higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1400(E)(N29)T

NATIONAL CERTIFICATE

# POWER MACHINES N6

(8190046)

**29 November 2018 (X-Paper)**
**09:00–12:00**

**REQUIREMENTS:** Properties of Water and Steam (BOE 173)
Superheated Steam Tables (appendix to BOE 173)
Candidates will require drawing instruments, pens, a pencil and a ruler.

**A nonprogrammable calculator may be used.**

**This question paper consists of 9 pages and 5 formula sheets.**

# DEPARTMENT OF HIGHER EDUCATION AND TRAINING
# REPUBLIC OF SOUTH AFRICA

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

---

**NOTE:** If you answer more than the required number of questions, only the required number will be marked. ALL work that you do not want to be marked must be clearly crossed out.

---

**INSTRUCTIONS AND INFORMATION**

1. Answer any FIVE of the seven questions.
2. Read ALL the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Questions may be answered in any order, however, subsections of questions MUST be kept together.
5. ALL sketches and diagrams must be neat, fully labelled and drawn in pencil in the ANSWER BOOK.
6. Write down ALL the formulae that you used.
7. Show ALL intermediate steps for calculations.
8. Questions must be answered in BLUE or BLACK ink only.
9. Final answers must be approximated correctly to THREE decimal places, unless stated otherwise.
10. Write neatly and legibly.

---

 

**Answer any FIVE of the seven questions in this question paper.**

## QUESTION 1

A vapour compression refrigerating plant uses methyl chloride as a refrigerant and operates at pressure limits of 289 kPa and 1 310 kPa.

At the entrance of the compressor the refrigerant is a wet vapour with a dryness factor of 0,984.

At the exit of the compressor the refrigerant has a temperature of 72 °C and an enthalpy of 1 610 kJ/kg.

The refrigerant is condensed but not undercooled.

The cooling water flows at a rate of 4 kg/s and its temperature rises by 16 °C.

The specific heat capacity of the cooling water is 4,2 kJ/kg.K.

The following is an extract of methyl chloride tables:

| PRESSURE (kPa) | SATURATION TEMPERATURE (°C) | SPECIFIC ENTHALPY | | SPECIFIC ENTROPY | |
|---|---|---|---|---|---|
| | | LIQUID ($h_f$) | VAPOUR ($h_g$) | LIQUID ($s_f$) | VAPOUR ($s_g$) |
| 289 | -8 | 144,5 | 1 435 | 0,578 | 5,449 |
| 1 310 | 32 | 332,9 | 1 470 | 1,235 | 4,962 |

Use the data given above to calculate the following quantities:

1.1 The specific enthalpy at the compressor entrance (3)

1.2 The actual coefficient of performance (3)

1.3 The specific entropy at the exit of the compressor (2)

1.4 The specific entropy at the entrance of the evaporator (3)

1.5 The dryness factor at the entrance of the evaporator (3)

1.6 The specific heat capacity of the superheated refrigerant (3)

1.7 The mass flow rate of the refrigerant in kg/s (3)

**[20]**

## QUESTION 2

A single-cylinder engine operating on the diesel cycle principle has a volumetric expansion ratio of 6,25:1 and a volumetric compression ratio of 15 : 1. The piston has a diameter of 89 mm and a stroke length of 90 mm. The compression index, $n_c$ is 1,32, while the expansion index, $n_e$ is 1,3. The temperature at the beginning of compression is 28 °C.

Assume $C_p$ for the gas as 1,005 kJ/kg.K and $C_v$ as 0,718 kJ/kg.K.

