

# PASS MOCK EXAM

– FOR PRACTICE ONLY –

Course: MAAE 2400 BC

Facilitator: Julie Love

Date and location of mock exam take-up: April 11<sup>th</sup>, 9:00am-12:00pm

It is **most beneficial** to you to write this mock midterm **UNDER EXAM CONDITIONS**. This means:

- Complete the exam in 3 hour(s).
- Work on your own.
- Keep your notes and textbook closed.
- Attempt every question.

After the time limit, go back over your work with a different colour or on a separate piece of paper and try to do the questions you are unsure of. Record your ideas in the margins to remind yourself of what you were thinking when you take it up at PASS.

The purpose of this mock exam is to give you practice answering questions in a timed setting and to help you to gauge which aspects of the course content you know well and which are in need of further development and review. Use this mock exam as a **learning tool** in preparing for the actual exam.

Please note:

- Come to the PASS session with your mock exam complete. There, you can work with other students to review your work.
- Often, there is not enough time to review the entire exam in the PASS session. Decide which questions you most want to review – the Facilitator may ask students to vote on which questions they want to discuss.
- Facilitators do not bring copies of the mock exam to the session. Please print out and complete the exam before you attend.
- **Facilitators do not produce or distribute an answer key for mock exams.** Facilitators help students to work together to compare and assess the answers they have. If you are not able to attend the PASS session, you can work alone or with others in the class.

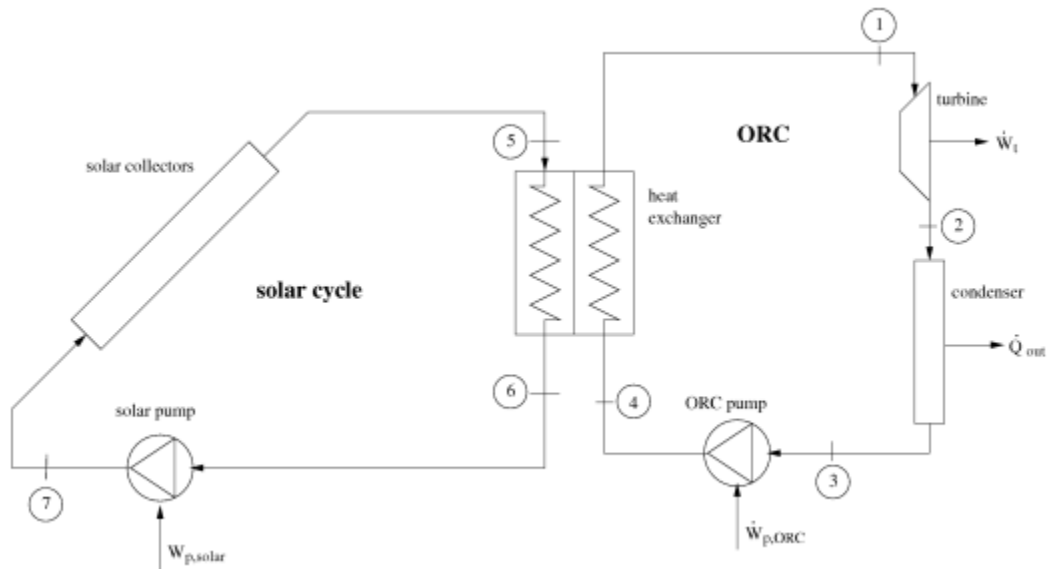
**Good Luck writing the Mock Midterm!!**

**DISCLAIMER:** PASS handouts are designed as a study aid only for use in PASS workshops. Handouts may contain errors, intentional or otherwise. It is up to the student to verify the information contained within.

**PLEASE NOTE: THIS HANDOUT IS NOT TO BE DISTRIBUTED.**

### Question 1

A small power plant uses solar-thermal collectors to provide the heat input to an organic Rankine cycle (ORC), as illustrated in the figure below. The power plant is composed of two cycles, which are labelled solar cycle and ORC in the figure. Each cycle has its own working fluid. The two cycles are coupled through the heat exchanger that is shown in the middle of the figure. This heat exchanger does not mix the working fluids but rather transfers energy from the solar cycle's working fluid to the ORC's working fluid by heat transfer.



