# TWO STAGE COGENERATION IN DISTRICT HEATING SYSTEMS

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**Abstract:** The usage of cogeneration units in heating systems is limited by the maximum outlet temperature of these units. In conditions when the built-in heating blocks of the cogeneration units are not fully utilized and when there is a possibility for additional utilization of the output energy from these units, it is possible to increase their energy efficiency. The additional increase of the output parameters of the utilization units, output temperature and thermal power, with a corresponding reduced temperature of the exhaust gases, are confirmed by the appropriate measuring systems. The main problem when connecting cogeneration units to heating systems is the water quality in these systems. In the considered system, due to safety in operation, the connection of the cogeneration block is done indirectly through a district heating station.
Increasing the energy parameters of the cogeneration units enables their greater participation in covering the heat balance of the heating system. This effect is especially noticeable at higher outdoor temperatures, while at lower outdoor temperatures there is an appropriate limitation in the use of cogeneration units.

**Key words**: cogeneration, energy efficiency, district heating

## 1. INTRODUCTION

Usage of cogeneration units for winter heating is usually associated with smaller systems. In the case of larger systems, with older equipment, it is usually not considered to upgrade them using cogeneration units due to the low output parameters of these units. In case of a possibility to increase the temperature at the outlet of the heating system of the cogeneration units, the situation can be significantly changed and it is possible to include the cogeneration units in the district heating systems.

### 1.1 Cogeneration block

The analysis takes a cogeneration block of 10 units with the following characteristics [1] :

- Electricity generation 3041 $kW_{el}$
- Heat production 1358 $kW_{th}$
- Steam production 1296 $kW_{th}$

The heat energy is obtained through plate heat exchangers (2), with the following parameters:

- primary side
  - flow 58.3 $m^3$ / h
  - inlet temperature 90 $^oC$
  - output temperature 70 $^oC$
- secondary side
  - flow 38.9 $m^3$ / h
  - inlet temperature 50 $^oC$
  - output temperature 80 $^oC$

Data in tab. 1 show the changes in the heat load of the exchangers depending of the flow in the secondary (external) circuit.

tab. 1 Heat load reserve at a given flow

| | | | |
|---|---|---|---|
| V [$m^3$/h] | **31.27** | **59.67** | **67.23** |
| k [W/($m^2$·°C)] | **1365** | **2547** | **3499** |
| PHE margin | **1.10** | **0.35** | **0.01** |

From the given data it can be seen that the built-in plate heat exchangers enable the achievement of the required operating parameters in case of variable flow from the secondary side, by limiting the flow in the secondary side to max 67 [$m^3$/ h], or in reality the flow can vary within 30 - 60 [$m^3$/ h] which covers the entire area of operation of the heating system.
When achieving the maximum flow through the heat exchangers of 67.23 [$m^3$/ h], significantly higher heat transfer can be expected, due to which the estimated inlet temperature of the circulating water from the district heating side can be increased up to 62.24 [$^oC$], which is positive in relation to the possibility of connecting to the external distribution heating network.

tab. 2 Estimated maximum inlet temperature from the distribution side

| | | | | |
|---|---|---|---|---|
| V | $m^3$/h | **31.27** | **59.67** | **67.23** |
| k | W/$m^2$K | **1365** | **2547** | **3499** |
| Tw1 | $^oC$ | 42 | 60 | **62.248** |
| Tw2 | $^oC$ | 80 | 80 | 80 |
| Q | kW | 1358 | 1358 | **1358** |

The transmitted thermal power is dictated by the primary circuit and it is constant (it depends only on the load of the units).

### 1.2 Secondary heat exchangers

The additional energy from the cogeneration units is used in the steam generators under the following conditions:

- heat capacity 1296 $kW_{th}$
- inlet temperature of gases 425 $^oC$
- outlet temperature of gases 185 $^oC$

Each built-in steam generators serve two cogeneration modules .

Due to the lack of a suitable steam consumer, who could use the entire amount of steam produced, the built-in steam generators can be reconstructed for direct connection to the heating installation. This preserves the possibility for simultaneous production of steam and heat energy for heating purposes by connecting a number of steam generators to the appropriate installation (steam ie district heating network).

Starting parameters for the reconstruction of the steam generator are the following:

| | |
|---|---|
| - temperature of circulating water, inlet | 80 $^{o}$C |
| - maximum working pressure | 9 bar |
| - test pressure in the water part of the steam generator | 17 bar |
| - working volume in steam production | 15500 L |
| - total water volume | 23050 L |

The thermal calculation of steam generators, as secondary heat exchangers, is performed in combination with the NTU method [5].

