UN 0702 POWER PLANT THERMODYNAMICS

QUESTION BANK
ANSWERS TO PROBLEMS

SECTION T THERMODYNAMICS

Assignment Problems

PROBLEM T-04	T-s Diagrams			
PROBLEM T-05				
PROBLEM T-13	(a)	h_1 = 2706.7 kJ/kg		s_1 = 7.1271 kJ/kg°K
		h_2 = 504.7 kJ/kg		s_2 = 1.5301 kJ/kg°K
		h_3 = 255.3 kJ/kg		s_3 = 0.8285 kJ/kg°K
		h_4 = 422.7 kJ/kg		s_4 = 1.3030 kJ/kg°K
	(b)	Ω = 16.740 kJ/s		
	(c)	M_{steam} = 7.6 kg/s		
	(d)	Δs_{steam} = -5.597 kJ/kg°K		
		$M_{steam}\,\Delta s_{steam}$ = -42.54 kJ/s°K		
	(e)	Δs_{water} = 0.4745 kJ/kg°K		
		$M_{water}\Delta s_{water}$ = 47.45 kJ/s°K		
	(f)	$M\Delta S$ = 4.91 kJ/s°K		
		Increase in entropy		

Steam Cycles

PROBLEM T-21	T-s and h-s Diagrams			
PROBLEM T-22	T-s Diagram			
PROBLEM T-23	T-s Diagram			
PROBLEM T-24		q_{in} = 1886 kJ/kg		
		$w_{turbine}$ = 726 kJ/kg		
		w_{pump} = 5 kJ/kg		
		η = 38.2%		
PROBLEM T-25	(a)	h_1 = 3330.3 kJ/kg		s_1 = 6.9363 kJ/kg°K
		h_2 = 2418.8 kJ/kg		s_2 = 7.9278 kJ/kg°K
	(b)	x_2 = 0.941		
		m_2 = 0.059		m = 5.9%
	(c)	ΔUE = 303.4 kJ/kg		
	(d)	a_1 = 1215.8 kJ/kg		
	(e)	M = 110 kg/s		
PROBLEM T-26	(a)	n = 0.182		
		p = 0.097		
		q = 0.081		
		η = 31.8%		
	(b)	M = 155 kg/s		
		n = 28 kg/s		

		p	= 15 kg/s
		q	= 13 kg/s

Plant Efficiency

PROBLEM T-31	(b)	(i) η_{cycle}	= 43.6%
		(ii) $P_{HP\ turbine}$	= 164.9 MW
PROBLEM T-32	(a)	(i) η_{cycle}	= 43.6%
		(ii) $P_{HP\ turbine}$	= 164.9 MW
		(iii) BFP	= 11.7 MW input (turbine side)
		BFP	= 11.8 MW input (water side)
PROBLEM T-33	(b)	(i) PWR: Ω_{cw}	= 2146 MJ/s
		$\Omega_{atmosphere}$	= 42 MJ/s
		(ii) Coal: Ω_{cw}	= 1499 MJ/s
		$\Omega_{atmosphere}$	= 204 MJ/s
PROBLEM T-34	(a)	P_{out}	= 666 824 kW
		Ω_{in}	= 2 061 738 kJ/s
		η_{cycle}	= 32.3%
	(b)	$\eta_{thermal}$	= 100%
		AE_{in}	= 16 525 kJ/s
		AE_{out}	= 14 391 kJ/s
		ε	= 87%
PROBLEM T-35	(a)	Ω_{in}	= 930 000 kJ/s
		P_{out}	= 430 000 kW
		η_{cycle}	= 46.2%
	(b)	M_{in}	= 1 272 912 kg/hr
		M_{out}	= 1 272 912 kg/hr
		P_{out}	= 133 MW
	(c)	P_{input}	= 8 862 kW
		P_{actual}	= 8741 kW
	(d)	P_{input}	= 8743 kW
	(e)	$P_{required}$	= 7574 kW
	(f)	$\eta_{pump\ unit}$	= 85.5 %
		$\eta_{pump\ only}$	= 86.6%

