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Design of Finned-Tube Assembly for Frozen Seal Valve

S.S.Biswas

Scientific Officer, BHAVINI, Kalpakkam-603102, India.

R. Manish Kumar

B.E.(Mech.), St. Peter's College of Engineering and Technology, Avadi, Chennai, India.

Seshadri. C

B.E.(Mech.), Rajalakshmi Engineering College, Chennai, India.

Abstract

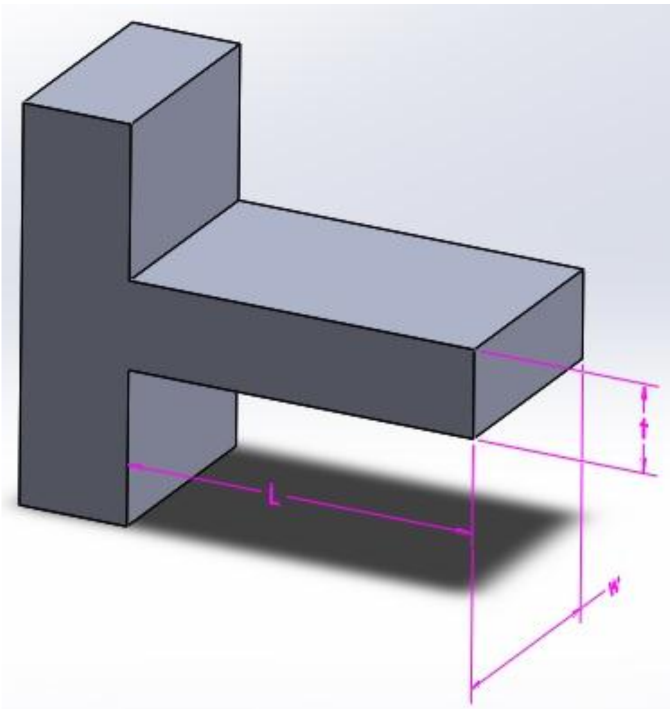
Special type of Valves are used to control High temperature sodium flow in secondary sodium system of FBR (i.e.) to isolate steam generators from sodium flow during its maintenance. These valves are known as frozen seal butterfly valves. A circular disc perfectly fitted in the valve seat provided in sodium pipes. The disc is attached to a cylindrical stem to provide stroke. The stem is covered by a sheath which itself attached to the sodium pipe line. There is an annular gap provided between the stem and sheath. Due to the pressure of secondary sodium line, sodium raises through this annular path. To avoid sodium leak through the gland of the valve, liquid is forced to freeze the annular path while it's raising. To promote this phenomena, heat transfer through the sheath needed to the augmented. This is achieved by providing the circular fins attached to the outer surface of the sheath. However large number of fins are uneconomical, fins of larger diameter reduce its efficiency. Hence the number of fins, geometry and its spacing should be optimum to freeze the sodium in the annular path while it's raising but before to reach the gland of the valve. This paper explains the mathematical modelling of the fins and its optimization to obtain better thermo-dynamical efficiency.

Keywords: Frozen Seal, Fin, Heat Transfer, Newton's Law of Cooling, Fourier's Law

INTRODUCTION

The fins are provided to augment the heat transfer while liquid is raising through the annular path provided in sheath. This fins are designed based on Fourier law of thermal conductivity and Newton laws of cooling with the boundary condition that tip of fin is insulated. Heat transfer coefficient reduces as the substrate temperature is low. This is a model study to observe the stem temperature from bottom to top. Due to thermo-dynamical phenomena, heat will be convected out through the fin by natural convection and a temperature curve will be obtained with Negative slope in Gradually Decreasing Fashion with the stem height increasing. The concern of this paper is to study the temperature distribution throughout stem and the freezing temperature of the liquid should reach as earliest as possible while it is raising through the annual path. Once the temperature profile of the stem is established line with the requirement, disc will be fixed with the stem.

