State your own assumptions and explanations if necessary

1. A counter-flow double-pipe heat exchanger is to heat water from 30 °C to 90 °C at a rate of 1.2 kg/s. The heating is to be accomplished by heating liquid at 160 °C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 15 mm. If the overall heat transfer coefficient is 640 W/m^{2}K, c_p of water is 4.2 KJ/ kg K, c_p of heating liquid is 5 kJ/kg K, please determine:
   (a) (10%) The heat transfer rate of the heat exchanger
   (b) (10%) The outlet temperature of the heating liquid
   (c) (10%) The logarithmic mean temperature difference (the ratio of difference of the temperature difference between the two streams at end A and end B over [ln(temperature difference between the two streams at end A)- ln(temperature difference between the two streams at end B)]
   (d) (10%) The length of the heat exchanger

2. One of versions of the Navier-Stokes equations are as follows.

$$\rho\frac{Du}{Dt}=\rho g_x-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x}\right)-\frac{2}{3}\nabla\cdot\vec{V}\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]$$

$$\rho\frac{Dv}{Dt}=\rho g_y-\frac{\partial p}{\partial y}+\frac{\partial}{\partial y}\left[\mu\left(2\frac{\partial v}{\partial y}\right)-\frac{2}{3}\nabla\cdot\vec{V}\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right]$$

$$\rho\frac{Dw}{Dt}=\rho g_z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial z}\left[\mu\left(2\frac{\partial w}{\partial z}\right)-\frac{2}{3}\nabla\cdot\vec{V}\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]$$

   Please answer questions or go on simplification based on the given conditions.
   (a) (10%) What is the definition and meaning of D/Dt?
   (b) (10%) In this flow, is it compressible? Why or why not?
   (c) (10%) Simplify the equations if steady
   (d) (10%) Simplify the equations if steady and inviscid.
   (e) (10%) Simplify the equations if steady, inviscid, and 2D flow (x-y coordinately only).

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3. (10%) A steel rod with an initial carbon concentration 0.2% by weight is to be hardened. An equilibrium concentration of carbon in iron at the phase interface of 1.5%. Calculate the time required for the location 1mm below the surface to have a carbon mass concentration of 0.8%. The diffusion coefficient of carbon in steel at the process temperature is 5.6×10^{-10} m^2/s.

Hints: The similarity variable for this problem is $\frac{x}{\sqrt{4Dt}}$, and the erfc(x)= 1- erf(x)

z	*erf*(*z*)	*z*	*erf*(*z*)	*z*
0	0	0.55	0.5633	1.3
0.025	0.0282	0.60	0.6039	1.4
0.05	0.0564	0.65	0.6420	1.5
0.10	0.1125	0.70	0.6778	1.6
0.15	0.1680	0.75	0.7112	1.7
0.20	0.2227	0.80	0.7421	1.8
0.25	0.2763	0.85	0.7707	1.9
0.30	0.3286	0.90	0.7970	2.0

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