1. Work (W) and Heat (Q)

(1) Use Heat Engines, Heat Pumps, and Refrigerators, to explain First Law and Second Law of Thermodynamics, and to express the thermal efficiency (η_{th})and the coefficient of performance (COP) for the Heat Engine, Heat Pump, Refrigerator, Carnot Cycle, and Reversed Carnot Cycle. (7%)

(2) Explain why an electric heater of 80% efficiency is costing more per kWh to perform heating than a gas heater of only 40% efficiency. (Costs of electricity and natural gas are $10/kWh and $50/therm, 1 therm≡30kWh) (6%)

(3) Use P-v diagram to explain why a steam power plant has a much lower back work ratio ($W_{compressor}$ / $W_{turbine}$) than a gas tubine power plant. (7%)

2. Gas Power Cycles

(1) Use T-s diagram to explain ideal Otto, Diesel, Carnot, Stirling, Ericsson, and Brayton cycles. (6%)

(2) Derive the following thermal efficiency for ideal Brayton cycle:

$$\eta_{th,\ Brayton} = 1 - [1/(PR^{(k-1)/k})]$$

where PR is the compressor pressure ratio, P_2/P_1, and k is the specific heat ratio. And write down your assumptions. (7%)

(3) Use T-s diagram to explain how the gas turbine cycle with inter-cooling, reheating, and regeneration to approach the Ericsson cycle. (7%)

3. Dynamic Similarity

A capillary tube has an 8-mm inside diameter through which liquid fluorine refrigerant R-11 ($\rho_r = 1480\ \text{kg/m}^3$ and $\mu_r = 4.2\times10^{-4}\ \text{N}\cdot\text{s/m}^2$) flows at a rate of $0.03\ \text{cm}^3/\text{s}$. The tube is to be used as a throttling device in an air conditioning unit. A model of this flow is constructed by using a pipe of 3 cm inside diameter and water as the fluid medium ($\rho_w = 1000\ \text{kg/m}^3$ and $\mu_w = 8.9\times10^{-4}\ \text{N}\cdot\text{s/m}^2$).

Please answer the following questions.

(i) What is the required velocity in the model for dynamic similarity? (10%)

(ii) When dynamic similarity is reached, the pressure drop in the model is measured as 50 Pa. What is the corresponding pressure drop in the capillary tube? (10%)

4. Laminar Flow

A wide moving belt passes through a container of a viscous liquid. The belt moves vertically upward with a constant velocity, V_0. Because of viscous forces, the belt picks up a film of fluid of thickness h. Gravity tends to make the fluid drain down the belt. Assume the flow is laminar and steady and is fully developed in the vertical direction.

(i) Use the Navier-Stokes equations to determine an expression for the velocity distribution of the fluid film as it dragged up the belt. (10%)

(ii) Determine the minimum V_0 so that there will be a net upward flow of liquid. (10%)

5. Laminar Flow

A pair of circular discs of radius R encloses a thin layer of liquid between their parallel faces, the thickness $h(t)$ of this layer decreasing with time at a constant speed v, i.e., $dh/dt = -v$. The liquid is expelled radially outward at a speed V_r that varies with radius r and t, but not with axial distance. The liquid pressure at the exit radius R is atmosphere pressure P_a. Assuming an incompressible flow, derive expressions for (i) the radial velocity V_r, (6%) (ii) the pressure P (6%) and (iii) the force F that must be applied to each disc to maintain the given motion. (8%)