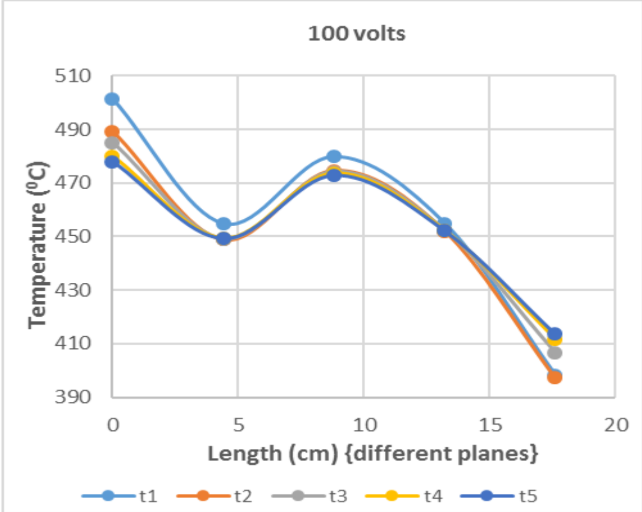

Fig. 11. Variation of temperature over the length for 100 volts

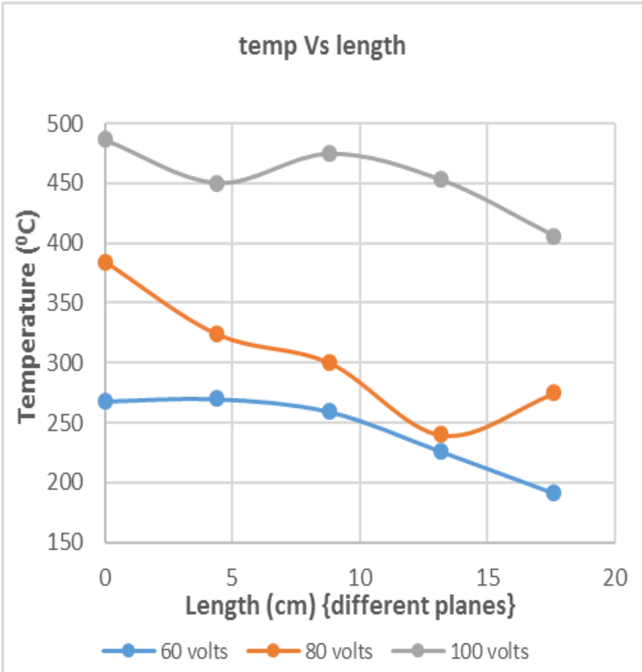

Fig. 12. Variation of temperature over the length for Different voltages

Figures 9 to 11 shows the variation of temperature over the length for 60, 80 and 100 volts respectively. Fig. 12 shows the average temperature variation at different planes under different input voltages. The variation over length in transverse direction might be due to reflection from the cylinder wall and the head. At 60 volts the heat is diffused to the wall and reflected from it which increases the temperature in 2, 3 and 4th planes. At 80 volts due to higher input, radiation may be propagated at the central zone of the domain to the cylinder and reflected back. Therefore the temperature increases in the fifth plane. At 100 volts the reflection may be faster from the cylinder head which leads to an increase in the temperature in 3rd and 4th plane.

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C. Variation of temperature over the diameter of the cylinder:

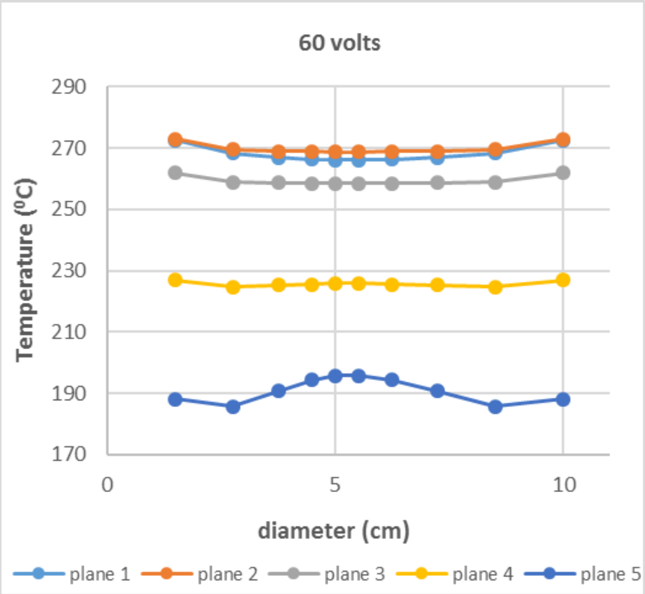

Fig. 13. Variation of temperature over the diameter for 60 volts

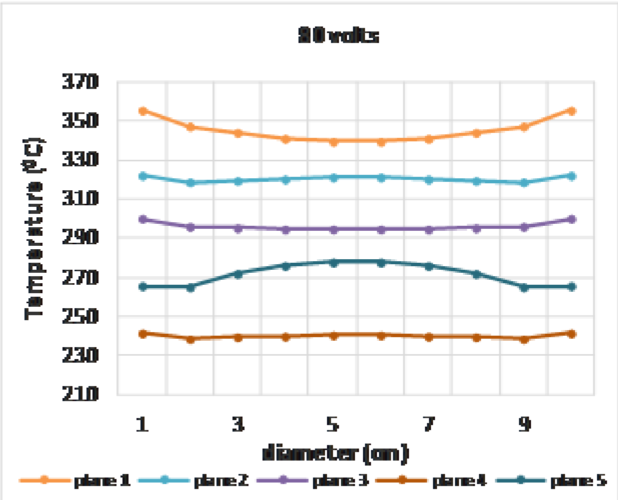

Fig. 14. Variation of temperature over the diameter for 80 volts

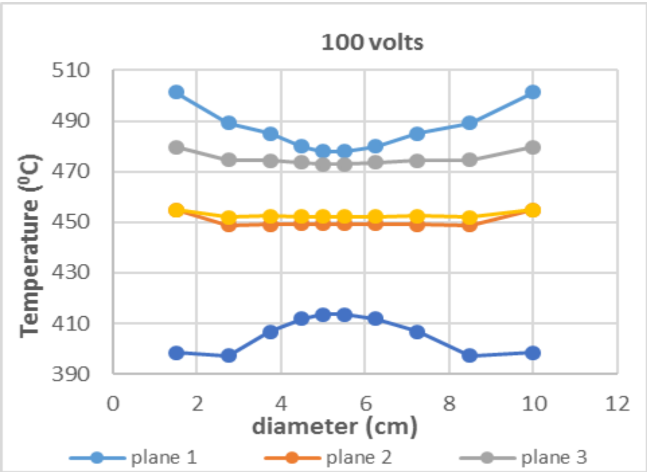

Fig. 15. Variation of temperature over the diameter for 100 volts

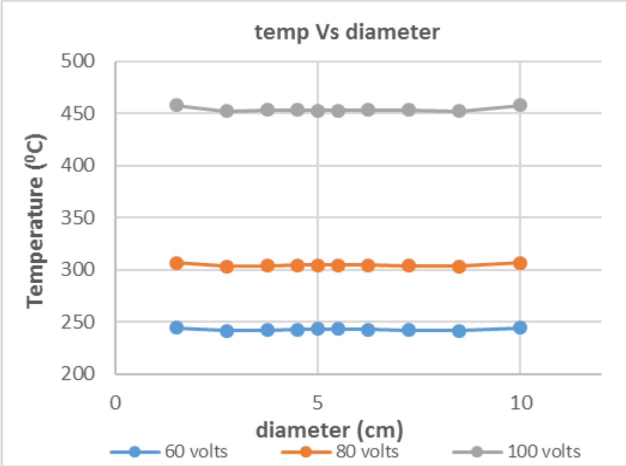

Fig. 16. Variation of temperature over the diameter for different voltages

Considering symmetrical conditions with respect to the axis of the cylindrical test domain the graphs in radial direction were plotted. Figures 13 to 15 show the temperature variation in radial direction and fig. 16 shows the average temperature under different input voltages. The temperature at the wall is maximum and gradually decreases as we move away from the wall. The temperature attained is maximum for plane 1 which is closer to the heater and minimum for plane 5 which away from the heater. Fig. 16 shows that that the temperature attained is directly proportional to the amount of heat input, the temperature is maximum for an input of 100 volts compared to an input of 60 or 80 volts. In fig. 13 the temperature with a decremental slope becomes straight hence the temperature is increased at the central zone for the planes 2, 3, 4 in radial direction. It might be due to the reflection from the cylinder wall. In fig. 14, temperature with a decremental slope becomes straight hence the temperature is increased at the central zone for the planes 2, 3, 4 in radial direction and its further increased for the plane 5. The magnitude of temperature for the plane 5 increases when compared to plane 4 and this might be because of the radiation reflection from the cylinder head which drastically affects the values at plane 5. In fig. 15. The same phenomenon of radiation reflection is faster and affects the planes 3 and 4 as well. Therefore the temperature level of the planes 3 and 4 is higher than that of plane 2.
The fig. 16 shows that as the input voltage increases, the temperature increases at different measured points in a proportional manner.