MATHEMATICAL MODELLING OF FIN



Q = Heat Transfer Rate

h = Heat Transfer Co-efficient

ΔT = Temperature Difference

A = Area of Cross-Section ($w \times t$ i.e., width × thickness)

$\theta = T - T_\infty$ = Temperature Excess

p = Perimeter of the Fin = $2(w + t)$

Boundary Conditions and Assumptions for Modelling:

At x = 0, $\theta = \theta_b$, T_∞ = constant , h = constant, 'T' is a function of 'x'(distance along the radius of the fin) only.

As per Fourier's Law,

$Q = -K*A*(\frac{dT}{dx})$

At x = L,

$Q = -K*(\frac{d\theta}{dx}) = h*\theta \, |x = L$

From the energy balance we have,

$Q_x=Q(x+\Delta x)+Q_{conv}=Q_x+\frac{dQx}{dx}*\Delta x+Q_{conv}$ ....(1)

$\frac{dQx}{dx}*\Delta x + Q_{conv} = 0$

We know that,

$Q = h*A*\Delta T$ and Surface area of Fin = $p*\Delta x$

Substituting the above in Equation 1, we have,

$\frac{d}{dx}(-K*A*\frac{dT}{dx})* \Delta x + h*p* \Delta x* (T - T_\infty) = 0$

$d^2x/d\theta^2 - (\frac{h*p}{K*A}) * \theta = 0$

Let $(\frac{h*p}{K*A}) = m^2$

Hence, $d^2x/d\theta^2 - m^2* \theta = 0$

$\theta = A*\cosh(mx) +B*\sinh(mx)$ ....(2)

From Boundary Condition x = 0, we have, $\theta_b = \theta$.

Hence, $A= \theta_b$

From Boundary Conditions, x = L, we have,

$B = - \theta_b *[Km*\sinh(mL) + h_{tip}* \cosh(mL)]/ [h_{tip}* \sinh(mL) + Km*\cosh(mL)]$

The heat transfer rate at the base is much higher than the heat transfer at tip. Hence 'h_{tip}' can be neglected considering it as adiabatic change. Therefore,

$B = - \theta_b* (\frac{\sinh(mL)}{\cosh(mL)})$

Solving equation 2 by substituting A and B, we get,

$\theta = \theta_b*\cosh[m(x-L)] / \cosh(mL)$

$Q_{fin} = -K*A* \frac{d\theta}{dx}$ at x = 0

Differentiating 'θ' wrt 'x,

$\frac{d\theta}{dx} = \theta_b * m* \sinh[m(x-L)]/\cosh(mL)$

Hence,

$Q_{fin} = K*A*m* \theta_b*\tanh(mL)$

And $Q_{maximum} = h*p*L* \theta_b$

Now, fin efficiency is given by,

$\eta = \frac{Qfin}{Qmaximum} = \frac{\tanh(mL)}{mL}$

$Q_{noFin} = h*A* \theta_b$

Now, Effectiveness is given by,

$\frac{Qfin}{QnoFin} = K*m*\frac{\tanh(mL)}{h}$

ESTIMATION OF HEAT TRANSFER CO-EFFICIENT

Normally the most convenient way to predict heat transfer co-efficient is the Nusselt Number (In this case, fins are stacked one over the other, hence conventional correlation of Nusselt number is not applicable). But this is highly applicable for standard geometry. When the geometry is complex, it become difficult. Nusselt Number is given as follows,

$Nu=Q_{conv}/Q_{cond}=hAdT/KA(dT/dx)=hdx/k$.

In finned-tube unit, circular fins are placed around a tube through which liquid flows. To model the assembly, it very essential to estimate a heat transfer co-efficient for all the surfaces. But the heat transfer co-efficient (h) is not constant throughout the surfaces. 'h' is a function of dT and flow, so at the base of the fin, heat transfer rate is higher than the tip of the fin. But if the non-uniform 'h' is considered in the mathematical modeling of the fin, it become too complicated to solve the differential equation. Moreover, radiation effects are also needed to be included to get an error free performance. To consider all the above constraints and to obtain an overall heat transfer co-efficient so that all three modes of heat transfer conduction, convection, and radiation, and their coupling with particle dynamics contributes equally, Multiphysics simulation is the most convenient way. In our experiment, Energy2D, a 'National Science Foundation' funded open source software has been used to find the surface temperature distribution through the fin radially. The parameter details used for the simulation are given below,

