1) Given,

$P_1 = 3.5$ bar $\quad P_b = 1$ bar

$T_1 = 405°C = 678$ K $\quad \dot{m} = 18$ kg/s

$C_d = 0.99$, $\eta_N = 0.94$, $V_1 = 0$ m s^{-1}, $\gamma = 1.33$

$C_p = 1.113$ kJ/k kg

Now,

$$C_d = \frac{\dot{m}}{\dot{m}_{is}} \Rightarrow \dot{m}_{is} = \frac{1}{\frac{0.99}{18}} = 18.182 \text{ kgs}^{-1}$$

$$v_1 = \frac{RT_1}{P_1} = \frac{276 \times 678}{3.5 \times 10^5} = 0.53 \text{ m}^3/\text{kg}$$

$$\frac{P_2}{P_1} = \frac{1}{3.5} = 0.286$$

$$\frac{P^*}{P_1} = \left(\frac{2}{n+1}\right)^{n/n-1} = \left(\frac{2}{2.33}\right)^{\frac{1.33}{0.33}} = 0.54$$

$$\Rightarrow P^* = 1.89 > P_b$$

$\therefore$ Ma = 1 at the throat

and $P_t = P^*$ at throat

$$\frac{\dot{m}_{is}}{A_t} = \sqrt{\frac{2n}{n-1}\frac{P_1}{v_1}\left[\left(\frac{P_t}{P_1}\right)^{2/n} - \left(\frac{P_t}{P_1}\right)^{n+1/n}\right]\eta_N}$$

$$\frac{18.182}{A_t} = 529.95$$

$$\Rightarrow A_t = 0.034 \text{ m}^2$$

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For exit area

$$\frac{\dot{m}_s}{A_{ex}} = \sqrt{\frac{2n}{n-1}\frac{P_1}{v_1}\left[\left(\frac{P_b}{P_1}\right)^{2/n} - \left(\frac{P_b}{P_1}\right)^{n+1/n}\right]\eta_N}$$

$$\Rightarrow \frac{18.182}{A_{ex}} = 450.96 \Rightarrow A_{ex} = 0.04\ m^2$$

Given,

$P_1 = 7$ bar, $T_1 = 473$ K, $P_b = P_2 = 3$ bar

$\dot{m} = 0.1$ kg/s

$v_1 = 0.3\ m^3/kg$, $s_1 = 6.887$ kJ/k kg $= s_2$, $h_1 = 2844.77$ k

$P_2 = 3$ bar

$s_g = 6.99$ kJ/k kg, $s_{fg} = 5.319$ kJ/k kg, $s_f = 1.671$ kJ/k kg

$$s_2 = s_f + x s_{fg}$$

$$\Rightarrow 6.887 = 1.671 + x(5.319)$$

$$x = 0.98$$

$$\Rightarrow h_2 = h_f + x h_{fg} = 561.16 + 0.98 \times 2163.47$$

$$= 2681.36\ \text{kJ/k kg}$$

$T_2 = T_{sat}$ @ 3 bar

$= 133.54°C = 406.54$ K

$$v_2 = v_f + x v_{fg} = 0.001073 + 0.98 \times 0.6046$$

$$= 0.5936\ m^3/kg$$

$$V_2 = \sqrt{2(h_1 - h_2)} = \sqrt{2(2844.77 - 2681.36) \times 10^3}$$

$V_2 = 371.68 \text{ m s}^{-1}$

$\dot{m} = \frac{A_2 V_2}{v_2} \Rightarrow A_2 = \frac{0.1 \times 0.3736}{371.68} = 1.0056 \times 10^{-4} \text{ m}^2$

) Supersaturated

$pv^{1.3} = \text{constant}$

$p_1 v_1^{1.3} = p_2 v_2^{1.3}$

$\Rightarrow v_2 = 0.376 \text{ m}^3/\text{kg}$

$$\frac{\dot{m}}{A_2} = \sqrt{\frac{2n}{n-1}\left(\frac{p_1}{v_1}\right)\left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{n+1/n}\right]}$$

