MODULE III

STEAM NOZZLES PROBLEMS

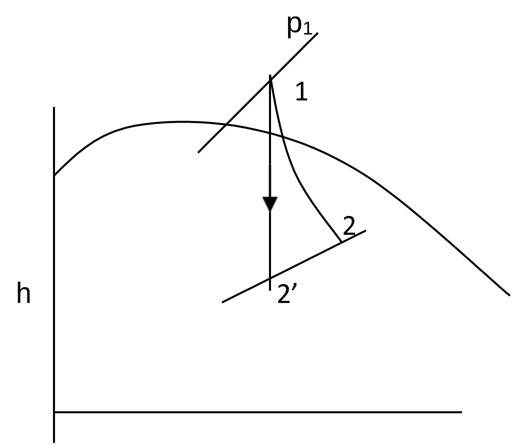
1. **A set of 16 nozzles for an impulse turbine receives steam at 16 bar, 300°C. The pressure of steam at exit is 10 bar. If the total discharge is 245 kg/min and nozzles efficiency is 90 %, find the cross sectional area of the exit of each nozzle. If the steam has a velocity of 100 m/s at entry to the nozzles, find the % increase in discharge.**

<u>Given</u>

Type	= Con
Number of nozzles	= 16
Inlet pressure (p_1)	= 16 bar
Inlet temperature (T_1)	= 300°C
Exit pressure (p_2)	= 10 bar
Mass flow rate (m)	= 245 kg/min = 4.083 kg/s

<u>Required:</u> A_2/nozzle if $V_1 = 0$, % increases in discharge if $V_1 = 100$ m/s

<u>Solution</u>



$$m = A_2V_2 / v_2$$

$$(V_2^2 - V_1^2) = h_1 - h_2$$

From chart, $h_1 = 3035$ kJ/kg

$h_{2'} = 2925$ kJ/kg

$v_{2'} = 0.22$ m³/kg

$$\text{Nozzle efficiency } (\eta_n) = \frac{h_1 - h_3}{h_1 - h_{3'}}$$

$$\therefore 0.9 = \frac{h_1 - h_2}{3035 - 2925}$$

$\therefore \quad h_1 - h_2 = 99$ kJ/kg

$V_2^2/2 = 99 \times 10^3$

$V_2 = 444.97$ m/s

$\therefore \quad 4.083 = A_2 \times 444.97 / 0.22$

$A_2 = 0.0020186 \text{ m}^2$

$\therefore \quad A_2/\text{noz} = 0.0020186 / 16 =$ **1.2616×10^{-4} m^2 --------- Ans**

$(V_2^{\ 2} - V_1^{\ 2}) / 2 = h_1 - h_2$

$(V_2^{\ 2} - 100^2) / 2 = 99 \times 10^3$

$V_2 = 456.07$ m/s

$m = A_2 V_2 / v_2$

$= 0.0020186 \times 456.07 / 0.22$

$= 4.1846$ kg/s

$\therefore$ % increase in mass flow rate $= \dfrac{4.1846 - 4.083}{4.083} \times 100$ **= 2.49 % --- Ans**

2. Steam enters a nozzle in a dry saturated condition and expands from a pressure of 2 bar to a pressure of 1 bar. It is observed that supersaturated flowis taking place and the steam flow reverts to a normal flow at 1 bar. What is thedegree of under-cooling, degree of super saturation, increase in entropy and loss in the available heat drop due to irreversibility?

<u>Given</u>

Inlet pressure (p_1) = 2 bar, Dry
Outlet pressure (p_2) = 1 bar
Flow = Supersaturated

<u>Required:</u> ($T_2 - T_{2'}$), ($p_2/p_{2'}$), (Δs), Loss in availability

<u>Solution</u>

Degree of undercooling $= T_2 - T_{2'}$

$T_2 = 99.63^oC$ from steam table at $p_2 = 1$ bar

<u>To find $T_{2'}$</u>

$$T_{2'}/T_1 = [p_2/p_1]^{(n-1)/n}$$

$T_1 = 120.2^oC$ from steam table at p_1

$\therefore \quad T_{2'}/(120.2 + 273) = [1 / 2]^{(1.3-1)/1.3}$

$T_{2'} = 335.07 \text{ K} = 62.07^oC$

$\therefore$ Degree of undercooling = 99.63 – 62.07 = **37.56^{o}C --------------Ans**

