CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY
MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 78 as amended MANAGEMENT ENGINEER REG. III/2 (UNLIMITED)

040-32 – APPLIED HEAT

MONDAY, 11 DECEMBER 2017

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Thermodynamic and Transport Properties of Fluids (5th Edition)
Arranged by Y.R. Mayhew and C.F.C. Rogers

APPLIED HEAT

Attempt SIX questions only

All questions carry equal marks

Marks for each part question are shown in brackets

1. A volume of 0.0869 m^3 of air is heated at a constant pressure of 15 bar until the temperature rises from 30°C to 500°C.

   It is then expanded according to the law $pV^{1.33}$ = constant, until the pressure is 1.5 bar.

   (a) Sketch the processes on pressure-Volume and Temperature-specific entropy diagrams. (2)

   (b) Calculate EACH of the following:

   (i) the total change in entropy; (8)

   (ii) the total work transfer; (4)

   (iii) the net change in the internal energy of the air. (2)

   Note: for air R = 287 J/kgK and c_v = 718 J/kgK

[OVER

2. Air enters an open cycle gas turbine plant at a pressure and temperature of 0.95 bar and 15°C respectively. It is then compressed to a pressure of 12 bar in two stages of equal pressure ratio with perfect intercooling.

The combustion products enter the single stage turbine at a pressure of 12 bar and temperature of 980°C and leave at a pressure of 0.95 bar.

The isentropic efficiency of each compressor stage is 0.8.

The isentropic efficiency of the turbine is 0.85.

The air to fuel ratio is 70:1

(a) Sketch the cycle on a temperature-specific entropy diagram. (4)

(b) Calculate EACH of the following:

(i) the specific net work output; (7)

(ii) the cycle thermal efficiency. (5)

Note: for air $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*
for the combustion products $\gamma = 1.33$ *and* $c_p = 1.15$ *kJ/kgK*

3. Benzene (C_6H_6) is burned in 15% excess air by mass.

Analysis of the exhaust gas shows they contain 0.05 kg of carbon monoxide per kg of fuel burned.

Calculate EACH of the following:

(a) the mass of carbon burned to CO_2 per kg of fuel; (4)

(b) the air to fuel ratio by mass; (4)

(c) the volumetric analysis of the exhaust gas. (8)

Note: atomic mass relationships H =1, C = 12, O = 16, N = 14.
air contains 23.3% oxygen by mass.

4. The plant shown in Fig Q4, produces 9 tonne /hour of dry saturated steam at a pressure of 1 bar from steam at 10 bar and 300ºC.

Some of the steam expands through a turbine producing 847 kW with an isentropic efficiency of 0.91.

Excess steam flow is passed through a throttle and then cooled at constant pressure. The amount of cooling is controlled to allow the adiabatic mixing of the two streams to give the required outlet condition.

Pressure losses in the cooler and mixing vessel may be ignored.

(a) Calculate EACH of the following:

(i) the dryness fraction of the steam leaving the turbine; (5)

(ii) the degree of superheat of the steam leaving the throttle; (3)

(iii) the heat removed in the cooler. (5)

(b) Sketch the processes on a specific enthalpy-specific entropy diagram. (3)

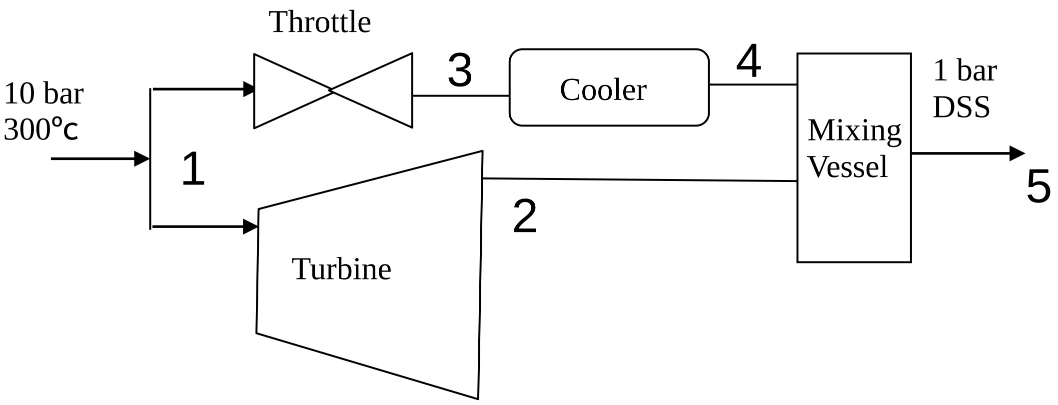

Fig Q4

5. In a 50% reaction turbine stage, the steam leaves the fixed blades with a velocity of 500 m/s.

The mean diameter of the blade ring is 900 mm and the speed of rotation is 8000 rev/min.

The inlet angle of the blading is 70°.

Calculate EACH of the following:

(a) the blading outlet angle; (4)

(b) the blade work per kg of steam flow; (4)

(c) the enthalpy drop across the moving blade; (4)

(d) the diagram efficiency. (4)

6. In a vapour compression refrigeration plant, the R134a enters the compressor at a pressure and temperature of 1.0637 bar and -20°C respectively. At these conditions the specific volume is 0.1859 m^3/kg.

The refrigerant undergoes isentropic compression to 8.8672 bar and leaves the condenser with 10 K subcooling.

The 6 cylinder single stage compressor runs at a speed of 200 rev/min and has a bore and stroke of 190 mm and 200 mm respectively.

The volumetric efficiency at this speed is 86%.

(a) Sketch the cycle on a pressure-specific enthalpy diagram indicating areas of heat and work transfer. (2)

(b) Sketch the cycle on a Temperature-specific entropy diagram indicating areas of superheat and sub cooling. (2)

(c) Calculate EACH of the following:

(i) the temperature at the end of compression; (5)

(ii) the coefficient of performance; (3)

(iii) the compressor Power. (4)

7. A spherical steel pressure vessel has an internal diameter of 1.5 m and a wall thickness of 20 mm.

It is covered with two layers of insulation, each 25 mm thick.

The inner surface temperature of the steel is 450°C and the surrounding air temperature is 25°C.

Calculate EACH of the following:

(a) the heat loss from the pressure vessel per m^2 of surface area. (8)

(b) the temperature drop across EACH layer. (6)

(c) the outer surface temperature. (2)

Note: the heat transfer coefficient of the inner surface may be ignored.
the thermal conductivity of steel = 52 W/mK
the thermal conductivity of the inner insulation = 0.04 W/mK
the thermal conductivity of the outer insulation = 0.25 W/mK
the heat transfer coefficient of the outer surface = 2 W/m^2K

8. In a single acting, single stage reciprocating air compressor, the conditions at the beginning of compression are 0.95 bar and 12°C. When the delivery valve opens the cylinder conditions are 7.6 bar and 157°C.

The diameter of the cylinder bore is 200 mm and the compressor stroke is 300 mm.

The clearance volume is 5% of the swept volume and the compressor runs at a speed of 360 rev/min.

(a) Sketch the cycle on a pressure-Volume diagram. (2)

(b) Calculate EACH of the following:

(i) the index of compression; (3)

(ii) the volumetric efficiency; (2)

(iii) the compressor indicated power; (5)

(iv) the compressor isothermal efficiency. (4)

9 A tank containing oil of density 850 kg/m^3 has two sharp edged outlet orifices on one side of the tank. The upper orifice is 15 mm diameter and has its centre 1.3 m below the oil surface. The lower orifice is 20 mm diameter and has its centre 2.8 m below the oil surface. Oil is supplied to the tank at 1.8 kg/s to maintain a constant tank level.

Calculate EACH of the following:

(a) the mass flow rate of oil from the 15 mm diameter orifice; (8)

(b) the coefficient of velocity for the 20 mm diameter orifice. (8)

Note: For 15 mm diameter orifice, Coefficient of Velocity = 0.97
Coefficient of Contraction = 0.68
For 20 mm diameter orifice, Coefficient of Contraction = 0.72

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM

SUBJECT: 040-32-Applied Heat
DATE: 11th December 2017

General Comments on Examination Paper
Candidates: Must start each new question at the top of a fresh page.
Should read the whole question carefully, paying particular attention to the units given and produce a solution based on what has been given and asked.
Should take care when answering questions they are "confident" with. Stating the correct formula and then inserting the wrong numbers or calculating an incorrect answer was common.
Should read what they have written eg $70^\circ + 130^\circ \neq 180^\circ$ (reference Q5 triangles)

General Comments of Specific Examination Questions
Q1. The T-s diagrams were poor, isothermal expansion (n=1) horizontal L to R, isentropic vertical ($n=\gamma$), polytropic $1<n<\gamma$ therefore process L to R downwards. Heat (Q) is not the same as internal energy (U). Treatment of energy flow was inconsistent, eg both processes were expansion therefore total work was the addition of both not the difference.
Units of $N/m^2 \times m^3 = Nm = J$ (work transfer), J/s = W (rate of work transfer), entropy J/K.
Q2.Numerous candidates did not read the question and produced a totally diferent solution. Flow processes involved $W = \Delta H$. $H= mc_{cp}\Delta T$. Isentropic efficency, ratio of actaul and isentropic enthalpy rise the numerator depends on the process. Compressor stage pressure ratio is √overall ratio.
AF ratio gives mass of gas which = 1.0143 mass of air. Total $W_{comp} = 2\ m_{air}c_{pair}\Delta T_{comp,}$
$W_{turbine}=1.0143m_{air}c_{pgas}\Delta T_{turbine}$ $Q_{supply} = 1.0143m_{air}c_{pgas}T_5 - m_{air}c_{pair}T_4$
Q3. Read the whole question including the information. 0.05 kg CO is not the same as 0.05 kmol CO. Air contains 23.3% O_2 by mass indicates a solution by mass is required. 1Kg fuel contains 0.923 kg carbon and 0.077 kg hydrogen. Carbon burned to CO = ((24/56)x0.05). Carbon burned to CO_2=0.923-carbon to CO. O_2 in gas from excess air and that not used in producing CO instead of CO_2.
Q4. ai for turbine $S_1=S_2$ at 1bar hence h_{2s} isentropic efficiency gives $h_{2a}=h_f+ x_{2a}h_{fg}$ at I bar
aii for throttle $h_1=h_3$ at 1 bar. Aiii Turbine power gives mass flow and mass through throttle is total – turbine. Adiabtic mixing $m_{total}h_5= m_{turbine}h_2 + m_{throttle}h_4$ hence h_4. Heat removed = $m_{throttle}(h_3-h_4)$
Q5. Question stated calculate! Many confused the absolute velocity with the relative velocity, some used the same value for relative and absolute velocity. Blade speed calculate $U = \omega r$, absolute velocity C_1 given, sin rule gives, $U/\sin u = C_1/\sin(180-70)$ gives angle u, hence (180-u-110) is required angle. Remaining values then calculated using right angle triangles and required formula.
Q6.The diagrams were generally poor and did not contain the required information. Many appeared to select random values from the tables and were confused by, Superheat ($T_{actual} - T_{saturated}$) , Subcooling ($T_{sat} - T_{actal}$), constant pressure cooling (condensation) and heating (evaporation). PV=mRT only applies to a gas.
Q7. The question stated a sphere it was not a pipe. Many used diameters instead of radii. Most stated the correct formula although some then used an incorrect one, whilest others could not calculate the correct radii. Most gave the interface temperature not the temperature drop. There were numerous calculation errors particularly from those attempting "single step" calculations.
Q8 The diagrams were poor. Many confused volumes, V_1 is the total cylinder volume = $V_{swept} + V_{clearance}$. $V_{induced} = V_1 - V_4$. In some cases rounding was consistent with a slide rule calculation. There was no need to assume a value for R and calculate the mass. Those doing so invariably made an error. Most were able to recall the correct equations but many were blighted by careless errors.
Q9.PE = KE, Q=Ca, $m=\rho Q$, coefficients take theoretical values to actual values

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MARITIME AND COASTGUARD AGENCY

STCW 78 as amended CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 12 DECEMBER 2016

1315 - 1615 hrs

Examination paper inserts:

Worksheet Q4 - Specific Enthalpy–Specific Entropy Chart for Steam

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate’s examination workbook
Graph paper
‘Thermodynamic and Transport Properties of Fluids’ by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. The initial pressure, volume and temperature of air in a cylinder are 1.0 bar, 0.2 m^3 and 25°C respectively. It is heated at constant volume to a temperature of 600°C and then reversibly expanded to the original pressure according to the law $pV^{1.35}$= constant.

(a) Calculate EACH of the following:

(i) the work done; (4)

(ii) the change in internal energy in the expansion process; (4)

(iii) the heat transferred in the expansion process; (2)

(iv) the overall change in entropy. (2)

(b) Sketch the processes on Pressure-Volume and Temperature-specific entropy diagrams. (4)

Note: for air c_v = 0.718 kJ/kgK and R = 0.287 kJ/kgK

[OVER

2. In an open gas turbine cycle, 4.5 kg/s of air is induced into a rotary compressor at a pressure and temperature of 1 bar and 18°C respectively.
It is compressed through a pressure ratio of 5:1 with an isentropic efficiency of 0.85.

The hot gases leave the combustion chamber and enter the turbine at a temperature of 810°C, expanding to the initial pressure with an isentroic efficiency 0.88.

The mass flow rate of fuel may be ignored.

(a) Sketch the cycle on a Temperature-specific entropy diagram. (4)

(b) Calculate EACH of the following:

(i) the net power output of the cycle; (6)

(ii) the work ratio; (2)

(iii) the thermal efficiency. (4)

Note: for air and the hot gas $\gamma = 1.4$ *and* $c_p = 1.006$ *kJ/kgK*

3. A fuel has a mass analysis of 80% carbon, 15% hydrogen, 1.5% sulphur and 2% water. The remainder being ash.

The fuel is completely burned in 10% excess air.

Calculate EACH of the following:

(a) the stoichiometric air fuel ratio by mass; (6)

(b) the mass of oxygen required to convert the SO_2 in the combustion products to soluble SO_3; (4)

(c) the volumetric analysis of the dry combustion products after the formation of the SO_3. (6)

Note: Relative Atomic masses: C=12, H=1, O=16 N=14, S=32.
Air contains 23% oxygen by mass

4. In a regenerative steam power plant, steam enters the turbine at a pressure and temperature of 60 bar and 540°C respectively and expands to a condenser pressure of 0.05 bar.
The specific entropy at exit is 10% greater than that at inlet.
Steam is bled from the turbine at a pressure of 2 bar and supplied to a surface feed heater, from which the drain is throttled to the main condenser.
There is no under cooling in the condenser and the feed water leaves the heater at the saturation temperature of the bled steam.
The feed pump work cannot be ignored.

