# Department of Mechanical Engineering, PEC University of Technology

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| **Subject:** Applied Thermodynamics (MEN-209) | **Instructor:** Prof. Ankit Yadav |
| **Assignment Topic:** Nozzle and Diffuser | **Semester:** 16172 |
| **Due date: 23 March 2017** | |

| Q.No. | Question |
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| **1** | Dry steam at 10 bar and 100 m/s enters a nozzle and leaves it with velocity of 300 m/s at 5 bar. For 16 kg/s of steam mass flow rate determine heat drop in nozzle and final state of steam leaving nozzle assuming heat loss to surroundings as 10 kJ/kg. |
| **Answer** | Heat drop in nozzle = 30 kJ/kg Total heat drop = 480 kJ/s Dryness fraction at exit = 0.99 |
| **2** | Determine the mass flow rate of steam through a nozzle having isentropic flow through it. Steam enters nozzle at 10 bar, 500 $^0$C and leaves at 6 bar. Cross-section area at exit of nozzle is 20 cm2. Velocity of steam entering nozzle may be considered negligible. Show the process on h-s diagram also. |
| **Answer** | Mass flow rate = 2.202 kg/s |
| **3** | In a nozzle steam expands from 12 bar and 300 $^0$C to 6 bar with flow rate of 5 kg/s. Determine throat and exit area if exit velocity is 500 m/s and velocity at inlet to nozzle is negligible. Also find coefficient of velocity at exit. Coefficient of velocity is the ratio of actual velocity of fluid at nozzle exit to the velocity at exit considering isentropic flow through nozzle. |
| **Answer** | Cross-sectional area at throat = 3.209 x10–3 m2 Cross-sectional area at exit = 3.647 x10–3 m2 Coefficient of velocity = 0.875 |
| **4** | In a steam nozzle steam expands from 16 bar to 5 bar with initial temperature of 300 $^0$C and mass flow of 1 kg/s. Determine the throat and exit areas considering (i) expansion to be frictionless and, (ii) friction loss of 10% throughout the nozzle. |
| **Answer** | (i) For frictionless expansion, Throat area = 4.78 cm2 Exit area = 5.41 cm2 (ii) Actual throat area = 5.11 cm2 Actual area at exit, = 5.875 cm2 |
| **5** | An impulse turbine of 1 MW has steam entering at 20 bar and 300 $^0$C and steam consumption of 8 kg per kW hour. Steam leaves at 0.2 bar and 10% of total heat drop is lost in overcoming friction in diverging portion of nozzle. If throat diameter of each nozzle is 1 cm then determine (i) the number of nozzles required (ii) exit diameter of each nozzle. Solve using mollier diagram. |
| **Answer** | Number of nozzles required = 11 Area at exit = 12.5 cm2 |
| **6** | A nozzle is supplied with steam at 0.7 MPa and 275 $^0$C. Determine temperature and velocity at throat considering no losses. If diverging portion of nozzle is 6 cm long and throat diameter of 0.5 cm, determine the angle of cone in nozzle so that steam leaves nozzle at 0.1 MPa. Assume heat utilization in diverging portion to be 85%. Solve using mollier diagram. |
| **Answer** | With no losses, Temperature at throat = 203 Velocity at throat = 525.35 m/s With losses, Cone angle = 1.72 |
| **7** | An impulse steam turbine generating 5000 hp requires 6 kg of steam per hp-hr at 16 bar, dry saturated. In the first stage the steam is expanded through nozzle with an efficiency of 0.90 to a pressure of 8 bar. These nozzles are placed so as to extend over approximately 1/3 rd of the circumference with the pitch circle diameter of 600 mm and pitch of 50 mm. Considering nozzle angle as $12^0$ to the plane of wheel and plates dividing being 3 mm thick, determine total length of nozzle arc and radial height of nozzles. |
| **Answer** | Length of nozzle = 65 cm Radial height of nozzle = 4.08 cm |
| **8** | Air is expanded reversibly and adiabatically in a nozzle from 13 bar and 150 $^0$C to a pressure |

