

Name: _____ Student ID: _____

- Water vapour h,s -diagram and a scientific calculator are allowed
- If a necessary initial value for a calculation task hasn't been given, select a typical value and use that.
- **This exam paper must be returned!**

Task 1 (12p) ANSWER ON THIS PAPER!

Circle the correct options (one option per subtask is correct). **Right answer +2 p, wrong -1 p, no answer 0 p**

a) Identify the adjacent component

1. Boiler drum
2. Merivesilauhduutin
3. Matalapaine-esilämmitin tai kaukolämpölauhduutin
4. Syöttövesisäiliö

b) If The efficiency of a power cycle increases, if

1. average temperature of heat input is increased
2. average temperature of heat rejection is increased
3. average pressure of heat input is increased
4. work fluid mass flow rate is increased

c) What is depicted as gray areaa in the adjacent T,s -chart drawing?

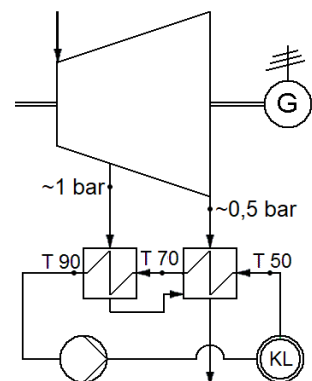
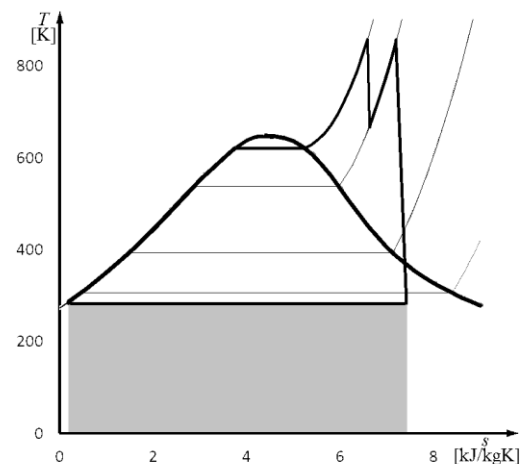
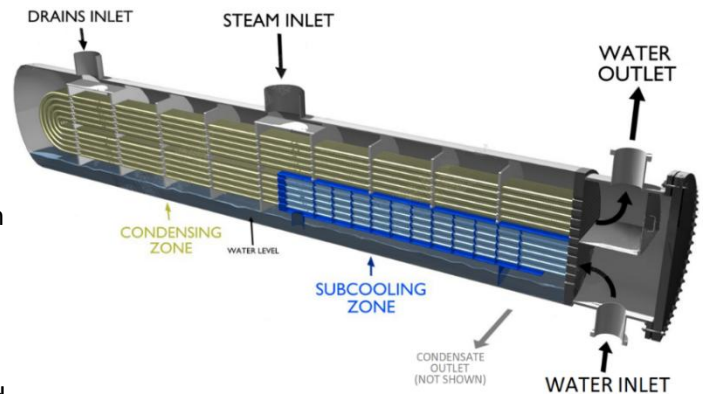
1. heat input into 2 pressure level combined cycle power plant
2. fuel power of a gas turbine power plant
3. net thermal work of a 2-T heat engine process
4. heat removed in the condenser of a steam power plant

d) CHP in a Nordic kraft pulp mill: select correct statement

1. Kraft pulping needs little heat, but a lot of electricity: for this, there is typically a coal-fired supercritical condensing power plant co-located at the mill site.
2. The energy from black liquor combustion is sufficient to cover the heat and power demands of the pulp mill, often with extra electricity left to be sold to the national power grid.
3. The white liquor from paper bleaching is combusted in a CFB boiler, producing kraft soda for the mill.
4. Minerals in the waste sludge are burned for energy, leaving the water to be released into nearby lake.

e) 2-stage district heat production (depicted in adjacent figure) is common in back pressure CHP plants. What is the advantage compared to 1-stage production?

1. Same heat load allows producing more electricity at unchanged CHP efficiency (fuel use therefore increases)
2. Efficiency increases: less fuel is used to produce the same district heat
3. Turbine expansion efficiency and thereby steam quality are increased
4. Back pressure increases, thus also increasing auxiliary and piping efficiencies.



Task 2 (8 p) – ANSWER ON THE SEPARATE ANSWER SHEET!

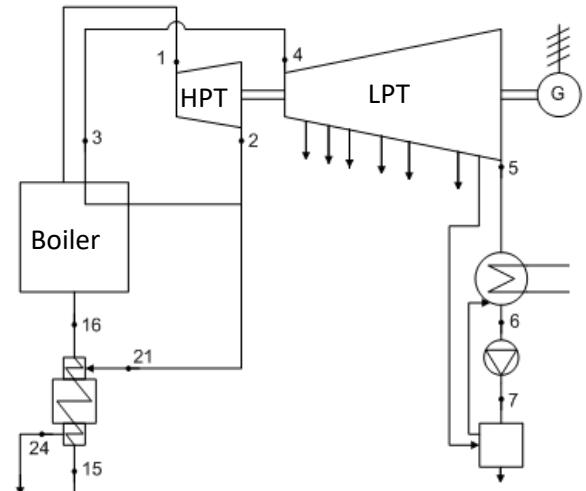
Compare the differences of i) ideal closed Brayton cycle, ii) real simple-cycle single-shaft open gas turbine, and iii) real recuperated single-shaft open gas turbines:

- Draw the schematic diagrams of all three process configurations, and number the main state points in the processes, starting from 1 = compressor inlet. **(3p)**
- sketch the ideal Brayton process (i) and real, irreversible simple-cycle gas turbine process (ii) on top of each other in a T,s chart. Mark the state point numbers in both, and using the T,s drawings, illustrate the main losses in the real process. Assume for both processes the same ambient (real GT) or heat removal heat exchanger outlet (Brayton) states; same compressor outlet p ; and the same turbine inlet T_{TIT} . **(3p)**
- sketch the process of the recuperated gas turbine (iii) in a separate, second T,s chart. Depict in it which part of heat input into compressed air takes place in the recuperator, which in the combustion chamber. **(2p)**

Task 3 (12 p) ANSWER ON THE SEPARATE ANSWER SHEET!

The adjacent figure depicts part of a reheat steam power plant process. Live steam values at 280 bar, 577 °C. Reheat pressure is 50 bar and isentropic expansion efficiency of HP turbine 86 %. Pressure drop and thermal losses in water and steam pipes are considered negligible.

- Thermal power released into HP turbine rotor by expanding steam. Live steam flow rate is 415 kg/s. **(4p)**
- Feedwater state at economizer inlet is $T = 265$ °C, $h = 1160$ kJ/kg. Feedwater enters the last HP feed heater at state 230 °C, 1000 kJ/kg. Determine TTD and DCA (select a typical value if unable to calculate), draw the temperature diagram, and depict both temperature differences in it. **(4p)**
- Calculate the thermal power and needed steam mass flow rate, when feedwater mass flow rate at last feed heater is 400 kg/s **(4p)**

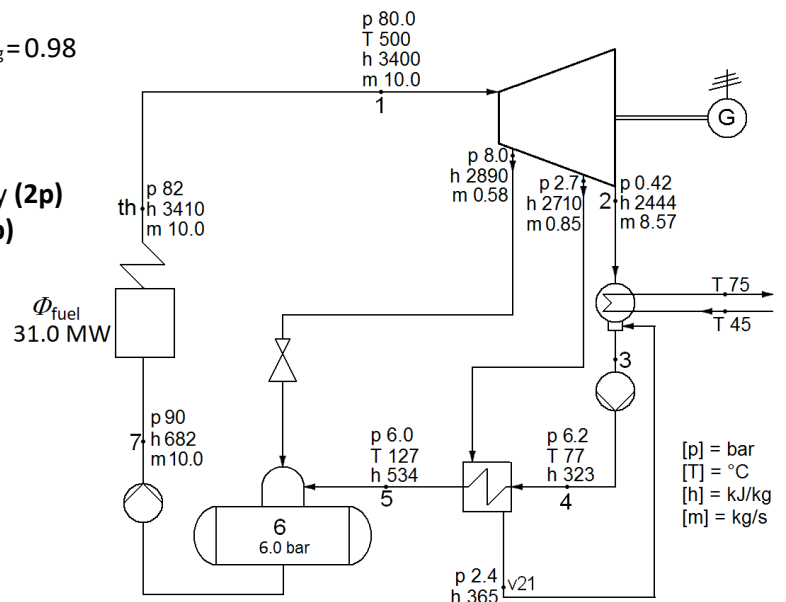


Task 4 (10 p) ANSWER ON THE SEPARATE ANSWER SHEET!

Below is depicted a process diagram of a small back pressure CHP plant producing district heat. Condensate enthalpy increase in the condensate pump, and boiler blowdown rate, can both be assumed negligible. Using the steam cycle state point data in the figure, and, if necessary, some of the additional parameters listed below, calculate the performance indicators of sub-tasks a) to f). If you are unable to calculate a parameter that is needed as input for further calculation, pick a typical value and use that to continue.

- Turbogenerator electromech. efficiency $\eta_{mg} = 0.98$
- Transformer efficiency $\eta_u = 0.97$
- Auxiliary efficiency $\eta_e = 0.92$

- Boiler thermal power and boiler efficiency **(2p)**
- Thermal efficiency of the power cycle **(4 p)**
- Net power generation **(2p)**
- District heat production Φ_{DH} [MW] and district heating water flow rate **(2p)**
- Electrical efficiency **(1p)**
- Total (CHP) efficiency **(1p)**



Task 5 (7 p) ANSWER ON THE SEPARATE ANSWER SHEET!

The annual fuel consumption of a back pressure district heating (DH) CHP plant is 250 GWh_{LHV}, DH production 160 GWh_{DH} and net electricity production 60 GWh_{el}. The plant operates annually for 5000 full-load hours, and the total capital investment, including construction-time expenses and interests, is 70 million EUR. Calculate:

- Primary energy saving ratio *PES*, assuming the reference efficiencies are 35 % for condensing power generation, and 85 % for DH production in a heat-only boiler (HOB) **(2p)**
- annual net cash flow rate with 25-year economic lifetime, and 5-% interest rate. **(5p)**

Prices and costs:

Fuel c_f	40 €/MWh _{LHV}
Electricity c_{el}	60 €/MWh _{el}
District heat c_{DH}	90 €/MWh _{DH}
Total capital Investment C_{TCI}	70 million €
Operation & maintenance $C_{O\&M}$	2 million € / a

NPV factor: $\frac{(i+1)^n - 1}{(i+1)^n i}$

annuity factor: $\frac{i(i+1)^n}{(i+1)^n - 1}$