(a) Using Worksheet Q4 plot the straight line expansion process. (2)

(b) Determine EACH of the following:

(i) the condition of the bled steam at entry to the feed heater; (2)

(ii) the mass of bled steam per kg of steam flow; (4)

(iii) the thermal efficiency of the cycle. (4)

(c) Sketch the cycle on a Temperature-specific entropy diagram. (4)

5. The blades of a particular stage in a 50% reaction turbine develop a power of 400 kW when the steam is dry saturated at pressure of 3 bar.
The speed of rotation is 5500 rev/min.
The mean blade ring diameter is 700 mm and the blade height is 50 mm.
The absolute velocity of the steam at the stage exit is in the axial direction.

(a) Sketch the velocity vector diagram for the stage and identify ALL velocities. (3)

(b) Calculate EACH of the following:

(i) the absolute velocity of the steam at exit; (6)

(ii) the fixed and moving blade angle; (2)

(iii) the absolute velocity of the steam at inlet; (2)

(iv) the specific enthalpy drop of the steam in the moving blades. (3)

6. In a vapour compression plant 0.452 tonne/hour of refrigerant R134a, leaves the evaporator at a pressure of 2.006 bar and temperature of 0°C. It is then compressed with an isentropic efficiency of 0.825 to a pressure of 8.8672 bar.

The refrigerant leaves the condenser with 5 K of sub-cooling.

(a) Sketch the cycle on EACH of the following:

(i) a Pressure-specific enthalpy diagram indicating the refrigeration effect, compressor work and condenser heat rejection; (2)

(ii) a Temperature-specific entropy diagram, indicating superheat and sub-cooling. (2)

(b) Determine EACH of the following:

(i) the cooling load; (5)

(ii) the compressor power required; (3)

(iii) the heat rejection in the condenser; (2)

(iv) the coefficient of performance when operating as a heat pump. (2)

7. Dry saturated steam at 10 bar enters a steam pipe 50 m in length with an inner diameter of 100 mm and wall thickness of 3 mm.

The pipe insulation limits the condensation of the steam to 6%, when the mass flow rate of steam in the pipe is 7200 kg/hr and the air temperature surrounding the pipe is 20° C.

Calculate EACH of the following:

(a) the thickness of the insulation surrounding the pipe; (8)

(b) the percentage reduction in condensation when the thickness of the insulation is doubled. (8)

Note: *inner heat transfer coefficient of the pipe = 545 W/m^{2}K*
thermal conductivity of steel = 50 W/mK
thermal conductivity of the insulation = 0.5 W/mK
the outer heat transfer coefficient of the pipe may be ignored

8. A two-stage, single acting, water cooled, reciprocating air compressor is designed for minimum work and fitted with an after cooler.

It delivers air at the rate of 17 m^3/min at free air conditions of 1.01325 bar 0° C.

The air is compressed from a pressure and temperature of 1 bar 33°C to a pressure of 30 bar and the air leaves the after cooler at a temperature of 45°C. The law for all expansion and compression processes is $pV^{1.3}$= constant.

(a) Sketch the cycle on a Pressure–Volume diagram. (2)

(b) Calculate EACH of the following:

(i) the stage power; (4)

(ii) the enthalpy rise of the air in each stage; (4)

(iii) the total heat removed by the cooling water. (6)

Note: for air R = 0.287 kJ/kgK, c_p=1.005 kJ/kgK

9. A rigid vessel contains 6 kg of oxygen and 9 kg of nitrogen at a pressure and temperature of 3 bar and 27° C respectively.

Calculate EACH of the following:

(a) the mole fraction of the oxygen and nitrogen; (2)

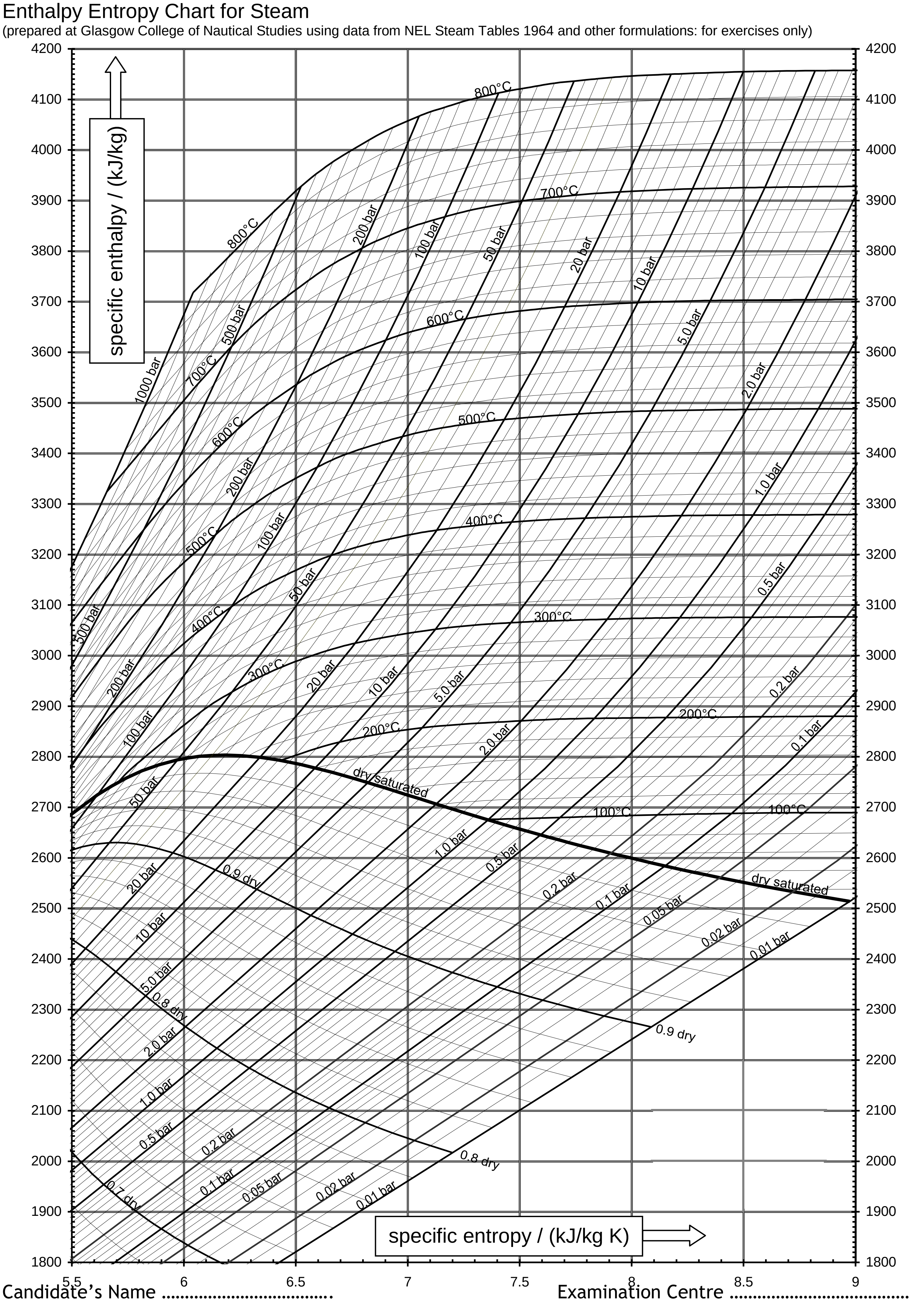
(b) the partial volumes of the oxygen and nitrogen; (4)

(c) the partial pressures of the oxygen and nitrogen; (4)

(d) the adiabatic index when the gasses are mixed. (6)

Note:
Atomic mass relationships: N = 14, O = 16.
the universal gas constant = 8.3145 kJ/kmolK.
the values of c_p at 300 K are: oxygen = 0.918 kJ/kgK, nitrogen = 1.040 kJ/kgK .

(This worksheet must be returned with your answer book)



Candidate's Name ....

Examination Centre ....

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32-Applied Heat

DATE: 12h December 2016

General Comments on Examination Paper Many candidates failed to read the questions fully and carefully, as a consequence they gave them selves unnecessary work which was invariably incorrect. Questions that state "calculate" need to be solved by calculation whereas "determine" allows the candidate to use charts or diagrams. Solutions are required to state the formula used followed by the formula containing numbers and finally the answer showing the units. Many candidates used incorrect units or paid no heed to then and consequently made numerous errors. Other common errors include transposition, use of the calculator and selecting random numbers to obtain a perceived correct answer. Using a rule to draw straight lines would also be good
General Comments of Specific Examination Questions Q1. The P-v diagram was generally good the T-s diagram were not, many candidates were unable to order the temperatures on the diagram. The calculation were on the whole satisfactory although there were many careless? errors. The fact that entropy change only depends on the end states was recognized by only one candidate everyone else chose to use constant volume plus the polytropic constant volume/pressure plus isothermal instead of a single constant pressure process. A good T-s diagram would have shown this. Q2. Many candidates apparently did not read the question consequently, the process diagram was either incorrect or meaningless. The concept of a pressure ratio and constant pressure process eluded many as did the fact that the turbine work must be greater than that of the compressor. Many could not apply the SFEE. Q3. The clue to this was in the question, air contains 23.3% oxygen by mass ie use a mass analysis. The majority of attempts produced the full combustion equation in kmols (not required). $2SO_2 + O_2$ - $2SO_3$ the oxygen comes from the excess air which is reduced in the final analysis. Q4. Those attempting this did not realise it was a surface heat exchanger. The T-s diagram was incorrectly drawn. The calculations were fairly consistent although most did not realise that feed pump work = v_f (P_b- P_c) and using the units as given on page 10 with bar gives kJ/kg. Q5. Question stated calculate! Some did not identify it as a reaction turbine while others used the units incorrectly and did not relate change in kinetic energy with enthalpy change.. Q6. Apart from using the incorrect tables and not recognising simple refrigeration systems operate between two pressure. Most of the diagrams were poor and did not contain the information requested. Many appear to be unaware of the relationship between pressure, temperature and the concepts of superheating and subcooling with respect to the saturation temperature. Interpolation also confused many ie 1.7126, 1.7647 1.747 is incorrect. Q7. Many could not determine the heat lost from the steam pipe. Some used the incorrect pressure and many struggled with the transposition of the formula, in particular the anti-log. Part B was a reversal of part a using the given condition. Q8. Almost ALL diagrams bore no resemblance to a two stage compressor whatsoever! Many have no concept of a stage pressure ratio or the conditions of minimum work. Some confused ENTROPY with ENTHALPY while others were unaware that it is c_pT. Application of the SFEE was almost non existent for parts bii and biii. Q9. Few attempts, most forgot mass = nxM, some used a gas and values not given in the question!!

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STCW 78 as amended CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 17 OCTOBER 2016

1315 - 1615 hrs

Examination paper inserts:

Datasheet Q6

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate's examination workbook Graph paper 'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A perfect gas expands reversibly in a cylinder according to the law $pV^{1.5}$=constant and is then heated at constant volume.

   The initial pressure and temperature are 90 bar and 1800°C respectively.
   The final pressure is 2 bar and the final volume is twenty times the initial volume.

   (a) Sketch the processes on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the temperature after expansion; (2)

   (ii) the final temperature; (2)

   (iii) the net change in specific entropy. (8)

   Note: For the gas $R = 0.287$ *kJ/kgK and* $\gamma = 1.33$

2. A compression ignition engine working on the ideal dual combustion cycle has a volume compression ratio of 14:1.
   The pressure and temperature at the beginning of compression are 0.95 bar and 30°C respectively. The maximum pressure of the cycle is 44 bar and the constant pressure heat transfer takes place for 1/18 of the stroke.

   (a) Sketch the cycle on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following per unit mass of air:

   (i) the heat supply; (6)

   (ii) the heat rejected; (2)

   (iii) the net work output; (2)

   (iv) the thermal efficiency. (2)

   Note: For air $c_p = 1.005$ *kJ/kgK* $c_v = 0.718$ *kJ/kgK*

3. A pure hydrocarbon fuel is completely burned in air.

The dry flue gas analysis shows they contain 15% carbon dioxide and 2.5% oxygen by volume.

(a) Determine the full combustion equation in kmols per kmol of fuel. (8)

(b) Calculate EACH of the following:

(i) the percentage mass analysis of the fuel; (4)

(ii) the gravimetric analysis of the wet exhaust gas. (4)

Note: Relative atomic masses H=1, C=12, N=14, O=16
Air contains 21% oxygen by volume.

4. A steam power plant operates between a boiler pressure and temperature of 50 bar and 450°C respectively and a condenser pressure of 45 millibar.

The steam expands isentropically from the boiler pressure to a dry saturated condition, at which point some steam is bled off to a direct contact feed heater. The feed water leaves the heater at the saturation temperature of the bled steam pressure.

The remainder of the steam expands isentropically to the condenser pressure. There is 4 K of sub-cooling in the condenser and the feed pump work may be ignored.

(a) Sketch the cycle on a Temperature-specific entropy diagram. (3)

(b) Determine EACH of the following:

(i) the percentage moisture in the turbine exhaust; (4)

(ii) the mass flow rate of bled steam per kg of steam flowing; (5)

(iii) the thermal efficiency of the cycle. (4)

5. The first stage of an impulse turbine is a two row Curtis wheel.
Steam leaves the nozzles at 830 m/s and the blade speed is 180 m/s.
The first row of moving blade rows are symmetrical with a blade angle of 30º.
The velocity coefficient of 0.85 for all blade rows.
The outlet angles from the fixed blades and the second row of moving blades are 35º and 24º respectively.

(a) Draw to a scale of 1 mm = 5 m/s the velocity diagram for each row. (6)

(b) Determine EACH of the following:

(i) the nozzle angle to the plane of the wheel; (2)

(ii) the inlet angle to the second row of moving blades; (2)

(iii) the power output of the stage per kg of steam flowing; (3)

(iv) the diagram efficiency. (3)

6. The cooling load in a vapour compression refrigeration plant using CO_2 is 50 kW. At this load, the refrigerant enters the compressor at a pressure of 17.314 bar and temperature of -14ºC. It is then compressed isentropically to a pressure of 54.65 bar and temperature of 68ºC.
After cooling the refrigerant enters the expansion valve as a saturated liquid.
The density of the CO_2 at the compressor suction is 34.66 kg/m^3.
The four cylinder single acting compressor has a bore and stroke of 100 mm with a volumetric efficiency of 85%.

