HOCHSCHULE RHEIN-WAAL
Rhine-Waal University of Applied Sciences

Period of Examinations
Summer semester 2016

Study Course: ____________________

Module Title: **Thermodynamics**

Examination Part: **Written exam**

Points: 75

Duration: 110 Minutes

Date: 2016-07-11

Family Name: ____________________ ____________________

First Name: ____________________ Signature (Student)

Student No.: ____________________

All calculations and sketches should be done on the sheets provided for this purpose. If more than one solution is given, mark clearly which one should be rated. Please write legibly!

Good luck!

FOR INTERNAL USE ONLY:

	Q1	Q2	Q3	Q4	Q5	Q6	Written exam	Stirling motor	Practical Training	Total
Max. Points	12	10	13	10	12	18	75	13	12	100
Achieved										
							≥ 38 Yes | No		Grade	

Graded by		Checked by

Final Grade

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

Register No.:

Question 1 (Ideal-gas law) **Points: 12**

The pressure in an automobile tire depends on the temperature of the air in the tire. When the air temperature is 25°C, the pressure gage reads 210 kPa.

a) If the volume of the tire is 0.025 m³, determine the pressure rise in the tire when the air temperature in the tire rises to 50°C.

b) Determine the amount of air that must be bled off to restore pressure to its original value.

Assumptions:

→ The tire is rigid. → $V = cons.$

→ The atmosphere pressure is 100 kPa.

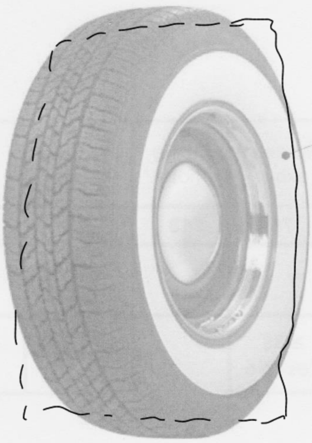
→ The air behaves as an ideal gas.

→ Gas constant: $R_{Air} = 287 \frac{J}{kg\,K}$

$P_1 = P_{atm} + P_{g_1} = (210 + 100)\,kPa$

$P_1 = 310\,kPa$

state 1



Air
$V = 0.025\,m^3$
$p_{g1} = 210\,kPa$
$T_1 = 25\,°C = 298K$

$V_2 = V_1$
$P_2 = ?$
$T_2 = 50°C = 323K$
$m_1 = m_2$

$V = cons$
$P_3 = P_1 = 310\,kPa$
$T_3 = 50°C = 323K$
$m_3 < m_1$
$\dot{m}_{out}$

Ideal gas law: $P_1 V_1 = mRT_1$, $P_2 V_2 = mRT_2$

a) $V_1 = V_2 \Rightarrow \frac{\cancel{m}\cancel{R}T_1}{P_1} = \frac{\cancel{m}\cancel{R}T_2}{P_2} \rightarrow P_2 = \frac{T_2 \cdot P_1}{T_1} = \frac{323\cancel{K}(310\,kPa)}{298\cancel{K}} = 336\,kPa \Rightarrow \Delta P = P_2 - P_1 = 26\,kPa$

$m_1 = \frac{P_1 \cdot V_1}{RT_1}$, $m_3 = \frac{P_1 \cdot V_1}{RT_2}$, $\Delta m = m_1 - m_3 = \frac{P_1 \cdot V_1}{R}\left(\frac{1}{T_1} - \frac{1}{T_3}\right) = \frac{310\,\overset{10^3 N/m^2}{kPa}(0.025\,m^3)}{287\,\frac{J}{kg \cdot K}}\left(\frac{1}{298K} - \frac{1}{323K}\right)$

$\Delta m = 7 \times 10^{-3}\,kg = 7g$

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Question 2 (Thermodynamic properties) Points: 10

a)

Determine the phase or phases in a system consisting of water at the following conditions and indicate clearly the location on p-v and T-v coordinates.

Use the templates below.

