Problem 2.3 15 points:

You are tasked to design a multiphase flow experiment which will help develop a cooling/heating system for a laboratory on a Moon surface. The experiment is to be performed in Earth gravity ($g = 9.81\ m/s^2$) while the results to be used on Moon ($g_M = 1.62\ m/s^2$)

If the water/vapor coolant in the heat exchanger will operate at 240 kPa and saturation temperature on Moon, provide the fluid properties necessary for the corresponding Earth-based experiment to maintain the same dimensionless parameters (assume the bubble characteristic length ratio between Earth and Moon is $\mathrm{L_M} = 3\mathrm{L_E}$):

(a) Eo number (5 points)

(b) Mo number (5 points)

(c) Find a fluid and pressure/temperature conditions which will work for your experiment on Earth with the closest possible match of either (or both) of the dimensionless numbers. (5 points)

Solution:

(a) The heat exchanger will operate at 180 kPa on Mars and the corresponding water saturation temperature is (https://www.nist.gov/system/files/documents/srd/NISTIR5078-Tab1.pdf, https://srd.nist.gov/JPCRD/jpcrd231.pdf,):

$$T = 399.0\ K$$

Look into fluid property tables:

$$\rho_{\mathrm{fM}} = 938.19\ kg/m^3$$

$$\sigma_{\mathrm{M}} = 0.0539\ N/m$$

$$\mu_{\mathrm{M}} = 220.6\ \mu\mathrm{Pa \cdot s}$$

(i) To main the same Eo number on Earth and Mars

$$\mathrm{Eo} = \frac{\rho_{\mathrm{fE}} g_{\mathrm{E}} L_E^2}{\sigma_{\mathrm{E}}} = \frac{\rho_{\mathrm{fM}} g_{\mathrm{M}} L_M^2}{\sigma_{\mathrm{M}}}$$

Gravitational acceleration on Mars and on Earth are:

$$g_{\mathrm{M}} = 1.62\ m/s^2$$

$$g_E = 9.81\ m/s^2$$

and $L_M = 3L_E$, thus

$$\frac{\rho_{\mathrm{fE}} * 9.81}{\sigma_{\mathrm{E}}} = \frac{938.19 * 1.62 * 9}{0.0539} = 253781$$

$$\Longrightarrow \frac{\rho_{\mathrm{fE}}}{\sigma_{\mathrm{E}}} = 25896\ \mathrm{kg/N}m^2$$

(ii) To main the same Mo number on Earth and Mars

$$\mathrm{Mo} = \frac{\mathrm{g_E}\mu_{\mathrm{E}}^4}{\rho_{\mathrm{fE}}\sigma_{\mathrm{E}}^3} = \frac{\mathrm{g_M}\mu_{\mathrm{M}}^4}{\rho_{\mathrm{fM}}\sigma_{\mathrm{M}}^3}$$

$$\frac{9.81 * \mu_{\mathrm{E}}^4}{\rho_{\mathrm{fE}}\sigma_{\mathrm{E}}^3} = \frac{1.62 * (220.6 \times 10^{-6})^4}{939.19 * (0.0539)^3} = 1.406 \times 10^{-15}$$

$$\Longrightarrow \frac{\mu_{\mathrm{E}}^4}{\rho_{\mathrm{fE}}\sigma_{\mathrm{E}}^3} = 1.4274 \times 10^{-16} Ns^4/kgm^2$$

(c) Find fluids that work for the experiment on Earth

For example:

- To match Eo number:

  Use water at pressure 2.3MPa at saturated temperature 492.7K:

  ρ_{fE} =843.778 $\mathrm{kg/m^3}$, σ_{E}=0.033 N/m

$$\frac{\rho_{\mathrm{fE}}}{\sigma_{\mathrm{E}}} = 25569\ \mathrm{kg/N}m^2$$

  The relative error is: (25569-25728)/25728 = -0.61%, which is a very close match.

- To match the Mo number:

  Use mercury-ethanol at temperature 10 degree Celsius, pressure at 0.1MPa.

$$\frac{\mu_{\mathrm{E}}^4}{\rho_{\mathrm{fE}}\sigma_{\mathrm{E}}^3} = \frac{(0.124 \times 10^{-6} \times 13534)^4}{13534 \times (0.389)^3} = 9.967 \times 10^{-15}\ Ns^4/kgm^2$$

  The error is: $(9.967 \times 10^{-15} - 7.5465 * 10^{-15})/\ 7.5465 * 10^{-15} = 32\%$ not close enough, but could be considered.