(a) Sketch the cycle on Pressure-specific enthalpy and Temperature-specific entropy diagrams. (4)

(b) Using Datasheet Q6, calculate EACH of the following:

(i) the mass flow rate of refrigerant; (3)

(ii) the compressor power; (2)

(iii) the coefficient of performance; (2)

(iv) the compressor speed of rotation (5)

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7. A furnace wall consists of fire-brick 440 mm thick supported externally by 10 mm thick steel plating.
The internal temperature of the furnace is 1500°C and the temperature of the surroundings is 25°C.
To reduce heat loss it is proposed to remove some of the firebrick and replace it with insulation. However, the maximum temperature the insulation can withstand is 850°C.

Calculate EACH of the following:

(a) the rate of heat loss per m^2 without insulation; (5)

(b) the maximum permissible thickness of the insulation; (6)

(c) the percentage reduction in heat loss when the insulation is fitted. (5)

Note: inner surface heat transfer coefficient = 10 W/m²K
thermal conductivity of the fire-brick = 1.6 W/mK
thermal conductivity of steel = 50 W/mK
thermal conductivity of the insulation = 0.45 W/mK
outer surface heat transfer coefficient = 5 W/m²K

8. A two-stage, single acting reciprocating compressor has a clearance volume of 4.5% of the swept volume in each stage. It is used to compress methane (CH_4).
The initial pressure and temperature are 0.95 bar and 25°C respectively and the maximum temperature of the methane must be limited to 150°C.
The polytropic index for each compression and expansion process process is 1.3 and inter-cooling is perfect.

(a) Sketch the process on a Pressure-Volume diagram indicating the work saved by inter-cooling. (2)

(b) Calculate EACH of the following:

(i) the interstage and delivery pressures; (2)

(ii) the volumetric efficiency of each stage; (2)

(iii) the specific work input; (4)

(iv) the isothemal efficiency. (6)

Note: Relative atomic masses H=1, C=12
The universal gas constant = 8.3145 kJ/kmolK

9. The volume of the shell of a steam condenser is 14.5 m^3.
The shell contains saturated water, dry saturated steam and air, all at a temperature of 39°C and vacuum gauge reading of 672 mm of mercury.
The mass of water present is 112 grammes.
After a period of time the temperature of the condenser shell rises to 50°C.
The atmospheric pressure remains constant at 996 mbar throughout the temperature change.

Determine EACH of the following:

(a) the mass of air present; (3)

(b) the mass of dry saturated vapour; (2)

(c) the partial pressure of the steam at 50°C; (4)

(d) the condition of the steam at 50°C; (3)

(e) the condenser pressure at 50°C. (4)

Note : for air R= 0.287 kJ/kgK
1 bar = 750 mm Hg

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM

SUBJECT: 041-32-Applied Heat

DATE: 17h October 2016

General Comments on Examination Paper

It is commendable that many candidates had prepared for the examination, unfortunately a significant number had not realized that principles are few but methods are many (from Harrington Emerson). Choosing the latter led many to confusion and carrying out unnecessary calculations.
Numerous candidates failed to use the data given or use the correct values they had just calculated preferring instead to use a value apparently selected at random. A significant number used the same equation correctly and incorrectly in the same question, sometimes on the same page and also alongside each other, suggesting candidates are following a perceived method and not considering what it is they are trying to achieve or indeed what they are writing.

General Comments of Specific Examination Questions

Q1. The P-v diagram was generally good the T-s diagram less so. they should also be labeled and the process direction indicated. Absolute values should be used in calculations as should the values given, this question suffering badly from random numbers even though correct values had been calculated. There was confusion in calculating the specific entropy, usually by selecting the incorrect combination of equations. Those using the single equations given in a text published in India need to be aware that there is little scope to identify where an error has occurred the equation being either right or wrong.
Q2. The process diagrams were generally good unfortunately few seemed to use them to help with the calculations, eg. many showed constant volume and pressure heat supply but then only used constant volume for the calculations. The relationship between compression ratio, cut off ratio and stroke eluded many, consequently V_4 ranged from $0.0555V_2$ to $18V_2$ (TDC, BDC?) $0.722\ V_2$ was popular but incorrect. T_4 did not equal T_3 neither could it be calculated from an imagined heat supply. W_{net} is the difference between Q_{supply} and $Q_{rejected}$ not the addition of.
Q3. This required the candidates to work in kmols for 1 kg of fuel, not 1 kg of dry gas, 100kg of fuel or even 100 kmol of dry gas which was common. Gravimetric means mass and mass = n x M.
Wet gas contains H_2O,
Q4. The T-s diagram should show the superheat temp at inlet to the turbine above the critical temperature. Isentropic gives a vertical line A diagram showing the enthalpies in and out of the heater would help to fix the correct values. Some used the same values for work output and heat supply, using the T-s diagram, the area of which represents heat, would have prevented this.
Q5. Most produced the velocity diagram to the correct scale although more care could have been taken. A considerable number having drawn the diagram correctly, produced pages of calculations to give incorrect answers!! Care with units m^2s^{-2} relate to J/kg not kJ/kg.
Q6. The diagrams were variable, irreversible process should be indicated as such. The operating principle of a throttle seemed to confuse many. Most were able to correctly obtain values from the data sheet after which many used random numbers in the calculations. Several struggled with the correct units although they were given on the data sheet. Identifying the cylinder swept volume, cylinder induced volume and the refrigerant flow volume seemed to cause problems.
Q7. This was a flat wall not a pipe. Most obtained part a but failed to read the question and simply added another layer. The interaction between layers of insulation was not widely recognised. Most deduced the heat flow would change but did not recognise the value depends upon the unknown thickness of the new insulating layer. Two equations are required to solve this working from common points and known values.

Q8. Diagrams were poor, several could not determine M for methane. The max, temp in each cylinder was 150 and he stage pressure ratio was based on this. Some were able to calculate this but then did not know how a pressure ratio works. Some very basic errors occurred eg pressure ratio 4.33/0.95 = 1.4. An efficiency is always less than unity otherwise it is called something else eg COP. A considerable number produced values in excess of unity while others rearranged numbers to give a value they expected.
Q9. No meaningful feedback can be given as there were only two in complete attempts, candidates clearly do not like gas and vapour mixtures.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY –
MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 78 (as amended) CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY,11 JULY 2016

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A theoretical engine cycle consists of the following four sequential processes:
compression according to the law $pV^{1.28}$ from the initial conditions;
constant volume heat addition;
expansion according to the law $pV^{1.33}$ to the initial volume;
constant volume heat rejection to the initial temperature.

The initial pressure and temperature are 1 bar and 43°C.

The volume compression ratio is 13:1.

The heat addition is 1200 kJ/kg of working fluid.

The working fluid has the properties of air throughout.

(a) Sketch the cycle on Pressure-Volume and Temperature-specific entropy diagrams. (4)

(b) Calculate EACH of the following:

(i) the heat transfer during the compression process; (6)

(ii) the heat transfer during the expansion process; (2)

(iii) the cycle efficiency. (4)

Note: for air $c_v = 0.718$ kJ/kgK, $R = 0.287$ kJ/kgK

[OVER

2. Air enters the compressor of simple gas turbine plant at a pressure and temperature of 1.013 bar and 298 K respectively and is compressed through a pressure ratio of 12:1 with an isentropic efficiency of 0.85.

The hot gases enter the turbine at a temperature of 1500 K and expand down to the initial pressure with an isentropic efficiency of 0.9.

The mass flow rate of air is 250 kg/min and the mass flow rate of fuel may be ignored.

(a) Sketch the cycle on a Temperature-specific entropy diagram. (2)

(b) Calculate EACH of the following:

(i) the compressor outlet temperature; (2)

(ii) the turbine outlet temperature; (2)

(iii) the net power output; (5)

(iv) the work ratio; (2)

(v) the thermal efficiency of the cycle. (3)

Note: for air $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*
for the hot gas $\gamma = 1.33$ *and* $c_p = 1.15$ *kJ/kgK*

3. A producer gas has the following volumetric composition: 49% H_2, 20% CH_4, 18% CO, 6% N_2, 4% CO_2, 2% C_3H_8, 1% O_2.

The gas is completely burned in 20% excess air.

Calculate EACH of the following:

(a) the volumetric air/fuel ratio for stoichiometric combustion; (6)

(b) the percentage volumetric analysis of the wet combustion products; (6)

(c) the gravimetric analysis of the dry products of combustion. (4)

Note: Relative atomic masses carbon = 12, hydrogen = 1, oxygen = 16, nitrogen = 14.
Air contains 21% oxygen by volume.

4. In a steam power plant, steam enters the turbine at a pressure and temperature of 60 bar and 500ºC respectively and expands to 0.08 bar dryness fraction 0.95.

There is 5.5 K sub-cooling in the condenser and the feed pump work may be ignored.

The boiler has an efficiency of 80% when burning fuel with a carbon content of 90% by mass and a calorific value of 39 MJ/kg.

The carbon dioxide in the exhaust gas is to be extracted which will reduce the work output by 1 MJ/kg CO_2 generated.

Calculate EACH of the following:

(a) the thermal efficiency of the plant before the CO_2 extraction takes place; (6)

(b) the mass flow of fuel per kg of steam produced; (2)

(c) the thermal efficiency when the CO_2 extraction takes place. (8)

5. The speed of rotation of a stage in a 50% reaction turbine is 4000 rev/min.

The mean blade velocity is 150 m/s and the mean blade height is 30 mm.

The blade speed ratio is 0.6 and the blade exit angle is 20º.

The specific volume of the steam at this stage is 0.65 m^3/kg.

(a) Sketch the velocity vector diagram for the stage and identify ALL velocities. (3)

(b) Calculate EACH of the following:

(i) the absolute velocity of the steam leaving the stage; (3)

(ii) the diagram efficiency for the stage; (3)

(iii) the mass flow of steam through the turbine in tonne/hour; (4)

(iv) the specific enthalpy drop across the stage. (3)

6. A vapour compression refrigeration plant using R134a operates between saturation temperatures of -20°C and +25°C.

The plant produces 200 kg/hour of ice at -12°C from water at +20°C.

The refrigerant enters the expansion valve at the rate of 531 kg/hour with 5 K of sub-cooling.

The isentropic efficiency of the compressor is 93.1%.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Calculate EACH of the following:

(i) the temperature of the refrigerant entering the compressor; (4)

(ii) the temperature of the refrigerant leaving the compressor; (6)

(iii) the cycle co-efficient of performance. (2)

Note: for water c_p = 4.187 kJ/kgK
for ice c_p = 2.1 kJ/kgK and enthalpy of fusion = 335 kJ/kg

7. An insulated container 3 m long, 2.4 m wide and 2.6 m high consists of an insulating layer of 200 mm thick cork placed between an inner layer of 5 mm thick aluminium and an outer layer of 5 mm thick steel.

The exposed surface of the aluminium is at -15°C when the outside atmosphere is at +25°C.

Calculate EACH of the following:

(a) the heat flow into the container per hour; (8)

(b) the interface temperatures between the cork and the steel; (3)

(c) the emissivity of the aluminium at -15°C when the contents of the container are at -25°C and the net emissive power from the aluminium is 15% of the value calculated in Q7(a). (5)

Note: thermal conductivity of aluminium = 205 W/mK
thermal conductivity of cork = 0.04 W/mK
thermal conductivity of steel = 54 W/mK
outer surface heat transfer coefficient =13 W/m^{2}K
Stefan-Boltzmann constant σ_{sb} = 56.7 x10^{-12} kW/m^{2}K^4

8. A two stage, single acting reciprocating air compressor is designed for minimum work and has perfect inter-cooling.

The pressure and temperature at inlet are 1 bar and 20°C respectively, the discharge pressure is 36 bar.

The swept volume of the first stage is 0.01 m^3 and the clearance volume is 3% of the swept volume.

The polytropic index for all the expansion and compression processes is 1.2, the mechanical efficiency of the compressor is 0.8 and the speed is 240 rev/min.

(a) Sketch the processes on a p-V diagram indicating the pressures and volumes. (4)

(b) Calculate EACH of the following:

(i) the first stage volumetric efficiency; (3)

(ii) the mass of air delivered per second; (4)

(iii) the input power. (5)

Note: for air R = 0.287 kJ/kgK

9. (a) State Dalton's law of partial pressures. (4)

(b) A reservoir containing a mixture of air and 375 grams of steam at a temperature of 250°C, has a volume of 0.6 m^3.

A gauge indicates a reservoir pressure of 2.1 bar when the atmospheric pressure is 744 mm of mercury.

Determine EACH of the following:

(i) the partial pressure of the steam; (4)

(ii) the mass of the air in the reservoir; (3)

(iii) the total enthalpy of the mixture. (5)

Note: for air *R = 0.287 kJ/kgK*, *γ = 1.4*
750 mm of Hg = 1 bar

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32-Applied Heat

DATE: 25th July 2016

General Comments on Examination Paper Candidates should:Read the question carefully and produce a solution based on what has been asked using the data given. Apply the given units and use them to confirm the correct equation, e.g. the concept of an efficiency as a non dimensional ratio eluded numerous candidates. Consider and practice the layout of questions, some failed to complete solutions in an apparent attempt to fit everything on a single page. Take care when using a calculator.
General Comments of Specific Examination Questions Q1. Most candidates were able to produce the P-v diagram but then failed to use it in their solution leading to numerous errors in process identification. The T-s diagram was poorly drawn in most cases, some showing an anticlockwise direction! Theoretical does not mean air standard. For a polytropic process heat is the summation of work AND internal energy. Q2. A simplified SFEE applies which requiring candidates to obtain the specific enthalpy at EACH cardinal point. Numerous candidates applied the mass flow to the compressor only, an error which would have been highlighted had the units been given due consideration. Q3. The majority of the candidates attempting this question wasted their time producing the full combustion equation. Part a required the stoichiometric O_2 by balancing the carbon and hydrogen then converting this to air. Part b then applies the excess air to answer a which also gives the total nitrogen some of which is from the fuel. Q4. Few attempts at this question. All obtained the correct data but then failed to apply the SFEE correctly. Q5. Most produced the velocity diagram but then struggled with the required (trig) calculations. There was confusion using subscripts as in axial, absolute and relative. The symbol for fluid velocity is “C”. Q6. A popular question. The diagrams were variable and for the most part inaccurate. The majority of candidates produced a solution using erroneous assumptions rather than the given facts. i.e. start at a known point, in this case the expansion valve, the cooling load (which many ignored) gives the specific enthalpy at compressor suction and the condition is obtained from the tables. Isentropic compression and application of the efficiency gives the actual condition at discharge. Q7. A popular question but few were able to calculate the surface area correctly (some used the volume). Those using Fourier’s equation made less errors than those using the electrical analogy, some attempted a solution based on a composite pipe. The Stefan Boltzmann equation requires the absolute temperatures and the units of heat to be the same as the Stefan Boltzmann constant. T_2^4-T_1^4 is not equal to ΔT^4 Q8. A popular question. Many candidates produced a poor diagram not showing the volumes as required. Consequently many confused the induced, swept and total volume. The conversion of volume per cycle to a mass flow seemed to cause problems. Numerous candidates also considered this to be a single stage machine. Q9. Few attempts, PV=mRT applies to gas only. Two property rule applies to gas and vapour e.g vapour specific volume and temperature give steam pressure from tables. Absolute pressure is required for calculations and tables.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 4 APRIL 2016

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A volume of 0.02 m^3 of air at a pressure and temperature of 1.05 bar and 15°C respectively is heated at constant volume until the pressure is 4.2 bar. It is then cooled at constant pressure to the initial temperature.

