Experimental Lumped Analysis of Different Solid Geometries

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Abstract. Present work describes the experimental analysis of unsteady state heat transfer of different solid geometries. Heat transfer process considered as a function of time only i.e. solid body behave as 'Lumped' means there is uniform temperature within the body and having negligible internal thermal conduction resistance. The lumped analysis is done with cylindrical, conical and mixed geometry of cylinder and cone of two different materials. Specimens are heated in water and cooled in air to estimate the heat transfer response of geometries in same ambient conditions MATLAB programming is done for calculation to obtain good and accurate results and to estimate heat transfer response of different geometries used in many engineering applications.

Keywords: Unsteady, lumped, MATLAB

1. Introduction
In some heat transfer analysis, bodies are observed to behave like a ‘Lumped’ whose “interior temperature remains essentially uniform at all times during a heat transfer process. The temperature of such bodies can be taken to be a function of time only, this lumped system analysis provide great simplification without much compromising from accuracy. H. Sadat Transient state one dimensional heat transfer conduction problem is analyzed with perturbation method using software. It is shown that first order model is developed for center, surface and average temperature, step response for the slab, infinite cylinder and sphere. It is concluded that the step response for the center, surface and average temperature are given by similar equation for the slab, infinite cylinder and sphere[1]. S. K. Sahu, P. Behera analyze one-dimensional heat conduction in both Cartesian and cylindrical geometries by employing the polynomial approximation method (PAM). Lumped analysis is done with internal heat generation. Comparison has been made with CLSA of result obtain from PAM and analyzes transient behavior of average temp of slab and cylinder” with various heat source parameters[2]. When we required measuring the temperature in many engineering application like refrigeration, air-conditioning and heat exchangers we required to insert our thermocouple in cup where fluid or refrigerant temperature has to be measured. Thus the geometry of thermocouple cover junction is play very important role how it attains thermal equilibrium with ambient. This paper describes the effective geometries using lumped analysis.

2. Objective And Methodology

2.1 Proposed Objective: This paper deals with the estimating temperature profile of three different geometries of two different materials using lumped analysis. These three different solid geometries, cylinder, cone and mixed shape of cylinder and cone, are consider for experiments having same length and diameter so we can optimize time constant to predict the following…
1. To estimate effect of heating and cooling media on unsteady state heat transfer.
2. Efforts are made to predict temperature field in various solid geometries using lumped system analysis experimentally.

2.2 Methodology: Consider a solid body as shown in figure 2.2(a) of arbitrary geometry of mass m, volume V, surface area A, density $\rho$ and specific heat $C_p$. Body is initially at a uniform temperature $T_i$. 
During the differential time interval \( dt \), the "temperature of body increased by a differential amount" \( dT \). An energy balance of solid geometries for the small time interval \( dt \) can be expressed as:

\[
(\text{Heat transfer in to the body during } dt) = (\text{The increase in the energy of body during } dt)
\]

\[
Q = hA_s(T_\infty - T(t)) = mC_p dT
\]

now we know that \( m = \rho V \) and \( dT = d(T - T_\infty) \)

integrating from \( t=0 \) at which \( T = T_i \) to any time \( t \) at which \( T = T(t) \) gives...

\[
\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt} \quad \text{..................}(1)
\]

where \( b = \frac{hA_s}{\rho V C_p} \)

'b' is a positive quantity whose reciprocal is called time constant so if the value of \( b \) will be more than time constant will be less which is desirable when we required to heat any object and attain steady state fastly.

3. Experimental Detail

Experimental setup of unsteady state heat transfer is designed for investigation of unsteady temperature variation with time and heat flow with solid geometries which are subjected for heating or cooling. Experimental setup consist of a cuboid water bath of galvanized iron sheet metal Having capacity of approximately 30 liters a There is 2 cm thickness thermocole insulation is provided to maintain the water bath temperature and minimize the heat transfer from water bath to the environment. The adjustment of thermostat heater allows the bath temperature become constant.
Figure 3.1 shows the block diagram of unsteady state heat transfer experimental setup. Main parts are following...
1 – Water bath
2 – Temperature controller
3 – Emerging rod
4 – Thermocouple sensor
5 – Hole on water tank for inserting specimen
6 – Water bath temperature indicator
7 – Specimen temperature and atmospheric temperature indicator
8 – Heater on/off switch
9 – Heating element
10 – Switch to display thermocouple temperature (7)

Experimental setup of unsteady state heat transfer is shown below…

Water bath is heated thermostatically by 2 kW electric heater in the bottom base of tank. When water bath temperature becomes constant at prefixed temperature then we can insert the specimen in water tank by holding in mild steel rod. Specimen is hold in immersing rod by threads provide in specimen internally and in rod external thread is provide so that testing specimen can be hold in rod. Bulk mass of water ensure that water temperature maintain constant during experiment which is desire to investigate lumped analysis at constant ambient temperature. There is temperature controller which controls the temperature of water bath. Once we have to fix the water temperature of with the help of small screw mounted just below the indicator as shown the figure 4(b). there is two temperature indicator first one tell us the temperature of water bath and second one tell us the temperature of center of specimen and atmospheric temperature”.

