NE620 Final Exam Report

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PROBLEM 1

Input Edits

There were many changes made to the RELAP input file before it was run. First, a variety of geometric parameters were calculated. Equation (1) calculates the flow area for 1 fuel rod,

$$A_{flow} = 2A_{triangle} - A_{rod} \tag{1}$$

where the $A_{triangle}$ is the area of an equilateral triangle and A_{rod} is the cross sectional area of one fuel rod. The hydraulic and heated diameters were calculated using Eq. (2)

$$D_h = \frac{4A_{flow}}{p} \tag{2}$$

where p is the wetted perimeter (the perimeter of the flow area) $p_{wet} = 4(pitch - D_{fuel}) + \pi D_{fuel}$ for hydraulic diameter and heated perimeter (the perimeter of the fuel region of the fuel rod) $p_{heat} = \pi(D_{fuel} - t_{clad})$ for the heated diameter.

The power of the channel was calculated by dividing the total thermal power

$$P_{chan} = \frac{P_{thermal} PF}{n_{rods}} \tag{3}$$

where PF is the radial power peaking factor of 1.2, $P_{thermal}$ is the total thermal power of the reactor and n_{rods} is the number of fuel rods in the core, 85.

These parameters were changed in the input file, along with the axial distribution of the power in the channel. That was simply a sine function that peaked in the center of the channels and was zero at the ends. Also changed in the input file was the minor edits. Minor edits were altered to output temperature of the fluid in the core, temperature of the cladding in the core, and velocity of the coolant in the core channel.

Table I includes all the values used in the calculation of the input parameters, and the parameters themselves.

TABLE I: Input Parameters

A_{flow}	0.00031043 m^2
p_{heat}	0.113097 m
p_{wetted}	0.128239 m
$A_{triangle}$	0.000692 m^2
D_{fuel}	0.037 m
n_{rods}	85
P_{chan}	17647 Wth
$P_{thermal}$	1.25 $MWth$
$D_{hydraulic}$	0.0096828 m
D_{heated}	0.0109792 m
t_{clad}	0.0005 m

Analytical Solution

After running the RELAP calculation, the velocity in the channel was averaged and used in the calculation of the analytical solutions.

$$T_c(z) = \frac{q_0' L}{m_{flow} C_p}(1 - \cos\frac{\pi z}{L}) + T_i \tag{4}$$

$$T_w(z) = \frac{q'(z)}{\pi D_{fuel} h} + T_c(z) \tag{5}$$

Equations (4) and (5) are used to calculate the coolant and cladding (wall) temperatures, respectively. Used in Eq. (5) is $q'(z)$, the linear heat rate, which is equal to $q_0' \sin\frac{\pi z}{L}$.To find the coveted h value, the Nusselt number must be found using the Dittus Boelter correlation, shown in Eq. (6)

$$Nu_D = 0.023 Re_D^{4/5} Pr^{0.4} \tag{6}$$

where the Reynold's Number, Re_D, is equal to $\frac{\rho v D}{\mu}$.

$$Nu_D = \frac{hD}{k} \tag{7}$$

Equation (7) can be solved for h to be used in Eq. (5).

TABLE II: Analytical Solution Parameters

h	37389.95 W/m^2K
N_u	24.4
k	14.83 W/mK
Pr	7.01
C_p	4180 J/kgK
L	0.371 m
Re_D	2288.25
q_0'	72755 W/m
ρ	1000 kg/m^3
v	0.2103 m/s

Table II lists the parameters and values calculated in the analytical portion of problem 1.

Results & Discussion

The temperatures found using RELAP and analytically were plotted against each other and shown in Fig. 1.

As shown, the results for the temperature of the coolant calculated using either method are almost identical. However, when studying the wall temperatures, there is actually a huge discrepancy between the methods. The first thing to note, is that if the coolant is removing heat and increasing temperature,

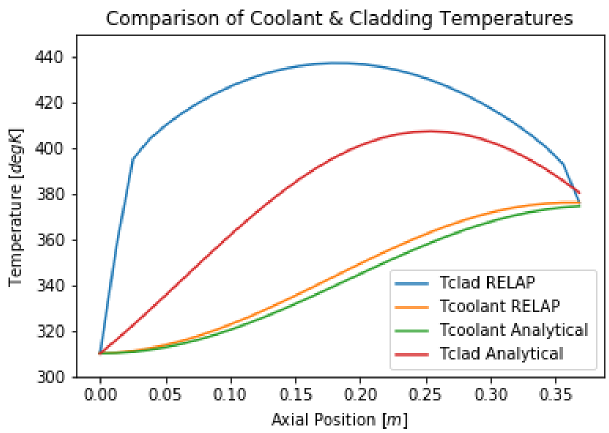

Fig. 1: A comparison of the temperatures found using RELAP and Analytical Methods

then the cladding's peak temperature should not be in the center of the fuel rod. An uncooled rod would certainly have it's peak temperature in the center (given a sinusoidal heat flux), but not a rod where coolant is flowing past and removing heat. The peak should be skewed towards the top of the rod, which is the case for the curve found using Eq. (5).

PROBLEM 2

Deriving the Maximum Flow Rate Condition

Conservation of energy says for a for a steady-state, single phase, adiabatic gas

$$0 = h_0 - (h_b + \frac{v_b^2}{2}). \tag{8}$$

and for an ideal gas, the mass flux is $G_b = \rho_b v_b$, or

$$G_b = \rho_b \sqrt{2(h_0 - h_b)} = \sqrt{2\rho_b^2 c_p (T_0 - T_b)}. \tag{9}$$

Knowing that the following correlations for an ideal gas expanding isentropically hold true,

$$\frac{\rho_b}{\rho_0} = (\frac{p_b}{p_0})^{1/\gamma} \tag{10}$$

$$\frac{T_b}{T_0} = (\frac{p_b}{p_0})^{(\gamma-1)/\gamma} \tag{11}$$

they can be substituted into Eq. (9) to give

$$G_b = \sqrt{2\rho_b^2 c_p T_0[(\frac{p_b}{p_0})^{2/\gamma} - (\frac{p_b}{p_0})^{(\gamma-1)/\gamma}]} \tag{12}$$

when $\frac{\delta G}{\delta p_b} = 0$, the mass flux is maximized, which gives the condition for the maximum flow rate.

$$(\frac{p_b}{p_0})_{critical} = (\frac{2}{\gamma+1})^{\gamma/(\gamma-1)} \tag{13}$$

Deriving the Maximum Flow Rate

Plugging the above condition into the mass flux equation and substituting Eq. (11) for T_0 gives

$$G_{cr} = \rho_b \sqrt{\gamma T_b R/M}. \tag{14}$$

where R/M is the ideal gas constant divided by the molar mass of the gas (this is just the specific gas constant). Studying the speed of sound for a perfect gas

$$c = \sqrt{\gamma(\frac{\delta p}{\delta \rho})_T}. \tag{15}$$

we can see that when plugging in its equation of state, $p = \rho RT/M$, we get

$$c = \sqrt{\gamma T_b R/M}. \tag{16}$$