The operating parameters of the steam generator on the gas side remain the same as in the production of steam, ie:

| | | |
|---|---|---|
| - amount of fuel | $Nm^3$ / h | 2 x 745 |
| - gas flow, mass | kg/ h | 2 x 17325 |
| - gas flow, volume | $Nm^3$ / h | 2 x 13783 |
| - gas temperature, inlet | $^{o}$C | 425 |

The temperature of the gases at the output of the generator is calculated depending on the flow of water through the generator and the heat balance for the built-in heat exchange surface.

tab.3 Generator heat balance

| | | | | |
|---|---|---|---|---|
| Gw [t/h] | 38,92 | 46,70 | 58,38 | 67,22 |
| Tg1 [$^{o}$C] | 425 | 425 | 425 | 425 |
| Tg2 [$^{o}$C] | 127,6 | 123,8 | 120,0 | 116,3 |
| Tw1 [$^{o}$C] | 80 | 80 | 80 | 80 |
| Tw2 [$^{o}$C] | 115,0 | 109,6 | 103,9 | 101,0 |
| Q [kW] | **1474** | **1521** | **1575** | **1549** |

From the review (tab.3) it can be noticed that the optimal flow of the secondary heat carrier through the generator is achieved at cca 60 [t / h], ie total flow of cca 120 [t / h].

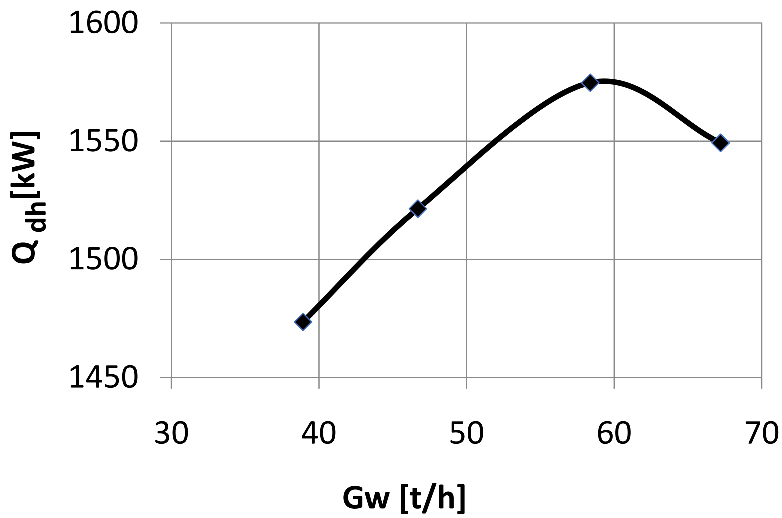


fig. 1 Water flow through section

The cross-flow control calculation [5] gives slightly higher values and they are for one bundle:

tab. 4 The cross-flow control calculation

| | | |
|---|---|---|
| Gw | [t/ h] | 58.38 |
| Tg1 | [$^o$C] | 425 |
| Tg2 | [$^o$C] | 110 |
| Tw1 | [$^o$C] | 80 |
| Tw2 | [$^o$C] | 106 |
| dT | [$^o$C] | 122,251 |
| F | - | 0.95165 |
| A | [$m^2$] | 203,245 |
| k | [W / $m^2$K] | 72,158 |
| Q | [kW] | 1706 |

These parameters coincide with the parameters of the connection point with the heating system, with a deviation of 4-5 $^o$C, due to changes in flow, heat loss through the pipelines from the cogeneration block to the connection point, and conected exchange heat transfer unit, where the reading is performed.

### 1.2.1 Output parameters of the heating system from the cogeneration plant

The total thermal power of the heating part of the cogeneration plant, when using both utilization stages, is:

- heat capacity of the cogeneration unit 1358 kW

| | |
|---|---|
| • number of cogeneration units | 10 |
| • total heat capacity of the cogeneration units | 13580 kW |
| • heat capacity of heating generators | 3412 kW |
| • number of heating generators | 5 |
| • total heat capacity of the heating generators | 17060 kW |
| • total heating capacity | 30640 kW |

The total flow of heat carrier in the heating system is estimated at 389- 596.7 $m^3$/h, ie a maximum of 672 $m^3$/h to the external user.
Efficiency of the system with this changes increases by a small but significant size, and it is

