NATIONAL EXAMINATIONS

May 2011

07-MEC-B3 ENERGY CONVERSION AND POWER GENERATION

Three hours duration

Notes to Candidates

1. This is a **Closed Book** examination.

2. Exam consists of two Sections, each has three (3) questions. **Section A is Calculative** and **Section B is Descriptive.**

3. **Do two (2) questions (including all parts of each question) from Section A (Calculative) and two (2) questions from Section B (Descriptive)** Note that Question 2 is on two pages.

4. **Four questions constitute a complete paper.** (Total 60 marks).

5. **All questions are of equal value.** (Each 15 marks).

6. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

7. Candidates may use one of the approved Casio or Sharp calculators.

8. **Reference data** for particular questions are given on pages 8 to 11. **These pages are to be returned with the Answer Booklet.**

9. **Reference formulae and constants** are given on pages 12 to 15.

10. **Steam Tables** from "Thermodynamics and Heat Power" are provided.

SECTION A CALCULATIVE SECTION

QUESTION 1 COAL FIRED AND HYDRO POWER PLANT EFFICIENCIES

PART I NANTICOKE EFFICIENCY

Refer to Examination Paper Attachments Page 8 **Nanticoke Generating Station.**

Using the data for Nanticoke do the following:

(a) Sketch a flow diagram of the system and identify the key points, at which the enthalpies will be determined, by number. Sketch a T-s diagram showing the components or processes and identify the same key points by number

(2)

(b) Calculate the enthalpy of the water entering the boiler and the superheated steam leaving the boiler.

(2)

(c) Calculate the enthalpy of the reheated steam entering and leaving the boiler

(2)

(d) Calculate the thermal efficiency of the boiler defined as heat absorbed by the steam over heat input by the fuel.

(1)

(e) Calculate the cycle efficiency of the steam system defined as electrical output of the generator over heat absorbed by the steam.

(1)

(f) Calculate the overall efficiency of the plant defined as electrical output of the generator over heat input by the fuel.

(1)

(g) Explain why the efficiencies in (c) and (d) are different.

(1)

(10 marks)

Question continued on next page.

PART II MACTAQUAC EFFICIENCY

Hydro turbines of the Kaplan type are installed at Mactaquac on the Saint John River. In order to determine the efficiency of the Mactaquac turbines the following hypothetical measurements are considered:

Turbine-Generator speed	112.5 rev/min
Generator electrical output	110 MW
Water flow rate	354 m^3/s
Inlet pipe diameter	6.4 m
Outlet pipe diameter	7.0 m
Inlet water pressure	226 kPa gauge
Outlet water pressure	-4.5 m H_2O

The elevation of the outlet pressure measuring point is 5.0 m below that of the inlet pressure measuring point.

Determine the efficiency of the turbine.

(5 marks)

[15 marks]

QUESTION 2 COMBINED CYCLE PLANT

Refer to the Examination Paper Attachments Page 9 **Combined Cycle Plant**

In a combined cycle power plant based on a Brayton and a Rankine Cycle, as shown in the attached sketch on Page 9, the gas turbine exhaust heat is used to generate steam. The gas turbine cycle is an open cycle while the steam turbine cycle is a closed cycle with one stage of feedwater heating operating on the direct contact principle with steam bled from the turbine. The gas cycle has an air compressor, a combustion chamber, a gas turbine and a heat recovery steam generator. The steam cycle has, besides the heat recovery steam generator, a steam turbine, a steam condenser, a condensate pump, a direct contact heat exchanger and a feedwater pump. The combined cycle is illustrated on Page 9 with appropriate conditions given at various points.

Assume a cold air standard cycle (constant specific heats with $k = 1.4$). For a gas mass flow of 100 kg/s calculate the following:

(a) Rate of heat input to combustion chamber. (1)
(b) Mass flow rate of main steam. (1)
(c) Mass flow rate of bled steam. (1)
(d) Power (net) generated by gas turbine. (2)
(e) Power generated by steam turbine. (2)
(f) Efficiency of air compressor. (2)
(g) Efficiency of gas turbine. (2)
(h) Efficiency (internal) of steam turbine. (2)
(i) Work done by pumps (1)
(j) Overall efficiency of plant assuming that the power for the condensate and feedwater pumps is taken from the steam turbine output. (1)

[15 marks]

QUESTION 3 FEEDWATER HEATERS AND CONDENSERS

PART I BELLEDUNE FEEDWATER HEATER

In a boiler plant the feedwater entering the boiler is progressively preheated in a series of feedwater heaters which draw heating steam from the steam turbine. At Belledune Generating Station in the last stage of feedwater heating the feedwater temperature is increased from 230°C to 280°C while the pressure remains constant at 20 MPa. The heating steam enters at 400°C (superheated), is condensed and leaves as water at 240°C (subcooled) while the pressure remains constant at 5 MPa. If the feedwater flow is 350 kg/s calculate the required steam flow. Use Steam Tables. Note that a sketch to properly identify the key points around the heater is required.