(a) Sketch the processes on a Temperature-specific entropy diagram. (3)

(b) Calculate EACH of the following:

(i) the net heat flow; (8)

(ii) the net change in entropy. (5)

Note: for air R = 0.287 kJ/kgK and γ = 1.4

2. A Morse test was carried out on a 4 cylinder, 4 stroke compression ignition engine and the following data was noted.

Engine speed 3000 rev/min,
Full load brake torque 255 Nm.
Air fuel ratio by mass 30:1,

Morse test result				
Cylinder cut out	1	2	3	4
Brake Power kW	57.77	57.40	57.11	57.90

Data Table						
	Flow rate Litres/ min	specific heat capacity kJ/kg,	inlet temperature °C	outlet temperature °C	Density kg/m^3	Calorific values MJ/kg
cooling water	9.87	4.18	48	80	1000	
lubricating oil	46.21	2.1	40	48	850	
Air			45			
Gas		1.15		450		
Fuel	0.344				720	43

(a) Calculate EACH of the following:

(i) the indicated power; (3)

(ii) the brake specific fuel consumption; (3)

(iii) the indicated thermal efficiency. (2)

(b) Draw up an energy balance as a percentage of the total energy supplied. (8)

3. A fuel of mass analysis 84% carbon and 16% hydrogen is completely burned in air. The dry flue gas analysis shows they contain 81% nitrogen by volume.

(a) Determine, using molar volumes, the full combustion equation for 1 kg of fuel. (8)

(b) Calculate EACH of the following:

(i) the air fuel ratio by mass; (2)

(ii) the mass of water condensed per kg of fuel when the flue gas is at 1.01 bar and 20°C. (6)

Note: Relative atomic masses H =1, C =12, N =14, O =16
Air contains 21% oxygen by volume.
The Molar mass of air may be taken as 29 kg/kmol.

4. In a regenerative steam power plant, steam enters the turbine at a pressure and temperature of 30 bar and 450°C respectively.
It then expands isentropically to a dry saturated condition at which point some steam is bled off to a direct contact feed heater.
The feed water leaves the heater 4.5 K below the saturation temperature of the bled steam pressure.
The remainder of the steam expands isentropically to a condenser pressure of 0.035 bar.
There is no under cooling in the condenser and the feed pump work may be ignored.

(a) Sketch the cycle on a temperature- specific entropy diagram. (4)

(b) Determine EACH of the following:

(i) the mass flow rate of bled steam per kg of steam flowing; (5)

(ii) the specific work output; (4)

(iii) the thermal efficiency of the cycle. (3)

5. The first stage of an impulse turbine is velocity compounded with two rows of moving blades.

The steam leaves the nozzles with an absolute velocity of 800 m/s at an angle of 17° to the plane of rotation.

The mean blade diameter is 750 mm and the exit angle from the first row of moving blades, the fixed blades and the second row of moving blades are 22°, 28° and 36° respectively.

The blade velocity coefficient is 0.92 over each of the three rows of blades.

The mass flow rate of steam is 6 tonne/hour and the turbine shaft speed is 3500 rev/min.

Determine EACH of the following:

(a) the fixed and moving blade inlet angles; (8)

(b) the power developed; (4)

(c) the axial thrust acting on the rotor. (4)

6. In a vapour compression refrigeration cycle Ammonia is compressed between saturation temperatures of -12°C and +22°C.
The refrigerant is dry saturated at entry to the compressor and leaves the condenser with 4 degrees of under-cooling.
The cooling load is 1.5 MW and the isentropic efficiency of the compressor is 82%.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Determine EACH of the following:

(i) the co-efficient of performance; (6)

(ii) the compressor power in kW; (2)

(iii) the Carnot co-efficient of performance between the same pressure limits. (4)

7. An annular cooling water jacket surrounds a 75 mm mean diameter pipe carrying a hot gas, in a counter flow arrangement.
The hot gas enters the cooler at 350°C and leaves at 100°C. The cooling water enters the cooler at 10°C.
The flow rate of the gas is 200 kg/hour and that of the water is 1400 kg/hour.
The wall thickness of the pipe may be ignored.

Calculate EACH of the following:

(a) the exit temperature of the water; (4)

(b) the log mean temperature difference; (6)

(c) the length of the cooler. (6)

Note: for cooling water c = 4.19 kJ/kgK
for the hot gas c_p *= 1.13 kJ/kgK*
the inner surface heat transfer coefficient = 0.3 kW/m^2*K*
the outer surface heat transfer coefficient = 1.5 kW/m^2*K*

8. In a single acting two stage reciprocating air compressor, air is compressed from an inlet pressure and temperature of 0.9 bar and 20°C respectively to a delivery pressure of 12 bar.

The low pressure cylinder has a bore of 250 mm, stroke of 160 mm and the clearance volume is 2.5% of the swept volume.

The air enters the second stage at a pressure and temperature of 3 bar and 35°C respectively.

The compressor speed is 300 rev/min.
The index of compression and expansion in both stages is 1.25.
The mechanical efficiency is 0.85.

(a) Sketch the process on a p-V diagram. (2)

(b) Calculate EACH of the following:

(i) the free air delivered per hour at free air conditions of 1 bar and 15°C; (6)

(ii) the input power required to drive the compressor; (5)

(iii) the heat removed in the inter-cooler. (3)

Note: *for air R = 0.287 kJ/kgK* c_p *= 1.005 kJ/kgK*

9. Steam enters a convergent-divergent nozzle with negligible velocity and expands into a space at 5 bar.

At inlet the pressure is 15 bar and temperature is 400°C.

The process from the inlet to the throat is isentropic with an index of 1.37.

The process from the throat to the exit has an isentropic efficiency of 0.9.

Calculate EACH of the following:

(a) the condition of the steam at the throat; (4)

(b) the velocity of the steam at the throat; (3)

(c) the throat area for a mass flow of 1 kg/s; (4)

(d) the exit velocity. (5)

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32-Applied Heat

DATE: 18th April 2016

General Comments on Examination Paper

Candidates should:

Read and heed the instructions given on the examination workbook;

Read the question carefully and produce a solution based on what has been asked using the data given.

General Comments of Specific Examination Questions

Q1. Popular question showing a range of marks. Those producing good property diagrams tended to produce accurate solutions. Common errors were, failure to use the mass of gas, confusing units and using a calculator.

Q2 Some good attempts, however numerous candidates confused Brake and indicated power, power with torque, specific fuel consumption (mass flow per hour /power) with Thermal efficiency (Power output / heat input)

Q3. Numerous candidates confused mass and moles (mass = n x M) and based calculations on 100kg rather than the 1 kg stated. bii required candidates to determine the moles of H_2O remaining in the gas the difference having condensed (P_{h2o}/ P_{total} = n_{h20} /n_{total})

Q4. Few attempts at this question. Most were able to determine the mass of bled steam but some failed to realise that this reduced the mass flow in the turbine after the extraction point. There were also errors in obtaining the correct data from the tables.

Q5. A popular question, those producing a better proportioned diagram had more accurate solutions and were able to answer the question fully.

Q6. A popular question. The diagrams were variable and for the most part inaccurate, there were also careless errors obtaining data from the tables. For the Carnot cycle it is best to use $Q=T\Delta s$ and apply the second law of thermodynamics

Q7. A popular question which was generally well executed. However there were a significant number of careless errors leading to inaccurate answers examples being 10 + 9.6 does not equal 29.6 and heat exchangers rarely have tubes 2km long.

Q8. A popular question. The stage pressure ratios were not equal. The free air delivery is based on induced volume not the total volume (confusion between V_1 and V_i). Confusion with units particularly volume per cycle, per second and per hour.

Q9. Few attempts at this steam nozzle. However some failed to notice the working fluid therefore erroneously used $h = c_p \times T$.

Marker:

Signature: ______________________________ Date April 2016

Note

There should be two copies of this document produced and forwarded to SQA. One copy must be a hard copy with the Markers name and signature the other an electronic copy without. There must be no reference to any college or student in this document as it may be forwarded to other colleges for information. If there are any confidential comments they <u>must</u> be made in part 2 and will be kept by the MCA and SQA for quality audit purposes.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY –
MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 14 December 2015

1315 - 1615 hrs

Examination paper inserts:

Worksheet Q4 Specific Enthalpy – Specific Entropy Chart for Steam

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook Graph paper ‘Thermodynamic and Transport Properties of Fluids’ by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. In an Ideal diesel cycle the pressure and temperature at the start of compression are 1.0 bar and 57°C respectively. The volume compression ratio is 16:1 and the heat energy added at constant pressure is 1250 kJ/kg.

   (a) Sketch the cycle on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the cycle efficiency; (6)

   (ii) the mean effective pressure. (6)

   Note: f*or air* c_p *= 1.005 kJ/kgK and* $\gamma = 1.4$

2. Air enters an open cycle gas turbine plant at a pressure and temperature of 1.013 bar and 27°C respectively and is compressed to 12.5 bar.

   The hot gases leave the combustion chamber and enter the turbine at a pressure of 12.5 bar and a temperature of 827°C expanding in two stages of equal pressure ratio to the initial pressure.

   The gases are reheated to 827°C between the turbine stages.
   The isentroic efficiency of the compressor is 0.8.
   The isentropic efficiency of each turbine stage is 0.85.
   The mass flow rate of fuel may be ignored.

   (a) Sketch the cycle on a Temperature-specific entropy diagram. (4)

   (b) Calculate EACH of the following:

   (i) the compressor outlet temperature; (4)

   (ii) the second stage turbine outlet temperature; (4)

   (iii) the work ratio. (4)

   Note: *for air* $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*
   for the hot gas $\gamma = 1.33$ *and* $c_p = 1.15$ *kJ/kgK*

[OVER

3. A marine diesel engine produces 60 MW of brake power with a brake thermal efficiency of 47% when completely burning a residual fuel oil.

The residual fuel consists of 96% hydrocarbon with a chemical formula of $C_{30}H_{62}$ and 4% non-combustible ash.

The air fuel ratio is 30:1.

Calculate EACH of the following:

(a) the lower calorific value of the residual fuel; (4)

(b) the mass flow rate of the fuel; (2)

(c) the gravimetric analysis of the exhaust gas. (10)

Note: Atomic mass relationships carbon = 12, hydrogen = 1, oxygen = 16.
the calorific value of carbon = 32.8 MJ/kg
the lower calorific value of hydrogen = 120.9 MJ/kg
Air contains 23% oxygen by mass

4. A three stage steam turbine with reheat operates under the following design conditions.

First stage: isentropic expansion from 60 bar 450°C to 10 bar, followed by constant pressure reheat to 370°C.
Second stage: isentropic expansion to 2 bar, followed by constant pressure reheating to 320°C.
Third stage: isentropic expansion to a condenser pressure of 0.2 bar.

The plant is also capable of operating with the re-heaters bypassed giving a single isentropic expansion from 60 bar 450°C to 0.2 bar.

In both cases there is no under cooling in the condenser and the feed pump work may be ignored.

(a) Plot on Worksheet Q4:

(i) the design expansion and reheat processes; (3)

(ii) the bypass expansion process. (1)

(b) Determine EACH of the following:

(i) the specific power output under the design conditions; (4)

(ii) the designed thermal efficiency of the cycle; (3)

(iii) the thermal efficiency of the cycle with the re-heaters by passed. (2)

(c) State the MAIN reason why the plant has been designed with reheat. (3)

5. The fixed blades of a particular stage in a 50% reaction turbine deliver 14 kg/s of steam at pressure of 4 bar and temperature of 200ºC.

The blade inlet and outlet angles are 30º and 20º respectively and the mean blade speed is 60 m/s.

The blade height is one tenth of the mean blade ring diameter and the stage efficiency is 0.85

(a) Sketch the velocity vector diagram for the stage and identify ALL velocities. (4)

(b) Calculate EACH of the following:

(i) the blade height; (4)

(ii) the power developed in the stage; (3)

(iii) the diagram efficiency for the stage; (3)

(iv) the specific enthalpy drop across the stage. (2)

6. In a vapour compression refrigeration plant using refrigerant R134a, the refrigerant enters the compressor at a pressure of 1.0637 bar and after isentropic compression leaves at a pressure and temperature of 7.7 bar 50ºC respectively.

The refrigerant leaves the condenser at the rate of 20 kg/min with 5 K of sub-cooling.

(a) Sketch the cycle on EACH of the following:

(i) a P-h diagram indicating the refrigeration effect, compressor work and condenser heat rejection; (2)

(ii) a T-s diagram, indicating superheat and sub-cooling. (2)

(b) Determine EACH of the following:

(i) the condition of the refrigerant at the compressor suction; (4)

(ii) the compressor power required; (3)

(iii) the heat rejection in the condenser; (3)

(iv) the coefficient of performance. (2)

7. Dry saturated steam at 14 bar enters a steam pipe 50 m long with an outer diameter of 150 mm. The pipe is covered with an inner layer of moulded insulation 50 mm thick and an outer layer of mineral felt 30 mm thick.

The mass flow rate of steam in the pipe is 500 kg/hr.

The air temperature surrounding the pipe is 15°C.

