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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1400**(E)**(A12)T

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

12 April 2019 (X-Paper)
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 5 pages.

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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. Questions may be answered in any order but 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. ALL formulae used must be written down.
7. Show ALL intermediate steps for calculations.
8. Final answers must be approximated to THREE decimals, unless stated otherwise.
9. Use only BLUE or BLACK ink.
10. Write neatly and legibly.

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QUESTION 1

A steam plant consisting of an economiser, an evaporator and a superheater generates 9,5 kg of steam per kg fuel burned at a pressure of 2 MPa.

The following data was recorded about the steam plant:

Calorific value of the fuel	31 MJ/kg
Thermal efficiency of the plant	82%
Temperature of the flue gases at the chimney base	200 °C
Air fuel ratio	18:1
Specific heat capacity of the superheated steam	2,6 kJ/kg.K
Temperature of the feed water entering the evaporator	107,1 °C
Temperature of the flue gases leaving the evaporator	465 °C
Temperature of the flue gases leaving the superheater	300 °C
Specific heat capacity of the flue gases	1,05 kJ/kg.K
Temperature of the boiler room	24 °C

Calculate the following quantities by using steam tables only:

1.1 Heat absorbed by the economiser in kJ/kg fuel (2)

1.2 Heat absorbed by the superheater in kJ/kg fuel (2)

1.3 Heat absorbed by the evaporator in kJ/kg fuel (3)

1.4 Dryness fraction of the steam entering the superheater (4)

1.5 Temperature of the superheated steam leaving the superheater (4)

1.6 Percentage of heat lost through the chimney and the percentage heat loss unaccounted for (5)

[20]

QUESTION 2

The cylinder volume of a single-cylinder engine operating on the dual-cycle principle is 0,045 m³.

The initial temperature of compression is 31 °C.

The adiabatic volumetric compression ratio is 9:1.

The constant volume heat addition pressure ratio is 1,5:1 and the constant pressure heat addition volumetric ratio is 2,4:1.

Assume C_p for air as 1,008 kJ/kg.K, C_v for air as 0,72 kJ/kg.K, and calculate the following quantities:

2.1 Missing volumes at the principal points in m³ (4)

2.2 Adiabatic volumetric expansion ratio (2)

2.3 Value of gamma (2)

2.4 Missing absolute temperatures at the principal points (8)

2.5 Heat received in kJ/kg (4)
[20]

QUESTION 3

A velocity-compounded impulse gas turbine receiving gas at a mass flow rate of 20 kg/s consists of two rows of moving blades separated by a row of fixed blades.

The average speed of the moving blades is 170 m/s.

The nozzle velocity and nozzle angle are 750 m/s and 20° respectively.

The inlet and outlet angles of the first row of moving blades are equal.

The inlet and outlet angles of the second row of moving blades are equal.

The exit angle of the fixed blades is 17°.

There is a 5% loss of velocity across ALL blades due to friction.

3.1 Use scale 1 mm = 5 m/s 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. (10)

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3.2 Determine the following from the velocity diagrams:

3.2.1 Inlet and outlet angles of the first row of moving blades (1)

3.2.2 Inlet and outlet angles of the second row of moving blades (1)

3.2.3 Inlet angle of the fixed blades (1)

3.2.4 Angle at which the gas leaves the turbine (1)

3.2.5 Velocity of the gas leaving the first stage in m/s (1)

3.2.6 Velocity of the gas leaving the fixed blades in m/s (1)

3.2.7 Axial thrust developed in the turbine in N (4)
[20]

QUESTION 4

Superheated steam at a pressure of 2 MPa and a temperature of 250 °C enters a convergent-divergent nozzle and it discharges at a pressure of 700 kPa.

At the throat, the steam has a pressure of 1,15 kPa, and a temperature of 188 °C, with a specific heat capacity of 2,3 kJ/kg.K.

The index (n) for the superheated steam at the throat is 1,35.

The steam flows at a rate of 510 kg/min.

There is an enthalpy drop of 200 kJ/kg through the nozzle.

Ignore the velocity of the steam at the inlet, and calculate the following quantities by using steam tables only:

4.1 At the throat of the nozzle:

4.1.1 Specific enthalpy of the steam

4.1.2 Velocity of the steam in m/s

4.1.3 Specific volume of the steam

4.1.4 Area in mm²

(4 × 3) (12)

4.2 At the exit of the nozzle:

4.2.1 Specific enthalpy of the steam (2)

4.2.2 Dryness factor of the steam (3)

4.2.3 Specific volume of the steam (3)
[20]

QUESTION 5

A two-stage single-acting reciprocating compressor takes in 54 000 cm³ of air per cycle at a pressure of 100 kPa and a temperature of 26 °C whilst rotating at 300 r/min.

The air is compressed to 400 kPa in the low-pressure cylinder, while the volumetric efficiency of the low-pressure cylinder is 89%.

The stroke length of the low-pressure cylinder is 1,2 times the diameter of the piston.

The index for compression for both cylinders is 1,3 and the intercooler extracts 26 kJ of heat per second.

Take R for air as 0,288 kJ/kg.K, C_p for air as 1,008 kJ/kg.K, and calculate the following quantities:

5.1 Mass of air delivered by the compressor in kg/min (3)

5.2 Absolute temperature of the air after compression in the low-pressure cylinder (3)

5.3 Absolute temperature of the air at the inlet to the high-pressure cylinder (3)

5.4 For the low-pressure cylinder:

5.4.1 Swept volume in m³/stroke (3)

5.4.2 Diameter of the piston in mm, and the stroke length in mm (5)

5.5 Volume of air taken in by the high-pressure cylinder in m³/stroke (3)
[20]

TOTAL: 100

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FORMULA SHEET

NOTE: This formula sheet may not necessarily be complete.

