higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

7 December 2023
09:00–12:00

REQUIREMENTS: **Properties of water and steam (BOE 173)**
Superheated steam tables (appendix to BOE 173)

Drawing instruments and nonprogrammable calculators may be used

This question paper consists of 6 pages and a formula sheet of 6 pages.

307Q1G2307

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DEPARTMENT OF HIGHER EDUCATION AND TRAINING
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NATIONAL CERTIFICATE
POWER MACHINES N6
TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer any FIVE questions.
2. Read all the questions carefully before attempting to answer them.
3. Number the answers according to the numbering system used in this question paper.
4. Start each question on a new page.
5. Use only a black or blue pen.
6. Write neatly and legibly.
7. Give all numerical answers correct to THREE decimal places.

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QUESTION 1

Air with a gas constant of 0,296 kJ/kg.K is compressed in a three-stage, single-acting reciprocating compressor from a pressure of 0,1 MPa and a temperature of 290 Kelvins. The compressor runs non-stop during an eight-hour shift with ideal intercooling for maximum efficiency and delivers air at 1,6 MPa. The low-pressure stage receives 19,025 kilograms of air per minute into a cylinder whose clearance volume is 0,0546 of its swept volume. The law of compression and expansion is $pv^{1,288} = c$.

Giving all answers correct to THREE decimal places, calculate:

1.1 The compressor pressure ratio and pressure in each intercooler (5)

1.2 The low-pressure cylinder volumetric efficiency and the induced volume in cubic metres per shift (6)

1.3 The compressor indicated power in kilowatts (4)

1.4 Sketch a labelled pressure-volume diagram for the compressor indicating at least THREE pressure values. (5)

[20]

QUESTION 2

Dry saturated steam enters a convergent-divergent nozzle at 1 100 kPa at a rate of 0,75 kilograms per second. At the throat and exit, steam pressure is 640 kPa and 270 kPa respectively. Due to enthalpy drop, steam is 2,18% wet at the throat and 6,27% wet at the exit.

Using steam tables and giving all answers correct to THREE decimal places, calculate:

2.1 The specific enthalpy at the nozzle throat and exit (5)

2.2 The velocity of steam at the nozzle throat and exit in m/s (5)

2.3 The specific volume of steam at the nozzle throat and exit (5)

2.4 The area in square millimetres at the throat and exit (5)

[20]

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QUESTION 3

3.1 Indicate whether the following statement is TRUE or FALSE by writing only 'True' or 'False' next to the question number (3.1) in the ANSWER BOOK.

A wind turbine is not strong enough to drive a generator for electricity generation. (2)

3.2 In a two-stage, velocity-compounded impulse turbine, the inlet relative angle in both moving-blade stages is 25°. Steam enters the stationary blades at an angle of 36° and leaves the turbine axially with a velocity of 216 kilometres an hour. Across all the blading, the velocity coefficient is 0,9182. The turbine shaft with the mean radius of 605 mm runs with a speed of 1 650 revolutions a minute.

Using a scale of 1 mm = 3 m/s; construct the velocity diagrams and indicate all the lengths in mm and angles in degrees. (11)

Using the diagrams from Question 3.2; determine:

3.2.1 The nozzle angle and the turbine specific work output (4)

3.2.2 The turbine diagram efficiency (3)

[20]

QUESTION 4

4.1 What is the property of steam called that stays unchanged during a reversible adiabatic process? (2)

4.2 The following data were recorded in a coal-fired steam power plant:

Economiser inlet and exit temperature	81,4 °C and 149,5 °C
Air pre-heater inlet and exit temperature	12,67 °C and 129,13 °C
Fuel heat content	36,3 MJ/kg
Superheater exit temperature	300 °C
Evaporator-exit steam dryness fraction	0,867
Air specific heat capacity	1,02 kJ/kg.K
Air-fuel ratio	18,95:1
Steam pressure and rate of generation	3 MPa and 11,37 kg/kg of fuel

Use steam tables and determine:

4.2.1 The heat-transfer in the air pre-heater per kilogram of fuel and express it as a percentage of the plant supply energy (4)

4.2.2 The heat-transfer in the economiser per kilogram of fuel and express it as a percentage of the plant supply energy (4)

4.2.3 The evaporator equivalent evaporation at 100 °C per kilogram of fuel (6)

4.2.4 The plant thermal efficiency (4)

[20]

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QUESTION 5

5.1 Explain the difference between *indicated power* and *brake power* in internal-combustion engines. (3)

5.2 A two-stroke, six-cylinder internal combustion engine running at 375,08 revolutions a minute has a clearance volume of 410 cm^3 and indicated mean effective pressure of 0,755 MPa. After expansion, the pressure is 0,39 MPa, and combustion stops 21,6 mm away from the top dead centre. The index of compression and expansion is 1,33 while the piston diameter and stroke length are 178,43 mm and 257,01 mm respectively.