Calculate EACH of the following:

(a) the rate of heat loss from the pipe; (8)

(b) the mass of steam condensed per hour. (8)

Note: inner heat transfer coefficient of the pipe = 1000 W/m²K
thermal conductivity of moulded insulation = 0.075 W/mK
thermal conductivity of mineral felt = 0.15 W/mK
outer heat transfer coefficient of the pipe = 13W/m²K

8. A single cylinder single acting air compressor has a bore of 268 mm and stroke of 535 mm with a clearance volume of 1.7 litres.

Air is induced at a pressure and temperature of 1 bar and 27°C respectively.

The law for both expansion and compression process is $pV^{1.3} = C$.

The temperature after compression is 225°C.

The compressor has a mechanical efficiency of 0.88 when delivering 650 kg/hr.

(a) Sketch the process on a p–V diagram, indicating ALL volumes. (3)

(b) Calculate EACH of the following:

(i) the delivery pressure; (2)

(ii) the volumetric efficiency; (4)

(iii) the input power at full load; (3)

(iv) the full load speed. (4)

Note: for air R = 0.287 kJ/kgK

9. An ideal gas mixture has the following mass composition: carbon monoxide 30%, hydrogen 18%, methane (CH_4) 10% and nitrogen 42%.

The mixture is isentropically compressed in a gas tight cylinder, from an initial pressure and temperature of 1.5 bar and 27°C respectively to a final pressure of 6 bar.

Calculate EACH of the following:

(a) the specific enthalpy of the mixture before compression; (4)

(b) the characteristic gas constant for the mixture; (3)

(c) the specific internal energy of the mixture after compression; (5)

(d) the volumetric composition of the mixture. (4)

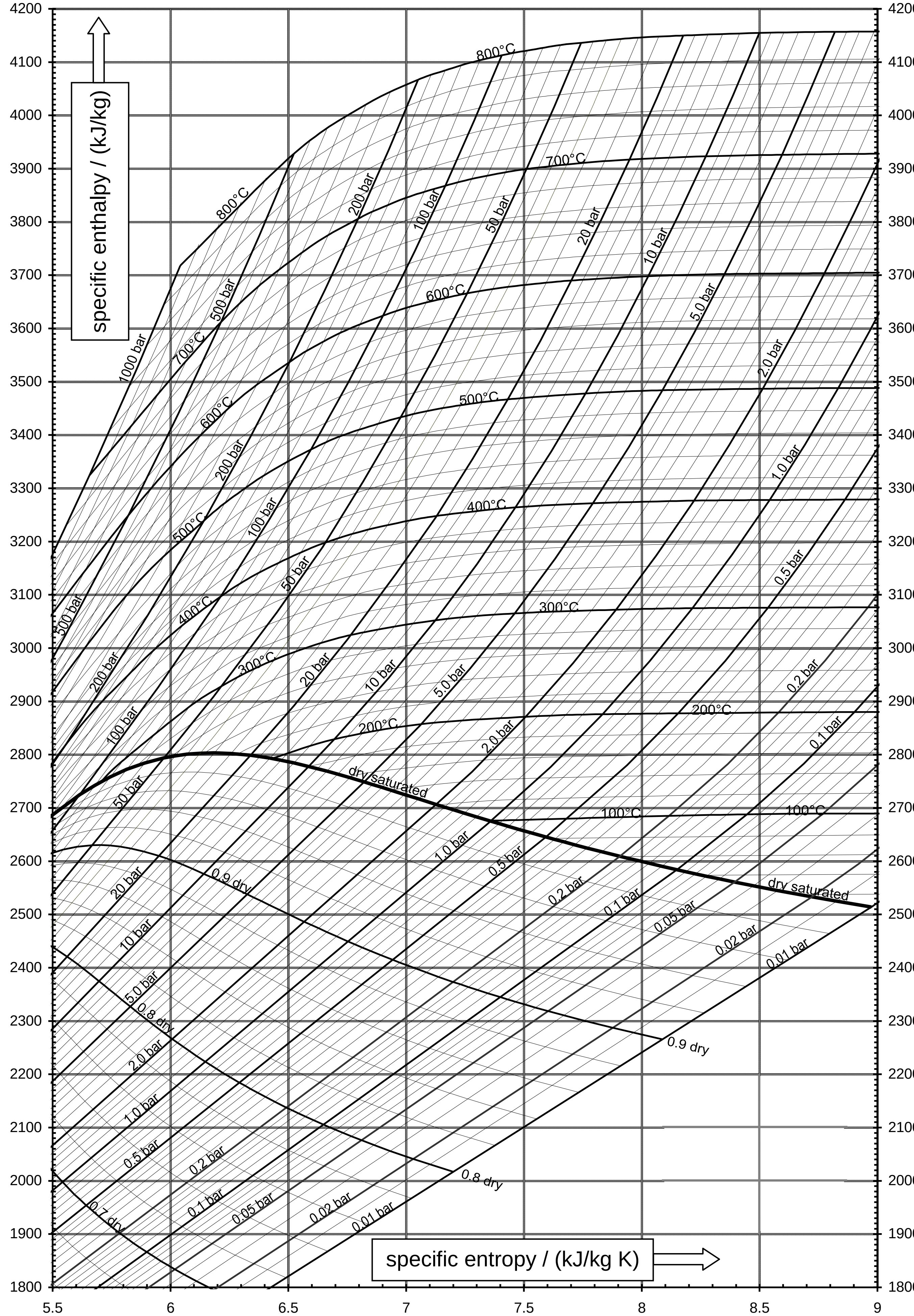
Note: *the universal gas constant = 8.3145 kJ/kmolK.*
for each constituent gas the values of c_p *at 300 K are:*
carbon monoxide = 1.040 kJ/kgK, hydrogen = 14.31 kJ/kgK,
methane = 2.226 kJ/kgK and nitrogen = 1.040 kJ/kgK .
Atomic mass relationships: H =1, C = 12, N = 14, O = 16.

041-32 APPLIED HEAT **WORKSHEET Q4** **14 DECEMBER 2015**

(This worksheet must be returned with your answer book)

Enthalpy Entropy Chart for Steam

(prepared at Glasgow College of Nautical Studies using data from NEL Steam Tables 1964 and other formulations: for exercises only)



Candidate's Name .... Examination Centre ....

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32-Applied Heat

DATE: 28th December 2015

General Comments on Examination Paper Candidates should read the questions carefully and answer accordingly. When asked to "Calculate" the values are obtained using formula, whereas if asked to "Determine" candidates may use graphs charts, tables and diagrams as well as formula to obtain values.
General Comments of Specific Examination Questions Q1. Popular question showing a range of marks. Those producing good property diagrams tended to obtain higher marks. Common errors included, use of the calculator, failing to use absolute values and confusing heat with work and entropy. Q2 In most solutions the property diagram was incorrect, consequently few realised that turbine stage pressure was √ of the overall pressure ratio and with the same inlet temperature the turbine values were identical. Q3. Numerous candidates confused mass and moles. Producing a percentage mass analysis of the fuel (mass = n x M) enabled calculations to based on mass throughout. Q4. Few attempts at this question which required candidates to plot given points on the h-s chart. Examination of the diagram obtained showed the design expansion superheat throughout providing a solution to part c, the remainder of the question required the addition of enthalpy changes. Q5. This question stated calculate! The vector diagram, which most candidates produced was to assist the calculation. It was a steam turbine, PV=MRT applies to GAS only. Q6. A popular question. The diagrams were variable but most were able to label them correctly. The starting point was the compressor outlet and isentopic means $S_2 = S_1$ not $h_2 = h_1$ and $S_2 › S_g$ at compressor suction. Numerous candidates appeared to be confused by this as well as by the isenthalpic expansion process. Q7. A popular question. Most achieved part "a" although there were calculation and formula errors. Part "B" required the dryness fraction at the outlet to be obtained hence the condensation per kg was 1-x. Calculations based on unit mass flow simplified the procedure. Q8. A popular question which in most cases was well executed however some candidates confused the induced, swept and total cylinder volumes. Q9. Few attempts at this gas mixture question. The combustion equation was not required. Values of c_p were given and $h = c_p$ x T.

Marker:

Signature: ______________________________ Date December 2015

Note

There should be two copies of this document produced and forwarded to SQA. One copy must be a hard copy with the Markers name and signature the other an electronic copy without. There must be no reference to any college or student in this document as it may be forwarded to other colleges for information. If there are any confidential comments they <u>must</u> be made in part 2 and will be kept by the MCA and SQA for quality audit purposes.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 12 OCTOBER 2015

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate's examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A volume of 1 m^3 of air at a pressure and temperature of 4 bar and 150°C respectively expands isentropically to 1 bar, after which 120 kJ of heat is added at constant pressure.

   The two processes can be replaced with a single polytropic process operating between the same initial and final states.

   (a) Sketch the processes on Pressure-Volume and Temperature-specific entropy diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the original total work done; (6)

   (ii) the index of expansion for the single polytropic process; (2)

   (iii) the total change in entropy. (4)

   Note: For air c_p= 1.005 kJ/kgK, R = 0.287 kJ/kgK and γ = 1.4

2. A six cylinder 4 stroke diesel engine has a bore of 230 mm and stroke of 600 mm. The brake mean effective pressure is 8 bar at 900 rev/min and the brake specific fuel consumption is 0.139 kg/kWh when burning a fuel with a calorific value of 46 MJ/kg.
   The air to fuel ratio by mass is 28:1 at atmospheric conditions of 0.95 bar and 17°C.

   (a) Show that the brake mean effective pressure is directly proportional to engine torque and independent of speed. (4)

   (b) Calculate EACH of the following:

   (i) the shaft torque; (2)

   (ii) the brake thermal efficiency; (4)

   (iii) the volumetric efficiency of the engine. (6)

   Note: For air R = 0.287 kJ/kgK

[OVER

3. A pure hydrocarbon fuel has the chemical formula C_nH_{2n+2} (where n is a positive integer).
When the fuel is burned in air the dry flue gas analysis shows they contain 10.50% carbon dioxide, 0.95% carbon monoxide, 4.55% oxygen by volume.

Calculate EACH of the following:

(a) the chemical formula of the fuel; (10)

(b) the percentage excess air supplied. (6)

Note: Relative atomic masses H=1, C=12, N=14, O=16
Air contains 21% oxygen by volume.

4. Steam enters the high pressure stage of a turbine at a pressure and temperature of 60 bar 450°C respectively and expands to 15 bar with an isentropic efficiency of 0.697.
The steam then enters a low pressure stage where it expands to 0.05 bar during which it develops 60% of the total power generated.
There is no under cooling in the condenser and the feed pump work may be ignored.

(a) Determine EACH of the following:

(i) the steam condition at the inlet to the low pressure turbine; (4)

(ii) the steam condition at the outlet from the low pressure turbine; (4)

(iii) the specific steam consumption; (2)

(iv) the thermal efficiency of the cycle. (2)

(b) Sketch the cycle on a temperature-specific entropy diagram. (4)

5. The nozzle angle of a two row Curtis wheel is 20º to the plane of rotation and the isentropic enthalpy drop in the nozzle is 222 kJ/kg.

The fixed and moving blade rows are symmetrical each with a velocity coefficient of 0.95.

The mean blade speed is 150 m/s and nozzles have an isentropic efficiency of 90%.

(a) Calculate the nozzle exit velocity. (2)

(b) Draw to a scale of 1 mm = 5 m/s the velocity diagram for each row. (6)

(c) Determine EACH of the following:

(i) the magnitude of the steam velocity entering and leaving each blade; (2)

(ii) the fixed and moving blade angles; (2)

(iii) the total blade work per kg of steam flowing; (2)

(iv) the diagram efficiency. (2)

6. A vapour compression refrigeration cycle using Ammonia operates between saturation temperatures of -24°C and +20°C.
The refrigerant enters the compressor as a dry saturated vapour and during compression the specific entropy increases by 2.95 %.
After cooling it enters the expansion valve as a saturated liquid.
The compressor has a stroke of 200 mm and a bore of 100 mm, with a volumetric efficiency of 85% at 300 rev/min.
The mechanical efficiency of the drive is 90%.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Calculate EACH of the following:

(i) the mass flow of refrigerant; (4)

(ii) the cooling load based on the mass flow obtained Q6b(i); (2)

(iii) the input power; (4)

(iv) the coefficient of performance of the plant, including the mechanical efficiency of the drive. (2)

7. A steel pipe 100 mm bore and 10 mm wall thickness carries dry saturated steam at 12 bar.
It is covered with a 50 mm layer of moulded insulation which in turn, is covered with a 60 mm layer of felt.
This combination gives an outer surface temperature of 30°C.
The felt is to be replaced with a new insulation which will maintain the original heat transfer rate but requires an interface temperature of 82.5°C between the felt and the insulation.

Calculate EACH of the following:

(a) the original rate of heat loss per unit length of pipe; (8)

(b) the change in the moulded insulation thickness to maintain the required condition. (8)

Note: inner surface heat transfer coefficient = 550 W/m²K
thermal conductivity of moulded insulation = 0.07 W/mK
thermal conductivity of felt = 0.09 W/mK

8. In a single acting two-stage reciprocating air compressor with negligible clearance, 30 m³ of air per minute are compressed through an overall pressure ratio of 16:1.
The initial pressure and temperature are 1 bar and 27°C respectively.
The pressure ratio in each stage is the same.
The polytropic index for each compression process is 1.35.
Inter-cooling is perfect and the mechanical efficiency of the compressor is 0.92.

(a) Sketch the process on a p-V diagram indicating the work saved by inter-cooling. (2)

(b) Calculate EACH of the following:

(i) the power input to the compressor; (4)

(ii) the heat transfer in the inter-cooler; (4)

(iii) the heat transfer to the jacket cooling during compression. (6)

Note: for air R = 0.287 kJ/kgK c_v *= 0.718 kJ/kgK*

9. A perfect gas at a pressure and temperature of 7 bar and 93°C respectively enters a circular section convergent-divergent nozzle with a negligible velocity.

It expands isentropically into a space at 3.6 bar.

The cross-sectional area of the nozzle throat is 0.196 m^2.

Calculate EACH of the following:

(a) the critical pressure; (4)

(b) the mass flow through the nozzle; (6)

(c) the diameter of the nozzle at exit. (6)

Note : *for the gas molecular mass M = 30 kg/kmol,* c_v *= 1.383 kJ/kgK*
The universal gas constant = 8.3145 kJ/kmolK

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 23 MARCH 2015

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate's examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. An ideal gas is heated in a cylinder at constant volume from a temperature of 300 K to a temperature of 1208 K. The initial pressure and volume are 1.02 bar, 0.084 m^3respectively.

