**Plasma Spray Coating Research for Pratt and Whitney by Max Plomer**

**Summary:** The following is a preliminary research of the Plasma Spray Coating process; we will review basic heat transfer material and then build a simple analytical/numerical estimate of the location of a particle when it has reached melting temperature and then when it has fully melted. There are 3 main problems that are combined into the solution:

(1) Lumped capacitance model is used for low Biot number spheres being heated to melting temperature

(2) Once particle reaches melting temperature this becomes a Stefan Problem where we calculate the particle’s solid fraction using it’s latent heat of melting

(3) Linear and quadratic drag coefficients are used to calculate the location of the particle when melted.

**Sources for the following material is:**

1. MIT material processing lecture notes part of the MIT Open Courseware initiative

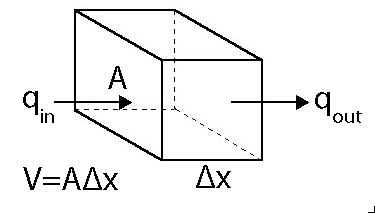
2. Classical Mechanics. John R. Taylor

3. Fundamentals of Heat and Mass Transfer. Incropera, DeWitt, Bergman and Lavine

4. “Scaling Analysis and Prediction of Thermal Aspects of the Plasma Spraying Process Using a Discrete Particle Approach” Jinho Lee and Theodore L. Bergman

**Fourier’s Law**

**Heat Balance in Small Element**



heat in – heat out + heat generation (chemical reaction) = heat accumulation

Limit as

If k is constant

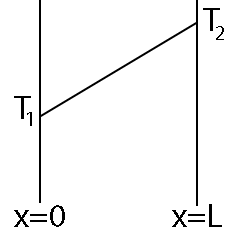
From definition of heat capacity at constant pressure

Divide by

**Heat Conduction Equation**

Assumes

**Steady State 1D Conduction**



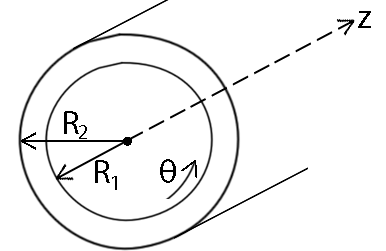
At x=0, T=T1

At x=L, T=T2

Dimensionless variables T\* and x\*

Constant heat flux

**Steady State in Cylinder**



T constant in z and directions

Note:

At r=R1, T=T1

At r=R2, T=T2

From eq1

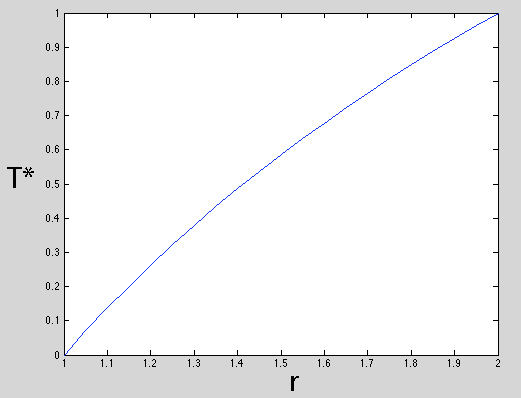
From eq2

Substitute eq2 eq1

Subtract T1, divide by (T1-T2)

Dimensionless variable T\*

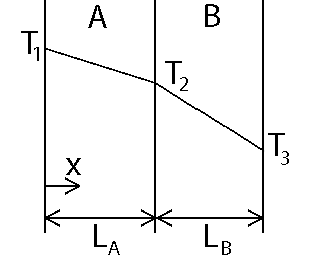
Constant total heat flux, but flux not constant



At r=1 T=T1

At r=2 T=T2

**Steady State in Composite Wall**



T2 is unknown

At x=LA, T=T2, qin=qout

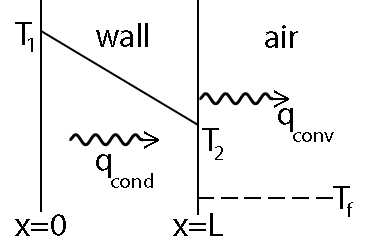
Useful conclusions

Thermal circuit

Note: since , we can use the q from the thermal circuit to go directly to the temperature gradient

