higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1350**(E)**(M31)T
**APRIL EXAMINATION**

# NATIONAL CERTIFICATE

# POWER MACHINES N6

(8190046)

**31 March 2016 (X-Paper)**
**09:00–12:00**

**REQUIREMENTS: Steam Tables (BOE 173)**

**Calculators may be used**

**This question paper consists of 7 pages and 1 formula sheet of 6 pages.**

# 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 FIVE questions, only the first five questions will be marked. All work you do not want to be marked must be clearly crossed out.

**INSTRUCTIONS AND INFORMATION**

1. Answer ANY FIVE 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, but subsections of questions must be kept together.
5. ALL formulae used must be written down.
6. Show ALL the intermediate steps.
7. Questions must be answered in BLUE or BLACK ink
8. All sketches and diagrams must be done in pencil in the ANSWER BOOK.
9. Write neatly and legibly.

---

NOTE: Answer ANY FIVE questions in this question paper.

**QUESTION 1**

A two-stage, single-acting, reciprocating compressor takes in air at a tempo of 0,4 m³/s. The compression index is 1,3. The delivery pressure is 800 kPa. The rotational frequency of the compressor is 550 r/min. The initial pressure and temperature for the low-pressure cylinder are 104 kPa and 19 °C respectively.
Conditions for maximum efficiency prevail and free volume is insignificant.
Assume R for air as 0, 287 kJ/kg.K.

Calculate the following:

1.1 The intermediate pressure in kPa (3)

1.2 The volume for the low-pressure and high-pressure cylinder in m³ (6)

1.3 The diameter (D) of the high-pressure cylinder in mm if D = L (4)

1.4 The power required to drive the compressor in kW if the mechanical efficiency is 88 percent. (7)
**[20]**

AND/OR

**QUESTION 2**

In a boiler plant consisting of an evaporator, an economiser and a superheater, steam is generated at a pressure of 1 500 kPa and a temperature of 350 °C at a rate of 5 400 kg/h. The dryness factor of the steam at entry to the super-heater is 0,9.
The temperatures of the feed water entering and leaving the economiser are 44,8 °C and 93,5 °C respectively. The boiler burns coal at a rate of 600 kg/h.
The heat value of the coal is 32 MJ/kg. The atmospheric temperature is 24 °C.
Air is supplied at a rate of 15 kg of air per kg of coal. The temperature of the flue gas at the outlet of the economiser is 210 °C. The specific heat capacity of the flue gases is 1,045 kJ/kg.K.

Calculate the following by using steam tables:

2.1 Efficiency of the plant (3)

2.2 Equivalent evaporation from and at 100 °C per kilogram of fuel (2)

2.3 Heat to the economiser in kJ/kg (2)

2.4 Heat to the evaporator in kJ/kg (3)

2.5 Heat to the superheater in kJ/kg (3)

2.6 Heat to the stack (chimney) in kJ/kg (2)

2.7 Draw up an energy balance in kJ/kg fuel, also as a percentage of the total heat. (5)

**[20]**

AND/OR

**QUESTION 3**

A compression-ignition engine working on the dual cycle takes in two thirds of its total heat supply at constant volume and one third at constant pressure expansion. The compression is adiabatic. Heat is lost at a constant volume.

The following data is applicable to the engine:

| | | |
|---|---|---|
| Intake conditions | = | 101,325 kPa and 16 °C |
| Maximum pressure | = | 5 MPa |
| Compression ratio | = | 13 : 1 |

Specific heat capacity at constant volume = 0,712 kJ/kg.K
Specific heat capacity at constant pressure = 1 kJ/kg.K

Calculate the following:

3.1 The temperature and pressure after compression (5)

3.2 The temperature after constant volume heat addition (2)

3.3 The temperature after constant pressure heat addition (5)

3.4 The volume before expansion in $m^3$ (2)

3.5 The temperature before constant volume heat addition rejection (2)

3.6 The Air Standard Efficiency (A.S.E) of the cycle. (4)

**[20]**

AND/OR

**QUESTION 4**

Air enters a nozzle at a pressure of 3 MPa, a temperature of 480 °C and a speed of 60 m/s. The air leaves the nozzle at a pressure of 600 kPa. The air flow rate through the nozzle is 1,2 kg/s. The expansion from the inlet to the throat takes place with an adiabatic efficiency of 90 percent while the adiabatic efficiency from the throat to the outlet is 85 percent.

