HOCHSCHULE RHEIN-WAAL
Rhine-Waal University of Applied Sciences

Period of Examinations
Summer semester 2019 / July

NEW Curriculum

Course of study: ______________________

Module Title: **ME_3_27081 / SE_3_27081 Thermodynamics (Prof. Gebel)**

Examination Part: **Written exam**

Points: 75

Duration: 110 Minutes

Date: 23.07.2019

Family Name: ______________________ ______________________

First Name: ______________________ Signature (Student)

Student No.: ______________________

The exam consists of 16 pages. First, check that your copy contains all pages.

All calculations and sketches should be done on the sheets provided for that purpose. If more than one solution is given, mark clearly which one should be graded.

Please write legibly! Good luck!

FOR INTERNAL USE ONLY:

	Q1	Q2	Q3	Q4	Q5	Written exam	≥ 38 Yes | No	Stirling motor	Practical Training	Total
Max. Points	12	16	12	15	20	75		13	12	100
Achieved										
									Grade	

Graded by		Checked by

Final Grade

Regular grading key.	
Adjusted grading key. (Please add the adjusted grading key to the exam-results)	X

Register No.:____________________

Question 1 … Ideal gas law **Points: 12**

A rigid piston-cylinder arrangement containing 1.0 kmol of the nearly ideal gas Helium is put through the following cycle:

Process 1 → 2	Constant-specific volume process
Process 2 → 3	Isothermal expansion
Process 3 → 1	Constant-pressure compression

At state 1, the volume V_1 is 22.4 m³, the pressure p_1 is 1.0 bar.

At state 2, the pressure p_2 has increased to 2 bars.

Employing the ideal gas law,

a) sketch the cycle on p-v coordinates in the below template, ✓

b) determine the temperatures at state 1, 2, and 3 in Kelvin,

c) determine the work done by the process on the surroundings.

Given:

Universal gas constant $\bar{R} = 8.314 \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}$

Molecular weight of helium $M_{\text{Helium}} = 4.0 \frac{\text{kg}}{\text{kmol}}$

b) $P_1V_1 = n\bar{R}T_1 \Rightarrow \boxed{T_1 = \frac{P_1 \cdot V_1}{n\bar{R}}} = \frac{100\,\text{kPa}\ (22.4\,m^3)}{1\,\text{kmol}\,(8.314\,\frac{kJ}{kmol\cdot K})} = 269.42\,K$ (kN/m²)

$R = \frac{\bar{R}}{M} = \frac{8.314\ kJ/kmol\cdot K}{4\ kg/kmol} = 2.0785\ kJ/kg\cdot K \Longrightarrow P_1V_1 = mRT \Rightarrow m_1 = \frac{P_1V_1}{RT_1} = 4\,Kg$

$v_1 = \frac{V_1}{m} = 5.6\ m^3/kg = v_2$ $\quad P_2v_2 = RT_2 \Rightarrow v_2 = \frac{RT_2}{P_2}$

$\therefore v_1 = v_2 \Rightarrow \frac{\cancel{R}T_1}{P_1} = \frac{\cancel{R}T_2}{P_2} \Rightarrow T_2 = P_2 \cdot \frac{T_1}{P_1} = \frac{2\,bar}{1\,bar}(269.42K) = 538.85\,K$

$\therefore$ Process $2 \to 3$ isothermal $\longrightarrow T_2 = T_3 = 538.85\,K$

c) Process $3 \to 1$ (isobaric) $\longrightarrow P_1 = P_3 = 1\,bar$

$V_3 = \frac{RT_3 \cdot m}{P_3} = 44.8\ m^3$

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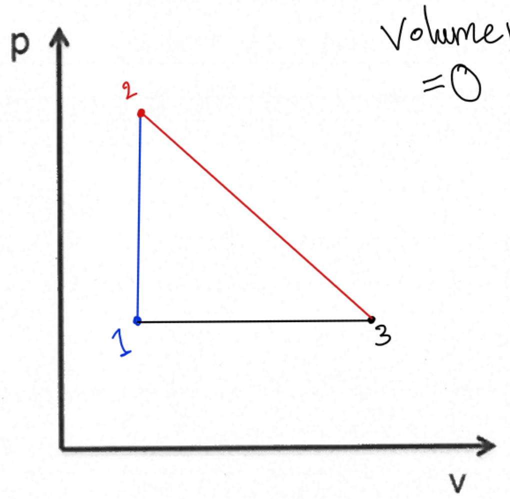
Answer sheet

Use this sheet for your answer only. Other notes will not be accepted.