- basic mode of operation

| | |
|---|---|
| - input energy | 7076 kW |
| - electricity | 3041 kW |
| - thermal energy output, total | 2654 kW (1358 + 1296) |
| - total efficiency | 80.5% |

- district heating mode, (with two stages)

| | |
|---|---|
| - input power | 7076 kW |
| - electricity | 3041 kW |
| - thermal energy output, total | 3064 kW (1358 + 1706) |
| - total efficiency | 86.3% |

### 1.3 District heating mode of cogeneration block

The connection of this cogeneration block will be considered for a heating system with the following parameters:

| | |
|---|---|
| - suppression temperature | 110 $^oC$ |
| - return temperature | 60 $^oC$ |
| - minimum heat capacity | 51600 kW |
| - maximum heat capacity | 81600 kW |

Connection heating mode of the cogeneration block is defined by:

| | |
|---|---|
| - suppression temperature | 106 $^oC$ |
| - maximum return temperature | 60 $^oC$ |
| - minimum return temperature | 44 $^oC$ |

Considering the characteristics of two systems, the cogeneration block is most convenient to be connected to the return pipeline of the heating system. This solution enables protection of the primary part of the heating system of the cogeneration modules from excessive pressure without additional interventions.

Another problem which arrives during connection of these systems is the quality of water in the main district heating system. Quality of water is out of doubt, but in pipelines
Another problem that occurs when connecting these systems is the water quality in the main central heating system. Water quality is beyond doubt, but oxides and sediments can occur in pipelines that can adversely affect heat exchange surfaces (plate heat exchangers in the first round) and in the secondary heating cycle where precipitation of these materials can occur. This problem can be overcome in two ways:

a) installation of a filter station between the two systems, and
b) indirect connection through a heat exchanger station.

The first solution allows raising the temperature mode during connection, and slightly better characteristics during operation.

The second solution is somewhat less favorable due to a small reduction in temperature in the return pipeline of the heating system after connection, due to the size of the temperature difference in the heat exchangers. This solution is applied in the system under consideration.

