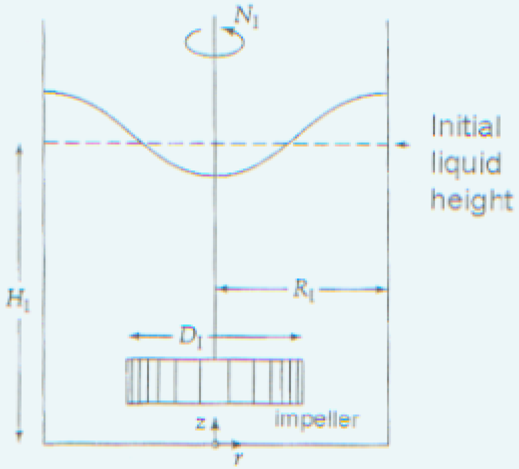
1. Please state definitions and the physical significances of following terms
(a) Newton's law of viscosity and Newtonian fluid (5%)
(b) Fick's first law and second law of diffusion (5%)
(c) Thermal boundary layer (5%)
(d) Fixed bed and Fluidized bed (5%)

2. **Scale-up of an agitated tank.** (20%) Experiments with a small-scale agitated tank shown below are to be used to design a geometrically similar installation with linear dimensions 10 times as large. The fluid in the large tank will be a heavy oil with $\mu$=0.198 poise and $\rho$=0.95 g/cm$^3$. The large tank is to have an impeller speed of 100 rpm. (a) Determine the impeller speed for the small-scale model, in accordance with the criteria (i) geometrically similar (same values of R/D and H/D, same impeller geometry and location) (ii) operated at the same values of Reynolds and Froude numbers (required equations shown below) (b) Determine the operating temperature for the model if water is to be used as the stirred fluid. [1 poise (g/cm· s) = 100 centipoise (cp)]




$$\frac{D_I N_I^2}{g_I} = \frac{D_{II} N_{II}^2}{g_{II}}$$

$$\frac{D_I^2 N_I}{\nu_I} = \frac{D_{II}^2 N_{II}}{\nu_{II}}$$

g : gravity
ν: Kinematic viscosity
N: impeller speed (rpm)

| Temperature T (°C) | Water (liq.)[a] Viscosity $\mu$ (mPa · s) | Water (liq.)[a] Kinematic viscosity $\nu$ (cm$^2$/s) | Air[b] Viscosity $\mu$ (mPa · s) | Air[b] Kinematic viscosity $\nu$ (cm$^2$/s) |
|---|---|---|---|---|
| 0 | 1.787 | 0.01787 | 0.01716 | 0.1327 |
| 20 | 1.0019 | 0.010037 | 0.01813 | 0.1505 |
| 40 | 0.6530 | 0.006581 | 0.01908 | 0.1692 |
| 60 | 0.4665 | 0.004744 | 0.01999 | 0.1886 |
| 80 | 0.3548 | 0.003651 | 0.02087 | 0.2088 |
| 100 | 0.2821 | 0.002944 | 0.02173 | 0.2298 |

**3.** In semiconductor industry, one of the main challenges for building a device is accurate control of the placement of the active doping region. Understanding and controlling diffusion and annealing behavior are extremely important to obtain desired electrical characteristics. Please design a boron diffusion process (create the well of a CMOS process, shown in Fig. 1), where the final surface concentration of boron is $4\times10^{17}$ cm$^{-3}$, final bottom concentration of boron is $1\times10^{15}$ cm$^{-3}$, and the depth of the well is 3 μm.

(a) Show the governing equation and boundary conditions. (10%)

(b) Calculate the initial dose concentration and drive-in time when annealed at 1100°C. (10%)

Hint:

- The diffusion coefficients of boron in silicon has the form $D = D^0 \exp\left(\frac{-E_A}{KT}\right)$, where $D^0$ is 1.0 cm$^2$sec$^{-1}$, $E_A$ is 3.5 eV, and K is $8.63\times10^{-5}$ eV/K.
- Take the Gaussian solution of a plane source as basis; derive the solution near a surface shown in Fig. 2. ( Consider one dimensional diffusion for this problem)

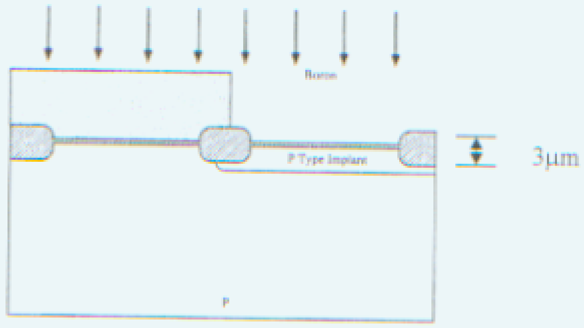



Fig. 1 Doping process.

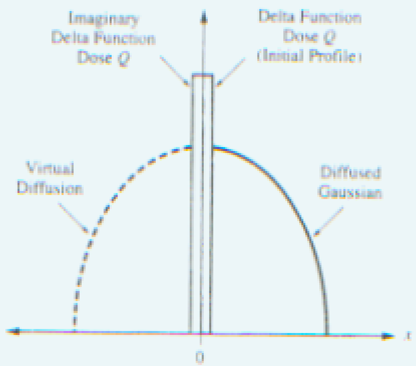



Fig. 2 Gaussian solution for a plane source.

4. Steam condenses on the outer surface of a 50-mm diameter and 5-m long thin-walled tube, shown in Fig. 3. The surface of the tube maintains a uniform temperature of 100 °C. Water flows through the tube at a rate of $\dot{m} = 0.25$ kg/s, and its inlet temperature is $T_{m,i} = 15$ °C. The average convection coefficient associated with the water flow is $\bar{h} = 750$ W/m$^2$ K. ($C_p$=4178 J/kg K for water at 36°C)

(a) Please write down the energy balance equation for this problem. (10%)

(b) What is the outlet temperature of inner flow water? (10 %)

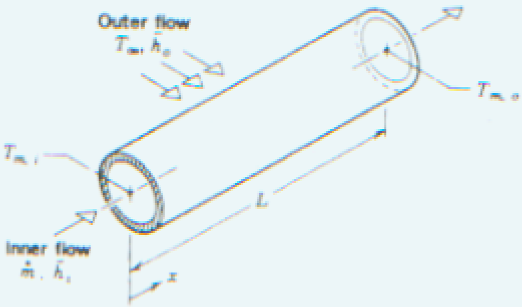



Fig. 3: Heat transfer between fluid flowing over and passing through the tube.

**5. Cyclone separator.** (20%)

(a) Sketch a cyclone separator and briefly explain it.

(b) Air carrying particles of density 2483 kg/m$^3$ and an average diameter of 20 μm enters a cyclone at a linear velocity of 18 m/s. The diameter of the cyclone is 356 mm. What is the approximate separation factor for this cyclone? [Separation factor: centrifugal force/ force of gravity (Fc/Fg)] and what fraction of the particles (10, 20 μm) will be removed from the gas stream? [ lb$_m$/ft$^3$ ≈ 16.02 kg/m$^3$ ]