   It is further heated at constant pressure to 1474 K. The gas then expands isentropically to ten times the initial volume.

   The change in specific entropy for the first process is 1.0 kJ/kgK and in the second process it is 0.2 kJ/kgK.

   (a) Sketch the p-V and T-s diagrams. (5)

   (b) Calculate EACH of the following:

   (i) the values of c_v, c_p, and γ for the gas; (3)

   (ii) the final temperature of the gas; (2)

   (iii) the specific work transfer. (6)

2. In an air standard diesel cycle the volume compression ratio is 18:1 and the volume cut off ratio is 1.8:1. The minimum pressure and temperature are 0.95 bar and 303 K respectively.

   (a) Sketch the cycle on a T-s diagram. (3)

   (b) Calculate EACH of the following:

   (i) the temperatures and pressures at the cardinal points in the cycle; (5)

   (ii) the thermal efficiency; (4)

   (iii) the mean effective pressure. (4)

   Note: For air $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*

3. A fuel with a mass analysis of 85% carbon 15% hydrogen is completely burned in air. The dry flue gas shows they contain 3.5% oxygen by volume.

(a) Use molar volumes to formulate the complete combustion equation in kmol per kg of fuel. (10)

(b) Calculate EACH of the following:

(i) the percentage excess air by volume; (3)

(ii) the fuel air ratio by mass. (3)

Note: Relative atomic masses H=1, C=12, N=14, O=16. Air contains 21% oxygen by volume

4. (a) A Carnot vapour power cycle uses saturated steam and water as the working fluid and operates between pressures of 0.05 bar and 80 bar.

(i) sketch the cycle on p-v and T-s diagrams; (2)

(ii) determine the thermal efficiency of the cycle; (2)

(iii) determine the specific steam consumption. (2)

(b) An Ideal Rankine vapour power cycle operates between the same pressure as the Carnot cycle in Q4(a). The steam is dry saturated at the beginning of expansion and there is no undercooling in the condenser.

(i) sketch the cycle on p-v and T-s diagrams; (2)

(ii) determine the thermal efficiency of the cycle; (6)

(iii) determine the specific steam consumption. (2)

5. In a 50% reaction turbine stage, the blade-to-steam speed ratio is 0.75 and the fixed blade outlet angle is 28°. The blade work is 35 kJ/kg and the mean blade ring diameter is 800 mm.

(a) Sketch the velocity vector diagram labelling all the velocities and angles. (5)

(b) Calculate EACH of the following:

(i) the blade inlet angle; (2)

(ii) the speed of rotation of the turbine rotor; (5)

(iii) the diagram efficiency. (4)

6. A reversed Carnot cycle uses Ammonia as the working fluid. The Ammonia is dry saturated at the end of compression and leaves the condenser as a saturated liquid. The cycle operates between temperatures of -12°C and 34°C respectively.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Determine EACH of the following:

(i) the dryness fraction at the compressor inlet; (2)

(ii) the coefficient of performance; (2)

(iii) the refrigerating effect per kg of ammonia. (4)

(c) Give TWO reasons why such a cycle would not be used in practice. (4)

7. An LNG carrier has three spherical tanks each of 55 m diameter. The tanks contain liquefied natural gas at a temperature of -163°C in a surrounding air temperature of 30°C.
The tanks are insulated with 300 mm of polyurethane foam.

The thermal resistance of the tank wall and internal fluid film may be disregarded.

Determine EACH of the following:

(a) the rate of heat flow into one tank in kW; (10)

(b) the total mass of gas which boils off each day. (6)

Note: The thermal conductivity of the polyurethane foam is 0.06 W/mK.
The outside surface heat transfer coefficient is 12 W/m^{2}K.
The latent heat of the gas is 515 kJ/kg
For a sphere; the surface area = $4\pi r^2$, the surface area at the mean radius = $4\pi r_1 r_2$

[OVER

8. In a two-stage, single acting reciprocating air compressor, the LP suction pressure is 1.05 bar, the inter-stage pressure is 3.15 bar and the HP delivery pressure is 10.2 bar. The LP suction temperature is 298 K and the HP suction temperature is 311 K. The index of compression and expansion for both stages is 1.29.

(a) Sketch the process on a p-V diagram indicating the areas which represent work saved by intercooling and the isothermal curve. (4)

(b) Calculate EACH of the following per kg of induced air:

(i) the indicated work; (4)

(ii) the heat removed in the intercooler; (2)

(iii) the work saved by intercooling. (3)

(c) Calculate the isothermal efficiencies with and without intercooling. (3)

Note: For air R = 0.287kJ/kgK and c_p *=1.005 kJ/kgK*

9. The volume of the shell of a steam condenser is 12 m^3. The shell contains saturated water, dry saturated steam and air, all at a temperature of 33°C.

The mass of water present is 200 grams.
The atmospheric pressure is 1.03 bar and the condenser vacuum gauge reads 720 mm of mercury.

After a period of time the temperature rises to 39°C.

(a) Determine EACH of the following:

(i) the initial mass of air present; (6)

(ii) the initial mass of dry saturated vapour. (2)

(b) Show that there is still water present at the final temperature. (4)

(c) Determine the final vacuum gauge reading. (4)

Note: For air R = 0.287 kJ/kgK 1bar = 750 mm of mercury.

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32-Applied Heat

DATE: 23rd March 2015

General Comments on Examination Paper

Candidates should read the instructions on the cover of the answer book and attempt 6 questions.

General Comments of Specific Examination Questions

Q1. A popular question with the majority of candidates producing good diagrams and calculating the gas properties accurately. However few were able to correctly calculate the work, using the equations for the at rather than work accounted for some errors while examination of the p-V diagram would have resolved the confusion of positive and negative work.

Q2 The diagrams were satisfactory although candidates did not appreciate that the heat addition was at constant pressure. There were numerous calculator errors

Q3. The majority of candidates attempting this produced a solution based on 100 kg of gas and confused the percentage dry flue gas given with the actual amount of O_2.

Q4. Few candidates attempted this question. The Carnot efficiency required the absolute temperatures and the equation $Q = T\Delta S$ should be used to determine heat and work.

Q5. A popular question with most producing good diagrams, however there were a significant number of basic Trig errors. Calculation errors were not recognised in respect of steam velocities which should be in the order of 3 figures not 2 and Rotor speeds 4 figures not 2 or 3.

Q6. A popular question with the majority incorrectly using isenthalpic expansion.

Q7. A popular question which in the main was well executed however there were numerous data input and calculator errors.

Q8. A popular question however the P-v diagrams bore little resemblance to that of a two stage p-V diagram, candidates would be advised to examine the relevant chapter in the latest edition of a popular text. The calculations were satisfactory although they contained a significant number of errors. Some candidates did not read the question and used equal pressure ratios!

Q9. Few attempts at this question, $pV = mRT$ only applies to air and the dryness fraction is mass of dry vapour / total mass of fluid kg/kg

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

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MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 15 DECEMBER 2014

1315 - 1615 hrs

Examination paper inserts:

Worksheet Q4 - Specific Enthalpy-Specific Entropy Chart for Steam

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidate's examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5^{th} edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. Air at a pressure and temperature of 1 bar and 32°C respectively is compressed in an isentropic process from BDC to TDC in an engine. Heat is then added reversibly at constant volume until the pressure reaches 35.5 bar.

   The clearance volume is 1.82 litres and the bore and stroke are 250 mm and 350 mm respectively.

   (a) Sketch the p-V and T-s diagrams. (3)

   (b) Calculate EACH of the following:

   (i) the compression ratio; (3)

   (ii) the work transfer; (4)

   (iii) the total change in entropy. (6)

   Note: For air c_v= 0.718 kJ/kgK and R = 0.287 kJ/kgK

2. Air enters the compressor of a simple gas turbine plant at a pressure and temperature of 1.03 bar and 305 K respectively. It is compressed to 6.18 bar with an isentropic efficiency of 83%.

   The hot gases leave the combustion chamber and enter the turbine at a pressure of 6.18 bar and a temperature of 1210 K.

   The turbine exhausts at a pressure of 1.03 bar and a temperature of 805 K.
   The fuel air ratio is 0.0125.

   (a) Sketch the cycle on a Temperature-specific entropy diagram. (3)

   (b) Calculate EACH of the following:

   (i) the isentropic efficiency of the turbine; (3)

   (ii) the net work output per kg of exhaust gas; (6)

   (iii) the thermal efficiency of the cycle. (4)

   Note: For air: γ = 1.4 and c_p = 1.005 kJ/kgK
   For the hot gas: γ = 1.33 and c_p = 1.15 kJ/kgK

[OVER

3. Octane (C_8H_{18}) is burned in 15% excess air.

The dry flue gas analysis shows they contain 2.5% carbon monoxide by volume.

Calculate, using molar volumes for 1 kmol of fuel, EACH of the following:

(a) the actual amount of oxygen supplied; (3)

(b) the full combustion equation; (10)

(c) the volumetric analysis of the total flue gas. (3)

Note: Air contains 21% oxygen by volume.

4. In a regenerative steam power plant, steam enters the turbine at a pressure and temperature of 80 bar and 500°C respectively.

It then expands to 0.1 bar with an isentropic efficiency of 85%.

Steam is bled from the turbine at 4.5 bar and is fed to a direct contact feed heater.
The feed water leaves the heater at the saturation temperature of the bled steam.
There is no under cooling in the condenser and the feed pump work may be ignored.

(a) Sketch the cycle on a temperature-specific entropy diagram. (4)

(b) Plot the straight line expansion process on Worksheet Q4. (2)

(c) Determine EACH of the following:

(i) the mass flow rate of bled steam per kg of steam flowing; (4)

(ii) the thermal efficiency of the cycle. (6)

5. In a two row velocity compounded impulse turbine stage, steam leaves the nozzles with a velocity of 950 m/s at an angle of 20º to the plane of rotation. The mean blade velocity is 190 m/s.

The fixed and moving blade rows are symmetrical each with a velocity coefficient of 0.92.

(a) Draw to scale a velocity diagram for each row. (4)

(b) Determine EACH of the following:

(i) the magnitude of the steam velocity entering and leaving EACH blade; (2)

(ii) the fixed and moving blade angles; (2)

(iii) the total blade work per kg of steam flowing; (4)

(iv) the diagram efficiency. (4)

6. A vapour compression refrigeration cycle operating between pressures of 2.006 bar and 10.163 bar is to be used as a heat pump supplying a heating load of 10 kW.

The working fluid is R134a which enters the compressor as a dry saturated vapour and leaves at a temperature of 50ºC.

The liquid enters the expansion valve with 5 K of sub-cooling.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Determine EACH of the following:

(i) the mass flow of refrigerant required; (3)

(ii) the cooling load based on the mass flow obtained Q6b(i); (2)

(iii) the heat pump co-efficient of performance; (3)

(iv) the isentropic efficiency of the compressor. (4)

7. A wire of 1.8 mm diameter carries an electric current which generates 2.1 watts of heat per metre length.

It is covered with insulation 1.22 mm thick and thermal conductivity 0.11 W/mK.

If the surrounding air temperature and surface heat transfer coefficient remain unchanged at 27°C and 12 W/m²K respectively.

(a) Calculate EACH of the following:

(i) the temperature of the wire without insulation; (3)

(ii) the temperature of the wire with insulation; (5)

(iii) the surface temperature of the insulated cable. (3)

(b) Comment on the values obtained in Q7(a)(i) (ii) and (iii). (5)

8. The free air capacity of a two stage reciprocating air compressor is 18 m^3/min. The free air suction pressure and temperature are 1.05 bar and 25°C respectively. The delivery pressure is 9.45 bar.

The stage pressure ratios are equal, inter-cooling is perfect and the polytropic index for EACH expansion and compression is 1.26.

(a) Sketch the cycle on a p-V diagram. (4)

(b) Calculate EACH of the following:

(i) the total indicated power; (5)

(ii) the rate of inter-cooling; (3)

(iii) the power saved by inter-cooling. (4)

Note: For air R = 0.287 kJ/kgK c_p*= 1.005 kJ/kgK*

9. Air leaks from a pressure vessel to the surroundings which are at a pressure of 1.02 bar.

The passage through which the air leaks may be considered as a convergent nozzle with an exit area of 0.6 mm^2. The flow within the passage is assumed to be isentropic and the temperature of the vessel remains constant at 28°C.

(a) With reference to nozzles, explain the term choked flow. (4)

(b) Calculate the critical pressure ratio. (2)

(c) Calculate the mass flow when the pressure in the vessel is:

(i) 2.5 bar; (6)

(ii) 1.4 bar. (4)

Note: For air: $c_v = 0.718$ *kJ/kgK and* $c_p = 1.005$ *kJ/kgK*

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

SCOTTISH QUALIFICATIONS AUTHORITY

MARKERS REPORT FORM

PART I

SUBJECT: 041-32-Applied Heat

DATE: 15th December 2014

General Comments on Examination Paper

Candidates are reminded to attempt six questions and use the data given. Calculations should be carried out with care and the correct units stated.
In all questions, errors could be attributed to poorly drawn process or system diagrams

General Comments of Specific Examination Questions

Q1. A popular question, however some were unable to sketch an Isnetropic process on the T-s diagram. Numerous candidates displayed little understanding of the relationship between the volumes or of the compression ratio. Most candidates attempted to calculate the entropy change for a polytropic process also they frequently used and stated incorrect units.

Q2 The cycle T-s diagrams were usually drawn incorrectly and even the best lacked all proportion.
Most candidates assumed the mass of air and gas to be the same whereas the question asked for 1kg of GAS and gave a Fuel/Air ratio. Similarly the fact that air enters the combustion chamber reacts with the fuel and the products leave as a gas was ignored.

Q3. There were few attempts, although some were very good, most were not. It would appear that candidates did not understand, the concept of stoichiometric combustion, the formation of CO, the origins of the oxygen in the exhaust gas or what an exhaust gas analysis is.

Q4. Few candidates attempted this question but most produced a "good" solution.

Q5. Numerous candidates did not produce a scaled velocity vector diagram while the second stage was frequently ignored. Some candidates used the equations for a reaction turbine.

Q6. A popular question with some "good" solutions. A large number of candidates showed little understanding of a reversed heat engine cycle or of a P-h diagram and failed to distinguish between the heat pump and refrigerator.