D. Variation of dT/dr over Length of the cylinder:

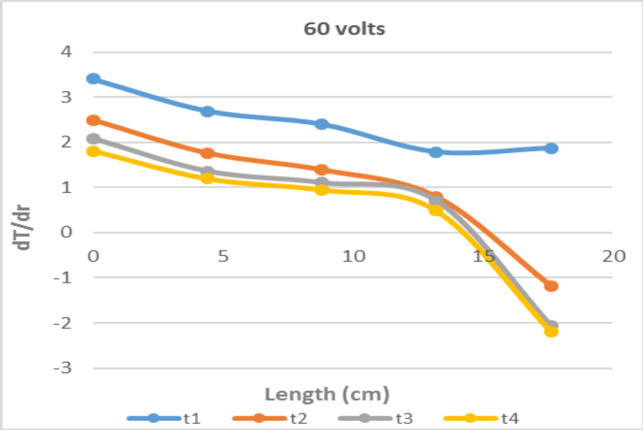

Fig. 17. Variation of dT/dr over the length for 60 volts

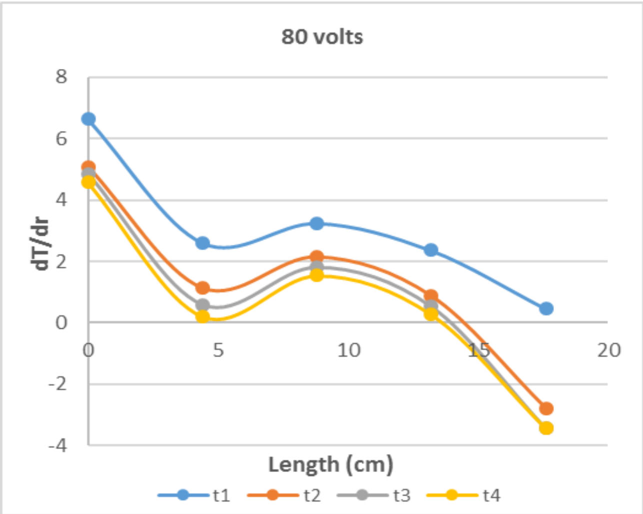

Fig. 18. Variation of dT/dr over the length for 80 volts

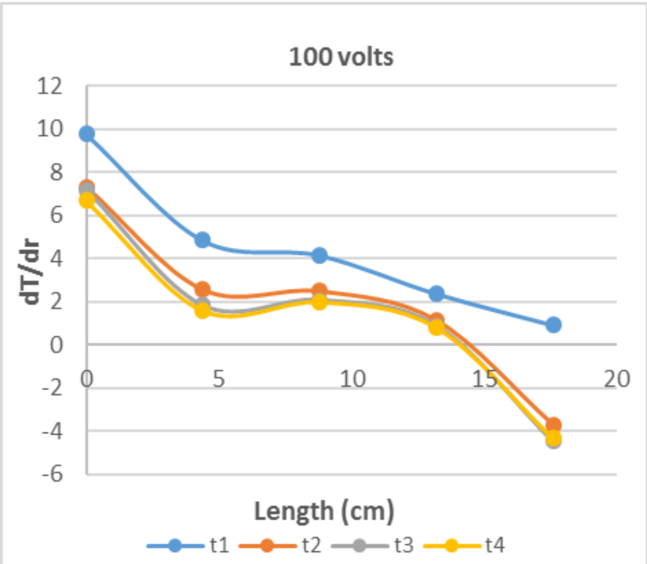

Fig. 19. Variation of dT/dr over the length for 100 volts

Figures 17 to 19 show that the temperature slope in the radial direction (dT/dr) decreases over length in general and varies in magnitude which might be due to reflection from the wall.

V. CONCLUSION

1. In a plane, the temperature varies with time exponentially at initial duration and gradually approaches constant status over time.
2. The temperature decreases in the transverse direction in a non linear way. This might be due to the reflection under high inputs leading to a relative temperature variation near the wall and cylinder head.
3. The decremental nature of the temperature in plane 1 gradually becomes straight over the length that is in planes 2, 3, 4. The wall and cylinder radiation reflection leads to a variation in the temperature magnitudes in planes 3, 4, and 5 at different input voltages.
4. The temperature slope in the radial direction continues to decrease. A steep decremental nature is observed between planes 1 & 2 and between planes 4 and 5.
5. Using sophisticated instruments by measuring the pressure and velocity variations in transverse and radial directions, under different heat inputs, the quantification of reflection, buoyancy and turbulence leading to the temperature variation can be determined.

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