Volume work $= 0$

C) Process $1 \rightarrow 2$: (v= cons. & closed system) $\Rightarrow V = cons.$

technical work $W_{12} = + \int_1^2 V dP = V_1 (P_2 - P_1)$

$W_{12} = 22.4\, m^3 (200 - 100) \overset{KN/m^2}{\cancel{KPa}} = 2240\, KJ$

Process $2 \rightarrow 3$: $PV = cons. \rightarrow T = cons.$

$W_{23} = \overset{by}{+} \int_2^3 P dv = \int_2^3 \frac{cons.}{V} dV = m R T_2 \cdot \ln\left(\frac{V_3}{V_1}\right)$

$W_{23} = 4\, \cancel{Kg} (2.0785\, KJ/\cancel{Kg} \cdot \cancel{K}) \cdot 538.85\, \cancel{K} \cdot \ln\left(\frac{44.8\, \cancel{m^3}}{22.4\, \cancel{m^3}}\right)$

$W_{23} = 3105.3\, KJ$

Process $3 \rightarrow 1$: $P = cons.$

$W_{31} = \overset{on}{-} \int_3^1 P\, dv = -P_1 (V_1 - V_3) = -100\, KPa (22.4 - 44.8)\, m^3$

$W_{31} = 2240\, KJ$

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Question 2 … Rigid tank expansion **Points: 16**

A rigid tank is divided into two equal parts by a partition. Initially, one side of the tank contains 5 kg of water at 200 kPa and 25°C, and the other side is evacuated. The partition is then removed, and the water expands to the entire tank. The water is allowed to exchange heat with its surroundings until the temperature in the tank returns to the initial value of 25°C.

a) Determine the volume of the tank.

b) Find the final pressure.

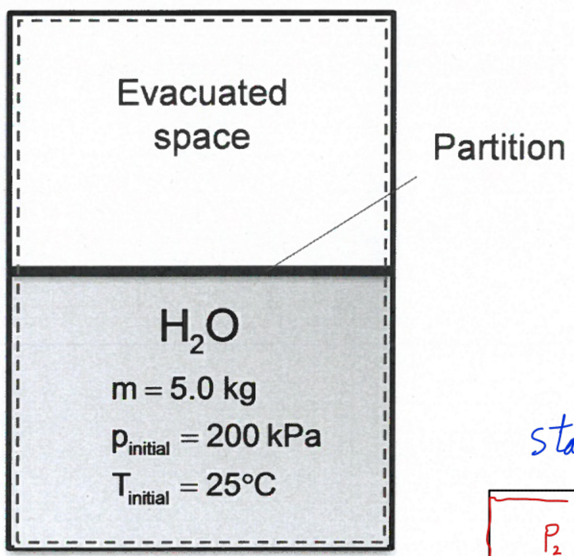
c) Calculate the heat transfer for this process.

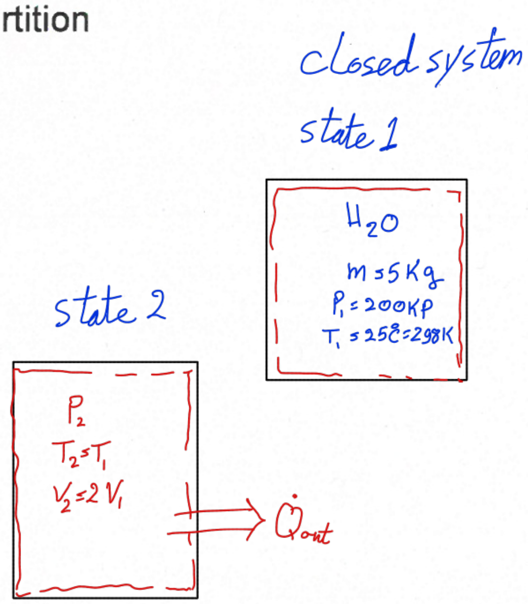
d) Show the process in a p-v diagram.

