Indian Institute of Technology Gandhinagar

Transient Heat Transfer Coefficient

ME 351: Mechanical Engineering Lab-I

Experiment Report

AUTHORS

Anutosh Jaishwal 20110020

Harshil Safi 20110073

Krish Raj 20110160

Shail Prajapati 20110188

Suhani Mittal 20110204

Under The Guidance Of:

Prof. Uddipta Ghosh

Prof. Jaichander Swaminathan

Objectives:

Measure the convective heat transfer coefficient (h) for transient heat transfer with various materials based on the lumped capacitance assumption.

Essential background:

1. What is the lumped heat capacity approximation, and when is it valid?

It can be approximated that the temperature throughout the solid is nearly uniform, i.e., there are no significant temperature gradients within the solid. This way, measuring the temperature at one point is sufficient to understand the average temperature of the entire object.

When the Biot number:

$$Bi = \frac{h L_c}{k_{solid}} < 0.1$$

Here, the characteristic length L_c can be defined as the ratio of the volume to the surface area of the object:

$$L_c = \frac{volume}{Surface\ area}$$

h is the convective heat transfer coefficient between the object surface and the fluid and k_{solid} is the thermal conductivity of the object.

2. For an object that can be approximated as a lumped heat capacitance, how does the temperature vary w.r.t. time when exposed to a fluid at different temperatures?

The non-dimensional temperature (θ) varies exponentially with time.

$$\theta(t) = \frac{T_\infty - T(t)}{T_\infty - T(t)} = e^{-\frac{hA}{\rho V C_p} t}$$

T_∞ = fluid temperature measured by the ST3 temperature sensor = 63 ∘C

$T(t)$ = instantaneous object temperature measured by the ST1 temperature sensor

T_{in} = initial object temperature T(t = 0)

Experimental Observations:

Experimental Set-Up

Given data,

Sr. No	Material	Density (kg/m^3)	Thermal Conductivity (W/m*K)	Specific heat capacity (J/kg*K)
1	Brass	8500	111	380
2	SS	8000	14	490
3	Aluminium	2700	190	890

Setup schematic:

ST-1: Temperature of the object
ST-2: Temperature near the object in the fluid
ST-3: Temperature of the fluid

1. Estimate and plot the instantaneous heat transfer coefficient h(t) by considering the instantaneous rate of heat transfer to the object. Also, compute the average heat transfer coefficient h.

$$Q = \rho V C_p \frac{dT(t)}{dt} = h(t)A(T_\infty - T(t))$$

$$h(t) = \frac{\rho V C_p}{A} \cdot \frac{\frac{dT(t)}{dt}}{(T_\infty - T(t))}$$

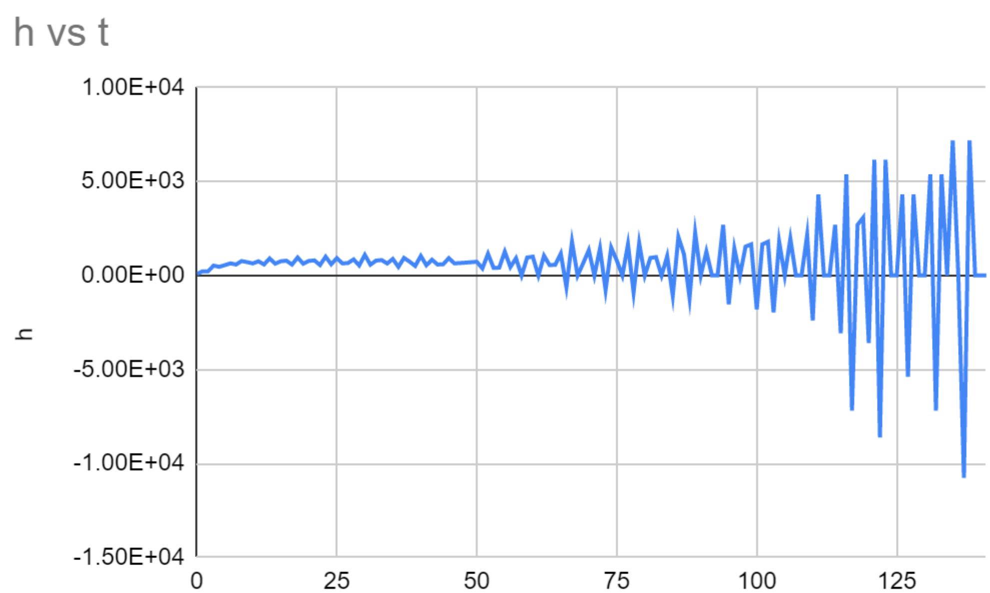
$$log(\frac{T_\infty - T(t)}{T_\infty - T(t)}) = \frac{A}{\rho V C_p} \int_0^t h(t)dt$$