Heat Exchanger Effectiveness

PROBLEM T-41	(a)	h_1	= 3249.6 kJ/kg	s_1	= 6.2671 kJ/kg°K
		h_2	= 3123.2 kJ/kg	s_2	= 6.0945 kJ/kg°K
		h_3	= 1133.5 kJ/kg	s_3	= 2.8459 kJ/kg°K
	(b)	M_{water}	= 15.88 kg/s		
	(c)	EX_{loss}	= 2528 kJ/s		
	(d)	EX_{loss}	= 0.735%		
	(e)	EX_{loss}	= 2022 kW (in electrical output)		
PROBLEM T-42	(a)	Ω_{in}	= 874 500 kJ/s		

		Ω_{out}	= 854 500 kJ/s
		$\eta_{thermal}$	= 97.7%
		AE_{in}	= 399 300 kJ/s
		AE_{cut}	= 372 200 kJ/s
		ε	= 93.2%
	(b)	Diagram	
	(c)	Diagram	
	(d)	P_{out}	= 249 MW
PROBLEM T-45	(a)	Feedwater: t_{out}	= 190°C
		Drains: t_{out}	= 170°C
	(b)	M_{steam}	= 31.0 kg/s
	(c)	Ω_{total}	= 65.4 kJ/s
	(d)	AE_{in}	= 22 106 kJ/s
		AE_{out}	= 21 750 kJ/kg
		ε	= 98.4%
		Diagram	
PROBLEM T-47		Ω_{in}	= 3 321 000 kJ/s
		Ω_{out}	= 3 261 000 kJ/s
		$\eta_{thermal}$	= 98.2%
		AE_{in}	= 1 606 000 kJ/s
		AE_{out}	= 1 449 000 kJ/s
		ε	= 90.2%
PROBLEM T-48	(a)	Ω_{in}	= 1 394 020 kJ/s
		P_{out}	= 608 068 kW
		η	= 43.6%
	(b)	Ω_{in}	= 65 778 kJ/s
		Ω_{out}	= 65 805 kJ/kg
		η_{cycle}	= 100.0%
		AE_{in}	= 29 699 kJ/s
		AE_{out}	= 29 304 kJ/s
		ε	= 98.7%
PROBLEM T-49	(a)	η_{cycle}	= 46.2%
	(b)	T_o	= 280°K
		Ω_{in}	= 25 871 kJ/s
		Ω_{out}	= 25 934 kJ/s
		η	= 100.2 %
		AE_{in}	= 5411 kJ/s
		AE_{out}	= 4552 kJ/s
		ε	= 84.1%

Exergy Flow Analysis

PROBLEM T-62	Exergy Flow Diagram	
PROBLEM T-63	Exergy Flow Diagram	Refer to Example in Notes

PROBLEM T-64	Exergy Flow Diagram		
PROBLEM T-65	Exergy Flow Diagram		
	$M_{turbine}$	=	44.25 kg/s
	$M_{auxiliary}$	=	3.59 kg/s
	M_{heater}	=	14.29 kg/s
	$M_{reactor}$	=	515.4 kg/s

Thermo-economic Analysis

PROBLEM T-71 Refer to Sample Calculation in Notes

SECTION R REACTOR HEAT GENERATION

Reactor Heat Generation

PROBLEM R-41 $q^* = 355\ 000\ kW/m^3$
$q/A = 727\ kW/m^2$ (on outer surface)

PROBLEM R-42
(a) $t_o = 1133°C$, $t_1 = 446°C$, $t_2 = 338°C$, $t_3 = 304°C$, $t_{water} = 286°C$
(b) Fuel centre (1133°C)
(c) $(q/A)_o = 0$, $(q/A)_1 = 650\ kW/m^2$, $(q/A)_2 = 637\ kW/m^2$, $(q/A)_3 = 549\ kW/m^2$
(d) Fuel surface (650 kW/m^2)
(e) $\Omega = 3880\ MW_{thermal}$

