Study of a Supercritical CO2 Power Cycle Application in a Cogeneration Power Plant

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Dr. Leonid Moroz, Dr. Maksym Burlaka, Dr. Oleksii Rudenko

Goal of the work:

Enhancement of CHP systems performance by using SCO2 Brayton cycle and its modifications.

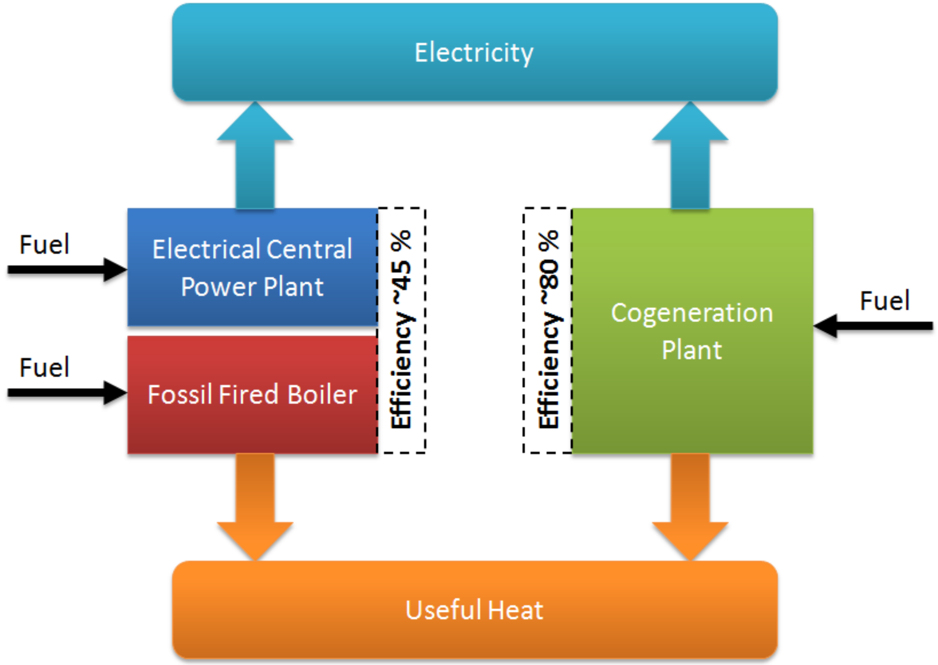
Contents :

1. Introduction
2. The first concept: Combination of steam Rankine cycle CHP plant with supercritical CO2 cycle
3. The second concept: CHP plant with single supercritical CO2 working fluid
4. Comparison of proposed CHP systems with typical steam cogeneration cycle
5. Conclusions

1. Introduction

CHP is the concurrent production of electricity or mechanical power and useful thermal energy from a single source of energy.

- Typical efficiency of separate producing useful heat and power is about 45 %.
- CHP systems can operate at efficiency levels as high as 80 %.
- Construction of CHP plants based on S-CO2 power cycle is perspective technology of CHP systems improvement.



Study details

1. Object of research: **T-250/300-23.5 unit**

2. Tools: **AxCYCLE** (Heat balance calculation), **NIST** (Fluids properties libraries)

3. Components detailing level: **Conceptual level** without mechanical design parameters

4. Assumed design values for components:

	Parameter	Value
1	Steam/CO2 Turbines efficiency, %	90
2	Compressors efficiency, %	90
3	Alternators efficiency, %	98
4	Water pumps efficiency, %	90
5	Heat losses in CO2 Recuperators, % from transferred heat	1
6	CO2 Recuperators efficiency, %	95

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Examined cycles

First concept

Embodiment 1.a: Combined Complex Steam-S-CO2 CHP Plant
Embodiment 1.b: Combined Simple Steam-S-CO2 CHP Plant

Second concept

Embodiment 2.a: Cascaded Supercritical CO2 CHP Plant
Embodiment 2.b: Single Supercritical CO2 CHP Plant

Flow diagram and performance of T-250/300-23.5 unit

The cogeneration steam turbine unit T-250/300-23.5 was taken as the object of research.