$\Rightarrow \frac{0.1}{A_2} = 987.83$

$\Rightarrow A_2 = 1.012 \times 10^{-4} \text{ m}^2$

Now,

$\left(\frac{p_1}{p_2}\right)^{\gamma-1/\gamma} = \frac{T_1}{T_2}$

$\Rightarrow T_2 = 388.99 \text{ K}$

degree of undercooling $= 406.54 - 388.98$
$= 17.55 \text{ K}$

P_{sat} @ $388.98 \text{ K} = 1.75$ bar

degree of supersaturation $= \frac{3}{1.75} = 1.71$

) $A_t = \pi/4 \times (0.05)^2$
$= 1.96 \times 10^{-5} \text{ m}^2$

$P_1 = 10$ bar $\quad P_2 = 1.5$ bar

$v_1 = 0.1945 \text{ m}^3/\text{kg}$

$\frac{p^*}{p_1} = \left(\frac{2}{n+1}\right)^{n/n-1} = \left(\frac{2}{2.135}\right)^{\frac{1.135}{0.135}} = 0.577$

$\Rightarrow$ $P^* = 5.77 > P_2$

$\Rightarrow$ nozzle is choked at throat

$$\frac{\dot{m}}{A_t} = \sqrt{\frac{2n}{n-1}\frac{P_1}{v_1}\left[\left(\frac{P^*}{P_1}\right)^{2/n} - \left(\frac{P^*}{P_1}\right)^{n+1/n}\right]}$$

$$\Rightarrow \frac{\dot{m}}{1.96\times10^{-5}} = 1441.19 \Rightarrow \dot{m} = 0.028\ kg\,s^{-1}$$

Now, $\eta_N = 0.9$

$$\frac{\dot{m}}{A_2} = \sqrt{\frac{2n}{n-1}\frac{P_1}{v_1}\left[\left(P_2/P_1\right)^{2/n} - \left(P_2/P_1\right)^{n+1/n}\right]} \times 0.9$$

$$\frac{0.028}{A_2} = 745.2$$

$$\Rightarrow A_2 = 3.757\times10^{-5}\ m^2$$

$$\Rightarrow \frac{\pi d^2}{4} = 3.757\times10^{-5}$$

$$\boxed{d = 0.69\ cm}$$

$C_1 = 1000\ ms^{-1}$, $\alpha_1 = 20^\circ$, $U = 400\ ms^{-1}$

$\beta_1 = \beta_2$

$$\omega_1^2 = C_1^2 + U_1^2 - 2C_1U\cos 20^\circ$$

$$\omega_1^2 = 408245.903$$

$$\Rightarrow \omega_1 = 638.94\ ms^{-1}$$

$$\omega_1 \sin\beta_1 = C_1 \sin\alpha_1$$

$\sin\beta_1 = 0.535$, $\beta_1 = 32.34^\circ$

$\Rightarrow \beta_2 = \beta_1 = 32.34°$

a) Neglecting friction effects, $w_2 = w_1 = 638.94\ m s^{-1}$

$\Delta c_\theta = \Delta w_\theta = w_1 \cos\beta_1 + w_2 \cos\beta_2$

$= 2 w_1 \cos\beta_1 = 2 \times 638.94 \times \cos 32.34$

$\Delta c_\theta = 1079.67\ m s^{-1}$

Tangential force $= \dot{m} \Delta c_\theta = 0.75 \times 1079.67$

$= 809.75\ N$

$P = \dot{m} U \Delta c_\theta$

$P = 809.75 \times 400 = 323.89\ kW$

$\Delta c_z = 0$ ($\because$ symmetric blades)

$\Rightarrow$ axial thrust $= 0$

$$\eta_b = \frac{U \Delta c_\theta}{c_1^2/2} = \frac{400 \times 1079.67}{1000^2/2} = 86.37\%$$

b) $k = 0.8$

$w_2 = k w_1 = 511.15\ m s^{-1}$

$\Delta c_\theta = \Delta w_\theta = w_1 \cos\beta_1 + w_2 \cos\beta_2$

$= (638.94 + 511.15) \cos 32.34$

$\Delta c_\theta = 971.69\ m s^{-1}$

$P = \dot{m} U \Delta c_\theta = 291.51\ kW$

$\therefore F_z = \dot{m} \Delta c_z$

$= 0.75 \times (w_1 \sin\beta_1 - w_2 \sin\beta_2)$

$F_z = 51.07\ N$

$$\eta_b = \frac{U \Delta c_\theta}{c_1^2/2} = \frac{400 \times 971.69}{1000^2/2} = 77.74\%$$