(5 marks)

PART II CONDENSER PERFORMANCE

Refer to the Examination Paper Attachments Page 10 **Koeberg Condenser** and Page 11 **Temperature Profiles.** Note that 1 bar = 0.1 MPa.

Consider the condenser to be operating under the given conditions. Sketch on the given axes the design temperature profile, with specified temperatures for both cooling water and steam, along the condenser tubes (from inlet to outlet). Show clearly the change in cooling water temperature ΔT and the difference between the average cooling water temperature and the condensing steam temperature θ.

No detailed calculations are required and temperatures should be rounded to nearest 1°C. The estimates should be based on average temperature differences (not log mean temperature differences) and in each case the new values for ΔT and θ should be stated.

If the conditions are changed as indicated below, sketch on the given axes the anticipated temperature profiles with numerical values for both cooling water and steam across the condenser for each of the following conditions:

(a) Cooling water inlet temperature increased to 18°C

(b) Turbine load reduced to one quarter of its original value.

(c) Cooling water flow reduced to one half of its original value which also results in the overall heat transfer coefficient being reduced to 70% of its original value

(d) Overall heat transfer coefficient reduced by 20% due to fouling of tubes.

(10 marks)
[15 marks]

SECTION B DESCRIPTIVE SECTION

QUESTION 4 COAL CHARACTERISTICS AND ANALYSIS

(a) Compare and state the characteristics (constituents and heating value) of coals of different grade or rank. Indicate how these characteristics change according to the degree of metamorphism.

(4)

(b) With regard to coal state what constitutes an Proximate Analysis and what constitutes an Ultimate Analysis. Clarify the usefulness of each.

(4)

(c) State what is meant by heating value and clarify the difference between higher heating value and lower heating value. State which is commonly used.

(3)

(d) Explain what characteristics in a coal are required for pulverised fuel firing and why the coal needs to be pulverised before firing. Clarify how the fineness of pulverised coal is measured.

(4)

[15 marks]

QUESTION 5 ENERGY STORAGE

(a) Sketch a typical daily demand curve (load versus time) for a typical electric power system with the time of day clearly indicated on the horizontal axis. Explain why the curve has the shape indicated and state what factors affect the shape.

(5)

(b) Explain what implications a significant difference between the maximum and minimum demand can have on the generation of electric power by thermal plants (coal, oil or nuclear), and on the operation and capital investment of these power plants.

(5)

(c) Explain the role of a pumped hydro storage system in alleviating the problems identified in (b) above. Sketch a revised daily demand and production curve for the system combining the power inputs of both thermal and pumped hydro plants

(5)

[15 marks]

QUESTION 6 WIND TURBINES

(a) Explain the basic principles of wind energy and show, in a suitable sketch, the changes in air pressure and velocity as the wind passes through the turbine blades.

(5)

(b) Explain why the ideal or theoretical efficiency (maximum power obtained from wind/total power in wind) of a wind turbine is no more than 59.3%. Explain also why the actual power produced by a wind turbine is only about three quarters of this value, that is, about 45%.

(5)

(c) Describe the operational limitations and possible environment effects (good and bad) of large scale use of wind energy.

(5)

[15 marks]

07-MEC-B3 NAME ....

EXAMINATION PAPER ATTACHMENTS

QUESTION 1 NANTICOKE GENERATING STATION

The data below is taken from the technical specifications for Nanticoke Generating Station:

Location	On the north shore of Lake Erie in the City of Nanticoke, Ontario, 13 kilometers east of Port Dover.

