Nuclear Reactor Thermal-Hydraulics

NUGN520 - Homework

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Chapter 1

Heat transfer and fluid flow, nonmetallic coolants

Several exercises from the book written by M. M. El Wakil [1] are tackled in this homework. The problems in this section relate to the eleventh chapter of the book, covering the subject of heat transfer with change in phase.

1.1 [11-1] - Liquid superheat

1.1.1 Problem

If the surface tension between the liquid and vapor for water at $212°F$ *is* $4.03 \times 10^{-3}\ lb_f/ft$*, calculate the amount of liquid superheat necessary to generate a* 4.68×10^{-3} *in. diameter bubble at atmospheric pressure (average).*

1.1.2 Solution

According to Equation 1.1 :

$$p_g - p_f = \frac{4\sigma_{fg}}{D} \tag{1.1}$$

We know that the liquid is at atmospheric pressure, $p_f = 1\ atm = 14.7\ psi$. We also know that the surface tension is $4.03 \times 10^{-3}\ lb_f/ft$ and that the diameter of the bubble is 4.68×10^{-3} in., or 3.9×10^{-4} ft. Consequently, we can obtain the required pressure inside the bubble, $p_g = 14.7 + \frac{4\sigma}{D} * c = 15.0\ psi$, $c = 1/144$ being a conversion factor from lb/ft^2 to psi.

According to tables, a steam pressure of 15 psi gives a saturated temperature equal to $213°F$. The vapor and the liquid must be at thermal equilibrium. We can thus assume with a reasonable margin of error that this will be the minimum required temperature for the superheated liquid around the bubble.

Thus, compared to the reference temperature of $212°F$, we have an amount of superheated liquid of around $1°F$.

1.2 [11-2] - Burnout temperature

1.2.1 Problem

In an experiment on pool boiling of water, the heat flux and water temperature and pressure were simultaneously increased so that saturation boiling occured at all times. Burnout occured when the pressure reached 300 psia. Assuming for simplicity that burnout heat transfer occurred solely by radiation, and that the radiation heat transfer coefficient is $200\ Btu.h^{-1}.ft^{-2}.°F^{-1}$*, estimate the temperature of the heating surface at burnout.*

1.2.2 Solution

We can use Equation 11-5 from the reference book to compute the heat flux. We will consider a standard gravity field, and data at burnout pressure, 300 psi.

$$q''_c = 143 h_{fg} \rho_g \left(\frac{\rho_f - \rho_g}{\rho_g} \right)^{0.6} \left(\frac{g}{g_c} \right)^{0.25} \tag{1.2}$$

In our case, $h_{fg} = 970.4\ Btu/lb$, $\rho_f = 52.919\ lb.ft^{-3}$ and $\rho_g = 0.648\ lb.ft^{-3}$. g and g_c have the same value, and will be used only for dimensional purposes. Then, we obtain q''_c equal to $1.25 \times 10^6\ Btu.ft^{-2}.h^{-1}$.

Using the relation $q'' = h\Delta T$, we can, knowing h, T_f and q''_c, estimate the surface temperature when the burnout occurs. T_f is taken as the saturated temperature at a pressure of 300 psi, $T_f = 417°F$.

$$T_s = T_f + \frac{q''_c}{h} = 417 + 6250 = 6667°F \tag{1.3}$$

1.3 [K1] - Ideal gas law

1.3.1 Problem

For an ideal gas in isothermal conditions, considering $\frac{dT}{dt} = 0$*, find the expression for* $\frac{d\rho}{dt}$.

1.3.2 Solution

The ideal gas law can be written:

$$PM = \rho RT \tag{1.4}$$

Consequently,

$$\rho = \frac{PM}{RT} \tag{1.5}$$

The temperature and molar mass being constant with respect to time:

$$\frac{d\rho}{dt} = \frac{M}{RT}\frac{dP}{dt} \tag{1.6}$$

From the ideal gas law, we can see that $\frac{M}{RT} = \frac{\rho}{P}$. Finally, we can write:

$$\frac{d\rho}{dt} = \frac{\rho}{P}\frac{dP}{dt} \tag{1.7}$$

BIBLIOGRAPHY

[1] M. M. EL-WAKIL, *Nuclear Heat Transport*, American Nuclear Society, 1993.