PROBLEM R-43
(a) $t_o = 1046°C$, $t_1 = 514°C$, $t_2 = 393°C$, $t_3 = 364°C$, $t_{water} = 345°C$
(b) Fuel centre (1046°C)
(c) $(q/A)_o = 0$, $(q/A)_1 = 727\ kW/m^2$,
$(q/A)_2 = 713\ kW/m^2$
$(q/A)_3 = 627\ kW/m^2$
(d) Fuel surface (727 kW/m^2)
(e) $\Omega = 2838\ MW_{thermal}$

PROBLEM R-44
(a) $t_o = 1332°C$, $t_1 = 539°C$, $t_2 = 322°C$, $t_3 = 305°C$, $t_{coolant} = 290°C$
(b) $(q/A)_{rod\ surface} = 606\ kW/m^2$
(c) $\Omega = 5.312$ MJ/s per channel
$\Omega = 2019\ MW_{thermal}$ for whole reactor

Reactor Heat Transfer

PROBLEM R-51 Sketch and Explanation

PROBLEM R-52 For $K_{fuel} = 2.5\ W/m°C$
$t_{water} = 285°C$, $t_3 = 302°C$, $t_2 = 358°C$
$t_1 = 672°C$, t_o - 2066°C (maximum)

PROBLEM R-53
$N_{ff} = (N_A/M_{ff})\ r\ f\ \rho\ i$
$N_{ff} = 0.704 \times 10^{21}$ nuclei/cm^3
$V = 10.78 \times 10^6\ cm^3$
$\Omega = N_{ff}\ \sigma_f\ \phi\ E_f\ V$
$\Omega = 267\ MW_{thermal}$

Steam Generator and Condenser Heat Transfer

PROBLEM R-61 Primary:
$p = 15$ MPa
$t = 304°C$
$\rho = 0.001396\ m^3/kg$
$\mu = 90.2 \times 10^{-6}$ kg/ms
$K = 0.553\ W/m°C$

h_{inside} = 37.5 kW/m^2°C
Secondary: p = 5.8 MPa
t = 273°C
$h_{outside}$ = 2.54 $(\Delta T_x^3)e^{p/1\,551}$
At outer surface: $\Omega_{from\ inside} = \Omega_{to\ outside}$
Thus: $(UA\ \Delta T)_{inside} = (h\ A\ \Delta T)_{outside}$
k_{wall} = 15 W/m°C
$U_{inside + wall}$ = 8.33 kW/m^2°C
Hence: $T_{wall} = 304 - 0.0128\ (T_{wall} - 273)^4$
$T_{wall} \approx$ 280°C
T_{water} = 273°C
$T_{inside\ wall}$ = 299°C
$T_{coolant}$ = 304°C

PROBLEM R-62

(a) p = 15 MPa
t = 304°C
ρ = 716 kg/m^3
μ = 90.2 x 10^{-6} kg/ms
k = 0.553 W/m°K
V = 6.0 m/s
h_{inside} = 37.5 kW/m^2°C
(b) p = 5.8 MPa
t = 273°C
$h_{outside}$ = 2.54 $(\Delta T_x^3)e^{p/1\,551}$
$h_{outside}$ = 107 $(T_{wall} - 273)^3$
(c) $A_{surface}$ = 4460 m^2
(d) Estimation to be proven
(e) $(UA\ \Delta T)_{inside} = (UA\ \Delta T)_{outside}$
K_{wall} = 15 W/m°C
U = 6.79 kW/m^2°C estimated
t_{wall}= 280°C
Ω = 939 $MW_{thermal}$
(f) Specified Ω = 928 $MW_{thermal}$