Boiler

Steam Generator Manufacturer	Babcock & Wilcox Canada Ltd.
Type	Natural Circulation Radiant Boiler
Design Steam Output	453.6 kg/s (3 600 000 lb/hr)
Superheater outlet pressure	16.9 MPa (2 450 lbf/in^2)
Superheater outlet temperature	538°C (1000°F)
Reheat steam pressure	4.0 MPa
Reheat inlet steam temperature	343°C (650°F)
Reheat outlet steam temperature	538°C (1000°F)
Coal consumption at full load	47.9 kg/s (190 ton/hr)
Coal calorific value	30 240 kJ/kg (13 000 Btu/lb)
Number of pulverizers	5 per unit
Economiser inlet water pressure	17.5 MPa
Economiser inlet water temperature	252.5° C (487° F)
Water temperature in steam drum	359.6°C (680°F)

Turbine

Manufacturer	C.A. Parsons and Company Ltd.
Type	Tandem Compound, Impulse Reaction, One Single Flow H P., One Double Flow I P., Two Double Flow LP Condensing.
Speed	3 600 rpm

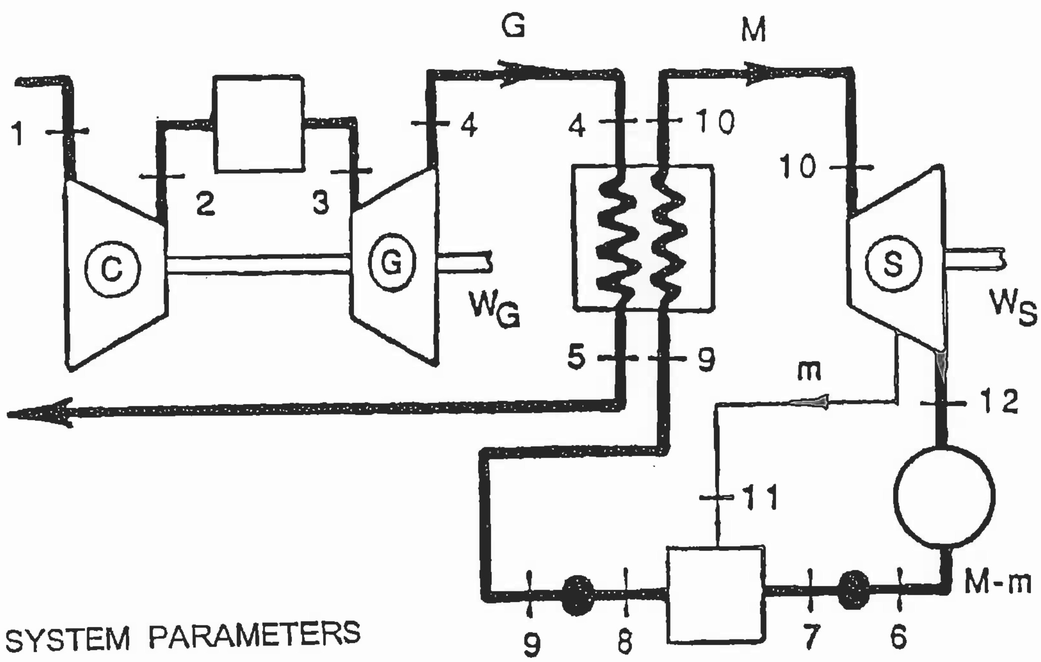
Generator

Rating	500 000 kW

07-MEC-B3 NAME ....

QUESTION 2 COMBINED CYCLE PLANT

SYSTEM DIAGRAM



SYSTEM PARAMETERS

Point	Pressure (MPa)	Temperature (°C)	Enthalpy (kJ/kg)
1	0.1	30	
2S	1.2	344	
2	1.2	422	
3	1.2	1000	
4S	0.1	353	
4	0.1	418	
5	0.1	159	
6	0.005	33	136
7	0.4	33	136
8	0.4	144	605
9	5.0	144	610
10	5.0	400	3196
11S	0.4	144	2634
11	0.4	144	2719
12SS	0.005	33	
12S	0.005	33	2025
12	0.005	33	2201

Note that s represents isentropic conditions.

QUESTION 3 KOEBERG CONDENSER

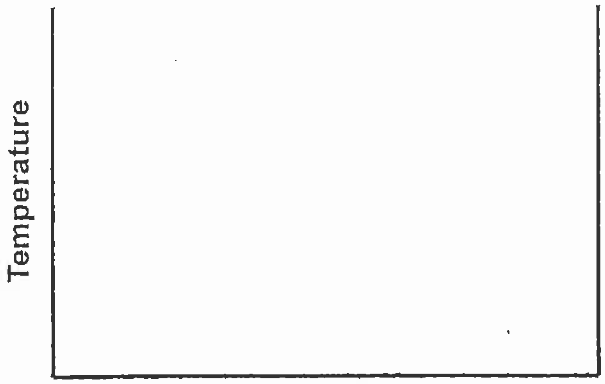
NAME ....