Calculate:

| | | |
|---|---|---|
| 2.1 | The swept volume in m³, correct to FIVE decimal places | (2) |
| 2.2 | The clearance volume in m³, correct to FIVE decimal places | (2) |
| 2.3 | The cylinder volume in m³, correct to FOUR decimal places | (1) |
| 2.4 | The volume after combustion in m³, correct to SIX decimal places | (1) |
| 2.5 | The missing absolute temperatures at ALL principal points | (4) |
| 2.6 | The heat received during combustion in kJ/kg gas | (1) |
| 2.7 | The heat rejected during exhaust in kJ/kg gas | (2) |
| 2.8 | The work done in kJ/kg gas | (4) |
| 2.9 | The heat transferred during expansion in kJ/kg gas | (3) |
| | | **[20]** |

**QUESTION 3**

A steam boiler plant produces superheated steam at a pressure of 2 MPa and a temperature of 350 °C from fuel with a calorific value of 32 MJ/kg fuel. The evaporator absorbs 19 586,91 kJ of heat per kg of fuel burned, while the economiser absorbs 2 352 kJ of heat per kg of fuel burned. The air-fuel ratio is 18:1 and the pressure of the flue gases at the chimney base is 100 kPa.

The atmospheric temperature is 20 °C, while the temperature at the chimney base is 200 °C. The mass of moisture formed in the flue gases is 0,6 kg/kg fuel burned.

The specific heat capacity of the flue gases is 1,045 kJ/kg.K, while the specific heat capacity of water is 4,2 kJ/kg.K.

The feedwater temperature into the economiser is 32,9 °C, and the thermal efficiency of the plant is 78,75%.

3.1 Make use of steam tables only, to calculate the following quantities:

3.1.1 The mass of steam generated in kg/kg fuel burnt (3)

3.1.2 The specific enthalpy of the feedwater entering the evaporator, and hence the feedwater temperature from the steam tables, in °C (3)

3.1.3 The dryness factor of the steam at the entrance to the superheater (4)

3.1.4 The heat lost to the dry flue gases in kJ/kg fuel burned (3)

3.1.5 The heat lost to the moisture in the flue gases in kJ/kg fuel burned (3)

3.2 Draw up a heat balance in kJ/kg fuel and also as a percentage, to determine the percentage of heat that is unaccounted for. (4)

**[20]**

**QUESTION 4**

A three-stage, single-acting, reciprocating compressor rotates at 516 r/min while delivering 583 cm³ of air per cycle to the aftercooler. The index for compression and expansion is both 1,32 and the pressure ratio for all stages is 3,6:1. The initial pressure and temperature for the low-pressure cylinder is 100 kPa and 26 °C respectively.

Intercooling is perfect for maximum efficiency and the clearance volume for the low-pressure cylinder is 4% of its swept volume.

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

Calculate:

4.1 The absolute delivery temperature (2)

4.2 The mass of air delivered in kg/s (3)

4.3 The power required to drive the compressor in kW (3)

4.4 The heat absorbed per intercooler in kJ/s (2)

4.5 The heat absorbed by the water jackets per stage in kJ/s (2)

4.6 For the low pressure-cylinder:

4.6.1 The effective swept volume in m³/cycle (2)

4.6.2 The clearance volume in m³/cycle, correct to SIX decimal places (3)

4.6.3 The swept volume in m³/cycle, correct to FOUR decimal places (1)

4.6.4 The cylinder volume in m³/cycle, correct to FIVE decimal places (2)

**[20]**

## QUESTION 5

The volumetric compression ratio for an engine operating on the dual cycle principle is 15:1.

Compression and expansion are both adiabatic and the initial conditions are 101,1 kPa and 27 °C respectively.

The temperature after expansion is 1,271 times the initial temperature and the total heat supplied during one cycle is 171,832 kJ/kg of gas.

Two-thirds of the total heat is supplied at constant volume and the rest is supplied at constant pressure. Take R for air as 0,287 kJ/kg.K and $C_v$ as 0,718 kJ/kg.K.