The collectors at the left side of the figure transfer energy from the incoming solar radiation to a working fluid of propylene glycol that is circulated by the solar pump. This propylene glycol working fluid can be treated as an incompressible liquid with a constant specific heat of  $3500 \text{ J/kgK}$ . The propylene glycol exits the solar collectors at a temperature of  $180^\circ\text{C}$  (state 5). The temperature of the propylene glycol as it exits the heat exchanger (state 6) is  $50^\circ\text{C}$ . The isentropic efficiency of the solar pump is 65%.

The Rankine cycle uses n-butane as its working fluid and operates under steady conditions. The mass flow rate of n-butane through the ORC is  $2 \text{ kg/s}$ . The pressure of the n-butane at the turbine's inlet is  $3.7 \text{ MPa}$  and its quality is 65%. The condenser pressure is  $400 \text{ kPa}$ . The isentropic efficiency of the ORC pump is 70% and the isentropic efficiency of the turbine is 91%. The rate of heat transfer from the n-butane to the surroundings in the condenser is  $740 \text{ kW}$ .

The turbine and the two pumps can be treated as adiabatic. The pressure drops of the n-butane working fluid as it flows through the heat exchanger and through the condenser are negligible. Likewise, the pressure drops of the propylene glycol working fluid as it flows through the heat exchanger and through the solar collectors are negligible. Kinetic and potential energy effects can also be ignored. Stray heat losses from the heat exchanger can be ignored.

Property data for n-butane are tabulated on last pages. Use the state point numbering scheme indicated in the above schematic for your analysis. Do the following:

- a) Determine the enthalpy at state 1. Is it in the sub-cooled, mixed or super-heated region? (circle one answer for enthalpy, and one answer for the region)
- A)  $h_1 = 699.53 \text{ kJ/kg}$    B)  $h_1 = 702.05 \text{ kJ/kg}$    C)  $h_1 = 710.64 \text{ kJ/kg}$    D)  $h_1 = 683.97 \text{ kJ/kg}$
- A) Sub-cooled Region   B) Mixed Region   C) Super-Heated Region   D) Super Critical Fluid

- b) Determine the enthalpy at state 2. Is it in the sub-cooled, mixed or super-heated region? (circle one answer for enthalpy, and one answer for the region)
- A)  $h_2 = 635.68$  kJ/kg    B)  $h_2 = 644.93$  kJ/kg    C)  $h_2 = 597.75$  kJ/kg    D)  $h_2 = 694.18$  kJ/kg  
 A) Sub-cooled Region    B) Mixed Region    C) Super-Heated Region    D) Super Critical Fluid
- c) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_4 = 286$  kJ/kg determine the enthalpy at state 3. Is it in the sub-cooled, mixed or super-heated region? (circle one answer for enthalpy, and one answer for the region)
- A)  $h_3 = 265.74$  kJ/kg    B)  $h_3 = 270.00$  kJ/kg    C)  $h_3 = 284.00$  kJ/kg    D)  $h_3 = 276.78$  kJ/kg  
 A) Sub-cooled Region    B) Mixed Region    C) Super-Heated Region    D) Super Critical Fluid
- d) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_3 = 265.68$  kJ/kg determine the enthalpy at state 4. Is it in the sub-cooled, mixed or super-heated region? (circle one answer for enthalpy, and one answer for the region)
- A)  $h_4 = 284.95$  kJ/kg    B)  $h_4 = 263.53$  kJ/kg    C)  $h_4 = 237.14$  kJ/kg    D)  $h_4 = 273.82$  kJ/kg  
 A) Sub-cooled Region    B) Mixed Region    C) Super-Heated Region    D) Super Critical Fluid
- e) What is the temperature at state 1?
- A)  $T_1 = 38.9$  °C    B)  $T_1 = 50.0$  °C    C)  $T_1 = 150.4$  °C    D)  $T_1 = 230.0$  °C
- f) What is the temperature at state 2?
- A)  $T_2 = 41.93$  °C    B)  $T_2 = 56.85$  °C    C)  $T_2 = 34.78$  °C    D)  $T_2 = 47.32$  °C
- g) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_3 = 265.68$  kJ/kg, find the temperature at state 3
- A)  $T_3 = 30.54$  °C    B)  $T_3 = 24.22$  °C    C)  $T_3 = 27.61$  °C    D)  $T_3 = 19.38$  °C
- h) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_4 = 286$  kJ/kg, find the temperature at state 4
- A)  $T_4 = 31.4$  °C    B)  $T_4 = 37.2$  °C    C)  $T_4 = 40.0$  °C    D)  $T_4 = 35.0$  °C
- i) Plot state points 1 through 4 on a T-s diagram (in exam booklet)
- j) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_3 = 265.68$  kJ/kg, calculate the work of the turbine in kW:
- A)  $W_t = 374.32$  kW    B)  $W_t = -374.32$  kW    C)  $W_t = 120$  kW    D)  $W_t = -120$  kW
- k) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg and  $h_4 = 286$  kJ/kg, calculate the rate of heat transfer from the propylene glycol to the n-butane in the heat exchanger, in kW
- A)  $Q_{HX} = -828$  kW    B)  $Q_{HX} = 828$  kW    C)  $Q_{HX} = -414$  kW    D)  $Q_{HX} = 414$  kW
- l) If  $h_1 = 700$  kJ/kg,  $h_2 = 640$  kJ/kg,  $h_3 = 265.68$  kJ/kg and  $h_4 = 286$  kJ/kg, calculate the ORC pump power, in kW
- A)  $W_p = 120.01$  kW    B)  $W_p = -120.01$  kW    C)  $W_p = -20.32$  kW    D)  $W_p = 20.32$  kW
- m) Calculate the rate of heat transfer from the n-butane in the condenser, in kW
- A)  $Q_{out} = -740$  kW    B)  $Q_{out} = 740$  kW    C)  $Q_{out} = 760$  kW    D)  $Q_{out} = -700$  kW
- n) Calculate the ORC cycle's back work ratio
- A)  $bwr = 0.094$     B)  $bwr = 0.169$     C)  $bwr = 0.102$     D)  $bwr = 0.245$