Steam flow rate	2996 t/h
Water make-up flow rate	9 t/h
Cooling water flow rate	141 000 t/h
Cooling water inlet temperature	13°C
Cooling water outlet temperature	24°C
Cooling water density	1.025
Cooling water friction head loss	4.7 m
Mean steam velocity at tube bank	92 m/s
Cooling water velocity inside tubes	2 m/s
Number of tubes	76968
Number of support plates	14 (per bundle)
Tube material	titanium
Cooling surface area	57 426 m^2
Tube overall length	12.84 m
Tube effective length	12.50 m
Tube diameter (OD)	19 mm
Tube wall thickness (normal tubes)	0.5 mm
Tube wall thickness (impact tubes)	0.6 mm
Tube configuration	diagonal array
Tube pitch across array	26 mm
Tube pitch along array	45 mm
Tube fixing method	expanding
Tube mass	132 t
Total volume under vacuum	7500 m^3
Steam inlet pressure	0.043 bar abs
Steam inlet temperature	30°C
Terminal temperature difference	6°C
Condenser hotwell capacity	700 m^3 (approx.)
Number of water boxes (inlet and outlet)	12
Water box internal lining	neoprene
Condenser shell thickness	18 mm
Tube plate thickness	25 mm
Support plate thickness	12 mm
Condenser length	43 m (approx.)
Condenser width	25 m (approx.)
Condenser mass without LP Heaters	1267 t

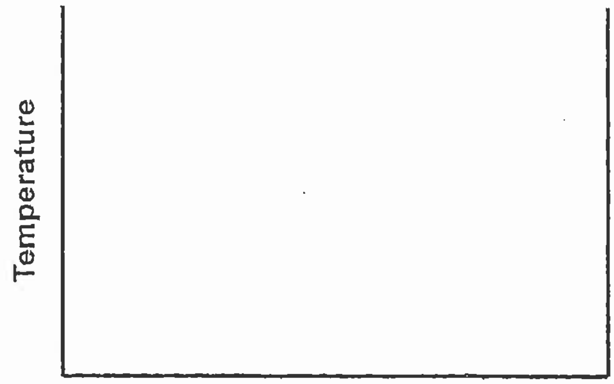
QUESTION 3 TEMPERATURE PROFILES NAME ....

Show initial conditions as dotted lines on each diagram
Show new conditions for each case as solid lines
Give temperatures on axes
Show basic calculations and new values for ΔT and θ below each diagram

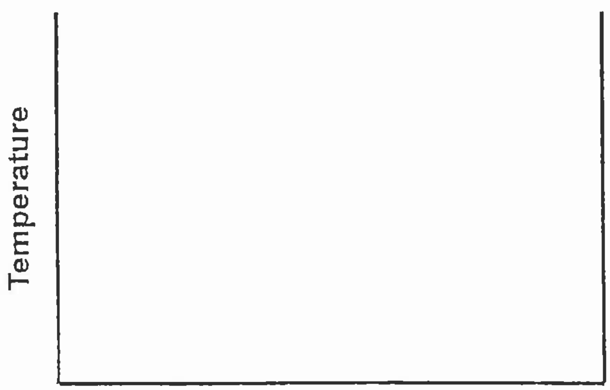
(a) Increase in cooling water temperature



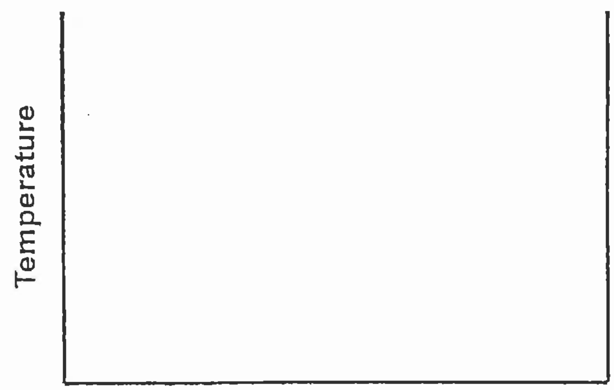
(b) Reduction in turbine load



(c) Reduction in cooling water flow



(d) Reduction in heat transfer coefficient



NOMENCLATURE FOR REFERENCE EQUATIONS (SI UNITS)