Assumptions:

→ Kinetic and potential energies are negligible.

→ There is no electrical, shaft, or any other kind of work involved.





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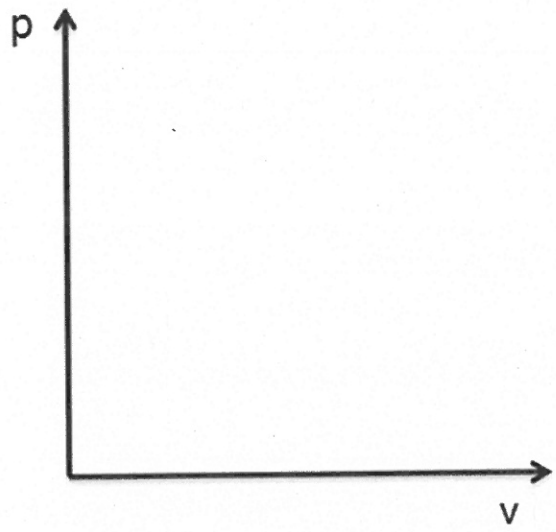

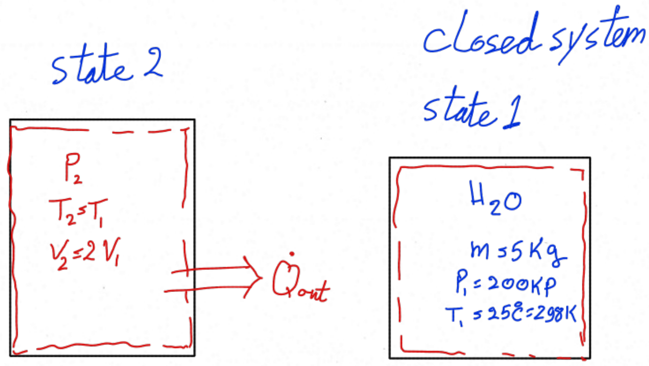

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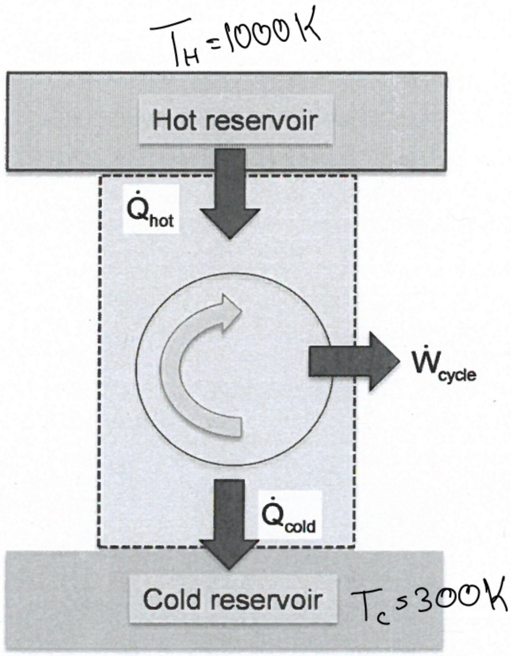
Question 3 … Reversible, irreversible or impossible cycles **Points: 12**

A power cycle operating at steady state receives energy by heat transfer from a hot reservoir at a temperature of 727°C. Energy is rejected by heat transfer to a cold reservoir at 27°C.



For each of the following four cases, determine by conclusive evidence whether the cycle operates reversibly, operates irreversibly or is impossible.