Q7. A popular question which in the main was well executed however there was confusion between the overall heat transfer coefficient U and thermal resistance R. There were also numerous calculator and unit errors e.g. answers for aiii ranged from 26.9K to 369°C

Q8. A popular question with in the main satisfactory calculations, however the P-v diagrams were very poor.
It is suggested that as part of their preparations candidates should draw a scaled pressure -volume diagram for a single and two stage reciprocating air compressor.

Q9. Choked flow requires reference to mass, critical pressure and sonic velocity, all attempts obtained the correct critical pressure ratio but some then failed to use the correct pressure ratio for expansion.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
ON BEHALF OF THE
MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 13 OCTOBER 2014

1315 - 1615 hrs

Examination paper inserts:

Datasheet Q6 - Property table for CO_2

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook Graph paper 'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A perfect gas is heated at constant pressure in a cylinder and then expands reversibly according to the law $pV^{1.32} = C$.

   The initial pressure and temperature are 10 bar 527°C respectively.

   The final pressure is 1.0 bar and the final volume is twenty times the initial volume.

   (a) Sketch the p-V and T-s diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the temperature after heating; (2)

   (ii) the final temperature; (2)

   (iii) the net heat transfer per kg of gas; (6)

   (iv) the net change in specific entropy during the constant pressure process. (2)

   Note: For the gas $\gamma = 1.67$, $c_p = 5.179$ *kJ/kgK* $R = 2.078$ *kJ/kgK*

2. The layout of a gas turbine plant is shown in Fig Q2. The plant operates between pressures of 0.98 bar and 7.01 bar. All the work produced by the HP turbine drives the compressor.

The LP turbine drives the load. Air enters the compressor at 26°C and the combustion gas enters the HP turbine at 985°C.

The isentropic efficiency of the compressor is 0.84 and that of each turbine is 0.86.

(a) Sketch the cycle on a T-s diagram. (4)

(b) Calculate EACH of the following:

(i) the temperature at the HP turbine exhaust; (4)

(ii) the pressure at the HP turbine exhaust; (4)

(iii) the net work output per kg of air. (4)

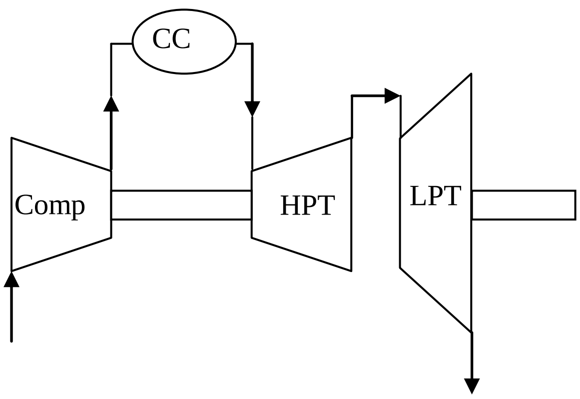

Fig Q2

Note: For all processes $\gamma = 1.4$ *and* $c_p = 1.005$ *kJ/kgK*

3. A fuel of mass analysis 84% Carbon and 16% Hydrogen is completely burned in air. The dry flue gas analysis shows that they contain 84% Nitrogen by volume.

(a) Use molar volumes to formulate the complete combustion equation in kmol/kg of fuel. (10)

(b) Calculate EACH of the following:

(i) the percentage excess air by volume; (3)

(ii) the air fuel ratio by mass. (3)

Note: Relative atomic masses H=1, C=12, N=14, O=16
Air contains 21% oxygen by volume

4. The volume of the shell of a steam condenser is 7.8 m^3. It contains 0.4 kg of wet steam and also a certain mass of air. The temperature is 34.6°C and the total pressure is 0.065 bar.

After a time, 38.9 grams of steam has condensed and an additional 0.04 kg of air has leaked in.

Determine EACH of the following:

(a) the initial mass of air present; (3)

(b) the initial mass of dry saturated vapour present; (2)

(c) the initial mass of saturated liquid present; (2)

(d) the final temperature; (5)

(e) the final total pressure. (4)

Note: For air R = 0.287 kJ/kgK

5. The blades in a certain stage in a 50% reaction turbine produce 200 kW when the steam is dry saturated at a pressure of 2.5 bar. The speed of rotation is 4500 rev/min.

The mean blade ring diameter is 800 mm and the blade height is 50 mm.

The absolute velocity of the steam at exit from the stage is in an axial direction.

(a) Sketch the velocity vector diagram identifying all the velocities. (3)

(b) Determine EACH of the following:

(i) the absolute velocity of the steam at exit; (7)

(ii) the fixed and moving blade angles; (2)

(iii) the absolute velocity of the steam at inlet; (2)

(iv) the blade to steam speed ratio. (2)

6. A vapour compression refrigeration cycle using CO_2 operates between pressures of 25.0095 bar and 68.9182 bar. It produces 6 tonnes per day of ice at -8°C, from fresh water at 20°C.
The refrigerant enters the compressor as a dry saturated vapour and leaves at a temperature of 78°C, it is then condensed and enters the expansion valve as saturated liquid.

(a) Sketch the cycle on P-h and T-s diagrams. (4)

(b) Using Datasheet Q6, determine EACH of the following:

(i) the swept volume of the compressor if the volumetric efficiency is 88%; (8)

(ii) the compressor power; (2)

(iii) the coefficient of performance of the plant. (2)

Note: For Ice: specific heat capacity 2.1 kJ/kgK, latent heat 335 kJ/kg
For water: specific heat capacity 4.2 kJ/kgK

7. In a counter flow oil cooler, the oil flows with a velocity of 1.2 m/s through a single pass of 35 tubes. Each tube has a bore diameter of 15 mm and wall thickness of 1.6 mm.

The oil enters at a temperature of 80°C and leaves at a temperature of 30°C.

The fresh water coolant enters at a rate of 7 kg/s and a temperature of 24°C.

The overall heat transfer coefficient is 2000 W/m^{2}K, referenced to the tube outer surface area.

Calculate EACH of the following:

(a) the total mass flow rate of oil; (2)

(b) the outlet temperature of the water; (3)

(c) the logarithmic mean temperature difference; (5)

(d) the length of each tube. (6)

Note: For water: specific heat capacity 4.2 kJ/kgK
For oil: specific heat capacity 2.0 kJ/kgK, density 860 kg/m^3

8. A single stage, single acting reciprocating air compressor is used to charge a large air receiver.

The bore has a diameter of 750 mm and the stroke has length of 900 mm. The clearance volume is 9.5% of the swept volume and the mechanical efficiency is 86%.
The suction pressure and temperature are 1.0 bar and 25°C respectively.
The delivery pressure is 7.5 bar when running at a speed of 200 Rev/min.
The polytropic index for the compression and expansion process is 1.25.

(a) Sketch the process on a p-V diagram. (2)

(b) Calculate EACH of the following:

(i) the power input required; (7)

(ii) the maximum theoretical pressure that can be achieved from the given suction conditions; (3)

(c) Explain why the mass flow rate of air alters as the delivery pressure increases. (4)

Note: For air R = 0.287 kJ/kgK c_p *= 1.005 kJ/kgK*

9. A compartment of volume 6 m^3 contains Nitrogen at a pressure of 1.5 bar and is separated by a bulkhead from a second compartment of volume 3 m^3 containing Carbon Dioxide at a pressure of 0.85 bar. The temperature in each compartment is 22°C.

A door in the bulkhead is opened and the gasses mix adiabatically and completely.

Calculate EACH of the following:

(a) the final pressure; (7)

(b) the total change in entropy. (9)

Note: The universal gas constant R_o *= 8.3145 kJ/kmolK*
Relative atomic masses H=1, C=12, N=14, O=16

SCOTTISH QUALIFICATIONS AUTHORITY

MARKERS REPORT FORM

SUBJECT: 041-32-Applied Heat

DATE: 13th October 2014

General Comments on Examination Paper

Targeted questions were usually successfully produced however they also contained what appeared to be careless calculator and unit errors.

General Comments of Specific Examination Questions

Q1. A popular question, however T-s diagrams were poorly drawn, numerous errors occurred in the calculations and incorrect units were stated. there also appeared to be limited understanding of process heat flow.

Q2 Numerous candidates failed to understand that the gas generator turbine requires a greater pressure drop than the independent power turbine. The cycle T-s diagrams were usually drawn incorrectly with even the best lacking all proportion.

Q3. It would appear that the majority of candidates attempting this did not read the question and produced parts of a solution which was only partially relevant. Most appeared to ignore the relationship between mass molar mass and the amount of substance.

Q4. Few candidates attempted this question. Those that did failed to appreciate the composition of wet vapour.

Q5. A popular question with most producing a satisfactory diagram however only a few candidates were able to develop this and answer the question fully.

Q6. A popular question, although few produced a "good" solution. A large number of candidates used the mass flow of ice as the mass flow of refrigerant! and ignored the cooling load.

Q7. A popular question which in the main was well executed however there were numerous calculator errors

perhaps due to complacency.

Q8. A popular question however the P-v diagrams bore little resemblance to those of polytropic and constant pressure processes, the calculations were satisfactory.

Q9. Few attempts at this question, part B appeared to be a problem

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

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STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY 21 JULY 2014

1315 - 1615 hrs

Examination paper inserts:

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.
2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. Air initially at a pressure of 1 bar and a temperature of 273 K undergoes the following cycle of steady flow processes: isothermal expansion to a pressure of 0.70 bar, followed by isentropic compression to the initial pressure, and then cooling at constant pressure to the initial temperature.

   (a) Sketch the processes on p-V and T-s diagrams. (6)

   (b) Calculate EACH of the following:

   (i) the temperature after compression; (2)

   (ii) the heat transfer per kg during cooling; (2)

   (iii) the net specific work transfer in the cycle; (4)

   (iv) the coefficient of performance of the cycle, regarded as a heat pump. (2)

   Note: For air, $\gamma = 1.4$ and $R = 0.287$ kJ/kg K.

2. A gaseous fuel consists of a mixture of methane (CH_4), 80% by volume, and pentane (C_5H_{12}), 20% by volume. It is burned in 10% excess air. The dry combustion gases contain 1% carbon monoxide (CO) by volume.

   (a) Formulate the full combustion equation per kmol of fuel. (13)

   (b) Calculate the percentage by volume of O_2 in the dry combustion products. (3)

   Note: atomic mass relationships: H = 1; C = 12; O = 16; N = 14
   Air contains 21% oxygen by volume.

3. The layout of a gas turbine plant is illustrated in Fig. Q3. The plant operates between pressures of 1.00 bar and 23.00 bar. The HP turbine drives the compressor, and the LP turbine drives the load. Air enters the compressor at temperature of 300 K. Combustion gases enter the HP turbine at 1530 K. The isentropic efficiency of the compressor is 0.80, and that of each turbine is 0.90. For the compression process, $\gamma = 1.4$ and $c_P = 1.005$ kJ/kg K. For the remaining processes, $\gamma = 1.33$ and $c_P = 1.150$ kJ/kg K. The mass flow rate of exhaust gas is 110 kg/s, and the calorific value of the fuel is 40 MJ/kg.

(a) Sketch the cycle on a T-S diagram. (4)

(b) Calculate EACH of the following:

(i) the temperature and pressure at HP turbine exhaust; (6)

(ii) the power output; (3)

(iii) the specific fuel consumption in kg/kWh. (3)

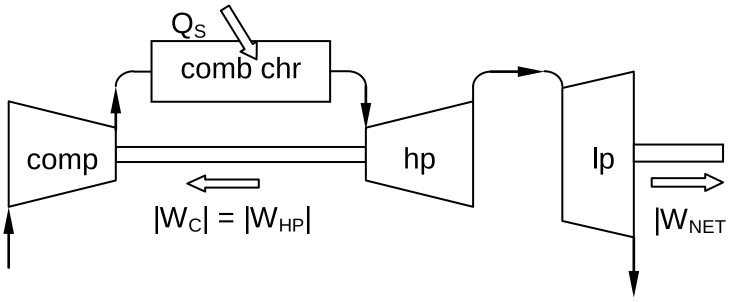

Fig Q3

4. A regenerative steam power cycle operates between pressures of 70 bar and 0.05 bar. The maximum temperature is 580°C. The optimum mass of steam is bled for feed heating at a pressure of 2 bar. A direct mixing feed heater is used. Expansion in the turbine and compression in the feed pumps are isentropic.

(a) Sketch the T-s diagram for the cycle. (5)

(b) Determine for the cycle EACH of the following:

(i) the specific work output (taking account of feed pump work); (9)

(ii) the thermal efficiency. (2)

5. The drop in specific enthalpy as steam passes through the nozzles of a two-row velocity compounded impulse turbine stage is 500 kJ/kg. The nozzle angle is 18° and the blade velocity is 235 m/s. All the blades are symmetrical, and blade friction is negligible. The axial velocity component remains constant throughout the stage.

(a) Sketch the combined velocity diagrams for each moving row, labelling velocities and angles. (6)

(b) Determine EACH of the following:

(i) all the blade angles; (6)

(ii) the diagram efficiency. (4)

6. Ammonia (R717) is used as the refrigerant in a simple vapour compression cycle to maintain the contents of a container at a temperature of 8°C. The temperature of the surroundings is 34°C. To achieve the required heat transfer, the temperature difference between the cold container and the evaporating refrigerant should be 6 K and the temperature difference between the condensing refrigerant and the surroundings should be 10 K. The refrigerant enters the compressor dry and saturated, and there is no undercooling in the condenser. The isentropic efficiency of the compressor is 0.85.

(a) Sketch the cycle on p-h and T-s diagrams. (5)

(b) Determine EACH of the following:

(i) the evaporating and condensing pressures; (2)

(ii) the temperature at compressor outlet; (6)

(iii) the coefficient of performance of the cycle. (3)

7. River water is to be used to cool engine cooling water in a single pass shell and tube heat exchanger. The cooling water is to enter the tubes at a temperature of 85°C and to be cooled to 28°C. The flow rate of cooling water will be 2.5 kg/s. The river water will enter at a temperature of 14°C and its flow rate will be 15 kg/s. The specific heat capacities of both cooling water and river water may be taken as 4.2 kJ/kg K. The overall heat transfer coefficient is expected to be 3200 W/m^2 K, based on the outside surface area of the tubes. The tube outside diameter is to be 60 mm.