Comparison of Steel vs. Mullite

**Steady State Convection on Wall**



T2 is unknown

At x=L

At x=L, qcond=qconv

Dimensionless variables T\* and x\*

Thermal circuit

Bi<<1

-Slow convection, no temperature gradients in solid

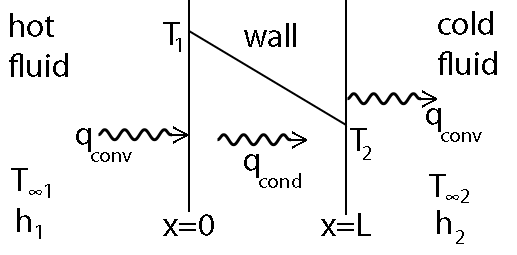
Bi1

-Conduction and convection equally important, transient solution

Bi>>1

-T2=Tf, rapid convection

**1D Plane Wall Conduction with Convection on Both Sides**



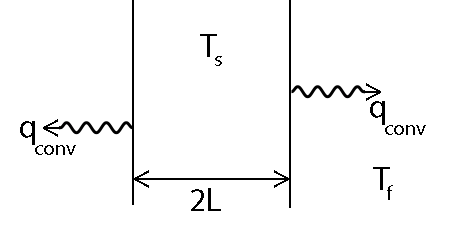
T1 and T2 are unknown, assuming k is constant otherwise

At x=0, qcond = qconv  At x=L, qcond=qconv

Solve for A

Thermal circuit

**Low Biot Number Solutions**



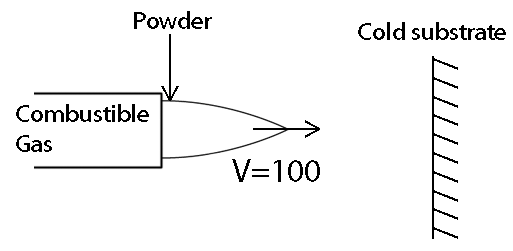
Global heat balance,

Separation of variable

Note: Integrate RHS using u-substitution,

At t=0, T=Ts

**Thermal Spray Coatings / Plasma Spray**



Spray is quasi-steady state because it is assumed that neither the plasma torch nor substrate moves with respect to the other, and that the particle is heated isothermally. This assumption is justified with Bi << 1 .

oxyacetylene torch: T = 3000K

powder: Ni alloy MAR-M200 R = 2 – 50 ()

Problem: need to find time that spherical particle reaches melting temperature Tm

At r=0, symmetry

At r=R convection into ambient air,

Governing equations

Lc is the character length defined as volume/area ratio, R/3 for sphere, L for wall of thickness 2L, R/2 for cylinder

Time to reach melting temperature

Once particle gets to melting temperature, still need to transfer energy to melt it

During heating:

During melting:

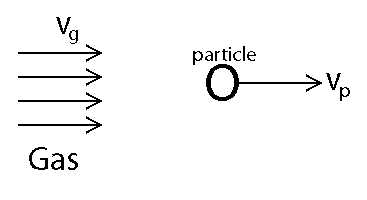
Separation of variable

At t=0, fs=1, C=1

Want time when fs=0

Add time to reach Tm and time to melt to get total time

**Calculating Acceleration and Velocity of Particle Using Air Resistance**



For speeds not approaching the speed of sound

For spherical projectile b and c have the form

For air at standard temperature () and pressure (1 atm), which is inaccurate but they were the values that were available

We can compare flin and fquad to see if one can be neglected, using v=100m/s and

Quadratic is dominant at v=100m/s but it’s dominance diminishes as the particle gets up to speed, for the sake of completeness we will solve using both linear and quadratic drag.

From F=ma

I chose to solve this numerically using Matlab

At distance traveled is 13.1060 m

Code used:

function velocity\_using\_quadandlinear\_drag

roe=8500;

R=50e-6;

D=2\*R;

gamma=0.25;

beta=1.6e-4;

c=gamma\*D^2;

b=beta\*D;

V=4/3\*pi\*R^3;

m=roe\*V;

vg=100;

%initial conditions

v0=0;

%time span 0 to 10 sec

tspan = [0 .1683];

[t ,v] = ode15s(@quaddrag, tspan, v0);

%calculate distance

distance=trapz(t,v)

function dvdt = quaddrag(t, v)%time, mass faction

dvdt = b/m\*(vg-v)+c/m\*(vg-v)\*abs(vg-v);

end

end