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| | of 6 bar. The inlet velocity of the nozzle is very small and the process occurs under steady flow conditions. Calculate the exit velocity of the nozzle. |
| **Answer** | Exit Velocity = 12.98 m/s |
| **9** | During a test on steam nozzle steam impinges a stationary flat plate which is perpendicular to the direction of flow and the force on the plate is measured. The force is found to be 350 N when dry saturated steam at 8 bar is expanded to 1 bar. Throat cross-section area is 5 $cm^2$ and exit area is such that the complete expansion is achieved under these conditions. Determine (i) the discharge at throat. (ii) the efficiency of nozzle assuming that all the losses occur after throat and that n = 1.13 for isentropic expansion. |
| **Answer** | Discharge at throat = 0.521 kg/s Nozzle efficiency = 55.37% |
| **10** | A convergent-divergent nozzle operates with 5 kg of steam per minute being discharged at 1 bar. For the steam supplied to nozzle being at 10 bar and 200 $^0$C and supersaturation occurring up to throat and normal afterwards, determine, (i) the diameter of nozzle at exit. (ii) the maximum degree of supersaturation. (iii) the amount of undercooling at throat.<br>For supersaturation take $Pv^{1.3}$ = constant and $\frac{P}{T^{\frac{1.3}{0.3}}} = Constant$ |
| **Answer** | Diameter of nozzle at exit = 1.33 cm Degree of supersaturation = 1.58 Amount of undercooling = 16.94 C |
| **11** | Steam undergoes expansion from 4 bar, 180 $^0$C to a pressure of 1.5 bar. If the expansion is supersaturated and occurs with friction loss of 5 percent, determine the actual heat drop and degree of undercooling. Following equations may be used for supersaturated steam,<br>P.v $*10^2$ = (h – 2614),<br>(Here P is in bar, v is specific volume in m3/kg, h is enthalpy in kJ/kg)<br>$\frac{P}{T^{\frac{1.3}{0.3}}} = Constant$<br>and $P.v^{1.3}$ = constant<br>Consider specific heat as 2.174 kJ/kgK. |
| **Answer** | Actual heat drop = 39.16 kJ/kg Degree of undercooling = 22.18 C |
| **12** | Steam is supplied at 14 bar, 400 $^0$C to set of 16 nozzles of impulse turbine. Pressure of steam at exit of nozzle is 10 bar and the discharge is 5 kg/s. Nozzle efficiency is 90%. Determine the crosssectional area at exit of each nozzle. Also determine the percentage increase in discharge if steam is supplied to nozzle with velocity of 100 m/s. |
| **Answer** | Cross-sectional area at exit of nozzle, = 2.13 cm2 % Increase in discharge = 4.4% |
| **13** | In a nozzle the steam enters at 20 bar, dry saturated and expands up to 5 bar. Considering the expansion to be frictionless throughout and steam remaining in dry state during expansion upto throat, determine the degree of supersaturation and degree of undercooling. Also determine the change of entropy, the loss due to undercooling and percentage loss if steam has to revert instantaneously to saturated state at constant enthalpy and if the further expansion takes place in thermal equilibrium. |
| **Answer** | Degree of supersaturation = 2.13 Degree of undercooling = 31.29C Entropy change = 0.2075 kJ/kgK Loss due to undercooling = 88.55 kJ/kg Percentage loss = 34.68% |
| **14** | A steam injector delivers 150 kg of water per minute from a water tank where the constant water level of 5 m below the axis of injector is maintained. Injector injects into the boiler having steam at 20 bar. Water level in boiler is 0.8 m above the injector. Steam for injector is taken from boiler and has dryness fraction of 0.95. Water is supplied at 25 $^0$C and velocity in delivery pipe is 20 m/s.<br>Determine, (i) the mass of water pumped per kg of steam (ii) the diameter of throat of mixing nozzle (iii) the diameter of the steam nozzle considering pressure at throat to be 0.7 times of supply pressure. (iv) the temperature of water coming out of injector. |
| **Answer** | Mass of water pumped per kg of steam = 3.98 kg Diameter of throat of mixing nozzle = 0.783 |

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| | cm Diameter of throat of steam nozzle = 1.69 cm Temperature of water coming out of injector = 148.92C |
| **15** | A steam injector is used for maintaining supply of the feed water to boiler producing steam at 20 bar. The pressure of exhaust steam for operating injector is 1.5 bar and dryness fraction is 0.9. The mass of water taken from feed water tank is 5000 kg/hr and temperature is 17 $^{0}$C. Determine the mass of water that can be pumped per kg of steam, area of steam and water discharge orifices. Delivery pressure may be assumed to be 20% more than boiler pressure so as to overcome frictional losses and positive delivery. Neglect change in elevation. |
| **Answer** | Mass of water pumped per kg of steam = 4.56 kg water/kg of steam Area of steam nozzle = 13.68 cm2 Area of discharge orifice = 0.244 cm2 |