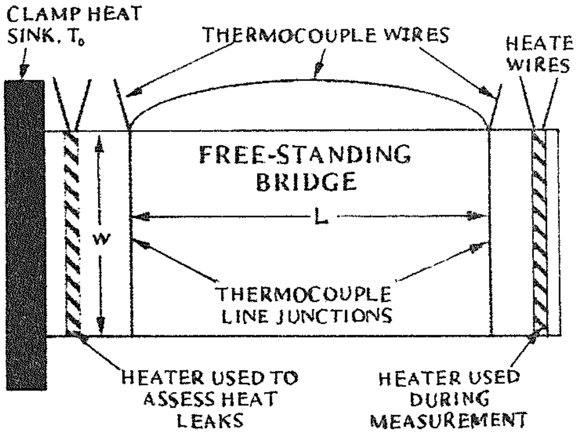
1. Terminology (15%)

   Please write the equations of the following physical laws and give the description of parameters listed in the equations:

   (a) Fourier Law of Heat Conduction
   (b) Newton's Law of Cooling
   (c) Stefan-Boltzmann Law in blackbody thermal radiation.
   (d) Kirchhoff's Law in thermal radiation
   (e) Wien's Displacement Law in blackbody thermal radiation

2. (15%) An experimental apparatus for measuring thermal conductivity of test piece is shown in the following figure. At the steady state, the current and voltage provided to the heater are 4A and 20V, respectively. The surrounding of test piece is completely adiabatic. The cross-sectional area and length of test piece are 20cm X 20 cm and 20cm, respectively. One thermocouple is installed at the interface of test piece and heater and the other is installed at the interface of test piece and heat sink, shown as the thermocouple wires in the figure. The EMF values of right-hand side thermocouple and left-hand side thermocouple are 0.6mV and 0.3mV, respectively. The measured EMP values of both thermocouples at ice point and boiling point of water at 1 atmosphere are 0.0mV and 1.0mV. Please assume that the EMF value and the temperature are linearly dependent.，Please determine the thermal conductivity of test piece (Free-Standing Bridge). The unit of thermal conductivity is W/m·K。



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3. (20%) Please find the surface temperature and mean air temperature at the exit of a circular pipe with D = 0.1 m, ε/D = 0.01, and L = 1m. The air flow in the circular pipe is assumed thermally and hydraulically fully developed at the inlet with $T_{\mathrm{inlet}} = 20\ {}^0\mathrm{C}$ and V = 15.16 m/s. The uniform heat flux is applied to the tube surface with a value of 1310W/ m^2. Please apply the following values for the physical properties of air at one atmosphere: Pr = 0.71, density = 1.2041 kg/m^3,ν = 1.516x10^{-5} kg/m·s and k = 0.02514W/m·K. The following equations are used to determine the heat transfer coefficient of turbulent flow in a circular pipe. The definition of Reynolds number and Nusselt number listed below:

$$\mathrm{Re} = \frac{VD}{\upsilon}$$

$$Nu = \frac{hD}{k}$$

$$\frac{1}{\sqrt{f}} \cong -1.8 \log\left[\frac{6.9}{\mathrm{Re}} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right]$$

$$\mathrm{Nu} = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$$

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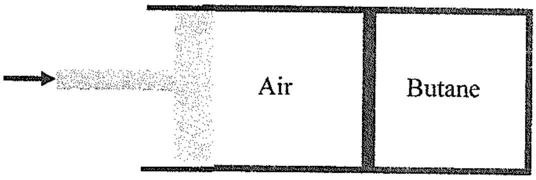
4. Terminology (12%)
   Please write the definition of the following laws or terms:
   (a) First law of thermodynamics
   (b) Second law of thermodynamics
   (c) Entropy
   (d) Exergy

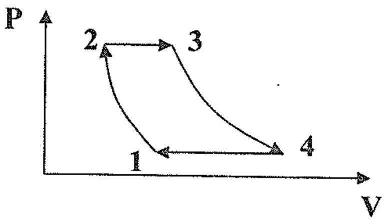
5. (20%) There are two chambers filled with air and butane in an insulated cylinder as shown in the figure below. The plate that separates the two chambers is rigid which means it does not move. Both chambers remain at the same temperature due to the heat transfer through the rigid plate. A piston is used to compress the air from the left side. Initially air is at 500 kPa, 200 °C with volume of 0.01 m^3 and butane is at 1500 kPa, 200 °C with the volume of 0.01 m^3. Air is compressed reversibly such that the temperature of the gases is raised to 225°C. Determine: (1) final pressure of both gases; (2) heat transferred between the chambers; (3) the work performed on air. All heat losses to the surroundings can be neglected. Assume air and butane to be ideal gases with constant specific heats. Air: C_{va}= 0.718 kJ/kg-K, R_a= 0.287 kJ/kg-K (gas constant). Butane: C_{vb}= 1.573 kJ/kg-K, R_b= 0.143 kJ/kg-K (gas constant).



6. (18%) A cycle consists of two iso-pressure process connected by two reversible adiabatic processes as shown in the figure below. Show that the thermal efficiency of a reversible heat engine operating on such an air-standard cycle with constant specific heats is

$$\eta = 1 - \left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} \quad \text{where } k=C_p/C_v\,.$$

Explain and justify each step of your calculation.



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