1. p = 7 bar ; T = 165.0 °C Saturated Liquid/vapour

2. p = 7 bar ; T = 200 °C Superheated vapour (steam)

3. T = 200 °C ; p = 2.5 MPa =25 bar compressed liquid

4. T = 151.9 °C ; p = 4.0 bar super heated vapour.

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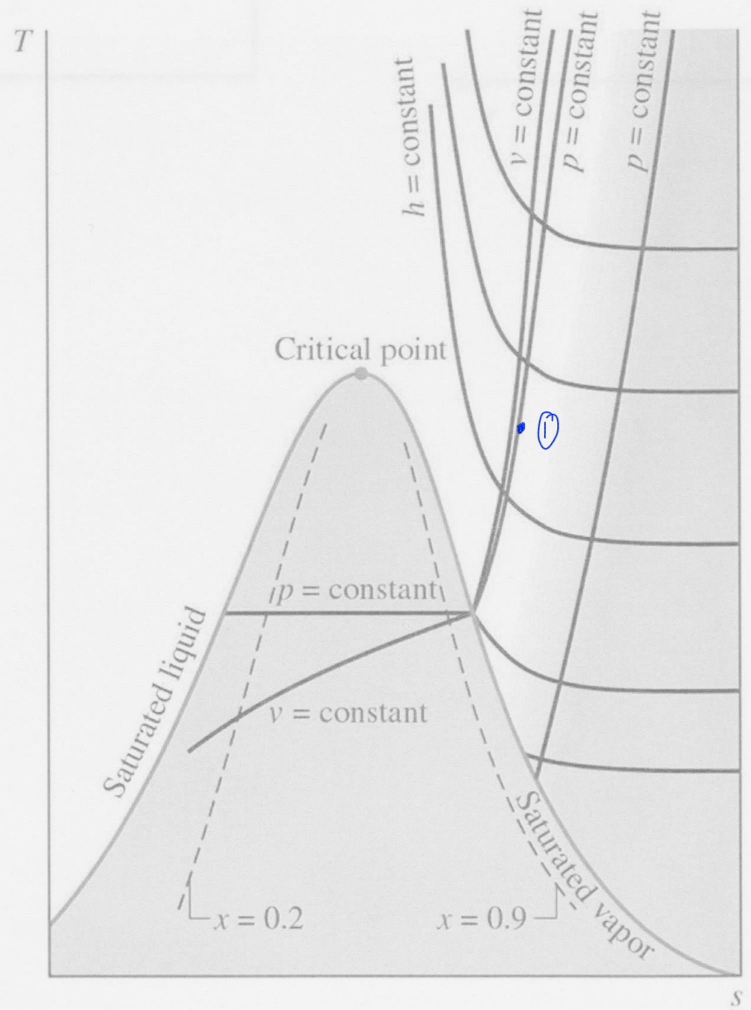
b)
Using Moran/Shapiro's tables for water, determine the specific entropy at the indicated states, in [kJ/kg·K[. In each case, mark the state by hand on the below sketch of a T-s diagram.

1. p = 8.0 MPa, T = 400°C $s_1 = 6.3634$ KJ/Kg·K
2. p = 10.0 MPa, T = 100°C (from A-5) → $s_2 = 1.2992$ KJ/Kg·K
3. p = 5.0 MPa, Internal energy u = 1,872.5 kJ/kg $X_3 = \frac{u - u_f}{u_g - u_f} =$

$S_3 = S_g \cdot X_3 + S_f(1 - X_3)$



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Question 3 (1st rule of thermodynamics) **Points: 13**

The machines of a big textile factory have an electrical power demand of 600 kW_{el} during normal operation. The efficiency of the machines is 95%. During summer months, a heat flow of 10 kW enters the room by sun radiation. The factory is equipped with an air-conditioning system. A fan is used to remove a volume flow of 5,000 m³/h from the room. The air has a temperature of 27°C. 50% of this flow is leaving the system to the atmosphere. The make-up for this loss of mass is fresh air at a temperature of 20°C.

Determine the heat flow ($\dot{Q}_c$), in [kW], which is to be removed by the cooler at steady-state conditions.