Calculate the following quantities:

5.1 The value of gamma (3)

5.2 The missing absolute temperatures at ALL principal points (8)

5.3 The missing pressures in kPa at ALL principal points (5)

5.4 The heat lost through the exhaust in kJ/kg gas (2)

5.5 The air standard efficiency (2)

**[20]**

**QUESTION 6**

A velocity compounded, two-stage, impulse gas turbine consists of two rows of moving blades with a row of fixed blades separating them. The inlet and outlet angles for the first row of moving blades are both 24°, while the inlet and outlet angles for the second row of moving blades are both 30°.

The exit angle of the fixed blades is 17° and the velocity coefficient of friction for ALL blades is 0,96.

Use the data above to answer the questions:

6.1 Use a length of 36 mm for the average blade velocity and construct velocity diagrams for the turbine in the ANSWER BOOK. Indicate the lengths of ALL the lines as well as the magnitude of ALL the angles on the diagrams. (9)

6.2 Calculate the scale, if the relative velocity at the outlet from the first stage is 575 m/s. (1)

6.3 Determine from the velocity diagrams:

6.3.1 The nozzle velocity in m/s (1)

6.3.2 The velocity at exit from the first stage in m/s (1)

6.3.3 The velocity at exit from the turbine in m/s (1)

6.3.4 The velocity at entrance to the second stage in m/s (1)

6.3.5 The relative velocity at inlet to the first stage in m/s (1)

6.3.6 The relative velocity at entrance to the second stage in m/s (1)

6.3.7 The relative velocity at exit from the second stage in m/s (1)

6.3.8 The angle at which the gas leaves the turbine (1)

6.3.9 The axial thrust developed in the turbine in N/kg (2)

**[20]**

**QUESTION 7**

Air exits a convergent-divergent nozzle at a pressure of 700 kPa with a velocity of 714,87 m/s and enters the nozzle at a pressure of 3 485 kPa and a temperature of 495 °C. The diameter at the throat of the nozzle is 67,151 mm and the overall efficiency of the nozzle is 90%.

Ignore the velocity of the air at the inlet to the nozzle. Assume gamma for air as 1,4.

Calculate the following quantities:

7.1 The absolute adiabatic temperature at the nozzle exit (2)

7.2 The absolute actual temperature at the nozzle exit (2)

7.3 The value of $C_p$ in kJ/kg.K (2)

7.4 The value of R in kJ/kg.K (3)

7.5 At the throat of the nozzle:

7.5.1 The pressure in kPa (2)

7.5.2 The absolute temperature (1)

7.5.3 The velocity in m/s (2)

7.5.4 The specific volume in m³/kg, correct to FOUR decimal places (2)

7.5.5 The area in mm² (1)

7.6 The rate at which the air flows through the nozzle in kg/s (2)

7.7 The Mach number of the nozzle (1)
**[20]**

**TOTAL : 100**

**FORMULA SHEET**

**NOTE:** This formula sheet may not necessarily be complete.

Any formulae utilised by candidates which do NOT appear on this list, must be written in full in the ANSWER BOOK.

| ENGLISH | GENERAL | AFRIKAANS |
| --- | --- | --- |
| | $P_a V_a = mRT_a$ | |
| | $R = C_p - C_v$ | |
| | $\gamma = \frac{C_p}{C_v}$ | |
| $PV = c$ | | $PV = k$ |
| $PV^n = c$ | | $PV^n = k$ |
| $PV^\gamma = c$ | | $PV^\gamma = k$ |
| | $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{(n-1)} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{n-1}{n}\right)}$ | |
| | $\Delta U = m.C_v.\Delta T$ | |
| $Q = \Delta U + Wd$ | | $Q = \Delta U + Av$ |
| | $\Delta s = m\left[C_v \,.\, \ln\left(\frac{P_2}{P_1}\right) + C_p \,.\, \ln\left(\frac{V_2}{V_1}\right)\right]$ | |
| | $\Delta s = m \,.\, C_v \,.\, \ln\left(\frac{P_2}{P_1}\right)$ | |
| | $\Delta s = m.C_p.\ln\left(\frac{V_2}{V_1}\right)$ | |
| | $\Delta s = m \,.\, R \,.\left(\frac{P_1}{P_2}\right)$ | |
| | $Q = m \,.\, C_p \,.\, \Delta T$ | |
| | $Q = m \,.\, C_v \,.\, \Delta T$ | |
| | $S_{su} = S_g + C_p.\ln\left(\frac{T_{su}}{T_s}\right)$ | |
| | $S_{fg} = S_g - S_f$ | |
| | $S = S_f + x \,.\, S_{fg}$ | |
| | $h_{su} = h_g + C_p \,.\, (t_{su} - t_s)$ | |
| | $T_a(s_a - s_b) = h_a - h_b$ | |