$$T(t) = T_\infty - (T_\infty - T_0)\, e^{-c\int_0^t h(t)dt} \quad \text{where, } c = \frac{A}{\rho V C_p}$$

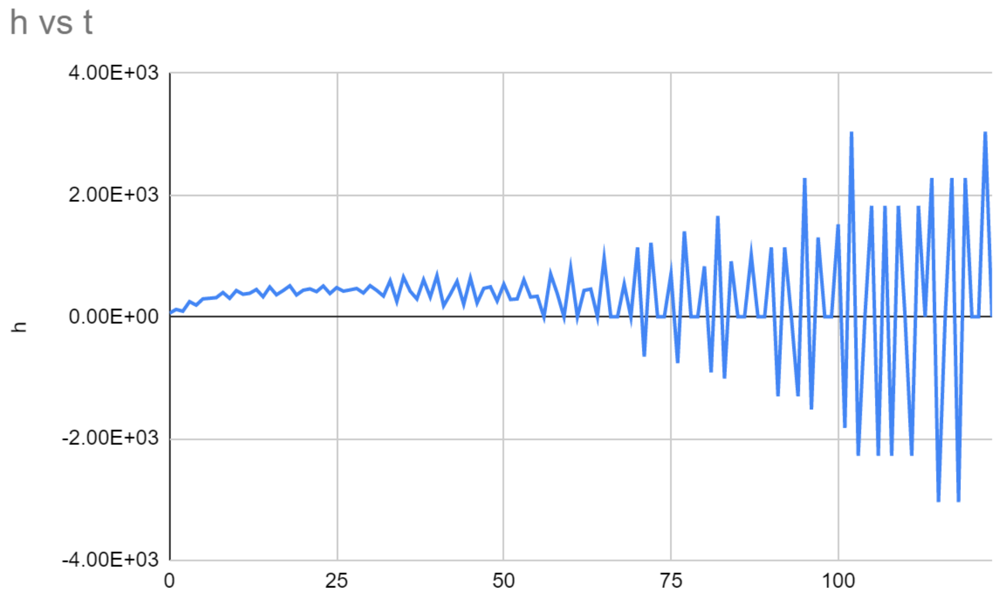
Object	Area (m^2)	Volume (m^3)	h $(W/m^2 K)$	L_c
Brass Sphere	0.005027	3.35 E-05	6.31 E+02	6.67 E-03
Aluminium Slab	0.0158	6.00 E-05	3.07 E+02	3.80 E-03
SS Cylinder	0.007422012644	2.65 E-05	5.18 E+02	3.57 E-03