Assumptions:

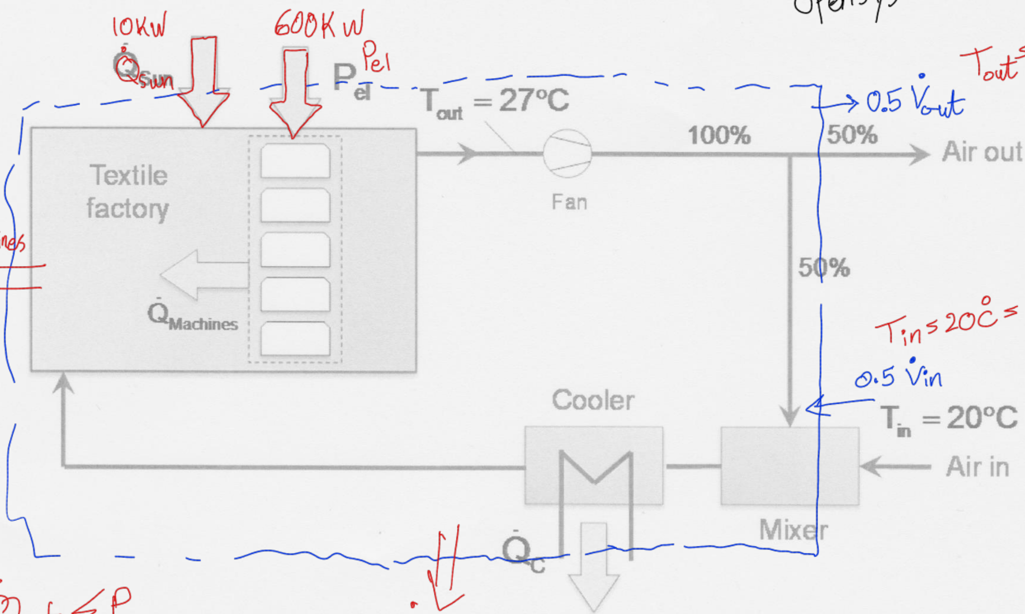
→ The specific heat capacity of air is c_p=1.0 kJ/kg K.

→ The density is ρ = 1.25 kg/m³.

→ Neglect the electrical power demand of the fan.

open system $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

$T_{out} = 27°C = 300K$



$\dot{Q}_{out} = \dot{Q}_{Machines}$

$\dot{Q}_{out} = (P_{el} + \dot{Q}_{sun}) \cdot \eta$

$T_{in} = 20°C = 293K$

$\dot{m}(dh) = \sum \dot{Q} + \sum P$

$\dot{m}(h_{out} - h_{in}) = \dot{Q}_{sun} + P_{el} - \dot{Q}_c - \dot{Q}_{out}$

solution

$\dot{m} = \rho \cdot (0.5 \dot{V})$

$dh = \int_1^2 c_p \, dT = c_p (T_{out} - T_{in})$

$$\boxed{\rho (0.5 \dot{V}) \cdot c_p (T_{in} - T_{out}) + \dot{Q}_{sun} + P_{el} - (\dot{Q}_{sun} + P_{el}) \cdot \eta = \dot{Q}_c}$$

$Q_c = 24.424$ KW

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Question 4 (Reversible, irreversible or impossible cycles) **Points: 10**

A cyclic machine receives 325 kJ from a 1,000 K energy reservoir. It rejects 125 kJ to a 400 K cold reservoir. The cycle produces 200 kJ of work as output.

a) Determine the amount of irreversibilities of the cycle, i.e. σ_{cycle}

b) Is this cycle reversible, irreversible or impossible? Give rationale.

c) What is to be adapted so that the process becomes possible?