1. $\dot{Q}_{Hot} = 500\ W$, $\dot{Q}_{Cold} = 100\ W$
2. $\dot{Q}_{Hot} = 500\ W$, $\dot{W}_{Cycle} = 250\ W$, $\dot{Q}_{Cold} = 200\ W$
3. $\dot{W}_{Cycle} = 350\ W$, $\dot{Q}_{Cold} = 150\ W$
4. $\dot{Q}_{Hot} = 500\ W$, $\dot{Q}_{Cold} = 200\ W$

1) Ideally $\longrightarrow \eta_{carnot} = \eta_{th} \Rightarrow 1 - \frac{T_c}{T_H} = 1 - \frac{\dot{Q}_c}{\dot{Q}_H}$

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Question 4 … 1st rule of thermodynamics **Points: 15**

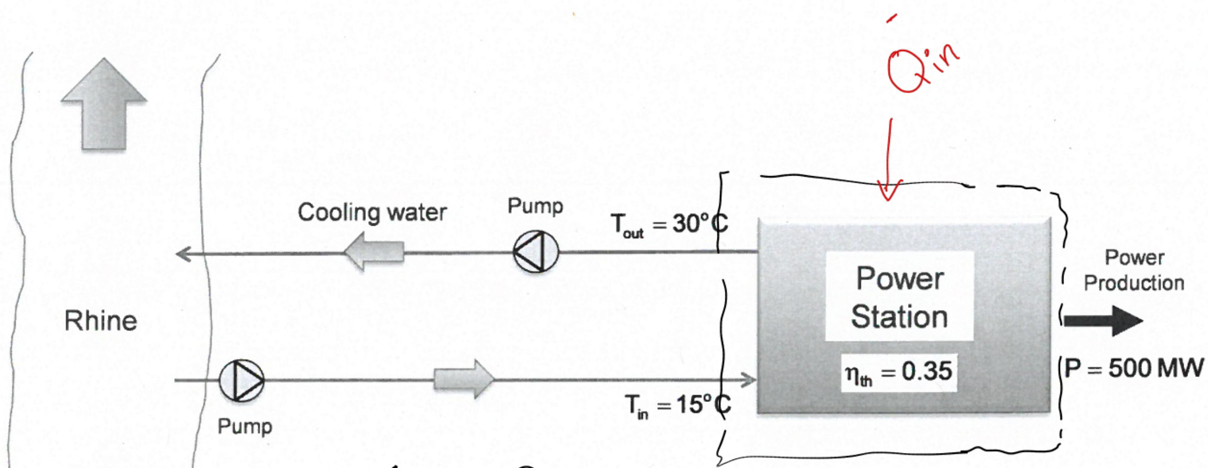
Heat has to be discharged from a power station. For this purpose water from the River Rhine is pumped through the condenser of the power station. The power station operates according to a Rankine cycle.

Determine the volume flow of cooling water, in [m³/h] under the following conditions:

Net power production	$P_{net} = 500 \ \text{MW}$
Thermal efficiency of the power plant	$\eta_{th} = 0.35$
Temperature of the cooling water at the outlet	$T_{Out} = 30°C$
Temperature of the cooling water at the inlet	$T_{in} = 15°C$
Constant specific heat capacity of cooling water	$\bar{c}_{P,CW} = 4.2 \ \frac{kJ}{kg\,K}$
Constant density of cooling water	$\rho_{CW} = 1{,}000 \ \frac{kg}{m^3}$

Assumptions:

Power demand of the cooling water pumps	- negligible
Kinetic and potential energies	- negligible



$$\dot{m}\, dh = \dot{Q}_{in} - P_{net}$$

$$\dot{m}\,(c_p\, dT) = \dot{Q}_{in} - P_{net}$$

$$\eta_{th} = \frac{P_{net}}{\dot{Q}_{in}} \Rightarrow \dot{Q}_{in} = \frac{P_{net}}{\eta_{th}}$$

$$\dot{m} = \rho \cdot \dot{V}$$

$$\dot{V} \cdot \rho \cdot c_p (T_{out} - T_{in}) = \frac{P_{net}}{\eta_{th}} - P_{net}$$

$$\boxed{\dot{V} = \frac{P_{net}\left(\frac{1}{\eta_{th}} - 1\right)}{\rho \cdot c_p (T_{out} - T_{in})}}$$

Solution

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Answer sheet

Use this sheet for your answer only. Other notes will not be accepted.