| ENGLISH | GENERAL | AFRIKAANS |
| --- | --- | --- |
| $h_{ws} = h_f + x.h_{fg}$ | $V_{su} = \dfrac{\frac{n-1}{n}(h_{su} - 1\,941)}{P_{su}}$ | $h_{ns} = h_f + x.h_{fg}$ |
| $V_{ws} = x.V_g$ | $r = \dfrac{V_s + V_c}{V_c}$ | $V_{ns} = x.V_g$ |
| | $V_s = \dfrac{\pi}{4} \times d^2 \times L$ | |
| | $P_2 = \sqrt{P_1 \times P_3}$ | |
| | $r_{ps} = \sqrt{\dfrac{P_{x+1}}{P_1}}$ | |

| Different formulae for work done (Wd) | | verskillende formules vir arbeid verrig (Av) |
| --- | --- | --- |
| | $= P \times \Delta V$ | |
| | $= P_1V_1.\ln\left(\dfrac{V_2}{V_1}\right)$ | |
| | $= \dfrac{P_1V_1 - P_2V_2}{n-1}$ | |
| | $= \dfrac{P_1V_1 - P_2V_2}{\gamma - 1}$ | |
| | $= m.C_p\,.\,\Delta T$ | |
| | $= \dfrac{xn}{n-1} \times P_1V_e\left[\left(\dfrac{P_{x+1}}{P_1}\right)^{\left(\frac{n-1}{xn}\right)} - 1\right]$ | |
| | $= \dfrac{xn}{n-1} \times mRtT_1\left[\left(r_{ps}\right)^{\left(\frac{n-1}{n}\right)} - 1\right]$ | |

| ENGLISH | GENERAL | AFRIKAANS |
|---|---|---|

Different formulae for work done (Wd)

= area of PV - diagram

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

$Wd_{nett} = Wd_t - Wd_c$

$Wd_{nett} = Q_{nett}$

Verskillende formules vir arbeid verrig (Av)

= area van PV - diagram

= arbeid verrig eerste stadium + arbeid verrig tweede stadium + ...

$Av_{nett} = Av_t - Av_k$

$Av_{nett} = Q_{nett}$

---

Different formulae for air standard efficiencies (ASE)

Verskillende formules vir lugstandaardrendemente (LSR)

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

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

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

---

Different volumetric efficiencies, $\eta_{vol}$

Verskilllende volumetriese rendemente, $\eta_{vol}$

$$= \frac{Volume\ of\ air\ taken\ in}{Swept\ volume} \qquad = \frac{Volume\ lug\ ingeneem}{Slagvolume}$$