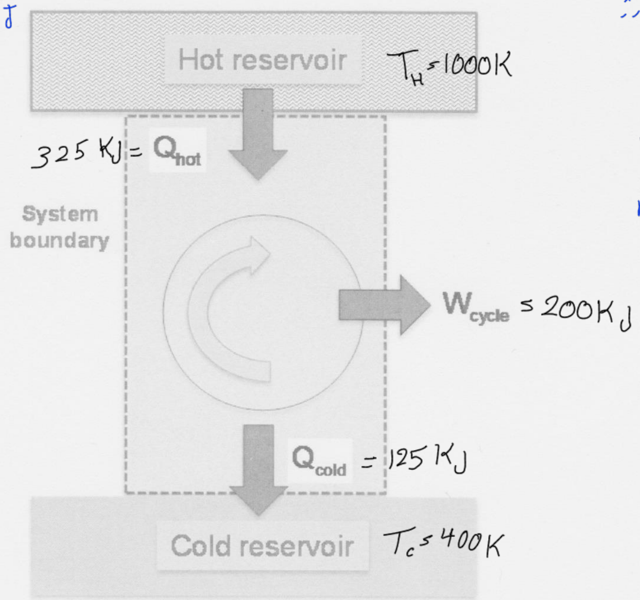
$$\frac{Q_{in}}{T_H} - \frac{Q_{out}}{T_c} = -\sigma_{cycle} \Rightarrow \frac{325\,KJ}{1000\,K} - \frac{125\,KJ}{400\,K} = 0.0125\ KJ/K$$

$\therefore \sigma_{cycle} = -12.5\ J/K < 0$

impossible

because σ_{cycle} is representing irreversabilities, it can not be negative.

c) We can increase Q_c to 150 KJ & that will cause W_{cycle} to reduce as well.



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Question 5 (Thermodynamic cycles) Points: 12

Sketch the following cycles on p-v coordinates. Use the templates below.

$\Delta T=0$ $\Delta P=0$ $\Delta V=0$ $\dot{Q}=0$

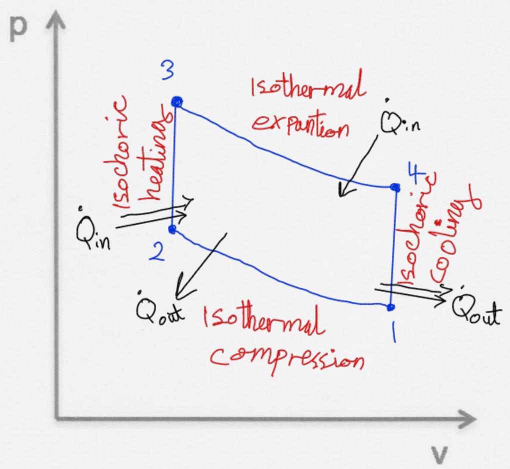
a) Specify the nature of each process (isothermal, isobaric, isochoric, adiabatic, or isentropic, expansion or compression or heating ….).

$ds=0$

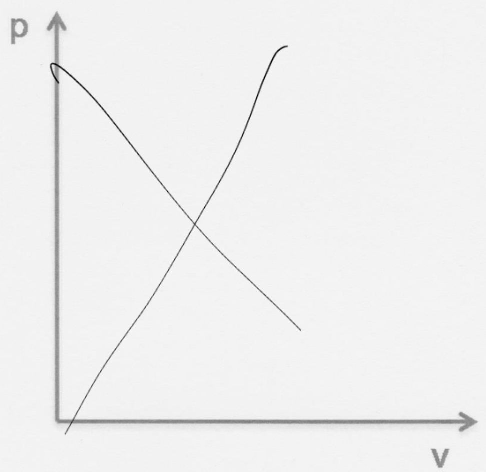
b) Indicate by arrows whether heat is transferred to the system or from the system to the surroundings, and whether work is done by the system or on the system.

Assume <u>ideal</u> cycles and <u>ideal</u> gas.

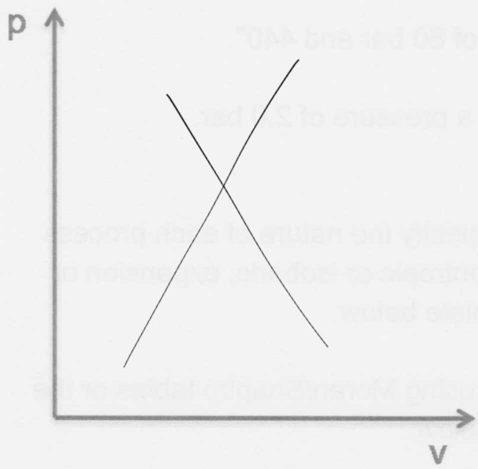
a) Stirling cycle



b) Otto cycle



c) Diesel cycle



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Question 6 (Rankine cycle)

Points: 18

Steam is the working fluid in an ideal Rankine cycle with superheating.