Variation of heat transfer with time for,

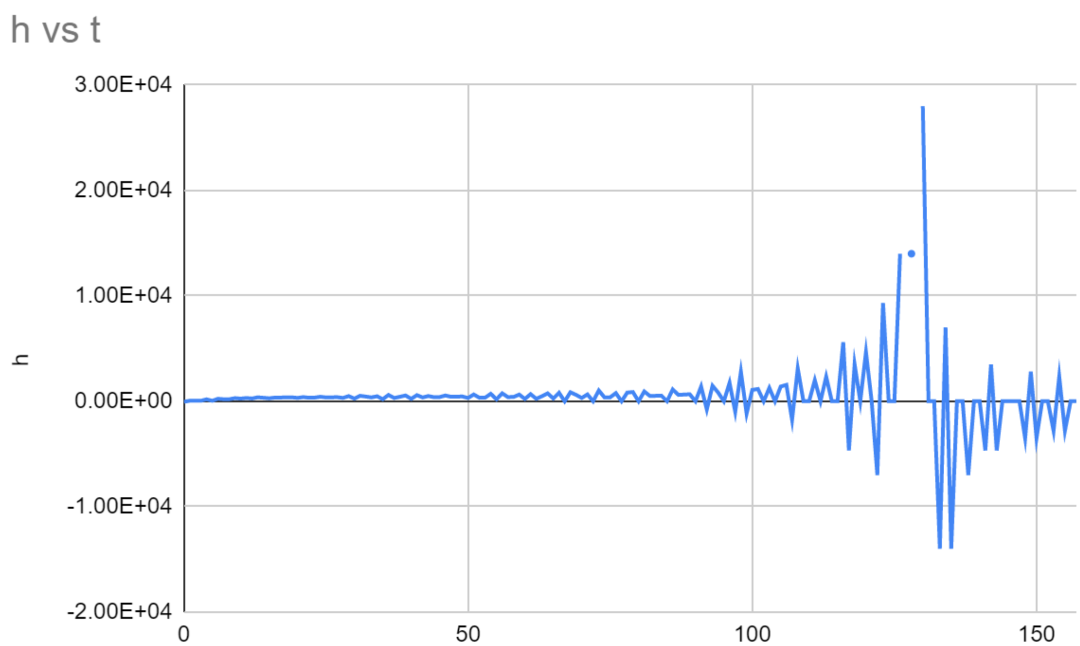
Brass Sphere



Aluminium Slab



SS Rod



2. Based on a best-fit temperature variation curve with time, estimate the average heat transfer coefficient $h_{overall}$.

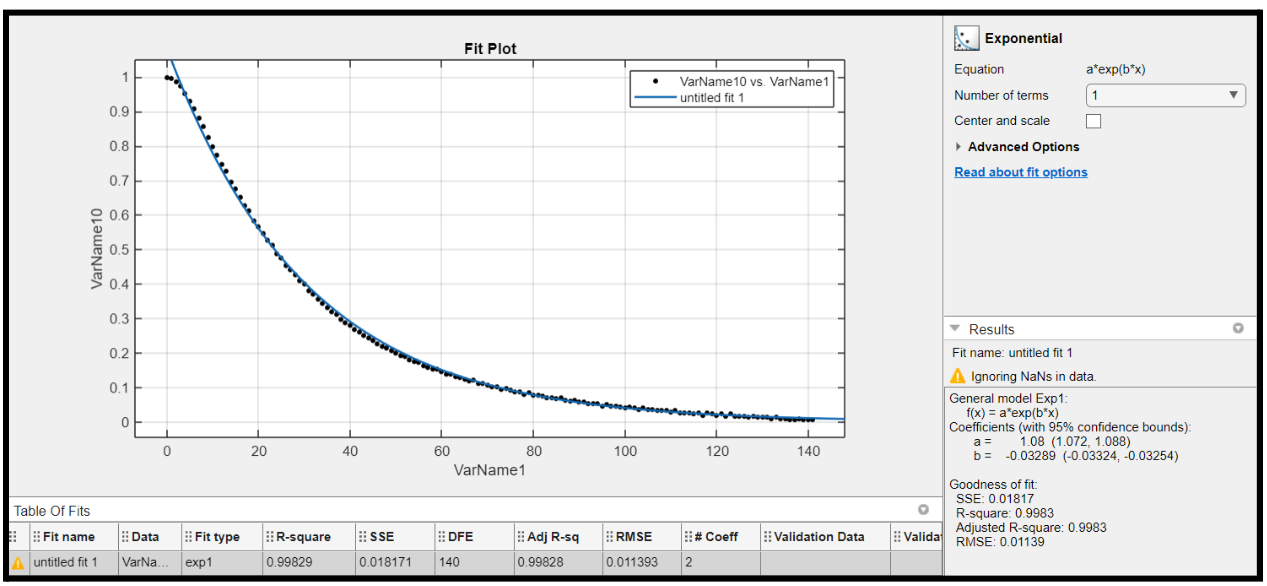
$$\theta(t) = \frac{T_\infty - T(t)}{T_{in} - T_\infty} = e^{-bt}$$

