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NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

17 April 2020 (X-paper)
09:00–12:00

REQUIREMENTS: Properties of Water and Steam (BOE 173)
Superheated Steam Tables (appendix to BOE 173)

Nonprogrammable calculators may be used.

This question paper consists of 7 pages and a formula sheet of 5 pages.

303Q1A2017

DEPARTMENT OF HIGHER EDUCATION AND TRAINING
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE
POWER MACHINES N6
TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer all the questions.
2. Read all the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Answer questions in any order, but keep subsections of questions together.
5. All sketches and diagrams must be neat, fully labelled and drawn in pencil in the ANSWER BOOK.
6. Write down all formulae used.
7. Show all intermediate steps for calculations.
8. Approximate final answers correctly to THREE decimal places unless stated otherwise.
9. Use only a black or blue pen.
10. Write neatly and legibly.

QUESTION 1

A four-cylinder engine operating on the four-stroke diesel cycle principle has an indicated power of 60 kW at 1 500 r/min.

The indicated mean effective pressure is 720 kPa.

The temperature after compression is 700 °C.

The volumetric compression ratio is 14:1.

The fuel is cut off at 10% of the stroke length after T.D.C.

The heat lost through the cylinder walls during the expansion stroke is 176,824 kJ/kg of gas.

The temperature loss during the expansion stroke is 982,354 °C.

The stroke length is 1,228 times the diameter of the piston.

The compression index (n_c) is 1,4.

Assume C_v as 0,72 kJ/kg.°C and R as 0,288 kJ.kg.°C.

Calculate:

1.1 The piston diameter in mm (4)

1.2 The unknown volumes in cm^3 at all principal points of the cycle (5)

1.3 The unknown absolute temperatures at all principal points of the cycle (5)

1.4 The expansion index n_e (3)

1.5 The heat rejected in kJ/kg of gas (3)
[20]

QUESTION 2

Steam expands through a convergent-divergent nozzle at a rate of 275 kg/min to the exit where the isentropic dryness factor is 0,94 and the diameter is 69 mm.

The specific volume of dry saturated steam at the exit is 0,72 m³/kg.

At the inlet the superheated steam has a pressure of 2 000 kPa, a temperature of 300 °C and a negligible velocity.

At the throat the superheated steam has a pressure of 780 kPa, a velocity of 495 m/s, a specific heat capacity of 2,6 kJ/kg.K with an index (n) of 1,3.

The isentropic dryness factor is 98,94% of the actual dryness factor.

Calculate the following by using steam tables only:

2.1 At the throat:

2.1.1 The specific enthalpy of the steam (2)

2.1.2 The temperature of the steam (3)

2.1.3 The specific volume of the steam (2)

2.1.4 The area in mm² (2)

2.1.5 The diameter in mm (2)

2.2 At the exit:

2.2.1 The actual dryness factor of the steam (1)

2.2.2 The specific volume of the steam (2)

2.2.3 The area in mm² (2)

2.2.4 The velocity of the steam in m/s (2)

2.2.5 The specific actual enthalpy of the steam (2)

[20]

QUESTION 3

A five-stage, single-acting, reciprocating compressor induces 14,4 m³ of air per minute at 96 kPa and 25 °C and delivers this air at a pressure of 31 MPa.

The index (n) for compression is 1,3.

Intercooling is perfect and the stage pressures are in a geometric sequence.

Assume R for air as 0,287 kJ/kg.K and C_p as 1,005 kJ/kg.K.

Calculate:

3.1 The power required to drive the motor if the mechanical efficiency is 89% (4)

3.2 The temperature ratio as well as the absolute temperature of the air exiting each stage (4)

3.3 The mass of air compressed in kg/min (2)

3.4 The heat transfer in the intercoolers in kJ/s (3)

3.5 The heat contained in the air leaving the compressor in kJ/s (1)

3.6 The heat transfer to the cooling water jackets in kJ/s (3)

3.7 The isothermal efficiency of the compressor (3)

[20]

QUESTION 4

An air preheater was installed in a boiler plant to improve the efficiency. During tests on the plant, the following data was recorded:

The mass of superheated steam generated increased from 9 kg/kg to 9,2 kg/kg fuel burned and the specific enthalpy of the steam generated increased by 9 kJ/kg.