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

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

---

| ENGLISH | GENERAL | AFRIKAANS |
| --- | --- | --- |
| Different thermal efficiencies, $\eta_{therm.}$ $= \dfrac{\text{Wd}}{\text{heat supplied}}$ | | Verskillende termiese rendemente, $\eta_{therm.}$ $= \dfrac{\text{Av}}{\text{warmte toegevoeg}}$ |
| $\eta_{brake\ therm.} = \dfrac{BP}{m_{f/s} \times CV}$ | | $\eta_{rem\ term.} = \dfrac{RD}{m_{b/s} \times WW}$ |
| $\eta_{ind.\ therm.} = \dfrac{IP}{m_{f/s} \times CV}$ | | $\eta_{ind.\ term.} = \dfrac{ID}{m_{b/s} \times WW}$ |
| $\eta_{therm.} = \dfrac{m_s(h_s - h_w)}{m_f \times CV}$ | | $\eta_{term.} = \dfrac{m_s(h_s - h_w)}{m_b \times WW}$ |
| $\eta_c = \dfrac{T_2' - T_1}{T_2 - T_1}$ | $\eta_t = \dfrac{T_3 - T_4}{T_3 - T_4'}$ | $\eta_k = \dfrac{T_2' - T_1}{T_2 - T_1}$ |
| $\eta_{mech.} = \dfrac{BP}{IP}$ | | $\eta_{meg.} = \dfrac{RD}{ID}$ |
| Indicated efficiency ratio $= \dfrac{\eta_{ind.\ therm.}}{ASE}$ | | Indikateurrendementverhouding $= \dfrac{\eta_{ind.\ term.}}{LSR}$ |
| Brake efficiency ratio $= \dfrac{\eta_{brake\ therm.}}{ASE}$ | | Remrendementverhouding $= \dfrac{\eta_{rem.\ term.}}{LSR}$ |
| $BP = 2\pi \dfrac{TN}{60}$ | $T = F \times r$ | $RD = 2\pi \dfrac{TN}{60}$ |
| $BP = P_{brake\ mean}\ L \times A \times N \times E$ | | $RD = P_{rem\ gem.}\ L \times A \times N \times E$ |
| $IP = P_{ind.\ mean}\ L \times A \times N \times E$ | | $ID = P_{ind.\ gem.}\ L \times A \times N \times E$ |
| $ISFC = \dfrac{M_{f/h}}{IP}$ | | $ISBV = \dfrac{M_{b/h}}{ID}$ |
| $BSFC = \dfrac{M_{f/h}}{BP}$ | | $RSBV = \dfrac{M_{b/h}}{RD}$ |
| $COP = \dfrac{T_1}{T_2 - T_1}$ | | $KVW = \dfrac{T_1}{T_2 - T_1}$ |
| $COP = \dfrac{RE}{Wd}$ | | $KVW = \dfrac{VE}{Av}$ |
| $P = m\ .\ U\ .\ \Delta Vw$ | | $D = m\ .\ U\ .\ \Delta Vw$ |
| $F_{ax.} = m\ .\ \Delta V_f$ | | $F_{aks.} = m\ .\ \Delta V_f$ |

ENGLISH GENERAL AFRIKAANS

$$\eta_{dia.} = \frac{2 \,.\, U \,.\, \Delta V_w}{(V_1)^2}$$

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

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

$$C_c = \sqrt{2\times10^3\left(h_1 - h_c\right) + (C_1)^2}$$

$$C_2 = \sqrt{2\times10^3\left(h_1 - h_2\right) + (C_1)^2}$$

$$C_c = \sqrt{2\times10^3 \times C_p\left(T_1 - T_c\right) + (C_1)^2}$$

$$C_2 = \sqrt{2\times10^3 \times C_p\left(T_1 - T_2\right) + (C_1)^2}$$

$$A_c = \frac{m \,.\, V_c}{C_c} \qquad A_2 = \frac{m \,.\, V_2}{C_2}$$

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

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

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

$$EE = \frac{m_s\left(h_s - h_w\right)}{m_f \times 2\ 257} \qquad EV = \frac{m_s\left(h_s - h_w\right)}{m_b \times 2\ 257}$$

$$\eta_{iso.} = \frac{Wd_{iso.}}{Wd_{poly.}} \qquad \eta_{iso.} = \frac{Av_{iso.}}{Av_{poli.}}$$

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

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

$$h = u + pV$$

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

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