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Question 5 … Ideal Rankine Cycle **Points: 20**

Steam is the working fluid in an <u>ideal</u> Rankine cycle with <u>superheating</u> and <u>reheating</u>.

Steam enters the first-stage (high pressure) turbine at p_1 = 60 bar, T_1 = 600°C, and expands to p_2 = 10 bar. It is then reheated to 600°C before entering the second-stage (low pressure) turbine, where it expands to the condenser pressure of 0.35 bar.

a) Sketch the cycle on T-s coordinates and specify the nature of each process (adiabatic or isothermal or isentropic or isobaric, expansion or compression and so on ….). Use the template below.

b) Determine the specific enthalpy and the specific entropy of each state and complete the table below.

c) Determine the thermal efficiency of the process.

<u>Assumptions</u>:

→ Label the states as follows: State 1 → Inlet of first-stage turbine

→ Neglect kinetic and potential energy effects.

→ Turbine and pump operate adiabatically.

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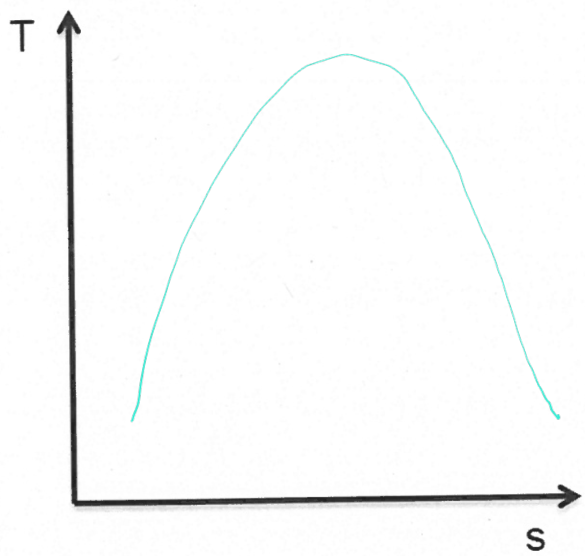

	p [bar]	T [°C]	x [–]	h [kJ/kg]	s [kJ/kgK]
1	60	600			
2		-----			
3					
4		-----			
5				303	
6		-----		303	

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End of exam

Formulary „Thermodynamics"

Equation of state for an ideal gas

$$p \cdot V = m \cdot R \cdot T$$

$$p \cdot v = R \cdot T$$

$$p \cdot \bar{v} = \bar{R} \cdot T$$

$$[T] = [K]$$

$$[p] = \left[\frac{N}{m^2} = Pa\right]$$

$$[V] = [m^3]$$

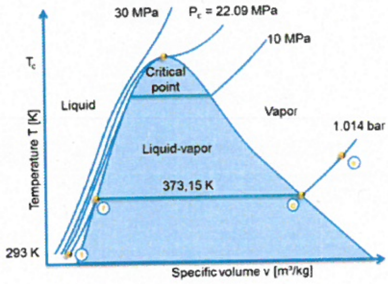
Universal gas constant

$$\bar{R} = 8.314 \frac{J}{mol \cdot K}$$

Special gas constant

$$R = \frac{\bar{R}}{M}$$

Equation of state for water



Liquid-vapor region

$$x = \frac{m_{vapor}}{m_{liquid} + m_{vapor}}$$

"x" is an intensive property

Moisture Content

$$1 - x = \frac{m_{liquid}}{m_{liquid} + m_{vapor}}$$

x = 0 → Saturated Liquid

x = 1 → Saturated Vapor

$$V = V_{liq} + V_{vap}$$

$$v = \frac{V}{m} = \frac{V_{liq}}{m} + \frac{V_{vap}}{m}$$

$$V_{liq} = m_{liq} \cdot v_f$$

$$V_{vap} = m_{vap} \cdot v_g$$

$$v = \left(\frac{m_{liq}}{m}\right) \cdot v_f + \left(\frac{m_{vap}}{m}\right) \cdot v_g$$

$$v = (1 - x) \cdot v_f + x \cdot v_g$$

First law of thermodynamics

Closed System

$$E_{Sys\,2} - E_{Sys\,1} = \sum Q + \sum W$$

The sum of kinetic and potential energy can be neglected.