Assuming that the engine is working on the diesel cycle principle, determine:

5.2.1 The swept volume and cylinder volume in each cylinder in cm^3 (5)

5.2.2 The indicated power of the engine in kilowatts (3)

5.2.3 The pressure at the end and start of compression in kilopascals (9)

[20]

QUESTION 6

A refrigerant flows at 4,36 kilograms a minute around a plant which operates between 235 kPa and 940 kPa. The refrigerant with superheated heat capacity of 4,211 kJ/kg.K enters the compressor 97,6% dry and enters the condenser with a temperature of 56,96 °C. The refrigerant exits the condenser as a saturated liquid without undercooling but is throttled before it enters the evaporator. The table below shows other properties of the refrigerant:

Pressure (kPa)	Saturation temperature (°C)	Enthalpy (kJ/kg)		Entropy (kJ/kg.K)	
		h_f	h_g	s_f	s_g
235	-16	113	1426	0,46	5,5
940	24	285	1470	-	-

Based on the above data, answer the following questions.

6.1 Sketch a labelled pressure-enthalpy diagram and indicate any TWO enthalpy values. (5)

6.2 Calculate the specific enthalpy at the compressor inlet and exit. (5)

6.3 Determine the specific enthalpy, dryness fraction and specific entropy at the evaporator inlet. (6)

6.4 Calculate the work done by the compressor in kilowatts. (4)

[20]

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QUESTION 7

7.1 In relation to thermodynamic cycles, explain the difference between *gross heat addition* and *nett heat addition.* (3)

7.2 A dual-combustion cycle has a minimum and maximum temperatures of 17 °C and 2 000 °C. The minimum and maximum pressures in the cycle are 100 kPa and 7 000 kPa. The compression ratio is 18:1. The air flowing in the cycle at a rate of 2 kg/s has a constant-volume heat capacity of 0,718 kJ/kg.K. The adiabatic index is 1,4.

Calculate each of the following:

7.2.1 The temperature and pressure at the end of adiabatic compression (4)

7.2.2 The temperature at the start of constant-pressure heat addition (3)

7.2.3 The temperature at the end of expansion (5)

7.2.4 The constant-volume heat addition and heat rejection in kJ/s (5)

[20]

TOTAL: 100

POWER MACHINES N6

FORMULAE SHEET

Note: This formulae sheet may not necessarily be complete.

Any formulae used by candidates that do not appear on this list must be written in full in the ANSWER BOOK.

$$P_a V_a = mRT_a$$

$$R = Cp - Cv$$

$$\gamma = \frac{Cp}{Cv}$$

$$\mathrm{PV} = \mathrm{c}$$

$$\mathrm{PV}^{\mathrm{n}} = \mathrm{c}$$

$$\mathrm{PV}^{\gamma} = \mathrm{c}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\Delta U = m \,.\, Cv \,.\, \Delta T$$

$$Q = \Delta U + Wd$$

$$\Delta s = m\left(Cv \,.\, \ln\frac{P_2}{P_1} + Cp \,.\, \ln\frac{V_2}{V_1}\right)$$

$$\Delta s = m \,.\, Cv \,.\, \ln\frac{P_2}{P_1}$$

$$\Delta s = m \,.\, Cp \,.\, \ln\frac{V_2}{V_1}$$

$$\Delta s = m \,.\, R \,.\, \ln\frac{P_1}{P_2}$$

$$Q = m \,.\, Cp \,.\, \Delta T$$

$$Q = m \,.\, Cv \,.\, \Delta T$$

$$S_{su} = S_g + Cp \,.\, \ln\frac{T_{su}}{T_s}$$

$$S_{fg} = S_g - S_f$$

$$S = S_f + xS_{fg}$$

$$h_{su} = h_g + Cp\ (t_{su - t_s})$$

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$$h_{ws} = h_f + xh_{fg}$$

$$V_{ws} = xV_g$$

$$V_{su} = \frac{\frac{n-1}{n}(h_{su} - 1941)}{P_{su}}$$

$$r = \frac{V_s + V_c}{V_c}$$

$$V_s = \frac{\pi}{4} d^2 \times L$$

$$P_2 = \sqrt{P_1 \times P_3}$$

$$r_{ps} = \sqrt[x]{\frac{P_{x+1}}{P_1}}$$

Different formulae for work done (Wd)

$$= P \times \Delta V$$

$$= P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$= m \,.\, Cp \,.\, \Delta T$$

$$= \frac{xn}{n-1} P_1 V_e \left[\left(\frac{P_{x+1}}{P_1} \right)^{\frac{n-1}{xn}} - 1 \right]$$

$$= \frac{xn}{n-1} mRT_1 \left[(r_{ps})^{\frac{n-1}{n}} - 1 \right]$$

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Different formulae for work done (Wd)

= area of PV-diagram

= work done first stage + work done second stage + ...