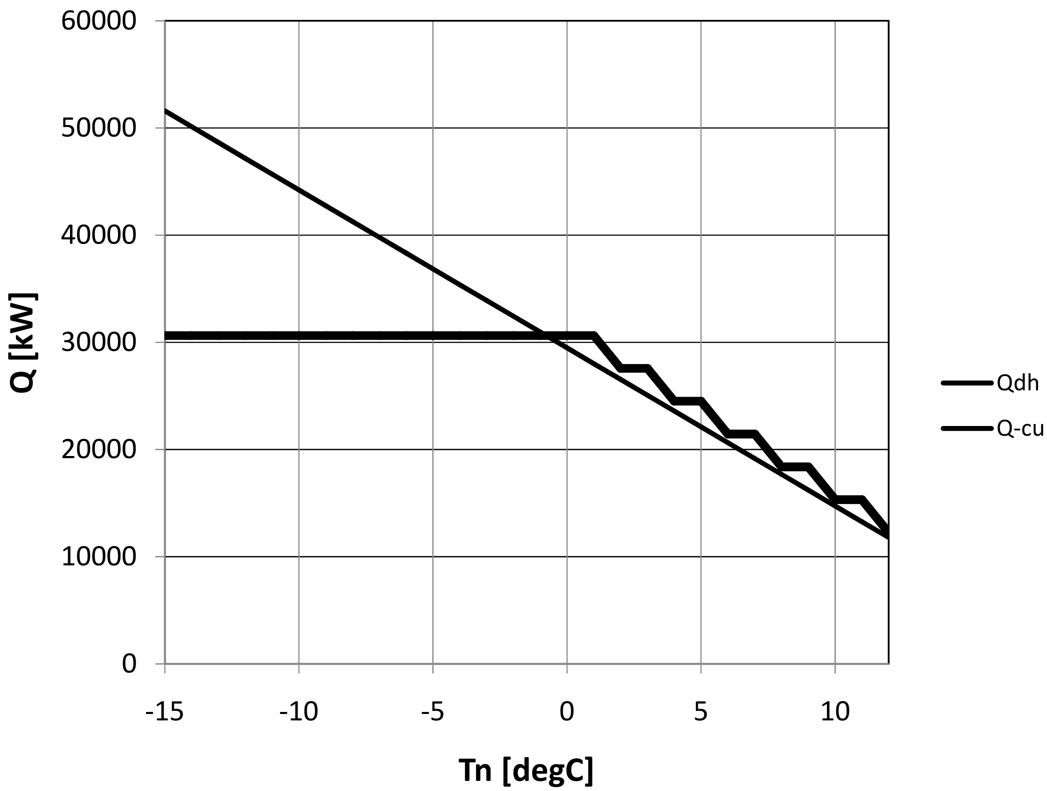


fig 2 Working regime of cogeneration block, 51.6 MW

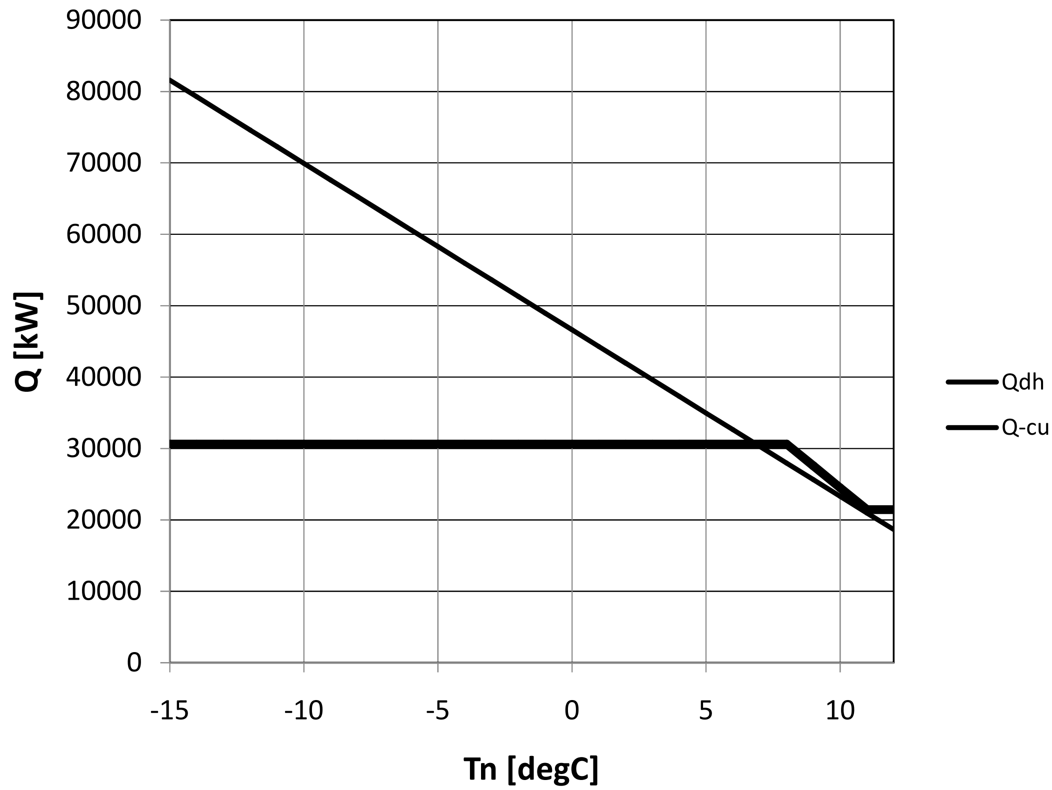


fig. 3 working regime of cogeneration block, 81.6 MW

From the given data it is noticed that the cogeneration heating source can cover the heat consumption in the area with external temperature from 12 to 5 $^{o}$C. At lower outdoor temperatures a larger number of cogeneration units can be activated in order to increase the flow of circulating water in the exchangers, but there is a limit in the heat transfer to the heating system due to the reduction of the temperature difference in the connection station.

Under lower external temperatures, the possibility of heat transfer decreases, which can be seen in fig. 4, ie fig. 5.

With the decrease of the outside temperature, the temperature regime in the heat exchanger station changes, ie the temperature difference in the heat exchangers decreases and thus the heat transferred to the heating system.