Degree of super saturation $= p_2 / p_{2'}$

$p_{2'} = 0.21838$ bar from steam table at $T_{2'} = 60.07^oC$

$\therefore$ Degree of super saturation = 1 / 0.21838 **= 4.579----------- Ans**

Loss in availability= $(h_1 – h_2)_{chart} – (h_1 – h_2)_{equ}$

3. In an installation 5 kg/s of steam at 35 bar and 350^{o}C is supplied to group of 6 nozzles in a wheel chamber maintained at 5 bar. (a) Determine the dimensions of the nozzles of rectangular cross sectional area with aspect ratio 3: 1. The expansion may be considered metastable and friction is neglected. (b) Also calculate, (i) degree of undercooling and super saturation (ii) loss in available

From chart, $h_1 = 2710$ kJ/kg

$h_2 = 2590$ kJ/kg

$\therefore \quad (h_1 – h_2)_{chart} = 2710 – 2590 = 120$ kJ/kg

$(h_1 – h_2)_{equ} = n / (n – 1)\ p_1 v_1 [1 – (p_2/p_1)^{(n – 1)/n}]$

$v_1 = 0.87$ m^3/kg from chart

$\therefore \quad (h_1 – h_2)_{equ} = 1.3 / (1.3 – 1) \times 2 \times 10^5 \times 0.87 \times [1 – (1/2)^{(1.3 – 1)/1.3}]$

$= 111456$ J/kg $= 111.5$ kJ/kg

$\therefore$ Loss = 120 – 111.5 = **8.5 kJ/kg ----------- Ans**

Increase in entropy $=$ Loss / T_2

= 8.5 / (99.63 + 273) = **0.02281 kJ/kgK --------- Ans**

4. Steam is supplied to a group of 4 nozzles at 18 bar and 250^{o}C. It is expanded down to 4 bar and friction loss may be neglected. If the expansion is metastable, calculate for a flow of 2.5 kg/s, the exit dimensions of nozzles if they are rectangular in shape and have length to breath ratio of 3: 1. What is the degree of undercooling and degree of super saturation? heat drop due to irreversibility (iii) increase in entropy and (iv) ratio of mass flow rate with metastable expansion to that if expansion in thermal equilibrium.

Given

No of nozzles	= 4
Inlet pressure (p_1)	= 18 bar
Inlet temperature (T_1)	= 250^{o}C
Exit pressure (p_2)	= 4 bar
Mass flow rate (m)	= 2.5 kg/s
l : b	= 3 : 1
Flow	= Supersaturated

Required: l_2, b_2, $(T_2 – T_{2'})$, $p_2/p_{2'}$

Solution

Mass flow rate (m) $= A_2V_{2'} / v_{2'}$

To find $v_{2'}$

Degree of supersaturation = $p_2 / p_{2'}$

$p_{2'}$ = 2.29327 bar from steam table at $T_{2'}$ = 124.6^{o}C

∴ Degree of supersaturation = 5/ 2.29327 **= 2.1803 ----------- Ans**

(ii) Loss in availability $= (h_1 – h_2)_{chart} – (h_1 – h_2)_{equ}$

From chart, h_1 = 3105 kJ/kg

h_2 = 2690 kJ/kg

∴ $(h_1 – h_2)_{chart}$ = 3105 – 2690 = 415 kJ/kg

$(h_1 – h_2)_{equ}$ = 411.5131 kJ/kg

∴ Loss = 415 – 411.5131 = **3.4869 kJ/kg ------------Ans**

(iii) Increase in entropy = Loss / T_2

= 3.4869 / (151.8 + 273) = **0.008208 kJ/kgK----------Ans**

(iv) Let m_t = Mass flow rate in thermal equilibrium flow

m_m = Mass flow rate in metastable flow

m_m = 5 kg/s (given in problem)

To find m_t

$m_t = A_2V_2 / v_2$

$V_2^2/2 = (h_1 – h_2)_{chart}$

∴ $V_2^2 / 2 = (3105 – 2690) \times 10^3$

$V_2 = 911.04$ m/s

$v_2 = 0.4$ m^3/kg from chart at $p_2 = 5$ bar

$m_t = 0.00184634 \times 911.04 / 0.4 = 4.205$ kg/s

$\therefore$ $m_m / m_t = 5 / 4.205$ **= 1.19 --- Ans**

5. In an installation 5 kg/s of steam at 35 bar and 350°C is supplied to group of 6 nozzles in a wheel chamber maintained at 5 bar. (a) Determine the dimensions of the nozzles of rectangular cross sectional area with aspect ratio 3 : 1. The expansion may be considered metastable and friction is neglected. (b) Also calculate, (i) degree of undercooling and super saturation (ii) loss in available Heat drop due to irreversibility (iii) increase in entropy and (iv) ratio o mass flow rate with metastable expansion to that if expansion in thermal equilibrium.