4. Specimens Specification
Following geometries are considered for lumped analysis...

a. Cylindrical Geometry: Cylindrical geometries of copper and aluminum of the dimension L*D:7*2.5 cm is below respectively
b. Conical Geometry: Conical geometries of copper and aluminium of the dimension L*D:7*2.5 cm of the dimension (L*D:7*2.5 cm) as follows.

Fig 4.2: Conical geometries of copper and aluminum

c. Mixed geometry: Mixed geometry of cylinder and cone was considered of the dimension L*D:7*2.5 cm shown below.

Fig 4.3: Mixed geometry of cylinder and cone geometries of copper and aluminum

5. RESULT AND DISCUSSION

Considering body as Lumped i.e negligible thermal conduction resistance with in th body. Calculation was done by MATLAB programming. Following are the result obtained:

1. Temperature Response of Copper Specimens Heated in Water
2. Temperature Response of Aluminium Specimens Heated in Water

3. Heat Transfer Coefficient of Copper Specimens in Water Heating

4. Heat Transfer Coefficient of Aluminium Specimens in Water Heating
5. Average Value of Heat Transfer Coefficient of Copper specimen Heated in Water

![Graph showing average heat transfer coefficient for different shapes of copper specimens heated in water.]

6. Average Value of Heat Transfer Coefficient of Aluminium Specimens Heated in Water

![Graph showing average heat transfer coefficient for different shapes of aluminium specimens heated in water.]

7. Temperature Response of Copper Specimens Cooled in Air

![Graph showing temperature response of copper specimens cooled in air for different shapes.][1]
8. Temperature Response Aluminium Specimens Cooled in Air

![Graph showing temperature response of aluminium specimens in air]

9. Average Heat Transfer Coefficient of Copper Specimens Cooled in Air

![Bar chart showing average heat transfer coefficient for different shapes]

10. Average Heat Transfer Coefficient of Aluminium Specimens Cooled in Air

![Bar chart showing average heat transfer coefficient for different shapes]
11. Biot No. at Average Heat Transfer Coefficient of Copper Specimens While Heating in Water

![Graph showing Biot No. at average heat transfer coefficient for copper specimens with different geometries.]

12. Biot No. at Average Heat Transfer Coefficient of Aluminum Specimens While Heating in Water

![Graph showing Biot No. at average heat transfer coefficient for aluminum specimens with different geometries.]

From the lumped analysis of different solid geometries of different materials, it is verified that materials higher thermal conductivity having lower Biot no. and faster response than lesser thermal conductivity materials. It is clear that specimen which has minimum characteristic length has faster response. all above shown figure are explained as below. Figure 1 shows the temperature response of copper specimens heating in water figure describes that temperature variation is exponential and conical geometry has faster response than other two because It has smaller characteristic length. Figure 2 shows the temperature response of aluminum specimens, it take more time than copper specimens when we compare the same geometry because It has lower thermal conductivity than copper. Figure 3 and 4 represented the variation of heat transfer of all geometries of both materials and the average value is represented in figure 5 and 6.

Figure 7 and 8 express the temperature response of copper and aluminum specimens while cooling in air respectively, because air has less thermal conductivity so take more time in cooling than heating in water accordingly. Figure 9 and 10 represented average value of heat transfer of copper and aluminium specimens. Figure 11 and 12 shows the value of Biot number at average value of heat
transfer coefficient of all three geometries in different mediums and finds good agreement with theoretical results.

6. Conclusion

Form the lumped analysis of different solid geometries it is concluded that which geometries consist small characteristic length has faster response with ambient. Because of this conical geometries either aluminium or copper have faster response than cylinder. We can also use mixed shape of cylinder and cone in place of cylindrical shape it has also faster response than cylindrical geometries. When we need to perform the experiments like refrigeration, air-conditioning and heat exchanger we required to measure the temperature of the fluid by thermocouple then we make a cup in which we can dip our thermocouple and can record the temperature. Here we required the optimum shape of our thermocouple tip cover which attains thermal equilibrium with ambient faster generally cylindrical geometries is used. One can use conical or mixed geometry of cylinder and cone in place of cylindrical geometry, both having faster response than cylindrical geometry.

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