Any formula which does not appear on this list must be written down in full in the ANSWER BOOK.

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

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

Different formulae for work done (Wd)

Verskillende formules vir lugstandaardrendemente (LSR)

$$= P \times \Delta V$$

$$= P_1 V_1 . \ln\left(\frac{V_2}{V_1}\right)$$

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

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

$$= m.C_p \ . \ \Delta T$$

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

$$= \frac{xn}{n-1} \times mRtT_1 \left[\left(r_{ps}\right)^{\left(\frac{n-1}{n}\right)} - 1\right]$$

ENGLISH	GENERAL	AFRIKAANS
Different formulae for work done (Wd)		Verskillende formules vir arbeid verrig (Av)
= area of PV - diagram		= area van PV - diagram
= work done first stage + work done second stage + ...		= arbeid verrig eerste stadium + arbeid verrig tweede stadium + ...
$Wd_{nett} = Wd_t - Wd_c$ $Wd_{nett} = Q_{nett}$		$Av_{nett} = Av_t - Av_k$ $Av_{nett} = Q_{nett}$
Different formulae for air standard efficiencies (ASE)	$=1-\left(\frac{1}{r}\right)^{(\gamma-1)}$ $=1-\frac{r_p \,.\, (r_c)^{(\gamma-1)}}{r_v^{(\gamma-1)}\left[(r_p-1)+\gamma^{r_p}(r_c-1)\right]}$	Verskillende formules vir lugstandaardrendemente (LSR)
$=\frac{\text{heat added} - \text{heat rejected}}{\text{heat added}}$	$=1-\frac{\beta^{\gamma}-1}{r^{(\gamma-1)}\times\gamma(\beta-1)}$	$=\frac{\text{warmte toegevoeg} - \text{warmte afgestaan}}{\text{warmte toegevoeg}}$
Different volumetric efficiencies, η_{vol}		Verskilllende volumetriese rendemente, η_{vol}
$=\frac{\text{Volume of air taken in}}{\text{Swept volume}}$		$=\frac{\text{Volume lug ingeneem}}{\text{Slagvolume}}$
$=\frac{\text{Volume of free air}}{\text{Swept volume}}$		$=\frac{\text{Volume vrylug}}{\text{Slagvolume}}$
	$=1-\left(\frac{V_c}{V_s}\right)\left[\left(\frac{P_2}{P_1}\right)^{\left(\frac{1}{n}\right)}-1\right]$	

ENGLISH	GENERAL	AFRIKAANS
Different thermal efficiencies, $\eta_{therm.}$		Verskillende termiese rendemente, $\eta_{therm.}$
$= \dfrac{\text{Wd}}{\text{heat supplied}}$		$= \dfrac{\text{Av}}{\text{warmte toegevoeg}}$
$\eta_{brake\ therm.} = \dfrac{BP}{m_{f/s} \times CV}$		$\eta_{rem\ term.} = \dfrac{RD}{m_{b/s} \times WW}$
$\eta_{ind.\ therm.} = \dfrac{IP}{m_{f/s} \times CV}$		$\eta_{ind.\ term.} = \dfrac{ID}{m_{b/s} \times WW}$
$\eta_{therm.} = \dfrac{m_s\left(h_s - h_w\right)}{m_f \times CV}$		$\eta_{term.} = \dfrac{m_s\left(h_s - h_w\right)}{m_b \times WW}$

$\eta_c = \dfrac{T_2' - T_1}{T_2 - T_1}$	$\eta_t = \dfrac{T_3 - T_4}{T_3 - T_4'}$	$\eta_k = \dfrac{T_2' - T_1}{T_2 - T_1}$
$\eta_{mech.} = \dfrac{BP}{IP}$		$\eta_{meg.} = \dfrac{RD}{ID}$
Indicated efficiency ratio		Indikateurrendementverhouding
$= \dfrac{\eta_{ind.\ therm.}}{ASE}$		$= \dfrac{\eta_{ind.\ term.}}{LSR}$
Brake efficiency ratio		Remrendementverhouding
$= \dfrac{\eta_{brake\ therm.}}{ASE}$		$= \dfrac{\eta_{rem.\ term.}}{LSR}$

$BP = 2\pi \dfrac{TN}{60}$	$T = F \times r$	$RD = 2\pi \dfrac{TN}{60}$
$BP = P_{brake\ mean}\ L \times A \times N \times E$		$RD = P_{rem\ gem.}\ L \times A \times N \times E$
$IP = P_{ind.\ mean}\ L \times A \times N \times E$		$ID = P_{ind.\ gem.}\ L \times A \times N \times E$
$ISFC = \dfrac{M_{f/h}}{IP}$		$ISBV = \dfrac{M_{b/h}}{ID}$
$BSFC = \dfrac{M_{f/h}}{BP}$		$RSBV = \dfrac{M_{b/h}}{RD}$
$COP = \dfrac{T_1}{T_2 - T_1}$		$KVW = \dfrac{T_1}{T_2 - T_1}$
$COP = \dfrac{RE}{Wd}$		$KVW = \dfrac{VE}{Av}$
$P = m\ .U\ .\Delta Vw$		$D = m\ .U\ .\Delta Vw$
$F_{ax.} = m\ .\ \Delta V_f$		$F_{aks.} = m\ .\ \Delta V_f$

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ENGLISH GENERAL AFRIKAANS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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

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