o) Calculate the ORC Cycle's thermal efficiency

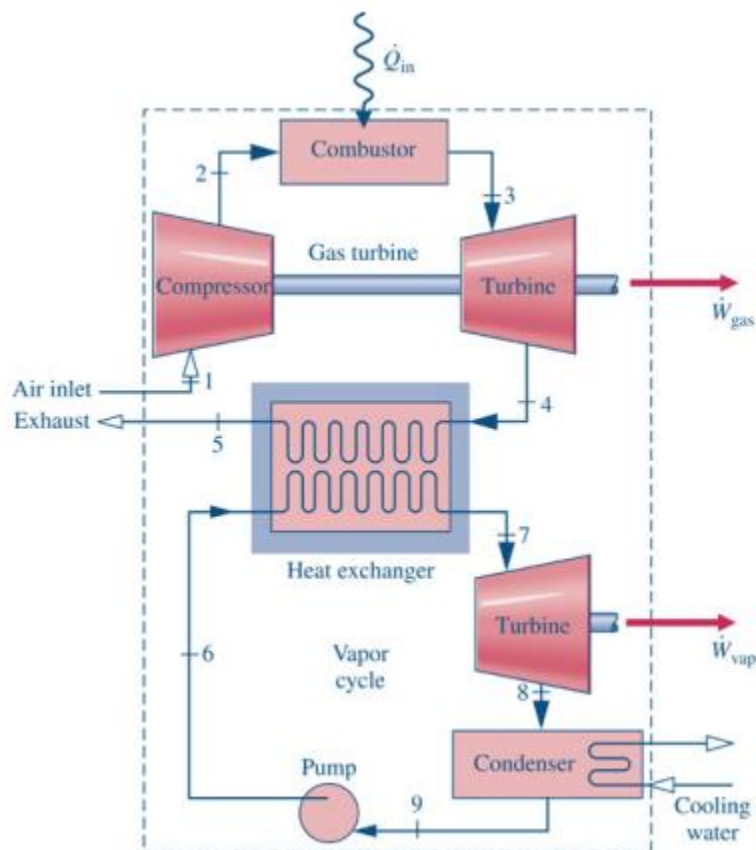
- A)  $\eta_{th} = 9.32\%$     B)  $\eta_{th} = 15.66\%$     C)  $\eta_{th} = 22.59\%$     D)  $12.04\%$

p) Calculate the mass flow rate of propylene glycol through the solar cycle if the heat exchanger is exchanging heat from the solar cycle to the ORC cycle at a rate of  $\dot{Q}_{HX} = 856.46 \text{ kW}$