Vapor at state 1 enters the turbine at a pressure of 80 bar and 440°.

Saturated liquid at state 3 exits the condenser at a pressure of 2.0 bar.

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

b) Determine the properties of each state by using Moran/Shapiro tables or the attached h-s diagram and fill in the table below.

c) Determine the thermal efficiency of the ideal cycle.

d) If the isentropic turbine efficiency of the actual process is 75%, determine the actual specific power developed per unit mass flow of steam flowing through the turbine, in [kJ/kg].

e) Provide an accurate drawing of the ideal and the actual expansion process in the attached h-s diagram.

Assumptions:

→ Label the states as follows
1 … Turbine in
2 … Turbine out
3 … Condenser out
4 … Boiler in

→ Neglect kinetic and potential energy effects.

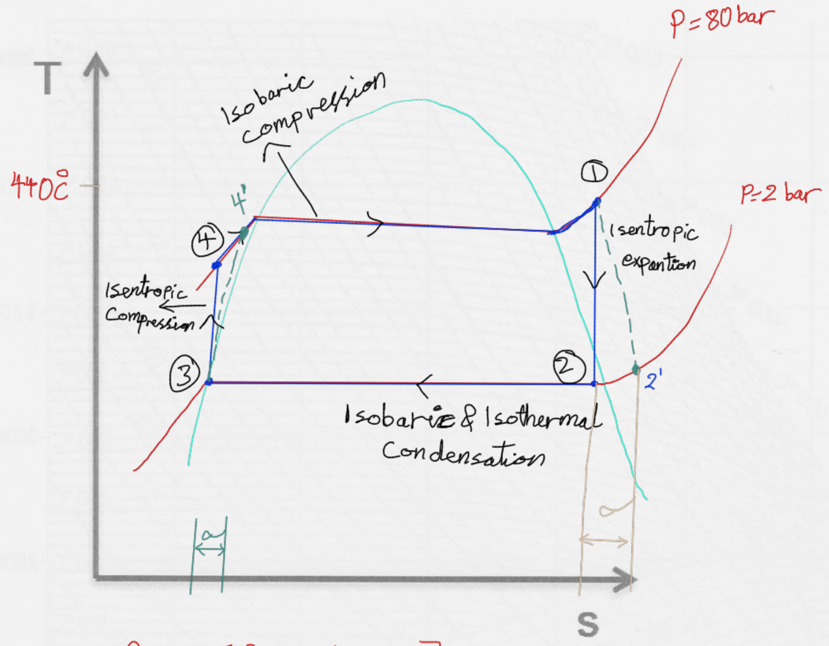
→ Turbine and pump operate adiabatically.

c) $\eta_{th} = \frac{P_T - P_P}{Q_B} = 1 - \frac{h_4 - h_3}{h_1 - h_2} = 1 - \frac{(513 - 504.7)\cancel{KJ/Kg}}{(3246.1 - 2467.46)\cancel{KJ/Kg}} = 0.989 = 98.9\%$

d) $\eta_{is} = \frac{P_T}{P_{Ts}} \Rightarrow P_T = \eta_{is}(h_1 - h_{2s}) = 0.75(3246.1 - 2467.46)\,KJ/Kg$

$\Longrightarrow P_T = 583.98\,KJ/Kg$

$h_2 = h_1 - P_T = 2662.12$



$$\left.\begin{aligned} S_{f_2} &= 1.5301 \ KJ/Kg.K \\ S_{g_2} &= 7.1271 \ KJ/Kg.K \end{aligned}\right\} X_2 = \frac{S_2 - S_{f2}}{S_{g2} - S_{f2}} = \frac{(6.519 - 1.5301)\cancel{KJ/Kg.K}}{(7.1271 - 1.5301)\cancel{KJ/Kg.K}} = 0.89$$

$$\left.\begin{aligned} h_{f_2} &= 504.7 \ KJ/K \\ h_{g_2} &= 2706.7 \ KJ/K \end{aligned}\right\} h_2 = x_2 h_{g_2} + (1-x_2) h_{f_2} = 2467.46 \ KJ/Kg$$

	p [bar]	T [°C]	h [kJ/kg]	s [kJ/kgK]	x [–]
1	80	440	3246.1	6.519	—
2	2 bar		2467.46	6.519	0.89
3	2 bar		504.7		0
4	80 bar	----	513.0		—