PROBLEM R-63

(a) p_{inlet} = 11 MPa, p_{outlet} = 10 MPa
t_{inlet} = 267°C t_{outlet} = 312°C
Primary: p = 10 MPa
t = 290°C
ρ = 737 kg/m^3
μ = 940 x 10^{-7} kg/ms
k = 593 x 10^{-3} W/m°C
Secondary: p = 4.7 MPa
t = 260°C
(b) Ω = 1862 MJ/s (ignoring boiling)
Ω = 2064 MJ/s (specified)
(c) $A_{surface}$ = 3139 m^3 (calculated)
$A_{surface}$ = 3127 m^3 (specified)

(d) Inside: $V = 4.93$ m/s
$h_{inside} = 36$ kW/m^2°C
$\Omega = 516$ MJ/s
$\Omega/A = 164$ kW/s
$\Delta T_{inside} = 5$°C
$\Delta T_{tube} = 13$°C
$t_{coolant} = 290$°C
$t_1 = 285$°C
$t_2 = 272$°C
$t_{water} = 260$°C

PROBLEM R-66

(a) $t_{steam} = 30$°C
$t_{inlet} = 13$°C
$t_{outlet} = 24$°C
$t_{average} = 18$°C (should be ~19°C)
$t_{wall} = 24$°C (should be ~25°C)

(b) Cooling Water: $\rho = 998$ kg/m^3
$\mu = 0.001056$ Ns/m^2 (0.0013158 Ns/m^2)
$c_p = 4.184$ kJ/kg°C
$k = 0.600$ W/m°C
$t = 30$°C (should be 27.5°C)

Condensate: $\rho = 996$ kg/m^3
$\mu = 0.000797$ Ns/m^2 (0.0010264 Ns/m^2)
$Cp = 4.179$ kJ/kg°C
$k = 0.618$ W/m°C
$h_{fg} = 2430$ kJ/kg

(c) Cooling Water: $R_e = 34\,000$ (27 000)
$Pr = 7.36$ (9.13)
$Nu = 216$
$h = 7200$ W/m^2°C (5200 W/m^2°C)

Condensate: $Nu = 342$
$h = 11\,124$ W/m^2°C (9 000 W/m^2°C)

(d) $U = 3979$ W/m^2°C (3290 W/m^2°C)

(e) $\theta_{average} = 11.5$°C
$\theta_m = 10.6$°C

(f) $\Omega = U\,A\,\theta_m = 2420$ MJ/s (2000 MJ/s)
(2405 MJ/s with steam at 27.5°C)
$\Omega = M\,Cp\,\Delta T = 1800$ MJ/s

(h) Numbers in brackets are more realistic values. Calculation does not take account of depth of tube bank and build up of condensation films

PROBLEM R-67

(a) Explanation and Sketch
(b) Temperature Profiles
(c) Temperature Profiles

PROBLEM R-69

SECTION H REACTOR THERMAL HYDRAULICS

Heat Transfer with Change in Phase

PROBLEM H-11
PROBLEM H-16
PROBLEM H-17

Fuel Channel Conditions

PROBLEM H-51

D_e = 0.007629 m
L = 11.15 m
p = 10 MPa (approximately)
t = 300°C (approximately)
ρ = 716 kg/m^3
μ = 905 x 10^{-7} kg/ms
M = 26.5 kg/s (22.5 kg/s)
V = 10.51 m/s (8.92 m/s)
Re = 6.36 x 10^5 (5.40 x 10^5)
f = 0.013
Δh = 107 m (77 m)
Δp = 0.752 MPa (0.541 MPa)
$\Delta p_{specified}$ = 0.88 MPa
Calculation ignores: Boiling frictional effect
Spacers in bundles
End effects of channels

PROBLEM H-52

D_e = 0.01178 m
L = 3.658 m
p = 15 MPa
t = 305°C
ρ = 715 kg/m^3
μ = 9.2 x 10^{-5} Ns/m^2
M = 17.64 m^3/s
V = 4.42 m/s
Re = 4.05 x 10^5
f = 0.013
Δp = 30 kPa