- A)  $\dot{m} = 2.36 \text{ kg/s}$     B)  $\dot{m} = 1.88 \text{ kg/s}$     C)  $\dot{m} = 0.89 \text{ kg/s}$     D)  $\dot{m} = 2.14 \text{ kg/s}$

## Question 2

A combined Brayton and Rankine cycle power plant is illustrated in the figure below. The Brayton cycle portion of the power plant can be treated with an air standard analysis. Air enters the compressor (state 1) at 310 K and 101 kPa and is compressed to 1.2 MPa by the compressor which has an isentropic efficiency of 88%



The specific heat addition at the combustor is 800 kJ/kg. The air is then expanded to 101 kPa (state 4) by the turbine, which has an isentropic efficiency of 91%. Finally the air is cooled to 150°C (state 5) by the heat exchanger that couples the Brayton and Rankine portions of the cycle before it is exhausted to the environment. The Brayton cycle transfers energy at the rate of 32 MW to the Rankine cycle through this heat exchanger.

The specific heat of air cannot be treated as a constant. List all assumptions used in your analysis and indicate all sources of data (e.g. Table A-1). Marks will be deducted if you neglect to adequately justify the form of the 1st law energy balances used to represent each process.

- a) Indicate state points 1 through 5 on a T-s diagram (in exam booklet). You must follow the state point numbering scheme utilized in the above figure
- b) Calculate the enthalpy at state 2  
 A)  $h_2 = 672.3 \text{ kJ/kg}$     B)  $h_2 = 612.9 \text{ kJ/kg}$     C)  $h_2 = 722.4 \text{ kJ/kg}$     D)  $h_2 = 704.6 \text{ kJ/kg}$
- c) If  $h_2 = 650 \text{ kJ/kg}$  and  $h_1 = 300 \text{ kJ/kg}$ , find the enthalpy at state 3  
 A)  $h_3 = 1400 \text{ kJ/kg}$     B)  $h_3 = 1500 \text{ kJ/kg}$     C)  $h_3 = 1450 \text{ kJ/kg}$     D)  $h_3 = 1475 \text{ kJ/kg}$
- d) If  $h_2 = 650 \text{ kJ/kg}$ ,  $h_1 = 300 \text{ kJ/kg}$  and  $h_3 = 1472.3 \text{ kJ/kg}$ , find the enthalpy at state 4  
 A)  $h_4 = 802.36 \text{ kJ/kg}$     B)  $h_4 = 793.58 \text{ kJ/kg}$     C)  $h_4 = 851.67 \text{ kJ/kg}$     D)  $h_4 = 812.85 \text{ kJ/kg}$
- e) If  $h_2 = 650 \text{ kJ/kg}$ ,  $h_1 = 300 \text{ kJ/kg}$  and  $h_4 = 820 \text{ kJ/kg}$ , calculate the mass flow rate of air through the Brayton cycle  
 A)  $\dot{m} = 80.9 \text{ kg/s}$     B)  $\dot{m} = 74.6 \text{ kg/s}$     C)  $93.7 \text{ kg/s}$     D)  $56.1 \text{ kg/s}$
- f) If  $\dot{m} = 76 \text{ kg/s}$ ,  $h_2 = 650 \text{ kJ/kg}$ ,  $h_1 = 300 \text{ kJ/kg}$  and  $h_3 = 720 \text{ kJ/kg}$ , calculate the work of the compressor  
 A)  $\dot{W}_{comp} = 26.6 \text{ MW}$     B)  $\dot{W}_{comp} = -26.6 \text{ MW}$     C)  $\dot{W}_{comp} = 31 \text{ MW}$     D)  $\dot{W}_{comp} = -31 \text{ MW}$
- g) If  $\dot{m} = 76 \text{ kg/s}$ ,  $h_2 = 650 \text{ kJ/kg}$ ,  $h_1 = 300 \text{ kJ/kg}$  and  $h_3 = 1472.3 \text{ kJ/kg}$  and  $h_4 = 820 \text{ kJ/kg}$ , calculate the work of the turbine  
 A)  $W_{turb} = 49.57 \text{ MW}$     B)  $W_{turb} = -49.57 \text{ MW}$     C)  $W_{turb} = 35.28 \text{ MW}$     D)  $W_{turb} = -35.28 \text{ MW}$
- h) Calculate the thermal efficiency of the brayton cycle if the work of the turbine is 50 MW, the work of the compressor is 28 MW, the heat added in the combustor is 65.6 MW and the heat rejected at the heat exchanger is 32 MW:  
 A)  $\eta_{th} = 33.5 \%$     B)  $\eta_{th} = 45.2 \%$     C)  $\eta_{th} = 24.2 \%$     D)  $\eta_{th} = 56.1 \%$