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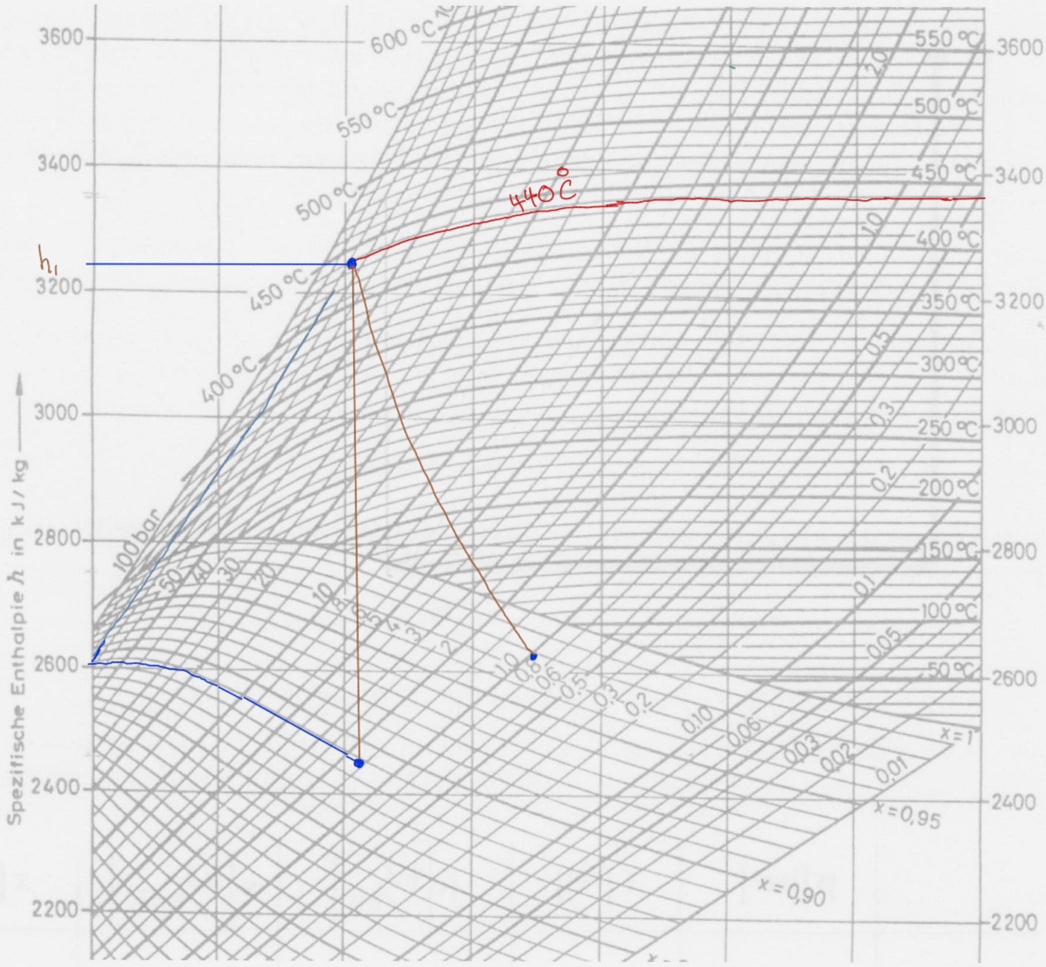

Spezifische Enthalpie h in kJ / kg
3600
3400
3200
3000
2800
2600
2400
2200
600 °C
550 °C
500 °C
450 °C
400 °C
100 bar
50
40
30
20
10
440°C
h_1
550 °C
500 °C
450 °C
400 °C
350 °C
300 °C
250 °C
200 °C
150 °C
100 °C
50 °C
x = 1
x = 0,95
x = 0,90