

22.313 - Homework on channel instability in heated laminar helium flow

One of the major challenges of gas cooled fast reactors is removal of the decay heat from the core after a large loss of coolant accident. One of the Generation IV concepts with helium coolant uses a passive decay heat removal system, which employs a water-cooled heat exchanger above the low-pressure drop core enclosed in a guard containment, as shown in Figure 1. In case of loss of coolant from the primary system, an equilibrium pressure between the primary system and the containment is reached and natural circulation of helium at the backup containment pressure ensues. However, in this situation the helium velocity in the core channels is small, resulting in laminar flow and core temperatures are high, in excess of 1000°C.

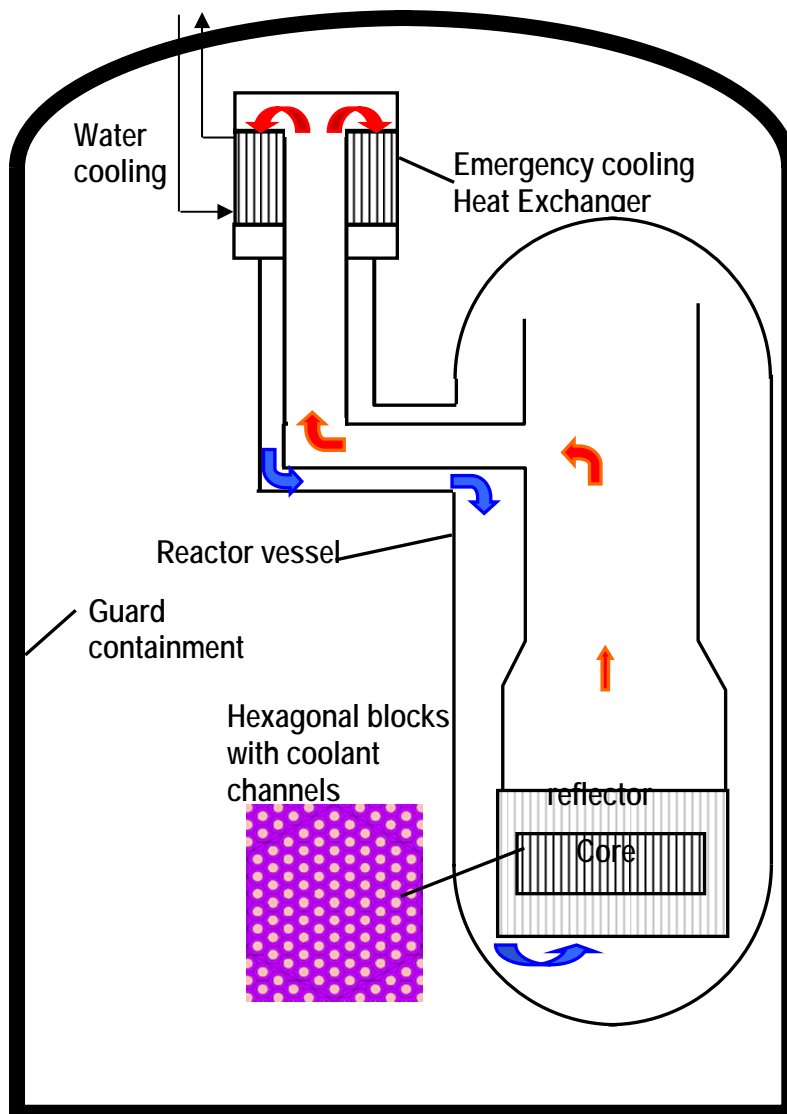


Figure 1 Schematic of passive decay heat removal

Computer code simulations predicted that, once the helium core outlet temperature exceeds 1200°C, the channels start to overheat rapidly. The designer suspects that

Ledinegg type-instabilities may be at work. Your task is to perform an analysis of the flow in one core channel and confirm his hypothesis.