...

$Wd_{nett} = Wd_t - Wd_c$

$Wd_{nett} = Q_{nett}$

Different formulae for air standard efficiencies (ASE)

$$= 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

$$= 1 - \frac{r_p r_c^{\gamma - 1}}{r_v^{\gamma - 1}[(r_p - 1) + \gamma^{r_p}\ (r_c - 1)]}$$

$$= \frac{heat\ added - heat\ rejected}{heat\ added} = 1 - \frac{\beta^{\gamma} - 1}{r^{\gamma - 1} \times \gamma\ (\beta - 1)} = \frac{warmte\ toegevoeg - warmte\ afgestaan}{warmte\ toegevoeg}$$

Different volumetric efficiencies, η_{vol}

$$= \frac{Volume\ of\ \ air\ taken\ in}{Swept\ \ volume}$$

$$= \frac{Volume\ of\ \ free\ air}{Swept\ \ volume}$$

$$= 1 - \frac{V_c}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$$

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Different thermal efficiencies, $0_{therm.}$

$$= \frac{Wd}{heat\ supplied}$$

$$\eta_{braketherm.} = \frac{BP}{m_{f/s} \times CV}$$

$$\eta_{ind.\,therm.} = \frac{IP}{m_{f/s} \times CV}$$

$$\eta_{therm.} = \frac{m_s\ (hs - hw)}{m_f \times CV}$$

$$\eta_c = \frac{T_2^{'} - T_1}{T_2 - T_1} \qquad \eta_t = \frac{T_3 - T_4}{T_3 - T_4^{'}}$$

$$\eta_{mech.} = \frac{BP}{IP}$$

Indicated efficiency ratio

$$= \frac{\eta_{ind.\,therm.}}{ASE}$$

Brake efficiency ratio

$$= \frac{\eta_{braketherm.}}{ASE}$$

$$BP = 2\pi \frac{TN}{60} \qquad T = F \times r$$

$$BP = P_{brakemean}\ LANE$$

$$IP = P_{ind.\,mean}\ LANE$$

$$ISFC = \frac{m_{f/h}}{IP}$$

$$BSFC = \frac{m_{f/h}}{BP}$$

$$COP = \frac{T_1}{T_2 - T_1}$$

$$COP = \frac{RE}{Wd}$$

$$P = m\,.\,U\,.\,\Delta Vw$$

$$F_{ax} = m\,.\,\Delta V_f$$

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$$\eta_{dia.} = \frac{2 \,.\, U \,.\, \Delta Vw}{V_1^2}$$

$$P_c = P_1\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

$$T_c = T_1\left(\frac{2}{\gamma + 1}\right)$$

$$C_c = \sqrt{2 \times 10^3 \ (h_1 - h_c) + C_1^2}$$

$$C_2 = \sqrt{2 \times 10^3 \ (h_1 - h_2) + C_1^2}$$

$$C_c = \sqrt{2 \times 10^3 \times C_p \ (T_1 - T_c) + C_1^2}$$

$$C_2 = \sqrt{2 \times 10^3 \times C_p \ (T_1 - T_2) + C_1^2}$$

$$A_c = \frac{mV_c}{C_c} \qquad A_2 = \frac{mV_2}{C_2}$$

$$\eta = \frac{h_1 - h_c}{h_1 - h_c^{'}} \qquad \eta = \frac{T_1 - T_c}{T_1 - T_c^{'}}$$

$$\eta = \frac{h_c - h_2}{h_c - h_2^{'}} \qquad \eta = \frac{T_c - T_2}{T_c - T_2^{'}}$$

$$\eta = \frac{h_1 - h_2}{h_1 - h_2^{'}} \qquad \eta = \frac{T_1 - T_2}{T_1 - T_2^{'}}$$

$$EE = \frac{m_s \ (h_s - h_w)}{m_f \times 2\,257}$$

$$\eta_{iso.} = \frac{Wd_{iso.}}{Wd_{poly.}}$$

$$\eta_{rank.} = \frac{Wd}{Q}$$

$$\eta_{carn.} = 1 - \frac{T_2}{T_1}$$

$$h = u + pV$$

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$$gZ_1 + U_1 + P_1V_1 + \frac{C_1^2}{2} + Q =$$

$$gZ_2 + U_2 + P_2V_2 + \frac{C_2^2}{2} + Wd$$

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