$$where, \qquad b = \frac{hA}{\rho V C_p}$$

b can find out using curve fitting and then compared to find $h_{overall}$.

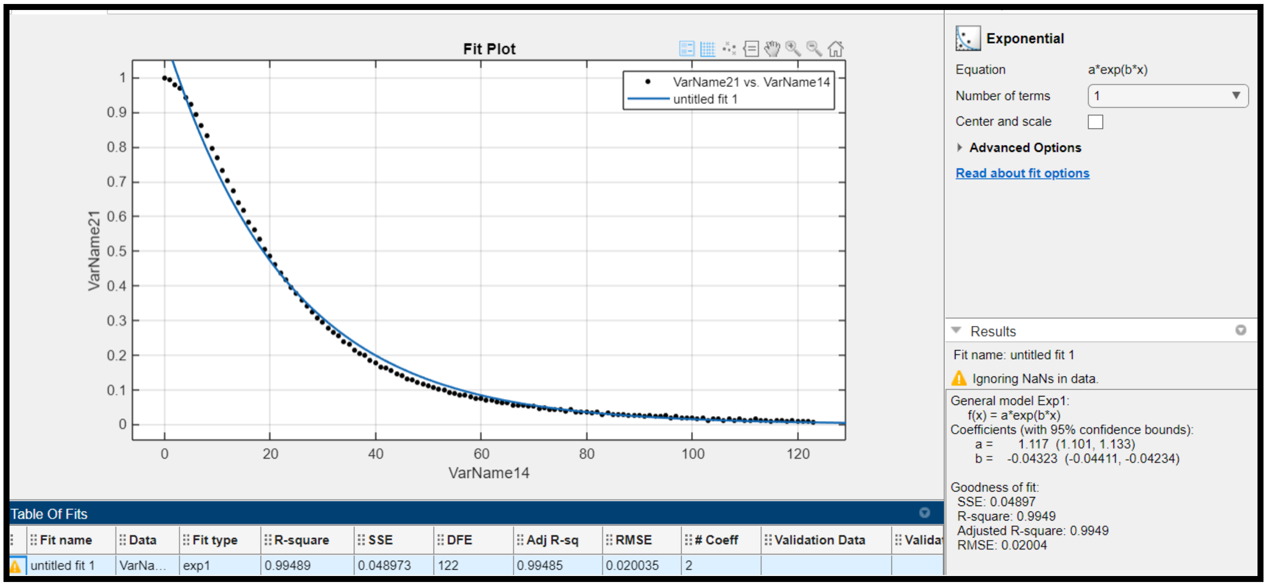
The following curves are between theta(θ) and time(t) for the different objects, and their best fit exponential curve. These are used to find the heat transfer coefficient by using the above equation for b.