Given

Given

No of nozzles	= 6
Inlet pressure (p_1)	= 35 bar
Inlet temperature (T_1)	= 350°C
Exit pressure (p_2)	= 5 bar
Mass flow rate (m)	= 5 kg/s
l : b	= 3 : 1
Flow	= Supersaturated

Required: (a) l_2, b_2, (b)(i) $(T_2 - T_{2'})$, $p_2/p_{2'}$ (ii) Loss (iii) Inc. in entropy (iv) m_t / m_m

Solution

(a) Mass flow rate (m_m) $= A_2V_{2'} / v_{2'}$

To find $v_{2'}$

(b) To find $v_{2'}$

$$v_{2'} / v_1 = (p_1/p_2)^{1/n}$$

$v_1 = 0.075$ m^3/kg from chart

n = 1.3 for supersaturated flow

$$\therefore \quad v_{2'} / 0.075 = (35/5)^{1.3}$$

$$v_{2'} = 0.335 \text{ m}^3/\text{kg}$$

To find $V_{2'}$

$$V_{2'}/2 = (h_1 - h_2)_{equ}$$

$$(h_1 - h_2)_{equ} = n / (n - 1)\, p_1\, v_1\, [1 - (p_2/p_1)^{(n-1)/n}]$$

$$= 1.3 / (1.3 - 1) \times 35 \times 10^5 \times 0.075 \times [1 - (5/35)^{(1.3-1)/1.3}]$$

$3a \times a = 3a^2 = 0.000307723$

∴ a **= 0.0101279 m ------- Ans**

and Length = 3a 3 x 0.010129 = **0.30384 m ----------Ans**

(c) (i) Degree of undercooling = $T_2 - T_{2'}$

$T_2 = 151.8^oC$ from steam table at $p_2 = 5$ bar

<u>find $T_{2'}$</u>

$T_{2'}/T_1 = [p_2/p_1]^{(n-1)/n}$

∴ $T_{2'}/(350 + 273) = [5 / 35]^{(1.3-1)/1.3}$

$T_{2'} = 379.6 \text{ K} = 124.6^oC$

∴ Degree of undercooling = 151.8 – 124.6 **= 27.2^{o}C--------------Ans**

Degree of super saturation = $p_2 / p_{2'}$

$p_{2'} = 2.29327$ bar from steam table at $T_{2'} = 124.6^oC$

∴ Degree of super saturation = 5/ 2.29327 **= 2.1803----------- Ans**

(v) Loss in availability = $(h_1 - h_2)_{chart} - (h_1 - h_2)_{equ}$

From chart, $h_1 = 3105$ kJ/kg

$h_2 = 2690$ kJ/kg

∴ $(h_1 - h_2)_{chart} = 3105 - 2690 = 415$

kJ/kg$(h_1 - h_2)_{equ}$ = 411.5131 kJ/kg

∴ Loss = 415 – 411.5131 = **3.4869 kJ/kg ------------Ans**

(vi) Increase in entropy = Loss / T_2

= 3.4869 / (151.8 + 273) = **0.008208 kJ/kgK----------Ans**

(vii) Let m_t = Mass flow rate in thermal

equilibrium flowm_m = Mass flow rate in

metastable flow

m_m = 5 kg/s (given in problem)

To find m_t

$$m_t = A_2V_2 / v_2$$

$$V_2^2/2 = (h_1 - h_2)_{chart}$$

$$\therefore \quad V_2^2 / 2 = (3105 - 2690) \times 10^3$$

$$V_2 = 911.04 \text{ m/s}$$

$v_2 = 0.4$ m^3/kg from chart at $p_2 = 5$ bar

$$m_t = 0.00184634 \times 911.04 / 0.4 = 4.205 \text{ kg/s}$$

$\therefore \quad m_m / m_t = 5 / 4.205$ **= 1.19 --- Ans**