Assume gamma = 1,4; R = 0,287 kJ/kg.K and Cp = 1,005 kJ/kg.K

Calculate the following:

4.1 The throat area in $mm^2$ (10)

4.2 The exit area in $mm^2$ (8)

4.3 The Mach number (2)
**[20]**

AND/OR

**QUESTION 5**

A ship is fitted with a turbo-charged two-stroke oil engine, with five single-acting cylinders.

The following data is applicable to the engine:

| | | |
|---|---|---|
| Cylinder diameter | = | 760 mm |
| Stroke length per cylinder | = | 1 500 mm |
| Engine speed | = | 112 r/min |
| Fuel consumption | = | 1 050 kg/h |
| Heat value of fuel | = | 44 200 kJ/kg |
| Air consumption | = | 22 kg/kg fuel |
| Brake mean effective pressure | = | 738 kPa |
| Mechanical efficiency | = | 86,5% |
| Atmospheric pressure | = | 101,325 kPa |
| Atmospheric temperature | = | 16 °C |
| Gas constant for air | = | 0,287 kJ/kg.K |

Calculate the following:

5.1 The brake power in kW (4)

5.2 The indicated power in kW (2)

5.3 The brake thermal efficiency (3)

5.4 The torque on the drive shaft in kN.m (3)

5.5 The volume of air induced per minute (3)

5.6 The swept volume per minute (3)

5.7 The volumetric efficiency (2)
**[20]**

AND/OR

**QUESTION 6**

A two-stage, velocity compound steam turbine has blading designed for an axial discharge of the steam from the second row of moving blades. All the moving blades are 30°. The blade circumferential speed, the nozzle angle and the fixed blade angles are designed for a nozzle discharge velocity of 500 m/s.
The velocity coefficient for all blades is 0,9.

6.1 Use a length of 3 cm for the blade circumferential speed and construct velocity diagrams for the turbine in the ANSWER BOOK. Indicate the lengths of ALL the lines as well as the magnitude of the angles on the diagrams and calculate the scale. (10)

6.2 Determine the following from the velocity diagrams:

6.2.1 The blade circumferential speed in m/s (2)

6.2.2 The power developed per kg of steam per second in kW (3)

6.2.3 The diagram efficiency (3)

6.2.4 The axial thrust in kN (2)
**[20]**

AND/OR

**QUESTION 7**

A refrigeration plant uses methyl chloride and operates between pressure boundaries of 215 kPa and 672 kPa.

The following information was obtained:

| | | |
|---|---|---|
| Specific enthalpy of dry saturated vapour at condenser pressure | = | 479 kJ/kg |
| Specific enthalpy of dry saturated vapour at evaporator pressure | = | 462, 8 kJ/kg |
| Specific enthalpy of saturated liquid at condenser pressure | = | 110, 2 kJ/kg |
| Specific enthalpy of saturated liquid at evaporator pressure | = | 51, 6 kJ/kg |
| Specific volume of dry saturated vapour at evaporator pressure | = | 0,168 $m^3$/kg |
| Temperature of the refrigerant in condenser | = | 31 ºC |
| Temperature of the refrigerant in evaporator | = | -6 ºC |

The methyl chloride enters the compressor as a wet vapour, the condenser as a dry saturated vapour and it leaves the condenser as a saturated liquid with no under-cooling.

The actual coefficient of performance is 90,23 percent of the ideal coefficient of performance.

The compressor bore size is 0,1285 m; it has a stroke length of 1,2 times the diameter of the piston, a volumetric efficiency of 90 percent and it rotates at 420 r/min.

Calculate the following:

7.1 The ideal coefficient of performance and the actual coefficient of performance (3)

7.2 The specific enthalpy of the refrigerant at the entrance to the compressor in kJ/kg and the dryness factor (5)

7.3 The swept volume of the compressor in m³ per stroke, the swept volume and the effective swept volume in m³/s (5)

7.4 The specific volume of the refrigerant at the entrance to the compressor in m³/kg and the mass flow rate in kg per minute (4)

7.5 The compressor power in kJ/s and the power required to drive the compressor in kW if the mechanical efficiency is 80% (3)

**[20]**

**TOTAL: 100**

# POWER MACHINES N6

## FORMULA SHEET

Any other applicable formula may also be used.