Brass Sphere



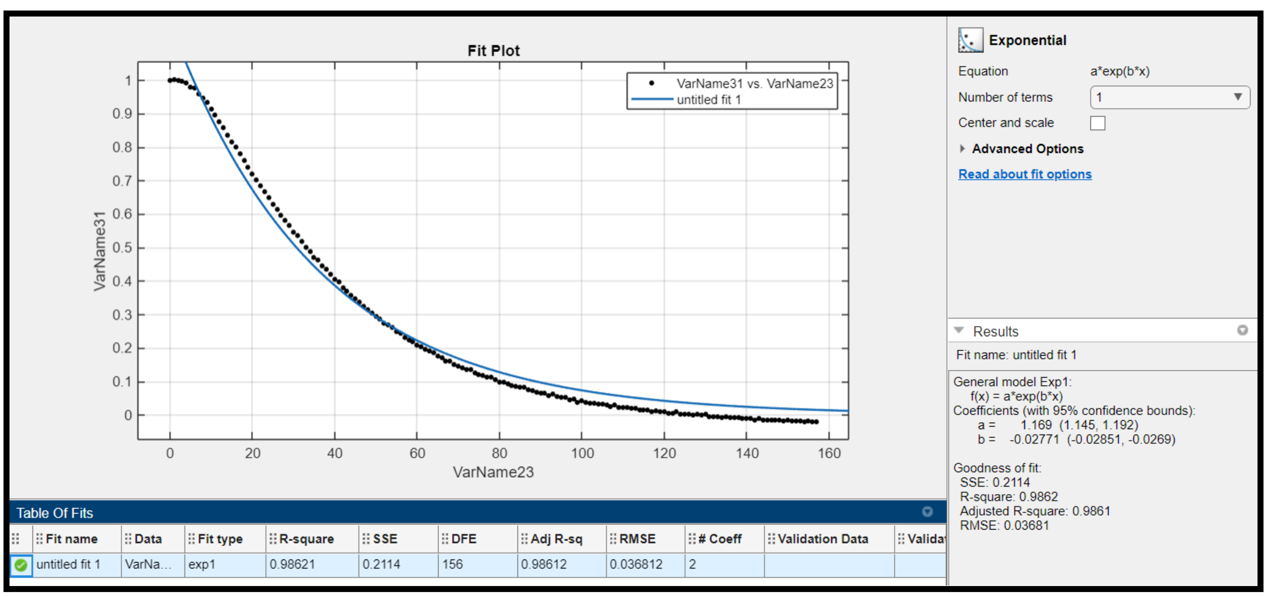
From curve fitting, b = 0.03289

Aluminium Slab



From curve fitting, b = 0.04323

SS Rod



From curve fitting, b = 0.02771

Overall Heat transfer coefficient using equation, $b = \frac{hA}{\rho V C_p}$

Which implies, $h = \frac{b \rho V C_p}{A}\ (W/\ m^2\ K)$

Object	*b*	$h_{overall}$ $(W/\ m^2\ K)$
Brass Sphere	0.03289	7.08 E+02
Aluminum Slab	0.04323	3.94 E+02
SS Cylinder	0.02771	3.88 E+02

3. Compare the values of the average heat transfer coefficient found through the above two methods.

Object	h $(W/\ m^2\ K)$	$h_{overall}$ $(W/\ m^2\ K)$	*Deviation*
Brass Sphere	6.31 E+02	7.08 E+02	10.9 %
Aluminum Slab	3.07 E+02	3.94 E+02	22.2 %
SS Cylinder	5.18 E+02	3.88 E+02	-33.5 %

4. Check and comment on the validity of the lumped capacitance approximation.

$$Bi = \frac{h\, L_c}{k_{solid}} < 0.1$$

$$L_c = \frac{volume}{Surface\ area}$$

Object	$h_{overall}$ $(W/\ m^2\ K)$	k, Thermal Conductivity (W/m*K)	L_c	**Bi**
Brass Sphere	7.08 E+02	111	6.67 E-03	4.25 E-02
Aluminum Slab	3.94 E+02	14	3.80 E-03	5.55 E-04
SS Cylinder	3.88 E+02	190	3.57 E-03	9.90 E-02

Since Bi < 0.1 in all three cases, The lumped capacitance heat model is valid.

Conclusion:

- The lumped capacitance model for transient conduction was tested for three heated spheres; a Brass Sphere, Aluminium Slab, and SS Rod.
- We can also see that the convective heat transfer coefficient varies depending on the shapes and material.
- The instantaneous heat transfer coefficient is not constant but continues to fluctuate. However, we can observe a trend that indicates that the heat transfer coefficient increases as the experiment proceeds.