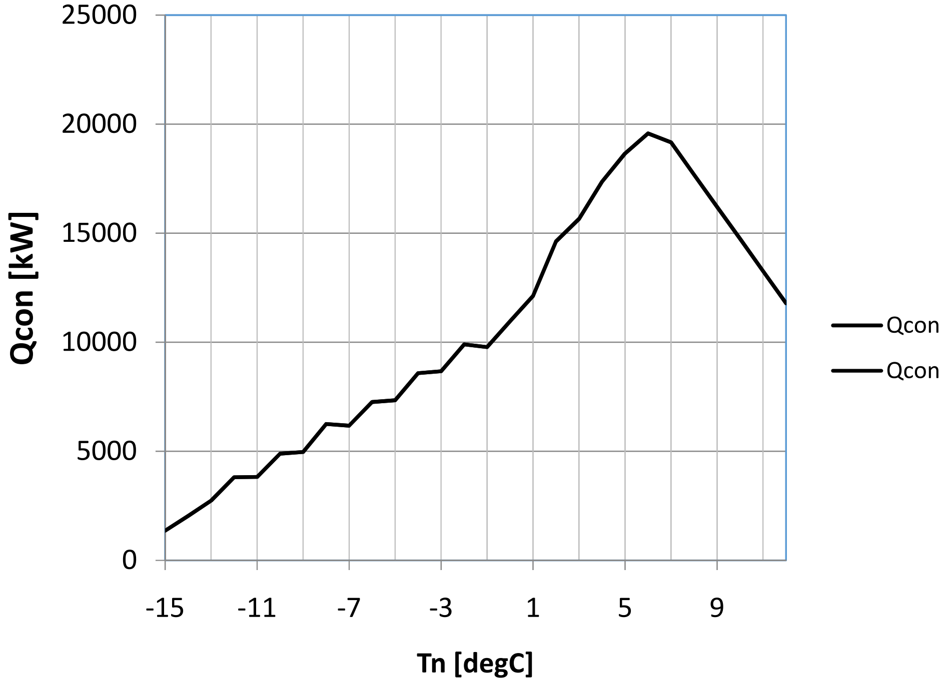


fig. 4 delivered thermal energy to the heating system, 51.6 MW

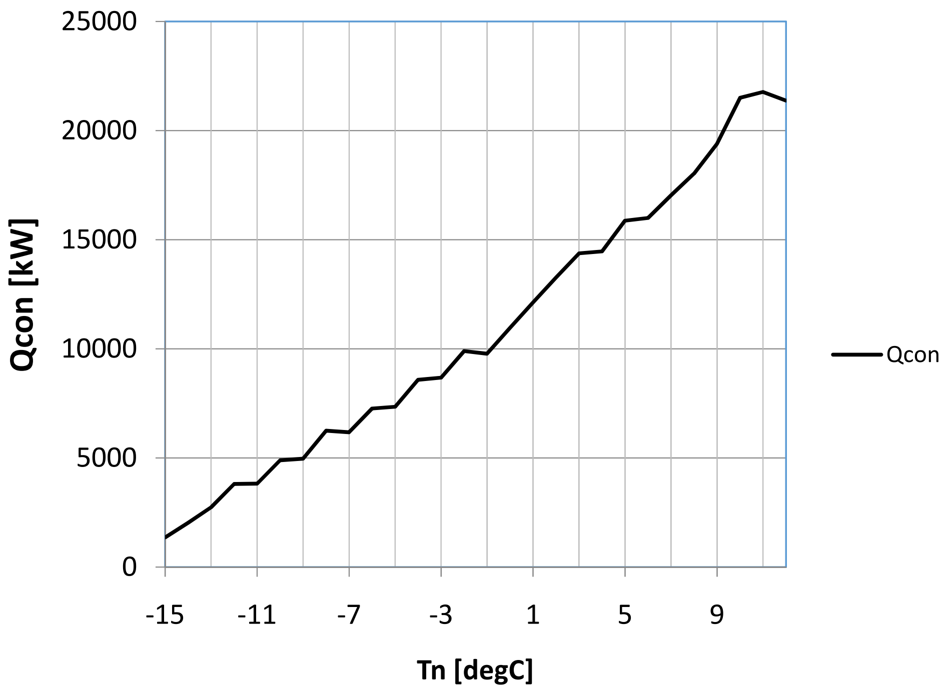


fig. 5 delivered thermal energy to the heating system, 81.6 MW

With direct connection of the cogeneration block, somewhat more favorable data can be obtained, as given in fig. 2 and fig.3. In this case, care must be taken of the water quality in the heating system in order to prevent the deposition of sludge in the heat exchangers from the primary circuit of the cogeneration units.

## 2. Conclusion

Usage of cogeneration units in district heating systems is an acceptable solution under the following assumptions:

- the temperature regime of district heating systems should enable connection of low temperature heat sources, ie cogeneration units,
- low temperature district heating systems enable connection / use of cogeneration units,
- the possibility of two-stage use of energy for heating purposes can positively affect the efficiency of cogeneration units,
- the direct connection of the cogeneration units of the heating system enables their use even at lower outdoor temperatures,
- the choice of the way of connection to the heating system should be analyzed in more detail, due to the impact on the economic parameters of operation.

## REFERENCES

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