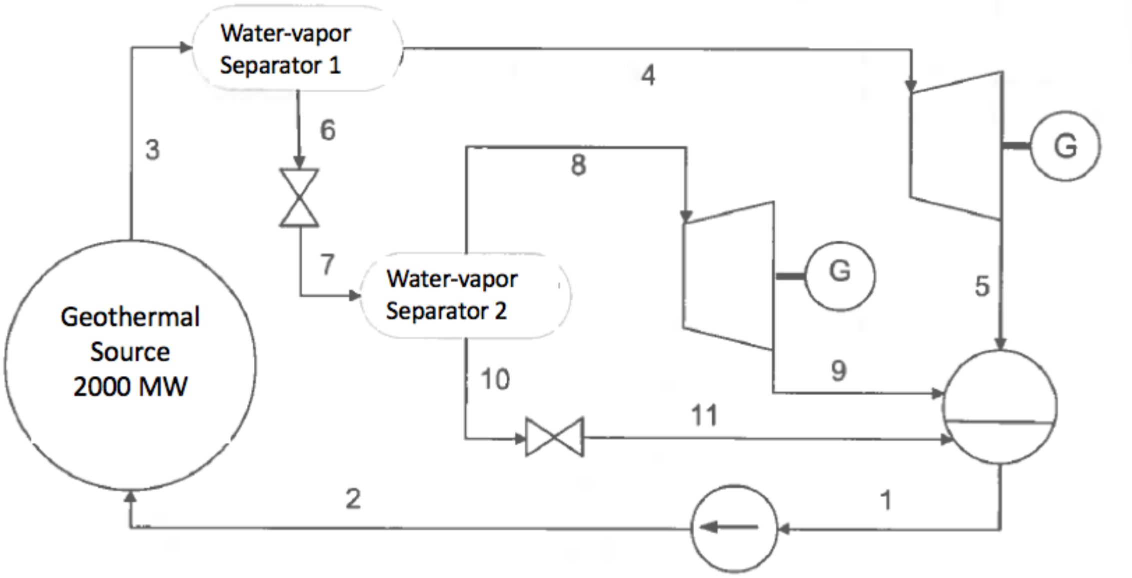


In Iceland electricity is generated in a geothermal power plant with a Rankine cycle with water as a working fluid. The water is originating from a geothermal source and used directly within the cycle. The power on geothermal heat which is extracted from the geothermal source is 2000 MW. Above a schematic picture is given of the geothermal power plant.

Water flow 3 is a saturated mixture with a liquid water content of 30% (quality x_3=0.7) and a pressure of 10 bar. The saturated mixture is led to the first water-vapor separator. In the separator the vapor is separated from the liquid. The saturated vapor flows to the first turbine, which has an isotropic efficiency of 85%. The vapor expands in the turbine to a pressure of 0.1 bar at the outlet of the turbine. After the turbine the vapor condenses in a condenser.

The saturated liquid from the first separator flows via a reducing valve to a second water-vapor separator. The pressure is reduced to 2 bar. In the separator again liquid-vapor separation takes place. The saturated vapor is led to a second turbine in which expansion of the vapor takes place to a pressure of 0.1 bar. The liquid content after the second turbine is 10% (Quality x_9=0.9). After the second turbine the mixture flows into the condenser.

The saturated liquid from the second water-vapor separator flows through a reducing valve also into the condenser. In the condenser, all three flows mix and condense fully. After the condenser, a pump is placed which compresses the liquid to 10 bar. The water is pumped into the ground, where it is heated again with the geothermal energy. The isentropic efficiency of the pump is 100%.

The kinetic and potential energies and the pressure losses in the ducts can be neglected. The pump and the turbines may be considered as adiabatic.

a) Find at each location of the installation two thermodynamic properties with which the cycle can be analyzed, and put these properties in the underneath table. Encircle these values in the table. Make your own choice which thermodynamic properties you will put in the table and fill in the other values later.

b) Make a T-S diagram of the installation. Put all numbers 1 till 11 in the diagram and give as much as possible values of temperatures. For some locations of the installation you might not yet know the precise position in the diagram. Put these points at a realistic position. Also, draw isobars in the diagram.
c) Determine in every point the specific enthalpy and gather these also in the table.
d) Express the mass flows at all locations into the mass flow of flow 3. Add these mass flows to the table.
e) Give the expression for the thermal efficiency of the installation and calculate the efficiency.
f) Give the expression with which the mass flow at point 3 in the cycle can be determined and calculate the mass flow.