PROBLEM H-53
PROBLEM H-54

M = 0.624 kg/s
x_e = 0.290
α_e = 0.776
$\overline{R}$ = 8.46
Δp_f = 1.75 kPa
G = 434 kg/s m^2
Δp_a = 0.81 kPa
Δp_{total} = 2.56 kPa

PROBLEM H-55

q_s = 1980 kJ/s
H_o = 0.650 m
$q_{boiling}$ = q_t - q_s = 3020 kJ/s
x_e = 0.077
α_e = 0.532
Re = $3{,}2 \times 10^5$
f = 0.014
$\overline{R}$ = 2.57
H_B = 0.85
G = 2363 kg/s m^2
r = 0.001493 m^3/kg
Δp_f = 11.5 kPa
Δp_a = 8.3 kPa
Δp_{total} = 19.8 kPa

PROBLEM H-56

Q_s = 47 kW/m length
T_2 = 305°C
h = 26 kW/m^2°C
p = 4.7 MPa

PROBLEM H-57

Q_s = 15.39 kW/m length
h = 32 kW/m^2°C
D_e = 0.008443 m
Pr = 0.870
Re = 65 000 V
Nu = 469
V = 4.0 m/s

PROBLEM H-58

Assume S = 1
x_e = 0.0364
M = 0.301 kg/s
Ω = 20.3 kW/m

PROBLEM H-59

Assume S = 1
x_e = 0.0712
α_e = 0.753

SECTION W TWO PHASE AND OPERATIONAL PHENOMENA

CANDU Operational Conditions

PROBLEM W-21

PROBLEM W-22 (a) Temperature Profile, $\theta = 20°C$, $\Delta T = 20°C$, $t_{in} = 310°C$
$t_{out} = 270°C$
(b) Temperature Profile, $\theta = 20°C$, $\Delta T = 20°C$,
$t_{sat} = 240°C$, $p_{sat} = 3.34$ MPa

PROBLEM W-23

PROBLEM W-24 Explanation

PROBLEM W-25 Explanation

PROBLEM W-26 Explanation

PROBLEM W-27 Explanation

PROBLEM W-28 Explanation

PROBLEM W-29 Explanation

PROBLEM W-30 Explanation

PROBLEM W-31 Explanation

PROBLEM W-32 Explanation

PROBLEM W-33 Explanation

PROBLEM W-35 Explanation

PROBLEM W-37 Explanation

PROBLEM W-38 Explanation

General Operational Conditions

PROBLEM W-52

PROBLEM W-53 Sketch

PROBLEM W-54 Sketches and Explanations

PROBLEM W-55 Explanation

PROBLEM W-57 Explanation

PROBLEM W-58 (a) At 0% load: Inventory = 56 000 kg
At 40% load: Inventory = 37 500 kg
At 80% load: Inventory = 31 500 kg
At 0% load: Volume % = 0%
At 40% load: Volume % = 33%
At 80% load: Volume % = 44%

(b) At 40% load and p = 4.8 MPa
V_{water} = 43.5 m^3
$V_{bubbles}$ = 21.4 m^3
At increasing load and p = 4.6 MPa
V_{water} = 43.5 m^3
$V_{bubbles}$ = 22.4 m^3
ΔV = 1.0 m^3 due to density change
m_{water} = 34 000 kg
$m_{bubbles}$ = 5 200 kg

$x_{4.8\ MPa}$ = 0.153
Assume isentropic conditions during flashing
$(s_f + x\ s_{fg})_{4.6\ MPa} = (s_f + x\ s_{fg})_{4.8\ MPa}$
$x_{4.6\ MPa}$ = 0.159
$m_{bubbles}$ = 5 400 kg
$V_{bubbles}$ = 23.2 m^3
ΔV = 1.8 m^3 due to flashing
ΔV total = 2.8 m^3
$D_{stream\ drum}$ = 4.2 m
Level Rise = 0.20 m