A	Flow area, Surface area	m^2
c_p	Specific heat at constant pressure	J/kg°C
c_v	Specific heat at constant volume	J/kg°C
D	Diameter	m
E	Energy	J
g	Gravitational acceleration	m/s^2
h	Specific enthalpy	J/kg
k	Ratio of specific heats	
L	Length	m
m	Fractional mass flow rate	
M	Mass flow rate	kg/s
p	Pressure	$Pa(N/m^2)$
q	Heat transferred	J/kg
Q	Heat	J
R	Specific gas constant	J/kg K
s	Entropy	J/kg K
T	Temperature	K
u	Specific internal energy	J/kg
v	Specific volume	m^3/kg
V	Velocity	m/s
w	Specific work	J/kg
W	Work	J
x	Length	m
z	Elevation	m
η	Efficiency	
θ	Nozzle angle	
μ	Dynamic viscosity	Ns/m^2
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
τ	Thrust	N
Ω	Heat transfer rate	J/s

GENERAL CONSTANTS

Acceleration due to gravity: $g = 9.81\ m/s^2$

Atmospheric pressure: $p_{atm} = 100$ kPa

Density of water: $\rho_{water} = 1000\ kg/m^3$

Specific heat of air: $c_p = 1.005$ kJ/kg°C

Specific heat of air: $c_v = 0.718$ kJ/kg°C

Specific heat of water: $c_p = 4.19$ kJ/kg°C

THERMODYNAMICS REFERENCE EQUATIONS

Basic Thermodynamics

First Law:	$dE = \delta Q - \delta W$
Enthalpy:	$h = u + pv$
Continuity:	$\rho VA = \text{constant}$
Flow Work:	$w = \Delta(pv)$
Energy Equation:	$zg + V^2/2 + u + pv + \Delta w + \Delta q = \text{constant}$
Entropy:	$\Delta s = \Sigma\delta q / T$ (reversibe conditions)

Ideal Gas Relationships

Gas Law:	$pv = RT$
Specific Heat at Constant Pressure:	$c_p = \Delta h / \Delta T$
Specific Heat at Constant Volume:	$c_v = \Delta u / \Delta T$
Gas Constant:	$R = c_p - c_v$
Specific Heat Ratio:	$k = c_p / c_v$
Isentropic Relations:	$p_1 / p_2 = (v_2 / v_1)^k = (T_1 / T_2)^{k/(k-1)}$

FLUID MECHANICS REFERENCE EQUATIONS

Fluid Mechanics

Continuity Equation: $\rho_1 V_1 A_1 = \rho_2 V_2 A_2 = M$

Bernoulli's Equation: $p_1/\rho g + z_1 + V_1^2/2g = p_2/\rho g + z_2 + V_2^2/2g$

Momentum Equation: $F = p_1 A_1 - p_2 A_2 - \rho VA(V_2 - V_1)$ (one dimensional)

Steam Turbines

Nozzle Equation: $h_1 - h_2 = (V_2^2 - V_1^2) / 2$

Work: $w = [(V_1^2{}_{absolute} - V_2^2{}_{absolute}) + (V_2^2{}_{relative} - V_1^2{}_{relative})] / 2$

Gas Turbines

State Equation: $pv = RT$

Isentropic Equation: $(T_2/T_1) = (p_2/p_1)^{(k-1)/k}$

Enthalpy Change: $h_1 - h_2 = c_p(T_1 - T_2)$ (ideal gas)

Nozzle Equation: $h_1 - h_2 = (V_2^2 - V_1^2) / 2$

Jet Propulsion

Thrust: $\tau = M(V_{jet} - V_{aircraft})$

Thrust Power: $\tau V_{aircraft} = M(V_{jet} - V_{aircraft})V_{aircraft}$

Jet Power: $P = M(V_{jet}^2 - V_{aircraft}^2) / 2$

Propulsion Efficiency: $\eta_p = 2V_{aircraft}/(V_{jet} + V_{aircraft})$

Wind Turbine

Maximum Ideal Power: $P_{max} = 8\ \rho\ AV_1^3 / 27$

NUCLEAR REFERENCE EQUATIONS

Number of nuclei per gram of material

$$N = N_A / M$$

Number of fissile nuclei per cm^3 of material

$$N_f = \gamma (N_A / M) \rho$$

Heat release rate in nuclear fuel

$$q^* = \phi N_f \sigma_f E_f$$

Nomenclature

N	=	number of nuclei (number/g)
N_A	=	Avogadro's Number
M	=	molecular weight
γ	=	fuel enrichment
ρ	=	density (g/cm^3)
q^*	=	heat release rate (J/cm^3)
ϕ	=	neutron flux (neutrons/cm^{2}s)
N_f	=	number of fissile nuclei (number/cm^3)
σ_f	=	cross section (barn) (1 barn = 10^{-24} cm^2)
E_f	=	energy release per fission of one atom

Avogadro's Number

$$N_A = 0.602 \times 10^{24} \text{ atoms/mole}$$