Assume a helium cooled channel of constant flow area heated by uniform heat flux, as shown in Figure 2. The channel inlet and outlet parameters are denoted by the subscripts 'in' and 'out', respectively, and subscript-less properties denote the values at the channel midplane. Channel average temperature (bulk) is defined as $T=(T_{in}+T_{out})/2$ and the channel-average properties are functions of this temperature as well as the system pressure. Since helium is an ideal gas with constant specific heat and the channel is heated by uniform heat flux, the use of channel average properties to characterize the channel flow should provide good results and allow significant analysis simplification. Neglect acceleration and form loss (inlet and outlet) pressure drops.

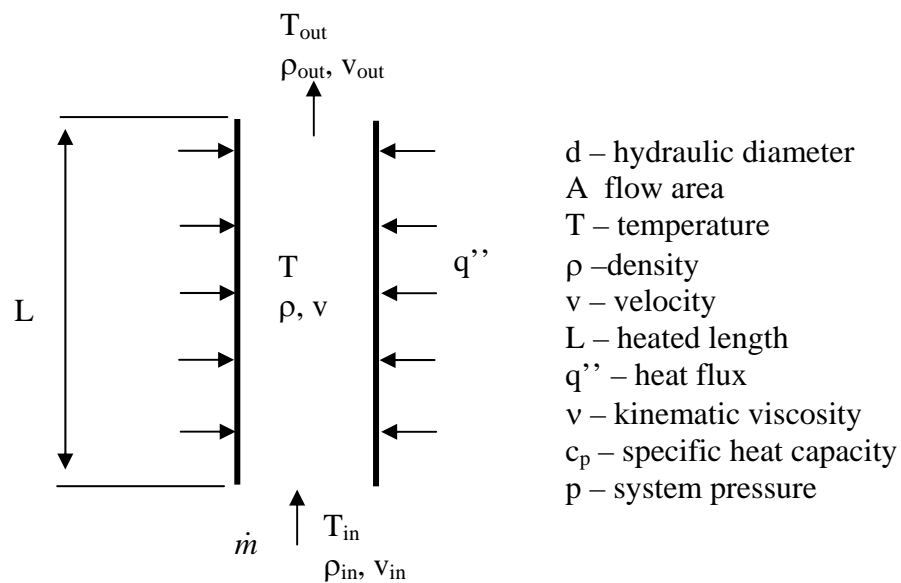


Figure 2 Schematic of heated channel with nomenclature

Both density and kinematic viscosity are strong functions of temperature. Density can be easily expressed using the ideal gas approximation, which holds almost perfectly for helium, i.e.,

$$\rho = \frac{p}{r(T + 273)}$$

where r is the ratio of universal gas constant $R=8314\text{J/kmol-K}$ and molecular weight, M . Kinematic viscosity (dynamic viscosity divided by density) is increasing with temperature according to the relation:

$$\nu = K_1 + K_2 T^m$$

where the coefficients and the exponent are given in Table 1. Table 1 also lists the channel geometry and other parameters important for the analysis.

Table 1 Parameters used for analysis

Parameter	Nomenclature (unit)	Value
First viscosity coefficient	K_1	1.70E-05
Second viscosity coefficient	K_2	6.614E-09
Viscosity exponent	M	1.5
Hydraulic diameter	D (m)	0.0122
Channel flow are	A (m ²)	1.16899E-04
Channel heated length	L (m)	1.34
Specific heat capacity	c_p (J/kg-K)	5192
Channel gas inlet temperature	Ti (°C)	127
Channel total power	Q (W)	564.95
System pressure	P (Pa)	0.693E6
Molecular weight	M (g/gmol)	4.00E+00

Tasks:

1. Plot a graph of channel pressure drop versus mass flow rate
2. Derive analytically the channel outlet temperature at which the flow becomes unstable and compare your results with the graph
3. Discuss the reasons for this instability in one-phase gas flow (is it not strange that such instability occurs in the absence of two-phase flow?)