Thermal conductivity (k) of material=16.2 W/m Deg.C

Specific Heat= 500 J/kg Deg.C

Density= 800kg/m^3

Background Tem. of Air 44 Deg.C

Conductivity= 0.03 W/m Deg.C

Specific Heat= 1012 J/ kg Deg.C

Density= 0.800 kg/m^3

Kinematic Viscosity= 0.000025 m^2/s

Thermal Expansion Co-efficient=0.0025 m/s^2 Deg.C

Bouyancy approximation = All-cell average

Gravity type= Uniform

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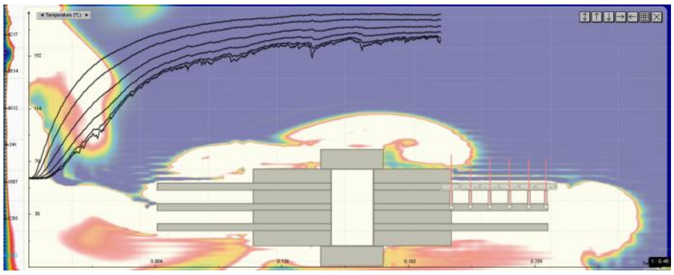
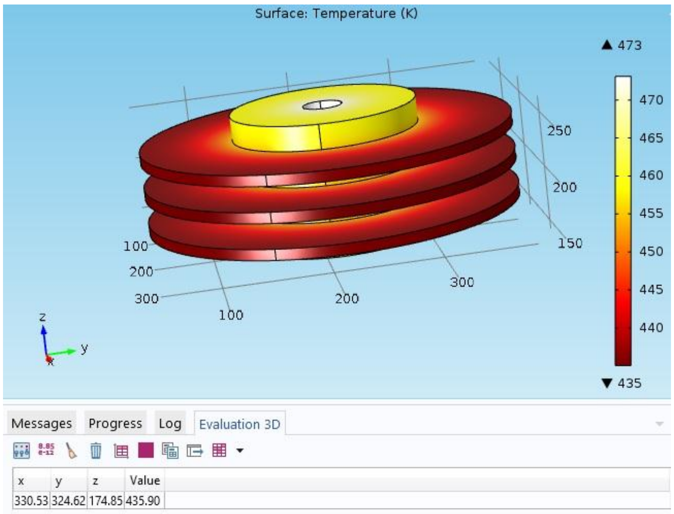


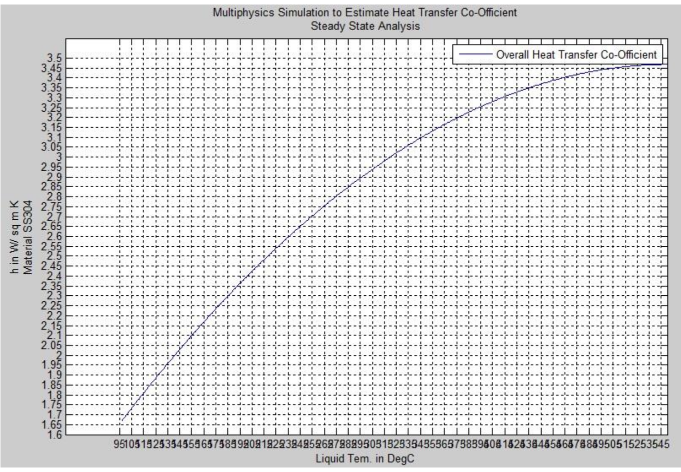
Temperature Distribution of the fin with liquid temperature 200 Deg.C

Base Temp. 181 Deg.C, Tip Temperature 162 Deg.C

The same temperature distribution is obtained with an overall h=2.4 W/mK, simulation result as follows,

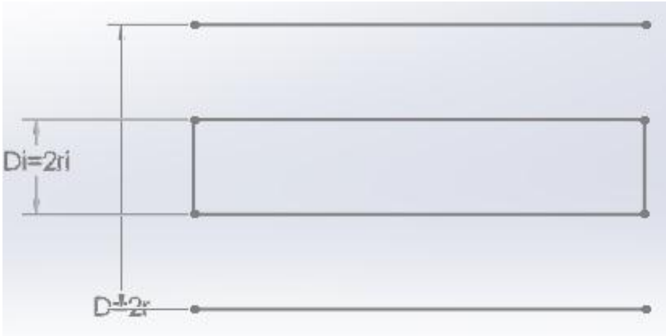


Likewise, several discrete values are obtained and the liquid temperature *vs* heat transfer co-efficient interpolated to establish the relationship,