The pressure of the flues at the chimney base remained unchanged at 150 kPa while the temperature at the chimney base decreased from 200 °C to 150 °C.

The boiler room temperature remained unchanged at 20 °C.

The air supplied decreased by 0,5 kg/kg fuel.

The mass of the combustion moisture formed remained unchanged at 0,58 kg/kg fuel.

The feed-water temperature remained unchanged at 95,2 °C.

The calorific value of the fuel remained unchanged at 30,46 MJ/kg. The fuel used contains 2% ash by mass.

The heat carried away by the dry flue gases before installing the air preheater was 3 762 kJ/kg fuel.

The plant efficiency before installing the air preheater was 78,004%.

The specific heat capacity of water was 4,2 kJ/kg.K and specific heat capacity of the dry flue gases was 1,045 kJ/kg.K.

Calculate the following by using steam tables only:

4.1 The heat lost to the moisture in the flue gases per kg fuel before installing the air preheater (4)

4.2 The heat lost to the moisture in the flue gases per kg fuel after installing the air preheater (4)

4.3 The mass of air used per kg fuel before installing the air preheater (3)

4.4 The heat carried away by the dry flue gases per kg fuel after installing the air preheater (3)

4.5 The specific enthalpy of the superheated steam before installing the air preheater (3)

4.6 The new plant efficiency after installing the air preheater (3)

[20]

QUESTION 5

The ammonia in a vapour-compression refrigerator leaves the compressor as a dry saturated vapour with a specific enthalpy of 482,1 kJ/kg.

The refrigerant enters the throttling valve as a saturated liquid with no undercooling.

The pressure in the evaporator is 136 kPa and at this pressure the latent heat of the refrigerant is 415,3 kJ/kg.

The flow rate of the ammonia is 0,125 kg/s.

At the evaporator entrance, the refrigerant is 19,119% dry and at the exit it is 96% dry.

The specific volume of the refrigerant at the compressor inlet is 0,2233 m^3/kg.

The condenser extracts 2 679,75 kJ of heat energy every minute.

The single-cylinder, single-acting compressor rotating at 120 r/min, has a volumetric efficiency of 94,79% and the stroke length is 1,2 times the piston diameter.

The cooling water flows at a rate of 32 kg/min with a specific heat capacity of 4,187 kJ/kg.K.

Calculate:

5.1 The specific enthalpy of the refrigerant at the exit of the condenser (2)

5.2 The specific enthalpy of the saturated liquid refrigerant at 136 kPa (2)

5.3 The specific enthalpy of the dry saturated vapour at 136 kPa (2)

5.4 The specific enthalpy of the wet vapour at the inlet to the compressor (2)

5.5 The refrigeration effect in kJ/min (3)

5.6 The volume of the vapour entering the compressor in m^3/min (3)

5.7 The diameter of the piston in mm (3)

5.8 The length of the stroke in mm (1)

5.9 The change in temperature of the cooling water (2)

[20]

TOTAL: 100

FORMULA SHEET

Any applicable formula may also be used.

$$P_a V_a = mRT_a$$

$$R = Cp - Cv$$

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

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

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

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

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

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

$$Q = \Delta U + Wd$$

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

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

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

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

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

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

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

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

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

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

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

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

$$V_{ws} = xV_g$$

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

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

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

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

Different formulae for work done (Wd)

$$= P \times \Delta V$$

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

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

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

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

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

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

= 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)

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

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

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

Different volumetric efficiencies, 0_{vol}

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

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

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

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

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

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

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

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

$$\eta_c=\frac{T_2^{'}-T_1}{T_2-T_1}$$

$$\eta_t=\frac{T_3\text{ - }T_4}{T_3\text{ - }T_4^{'}}$$

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

Indicated efficiency ratio $= \dfrac{\eta_{ind.\,therm.}}{ASE}$

Brake efficiency ratio $= \dfrac{\eta_{brake\,therm.}}{ASE}$

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

$BP = P_{brake\,mean}\,LANE$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

$$gZ_1 + U_1 + P_1V_1 + \frac{C_1^2}{2} + Q = gZ_2 + U_2 + P_2V_2 + \frac{C_2^2}{2} + Wd$$