Calculate EACH of the following:

(a) the outlet temperature of the river water; (3)

(b) the logarithmic mean temperature difference for EACH of the following cases:

(i) counter flow; (3)

(ii) parallel flow; (3)

(c) the total length of tubing required for EACH of the following cases:

(i) counter flow; (4)

(ii) parallel flow. (3)

8. At the beginning of compression in a single stage, single acting reciprocating air compressor, the air is at a pressure of 1.03 bar and a temperature of 35°C. The delivery valve opens at a pressure of 8.3 bar. The delivery temperature is 195°C. The bore diameter and stroke length are 0.48 m and 0.53 m respectively. The clearance volume is 5.2% of the swept volume and the compressor runs at 600 rev/min.

(a) Sketch the p-V diagram. (2)

(b) Calculate EACH of the following:

(i) the index of compression; (4)

(ii) the volumetric efficiency; (3)

(iii) the indicated work per kg of air; (3)

(iv) the free air capacity in m^3/min, given that free air conditions are 1.013 bar and 25°C. (4)

Note: For air, R = 0.287 kJ/kg K.

9. (a) State why impulse turbine nozzles have convergent-divergent form. (2)

(b) Air expands isentropically in a convergent-divergent nozzle. The pressure at nozzle inlet is 15 bar and the inlet temperature is 450 K. The outlet pressure is 4 bar. The mass flow rate is 8.5 kg/s.

Calculate EACH of the following:

(i) the throat area; (7)

(ii) the exit area. (7)

Note: $p_c = p_0 \times \left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$; $T_c = T_0 \times \left(\frac{2}{\gamma+1}\right)$; $a = \sqrt{\gamma RT}$

For air, R = 0.287 kJ/kg K and γ = 1.4.

CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY – MARINE ENGINEER OFFICER

EXAMINATIONS ADMINISTERED BY THE
SCOTTISH QUALIFICATIONS AUTHORITY
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MARITIME AND COASTGUARD AGENCY

STCW 95 CHIEF ENGINEER REG. III/2 (UNLIMITED)

041-32 – APPLIED HEAT

MONDAY, 7 APRIL 2014

1315 - 1615 hrs

Examination paper inserts:

Datasheet Q6 (Property table for CO_2)

Notes for the guidance of candidates:

1. Non-programmable calculators may be used.

2. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Materials to be supplied by examination centres:

Candidates' examination workbook
Graph paper
'Thermodynamic and Transport Properties of Fluids' by Mayhew & Rogers (5th edition)

APPLIED HEAT

Attempt SIX questions only.

All questions carry equal marks.

Marks for each part question are shown in brackets.

1. A perfect gas expands reversibly in a cylinder according to the law $pV^{1.13}$ = constant and is then cooled at constant volume. The initial pressure is 60 bar, the initial temperature is 1500°C and the final pressure is 2.8 bar. The final volume is five times the initial volume.

   (a) Sketch the processes on p-V and T-S diagrams. (4)

   (b) Calculate EACH of the following:

   (i) the temperature after expansion; (2)

   (ii) the final temperature; (2)

   (iii) the total heat transfer per kg; (5)

   (iv) the total change in specific entropy. (3)

   Note: For the gas, R = 0.189 kJ/kg K and γ = 1.23

2. The following data refer to a 4 cylinder 4-stroke diesel engine under test:

bore diameter	83 mm
stroke length	92.4 mm
speed of rotation	2800 rev/min
brake torque	0.11 kNm
fuel consumption	7.65 kg/h
calorific value of fuel	35 MJ/kg
indicated MEP:	
cylinder 1	7.65 bar
cylinder 2	7.81 bar
cylinder 3	7.72 bar
cylinder 4	7.69 bar

Calculate EACH of the following:

(a) the brake power; (2)

(b) the mechanical efficiency; (5)

(c) the brake specific fuel consumption (kg/kW h); (2)

(d) the brake thermal efficiency; (3)

(e) the value to which the brake torque must be reduced to restore the speed to 2800 rev/min if the fuel supply to cylinder 1 is cut off. (4)

3. The mass analysis of a fuel is: carbon 80%; hydrogen 14%; sulphur 3%; water 3%.

Determine EACH of the following:

(a) the theoretical air/fuel ratio by mass; (6)

(b) the volumetric analysis of the dry products (ie excluding H_2O and soluble SO_2) when the fuel is burned completely in 30% excess air; (6)

(c) the dew point temperature of the combustion products if the total pressure is 1.0462 bar. (4)

Note: atomic mass relationships: H = 1; C = 12; O = 16; N = 14; S=32
Air contains 21% oxygen by volume and 23.3% oxygen by mass.

4. A steam power plant consists of turbine, condenser, feed pump and boiler. Steam enters the turbine at a pressure of 40 bar and a temperature of 450°C, and expands to 0.5 bar, dryness fraction 0.98. The steam is then fully condensed without undercooling. Feed pump work may be disregarded. The boiler efficiency is 90% and the calorific value of the fuel is 39.0 MJ/kg.

The condenser cooling water, which is used to supply heat to an industrial process, enters the condenser at a temperature of 50°C and leaves at a temperature of 70°C. The process heat requirement is 2 MW.

Determine EACH of the following:

(a) the mass flow rate of water; (2)

(b) the mass flow rate of steam; (2)

(c) the power output of the steam plant; (2)

(d) the mass flow rate of fuel; (5)

(e) the condenser tube surface area required if the U-value is 2.8 kW/m^2 K. (5)

Note: for water, $c_P = 4.2$ *kJ/kg K*

5. (a) Define the term *degree of reaction* relating to a turbine stage. (3)

(b) In a 50% reaction turbine stage the steam leaves the fixed blades with a velocity of 299 m/s. The axial velocity component is 154 m/s and the blade velocity is 200 m/s.

Determine EACH of the following:

(i) the blade inlet and outlet angles; (5)

(ii) the blade work per kg; (3)

(iii) the diagram efficiency. (5)

6. A vapour compression cooling cycle using CO_2 operates between pressures of 20.9384 bar and 72.1369 bar. The refrigerant enters the compressor at a temperature of -16°C and leaves the condenser as saturated liquid. The temperature at compressor outlet is 80°C.

(a) Sketch the cycle on a p-h diagram. (4)

(b) Using Datasheet Q6, determine the coefficient of performance of the cycle. (6)

(c) Determine the isentropic efficiency of the compressor. (6)

7. Wet steam at a pressure of 12.0 bar flows in a 10 m long pipe of inside diameter 30 mm and wall thickness 4 mm. The pipe is surrounded with a layer of lagging 20 mm thick. The thermal conductivity of the lagging is 0.04 W/m K and the outside surface heat transfer coefficient is 15 W/m^2 K. The outside air temperature is 32°C. The thermal resistances of steam film and pipe wall may be disregarded.

Determine EACH of the following:

(a) the rate of heat loss; (7)

(b) the outside surface temperature of the lagging; (3)

(c) the increase in the rate of heat loss which would result if the thickness of the lagging were reduced to 15 mm. (6)

8. A reciprocating compressor is to be used to compress CO_2 which enters at a temperature of 20°C and a pressure of 15.0 bar. The delivery temperature is not to exceed 100°C. The index of compression is 1.2.

Calculate EACH of the following:

(a) the specific gas constant R for CO_2; (2)

(b) the maximum pressure which can be obtained in a single stage; (2)

(c) the volumetric efficiency of the single stage machine if the clearance volume is 5% of the swept volume; (3)

(d) the maximum pressure which can be obtained using two stages with perfect intercooling; (3)

(e) the isothermal efficiency of the two stage compressor. (6)

Note: atomic mass relationships: O = 16; C = 12
The universal gas constant is 8.314 kJ/kmol K

9. (a) Explain the term *choked flow* with reference to a convergent nozzle. (4)

(b) Air leaks out of a pressure vessel to the surroundings which are at a pressure of 1.00 bar. The passage through which the air leaks may be considered as a convergent nozzle with exit area 0.5 mm^2, and the flow within the passage may be assumed isentropic. The temperature of the air in the vessel is 30°C.

Calculate the mass flow rate when the pressure in the vessel is:

(i) 2.0 bar; (6)

(ii) 1.2 bar. (6)

Note: For air, $\gamma = 1.4$ and $R = 0.287$ kJ/kg K

$$p_c = p_0 \times \left(\frac{2}{\gamma + 1} \right)^{\gamma/(\gamma - 1)} ; \qquad a = \sqrt{\gamma R T}$$

refrigerant:	*CO_2*									
saturation values							*superheat (T - T_s)*			
							50 K		100 K	
T	p_s	v_g	h_f	h_g	s_f	s_g	h	s	h	s
(°C)	(bar)	(m³/kg)	(kJ/kg)		(kJ/(kg K))		(kJ/kg)	(kJ/(kg K))	(kJ/kg)	(kJ/(kg K))
-50	6.8234	0.0558	-19.96	319.77	-0.0863	1.4362	365.1	1.620	409.9	1.770
-45	8.3184	0.0460	-10.03	321.23	-0.0428	1.4091	367.81	1.594	413.26	1.744
-40	10.0450	0.0383	0.00	322.42	0.0000	1.3829	370.35	1.569	416.53	1.720
-35	12.0242	0.0320	10.15	323.33	0.0423	1.3574	372.75	1.546	419.70	1.696
-30	14.2776	0.0270	20.43	323.92	0.0842	1.3323	375.00	1.524	422.77	1.674
-28	15.2607	0.0252	24.60	324.06	0.1009	1.3224	375.85	1.515	423.97	1.666
-26	16.2926	0.0236	28.78	324.14	0.1175	1.3125	376.68	1.507	425.15	1.657
-24	17.3749	0.0220	33.00	324.15	0.1341	1.3026	377.48	1.498	426.31	1.649
-22	18.5089	0.0206	37.26	324.11	0.1506	1.2928	378.25	1.490	427.45	1.641
-20	19.6963	0.0193	41.55	323.99	0.1672	1.2829	378.99	1.482	428.58	1.633
-18	20.9384	0.0181	45.87	323.80	0.1837	1.2730	379.70	1.474	429.68	1.626
-16	22.2370	0.0170	50.24	323.53	0.2003	1.2631	380.39	1.466	430.77	1.618
-14	23.5935	0.0159	54.65	323.19	0.2169	1.2531	381.04	1.458	431.83	1.610
-12	25.0095	0.0150	59.11	322.76	0.2334	1.2430	381.66	1.450	432.88	1.603
-10	26.4868	0.0140	63.62	322.23	0.2501	1.2328	382.25	1.443	433.90	1.596
-8	28.0269	0.0132	68.18	321.61	0.2668	1.2226	382.81	1.435	434.91	1.589
-6	29.6316	0.0124	72.81	320.89	0.2835	1.2121	383.34	1.428	435.89	1.582
-4	31.3027	0.0116	77.50	320.05	0.3003	1.2015	383.83	1.420	436.85	1.575
-2	33.0420	0.0109	82.26	319.09	0.3173	1.1907	384.29	1.413	437.79	1.568
0	34.8514	0.0102	87.10	317.99	0.3344	1.1797	384.71	1.405	438.71	1.561
2	36.7329	0.0096	92.02	316.75	0.3516	1.1683	385.10	1.398	439.61	1.554
4	38.6884	0.0090	97.05	315.35	0.3690	1.1567	385.45	1.391	440.49	1.548
6	40.7202	0.0084	102.18	313.77	0.3866	1.1446	385.77	1.384	441.34	1.541
8	42.8306	0.0079	107.43	311.99	0.4045	1.1321	386.05	1.377	442.17	1.535
10	45.0218	0.0074	112.83	309.98	0.4228	1.1190	386.29	1.369	442.97	1.528
12	47.2966	0.0069	118.38	307.72	0.4414	1.1053	386.49	1.362	443.76	1.522
14	49.6577	0.0064	124.13	305.15	0.4605	1.0909	386.65	1.355	444.51	1.516
16	52.1080	0.0060	130.11	302.22	0.4802	1.0754	386.77	1.348	445.25	1.509
18	54.6511	0.0056	136.36	298.86	0.5006	1.0588	386.85	1.341	445.95	1.503
20	57.2905	0.0051	142.97	294.96	0.5221	1.0406	386.88	1.334	446.64	1.497
22	60.0308	0.0047	150.02	290.36	0.5449	1.0203	386.87	1.327	447.29	1.491
24	62.8773	0.0043	157.71	284.80	0.5695	0.9972	386.81	1.320	447.91	1.485
26	65.8368	0.0039	166.36	277.80	0.5971	0.9697	386.70	1.313	448.51	1.478
28	68.9182	0.0035	176.72	268.30	0.6301	0.9342	386.53	1.305	449.07	1.472
30	72.1369	0.0029	191.65	252.23	0.6778	0.8776	386.30	1.298	449.58	1.466
30.98	73.7730	0.0021	219.34	219.34	0.7680	0.7680	386.15	1.294	449.82	1.463

based on data from NIST: ***www.nist.gov***

SCOTTISH QUALIFICATIONS AUTHORITY
MARKERS REPORT FORM
PART I

SUBJECT: 041-32 APPLIED HEAT

DATE: 7^{TH} APRIL 2014

General Comments on Examination Paper

Candidates would benefit from reading the instructions on the answer books and the questions carefully. Numerous candidates appeared to "lose their way" in solutions by not stating formula or attempting calculations in a single operation, this trend also highlighted a general weakness in mathematical and calculator skills. The use of incorrect units and data not given in the question was also a common occurrence.

General Comments of Specific Examination Questions

Q1. The property diagrams produced were very poor, few candidates were able to sketch the T-s diagram even though the data showed reducing pressure, increasing volume and falling temperature.
The relationship between, heat, work and internal energy in a non-flow process appeared to be not well understood.

Q2 Those that attempted this question did so very well however there were (careless?) errors.
Part 2e was a Morse test.

Q3. Converting mass to molar volume in the reactant equation led to confusion when determining the product coefficients, partial pressures were not fully understood

Q4. No comments regarding this question.

Q5.Most of the candidates attempting this question did so very well. Some candidates used the equations for an impulse turbine. The accuracy of graphical solutions could be improved by using larger scales.

Q6. Few candidates produced a property diagram that showed the compressor suction in the superheat region with the compression and expansion processes as irreversible. The calculations however, were well done.

Q7. The use of the pipe diameter rather than radius led to errors in the calculations, numerous candidates used the incorrect units for heat flow, while others did not read part C carefully.

Q8. Stating the incorrect units stated in part A and calculating the maximum pressure based on volume rather than temperature were common. Some candidates confused stage pressure ratio and overall pressure ratio for the two stage machine

Q9. Few candidates were able to fully describe choked flow. Although most successfully completed part bi, a significant number did not appreciate that in bii the gas could only expand down to the back pressure and critical conditions were not achived at exit.