### Question 3

An Air-Standard otto cycle has a volumetric compression ratio of 7.5. At the beginning of compression the 2 kg of air are at  $T_1 = 305 \text{ K}$  and  $P_1 = 85 \text{ kPa}$ . The maximum temperature in the cycle is 960 K.

- a) Draw the P-v diagram in your exam booklet
- b) Determine the heat addition  
 A)  $Q_H = 451.5 \text{ J}$     B)  $Q_H = 536.2 \text{ J}$     C)  $Q_H = 476.5 \text{ J}$     D)  $511.7 \text{ J}$
- c) Determine the heat loss  
 A)  $Q_C = 249.7 \text{ J}$     B)  $Q_C = 222.7 \text{ J}$     C)  $Q_C = 197.4 \text{ J}$     D)  $284.6 \text{ J}$
- d) If  $Q_C = 200 \text{ J}$  and  $Q_H = 500 \text{ J}$ , what is the net work?  
 A)  $W_{NET} = 700 \text{ J}$     B)  $W_{NET} = -700 \text{ J}$     C)  $W_{NET} = 2.5 \text{ J}$     D)  $W_{NET} = 300 \text{ J}$
- e) If  $Q_C = 220 \text{ J}$ ,  $Q_H = 550 \text{ J}$  and  $W_{NET} = 330 \text{ J}$ , what is the thermal efficiency of the otto cycle?  
 A) 60 %    B) 50 %    C) 70 %    D) 55%

#### Question 4

A 35 m length of pipe is used to transport steam from the boiler to the turbine in a Rankine cycle power plant. The rate of heat addition at the Rankine cycle's boiler is 1.3 GW. The pipe is 2.2 m in diameter and its surface temperature is 440°C.

Energy is lost from the pipe to the surroundings due to heat transfer by convection and by radiation. The convection coefficient between the pipe and the surrounding air is 9 W/m<sup>2</sup>K and the air temperature is 19°C.

The radiation portion of the heat transfer can be treated as emission from a grey body to an enclosure. The enclosure temperature (i.e. the surfaces formed by the power plant containing the pipe and turbine) can be taken as 16°C. The emissivity of the surface of the pipe is 0.2.

- a) Calculate the rate of convective heat transfer per surface area of the pipe, in W/m<sup>2</sup>  
A)  $\frac{Q_{conv}}{A} = 4215 \text{ W/m}^2$     B)  $\frac{Q_{conv}}{A} = 3789 \text{ W/m}^2$     C)  $\frac{Q_{conv}}{A} = 3541 \text{ W/m}^2$     D)  $\frac{Q_{conv}}{A} = 4169 \text{ W/m}^2$
- b) Calculate the rate of radiation heat transfer per surface area of the pipe, in W/m<sup>2</sup>  
A)  $\frac{Q_{rad}}{A} = 2853 \text{ W/m}^2$     B)  $\frac{Q_{rad}}{A} = 2764 \text{ W/m}^2$     C)  $\frac{Q_{rad}}{A} = 4213 \text{ W/m}^2$     D)  $\frac{Q_{rad}}{A} = 3140 \text{ W/m}^2$
- c) If  $\frac{Q_{conv}}{A} = 4000 \text{ W/m}^2$  and  $\frac{Q_{rad}}{A} = 3000 \text{ W/m}^2$ , what is the total heat transfer per surface area lost from the pipe?  
A)  $\frac{Q_{Total}}{A} = 1000 \text{ W/m}^2$     B)  $\frac{Q_{Total}}{A} = 7 \text{ kW/m}^2$     C)  $\frac{Q_{Total}}{A} = 700 \text{ W/m}^2$     D)  $\frac{Q_{Total}}{A} = 2000 \text{ W/m}^2$
- d) In your exam booklet, comment on whether it would be a reasonable assumption to neglect heat losses from the pipe when analyzing the Rankine cycle to determine the cycle's thermal efficiency.