'h' *vs* Fluid temperature obtained from Multiphysics analysis

DETERMINATION OF ANNULAR LIQUID VELOCITY



The velocity distribution and the mean velocity of a fluid flowing through an annulus of outer radius r and inner radius r_i is more complex. If, as shown in above Figure, the pressure changes, by an amount ΔP as a result of friction in a length 'l' of annulus, the resulting force may be equated to the shearing force acting on the fluid. For the flow, the shear force acting on this fluid consists of two parts: one is the drag on its outer surface which may be expressed in terms of the viscosity of the fluid and the velocity gradient at that radius and the other is the drag occurring at the inner boundary of the annulus. By considering all, the average velocity is expressed as,

$$u = (\Delta P/8\mu l)\times(r^2+r_i^2-(r^2-r_i^2)/\ln(r/r_i))$$

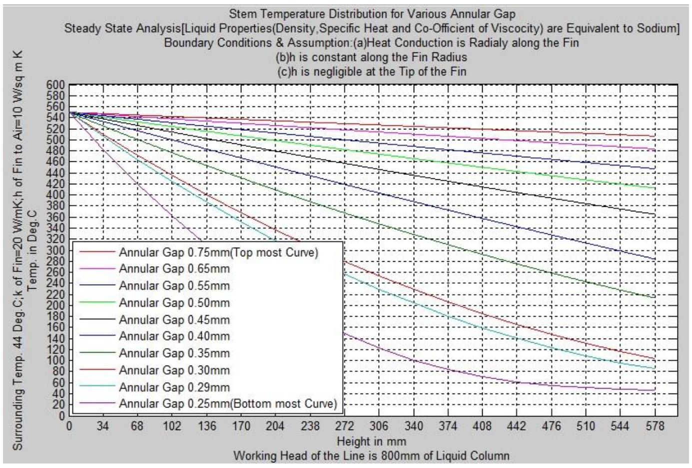
MATLAB CODE FOR TEMPERATURE CALCULATION

```
q=550+273;%Liquid Temp in K
syms T;
mu=exp(-6.4406-(0.3958*log(T))+(556.835/T));%Expression for Viscosity
syms Te;
x=subs(mu,T,(q+Te)/2);%Viscosity
Tc=2503.7;
rc=219;
f=275.32;
g=511.58;
d=rc+(f*(1-(T/Tc)))+(g*(1-(T/Tc))^0.5);%Expression for Density
y=subs(d,T,(q+Te)/2);%Density
z=1.27;%Average Specific Heat
H=800/1000;
r=18.29/1000;%Annular Gap of 0.29mm
ri=18/1000;
l=34/1000;
```

```
dp=H*y*9.81;%Line differential Pressure
A=r^2+ri^2;
B=r^2-ri^2;
u=dp*(A-(B/(log(r/ri))))/(8*x*l);%Liquid Raising Velocity
mfr=u*pi*B*y;%Mass Flow Rate
hfr=mfr*z*(q-Te)*1000;%Heat Flow Rate
d1=340/1000;%Fin OD
d2=170/1000;%Fin ID
k=20;%W/mK
hd=10;%W/sq mK
w=10/1000;
ar=pi*(d1+d2)*w/2;
m=(2*hd/(k*w))^0.5;
Ll=(d1-d2)/2;
f=2*m*Ll;
g=(exp(f)-1)/(exp(f)+1);
tb=(q+Te)/2;
tinf=(44+273);
th=tb-tinf;
Qf=17*m*k*ar*th*g;
C=hfr-Qf;
m=solve(C,Te);
disp(m-273)%Average Temp.in Deg.C
```

TEMPERATURE DISTRIBUTION PLOT

Using the relations in previous clause, various discrete data obtained for different annular gap and the same has been plotted below,



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