$$E_{Sys} = U(T, v) = m \cdot u(T, v)$$

$$U_{Sys\,2} - U_{Sys\,1} = \sum Q + \sum W$$

$$u_2 - u_1 = q_{12} + w_{12}$$

First law of thermodynamics

Open System

Pure, simple

$$E_{Sys\,2} - E_{Sys\,1} = \sum Q + \sum W + \sum m \cdot e$$

Steady-state

$$0 = \sum \dot{Q} + \sum P + \sum \dot{m} \cdot e$$

The sum of kinetic and potential energy can be neglected.

$$\dot{m} \cdot e = \dot{m} \cdot h$$

$$H_2 - H_1 = \sum \dot{Q} + \sum P$$

$$h_2 - h_1 = q_{12} + w_{12}$$

!

Specific heat capacity

$$du = c_v \cdot dT$$

Ideal gas and incompressible fluids

$$u_2 - u_1 = \int_{T_1}^{T_2} c_V(T) \cdot dT$$

Ideal gas and incompressible fluids

$$dh = c_p \cdot dT$$

$$h_2 - h_1 = \int_{T_1}^{T_2} c_p(T) \cdot dT$$

Second law of thermodynamics

Internal energy $\longrightarrow$ U $dU = TdS - p \cdot dV$ $TdS = dU + p \cdot dV$

Enthalpy $\longrightarrow$ $H = U + p \cdot V$ $dH = TdS + Vdp$ $TdS = dH - Vdp$

Entropy balance

$$S_2 - S_1 = \underbrace{\int_1^2 \frac{dQ}{T}}_{\text{Entropy transfer by heat transfer to or from the system}} + \underbrace{\sigma}_{\text{Entropy production by internal irreversibilities}}$$

σ is *positive* when internal irreversibilities are present.

σ is *zero* when no internal irreversibilities are present (reversible process).

The *direction of entropy transfer* is the same as the direction of the heat transfer.

When there is *no heat transfer*, there is no entropy transfer.

There is no entropy transfer associated with *work*.

Clausius inequality

Applicable for systems undergoing cycles while communicating thermally with two reservoirs, a hot reservoir and a cold reservoir.

The *Clausius inequality* states that for any thermodynamic cycle:

$$\oint dS = \oint \frac{dQ}{T} \leq 0 \qquad \text{or} \qquad \oint dS = \oint \frac{dQ}{T} = -\sigma_{cycle}$$

$\sigma_{cycle} = 0 \longrightarrow$ No irreversibilities present within the system

$\sigma_{cycle} > 0 \longrightarrow$ Irreversibilities present within the system

$\sigma_{cycle} < 0 \longrightarrow$ impossible

Carnot cycle

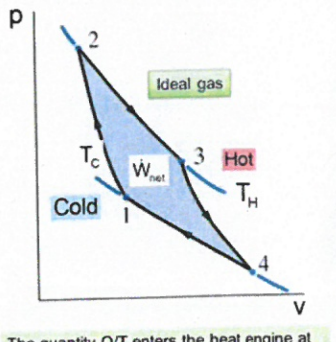
Thermal efficiency in general

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}$$

$$\eta = 1 - \frac{\dot{Q}_{41}}{\dot{Q}_{23}} = 1 - \frac{\dot{Q}_{Cold}}{\dot{Q}_{Hot}}$$

Carnot efficiency $\qquad \eta_{Carnot} = 1 - \frac{T_C}{T_H}$

$$1 - \frac{T_C}{T_H} = 1 - \frac{Q_{Cold}}{Q_{Hot}} \longrightarrow \frac{Q_{Hot}}{T_H} = \frac{Q_{Cold}}{T_C}$$



The quantity Q/T enters the heat engine at high temperature and leaves it – unchanged in value – at low temperature.