Table 1: Properties of saturated n-butane

$P_{\text{sat}}$ (kPa)	$T_{\text{sat}}$ (°C)	$h_f$ (kJ/kg)	$h_g$ (kJ/kg)	$s_f$ (kJ/kgK)	$s_g$ (kJ/kgK)	$v_f$ (m <sup>3</sup> /kg)	$v_g$ (m <sup>3</sup> /kg)
100	-0.8664	198.2	583.3	0.9935	2.408	0.001663	0.3734
200	18.79	244.4	611.3	1.156	2.413	0.001725	0.1949
300	31.85	276.2	629.9	1.262	2.422	0.001771	0.1326
400	41.93	301.4	644.2	1.343	2.431	0.001811	0.1006
500	50.26	322.8	655.9	1.41	2.439	0.001846	0.08097
600	57.43	341.6	665.9	1.467	2.447	0.001878	0.06766
700	63.76	358.5	674.6	1.517	2.455	0.001909	0.05802
800	69.45	374	682.3	1.562	2.462	0.001939	0.05069
900	74.64	388.4	689.3	1.603	2.468	0.001967	0.04492
1000	79.42	401.8	695.5	1.641	2.474	0.001995	0.04027
1100	83.86	414.5	701.3	1.676	2.479	0.002023	0.03642
1200	88.01	426.5	706.5	1.709	2.484	0.002051	0.03318
1300	91.92	438.1	711.3	1.74	2.488	0.002079	0.03041
1400	95.61	449.1	715.8	1.769	2.493	0.002106	0.02802
1500	99.11	459.7	719.9	1.798	2.496	0.002134	0.02593
1600	102.4	470	723.7	1.824	2.5	0.002163	0.02409
1700	105.6	479.9	727.1	1.85	2.503	0.002191	0.02245
1800	108.7	489.6	730.3	1.875	2.506	0.002221	0.02097
1900	111.6	499	733.3	1.899	2.508	0.002251	0.01964
2000	114.4	508.2	735.9	1.922	2.51	0.002281	0.01844
2100	117.1	517.2	738.4	1.945	2.512	0.002313	0.01733
2200	119.7	526	740.5	1.967	2.513	0.002346	0.01632
2300	122.2	534.7	742.5	1.988	2.514	0.00238	0.01538
2400	124.6	543.3	744.2	2.009	2.514	0.002416	0.01451
2500	127	551.7	745.6	2.03	2.514	0.002453	0.0137
2600	129.3	560.1	746.8	2.05	2.514	0.002493	0.01294
2700	131.5	568.3	747.7	2.07	2.513	0.002535	0.01222
2800	133.6	576.6	748.3	2.089	2.512	0.002579	0.01154
2900	135.7	584.8	748.6	2.109	2.51	0.002627	0.01089
3000	137.8	593	748.5	2.128	2.507	0.002679	0.01027
3100	139.7	601.4	748.1	2.148	2.503	0.002737	0.009674
3200	141.6	609.8	747.1	2.168	2.499	0.002801	0.009091
3300	143.5	618.4	745.6	2.188	2.493	0.002873	0.008516
3400	145.3	627.3	743.3	2.208	2.485	0.002958	0.007939
3500	147.1	636.8	739.9	2.23	2.475	0.003062	0.007345
3600	148.8	647.2	734.5	2.254	2.461	0.003197	0.006698
3700	150.4	659.8	724.8	2.283	2.437	0.003402	0.005892

Table 2: Properties of subcooled liquid n-butane at  $P = 400$  kPa

T (°C)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/kgK)
10	0.001694	223.5	1.083
15	0.00171	235.3	1.124
20	0.001727	247.2	1.165
25	0.001745	259.3	1.206
30	0.001763	271.5	1.247
35	0.001782	283.9	1.287
40	0.001802	296.5	1.328

Table 3: Properties of subcooled liquid n-butane at  $P = 3.7$  MPa

T (°C)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/kgK)
10	0.001681	226.2	1.072
15	0.001696	237.9	1.113
20	0.001712	249.7	1.154
25	0.001728	261.7	1.195
30	0.001745	273.8	1.235
35	0.001763	286	1.275
40	0.001781	298.4	1.315
45	0.0018	310.9	1.354
50	0.00182	323.6	1.394
55	0.00184	336.4	1.433