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

 

***ENGLISH*** | ***GENERAL*** | ***AFRIKAANS***

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

$V_{ws} = xV_g$

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

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

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

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

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

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

$V_{ns} = xV_g$

---

*Different formulae for work done (Wd)*

*Verskillende formules vir arbeid verrig (Av)*

$$= P \times \Delta V$$

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

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

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

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

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

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

---

| ***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)*

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

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

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

---

*Different volumetric efficiencies,* $0_{vol}$

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

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

*Verskillende volumetriese rendemente,* $0_{vol}$

$$= \frac{Volume\ lug\ ingeneem}{Slagvolume}$$

$$= \frac{Volume\ vrylug}{Slagvolume}$$

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

| ***ENGLISH*** | ***GENERAL*** | ***AFRIKAANS*** |
|---|---|---|
| *Different thermal efficiencies,* $0_{therm.}$ $= \dfrac{Wd}{heat\ supplied}$ | | *Verskillende termiese rendemente,* $0_{term.}$ $= \dfrac{Av}{warmte\ toegevoeg}$ |
| $\eta_{brake\ therm.} = \dfrac{BP}{m_{f/s} \times CV}$ | | $\eta_{rem\ term.} = \dfrac{RD}{m_{b/s} \times WW}$ |
| $\eta_{ind.\ therm.} = \dfrac{IP}{m_{f/s} \times CV}$ | | $\eta_{ind.\ term.} = \dfrac{ID}{m_{b/s} \times WW}$ |
| $\eta_{therm.} = \dfrac{m_s\ (hs - hw)}{m_f \times CV}$ | | $\eta_{term.} = \dfrac{m_s\ (hs - hw)}{m_b \times WW}$ |
| $\eta_c = \dfrac{T_2' - T_1}{T_2 - T_1}$ | $\eta_t = \dfrac{T_3 - T_4}{T_3 - T_4'}$ | $\eta_k = \dfrac{T_2' - T_1}{T_2 - T_1}$ |
| $\eta_{mech.} = \dfrac{BP}{IP}$ | | $\eta_{meg.} = \dfrac{RD}{ID}$ |
| *Indicated efficiency ratio* $= \dfrac{\eta_{ind.\ therm.}}{ASE}$ | | *Indikateurrendementverhouding* $= \dfrac{\eta_{ind.\ term.}}{LSR}$ |
| *Brake efficiency ratio* $= \dfrac{\eta_{brake\ therm.}}{ASE}$ | | *Remrendementverhouding* $= \dfrac{\eta_{rem.\ term.}}{LSR}$ |
| $BP = 2\pi \dfrac{TN}{60}$ | $T = F \times r$ | $RD = 2\pi \dfrac{TN}{60}$ |
| $BP = P_{brake\ mean}\ LANE$ | | $RD = P_{rem\ gem.}\ LANE$ |
| $IP = P_{ind.\ mean}\ LANE$ | | $ID = P_{ind.\ gem.}\ LANE$ |
| $ISFC = \dfrac{m_{f/h}}{IP}$ | | $ISBV = \dfrac{m_{b/h}}{ID}$ |
| $BSFC = \dfrac{m_{f/h}}{BP}$ | | $RSBV = \dfrac{m_{b/h}}{RD}$ |
| $COP = \dfrac{T_1}{T_2 - T_1}$ | | $KVW = \dfrac{T_1}{T_2 - T_1}$ |
| $COP = \dfrac{RE}{Wd}$ | | $KVW = \dfrac{VE}{Av}$ |
| $P = m\ .U\ .\Delta Vw$ | | $D = m\ .U\ .\Delta Vw$ |
| $F_{ax} = m\ .\Delta V_f$ | | $F_{aks.} = m\ .\Delta V_f$ |

***ENGLISH*** ***GENERAL*** ***AFRIKAANS***

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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