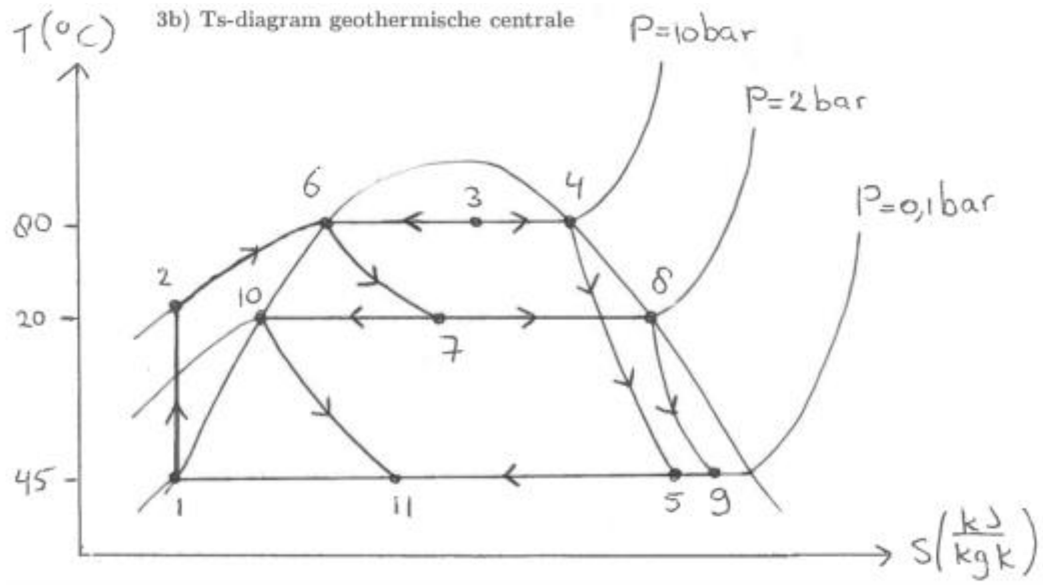
	P (bar)	T (C)	X (-)	Other known value	H (kJ/kg)	m-flow
1						
2						
3						
4						
5s						
5						
6						
7						
8						
9						
10						
11						

Attention: It is not necessary to fill in all properties at all locations. If you do not need a value at a specific location you do not have to fill in a value in the table.

Answers to the problem

a) At all locations the pressure is known. At the locations 1, 3, 4, 6, 8, 9 and 10 the quality is known. At location 2 we know that the pump efficiency is equal to 100%. At location 5s we know that the entropy is equal to the entropy at location 4. At location 5 we know that the isentropic efficiency is 85%. In the reducing valves adiabatic processes take place so we know that the enthalpy at location 7 is equal to the enthalpy at location 6, and the enthalpy at location 11 is equal to the enthalpy at location 10. In the table the values are not encircled, but given in red color.

b)



c) See the values in the Table

d) See the values in the Table

e) $\dot{W}_{net} = \dot{m}_4(h_4 - h_5) + \dot{m}_8(h_8 - h_9) - \dot{m}_1(h_2 - h_1)$

$$\dot{Q}_{in} = \dot{m}_3(h_3 - h_2)$$

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

This leads to thermal efficiency of 21%.

f) $\dot{m}_3 = \frac{\dot{Q}_{in}}{(h_3 - h_2)}$ leads to 1009 kg/s

	P (bar)	T (C)	x (-)	Other known value	h (kJ/kg)	m-flow
1	0.1	45	0		192	$\dot{m}_3$
2	10			$\eta_{s,p} = 1$	193*	$\dot{m}_3$
3	10	180	0.7		2175	$\dot{m}_3$
4	1	180	1		2780	$0.7\dot{m}_3$
5s	0.1			$S_{5s} = S_4$	2100	$0.7\dot{m}_3$
5	0.1			$\eta_{s,t} = 0.85$	2202**	$0.7\dot{m}_3$
6	10	180	0		762	$0.3\dot{m}_3$
7	2	120	0.12***		$h_7 = h_6$	$0.3\dot{m}_3$
8	2	120	1		2700	$0.036\dot{m}_3$****
9	0.1		0.9		2350	$0.036\dot{m}_3$
10	2	120	0		505	$0.026\dot{m}_3$*****
11	0.1	45			$h_{11} = h_{10}$	$0.026\dot{m}_3$

*$h_2 = h_1 + v_1(p_2 - p_1)$

**$\eta_{s,t} = \frac{h_4 - h_5}{h_4 - h_{5s}}$ gives the value of h_5

***$x_7 = \frac{h_7 - h_{10}}{h_8 - h_{10}}$ gives the value of x_7

****$\dot{m}_8 = x_7 \dot{m}_7$

*****$\dot{m}_{10} = (1 - x_7)\dot{m}_7$