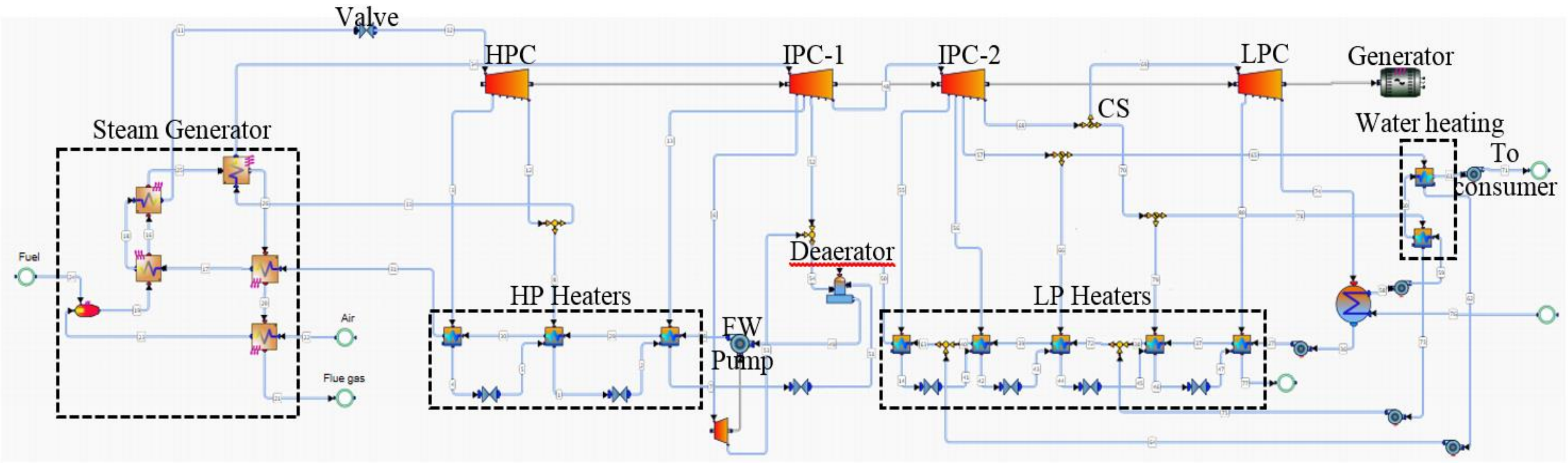


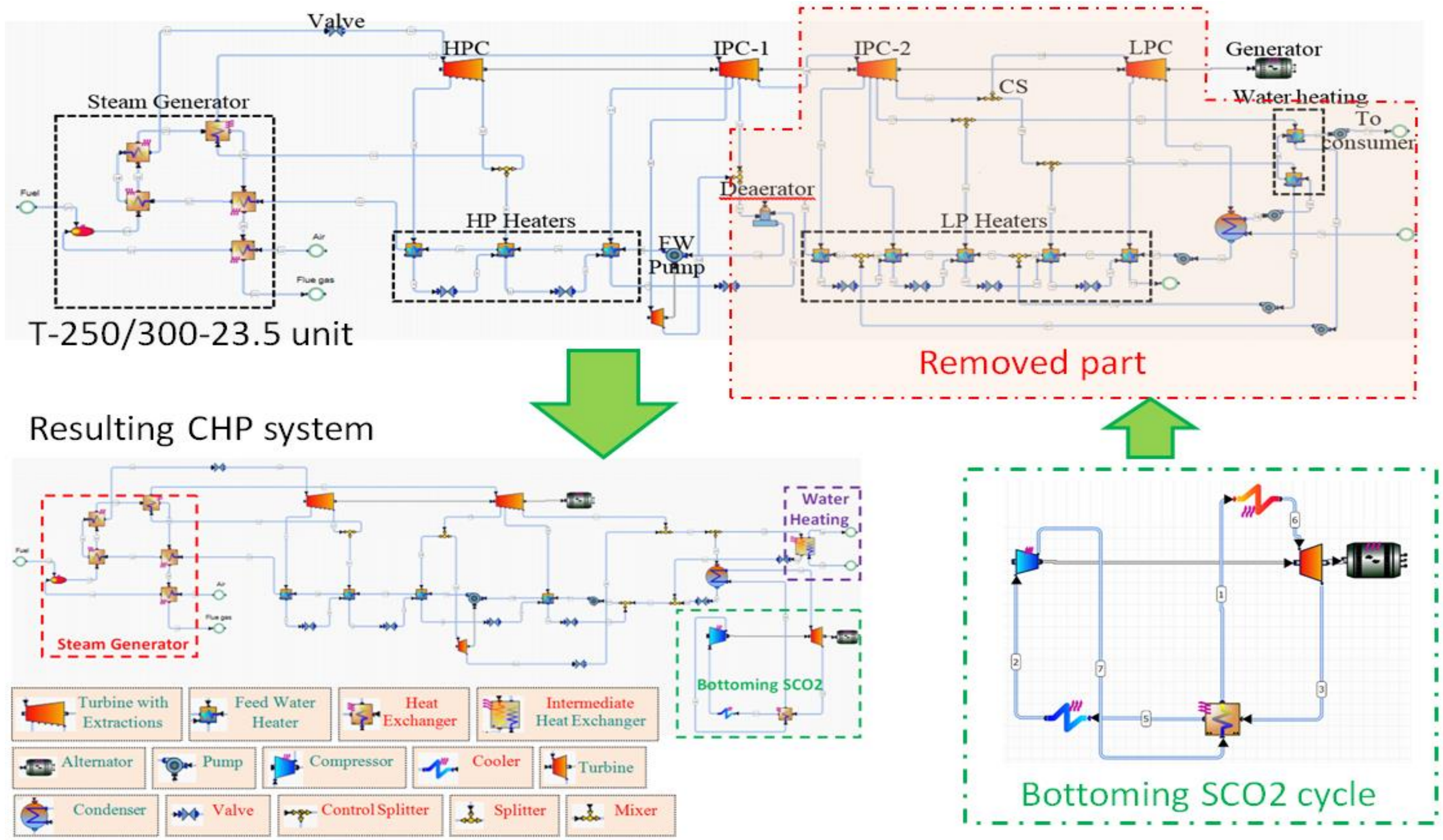
Table 1. T-250/300-23.5 performance warranty

Parameter	Unit	No Heat Load	Maximum Heat Load
Total heat consumption	MW	790	790
Live steam temperature	°C	540	540
Live steam pressure	MPa	23.5	23.5
Net electrical power	MW	300	253
Heat production	MW	0	384

2. The first concept: Combination of steam Rankine cycle CHP plant with supercritical CO2 cycle

Cycle development:

- removing of IPC-2, LPC and partial removing of regeneration system;
- addition of bottoming SCO2 cycle.



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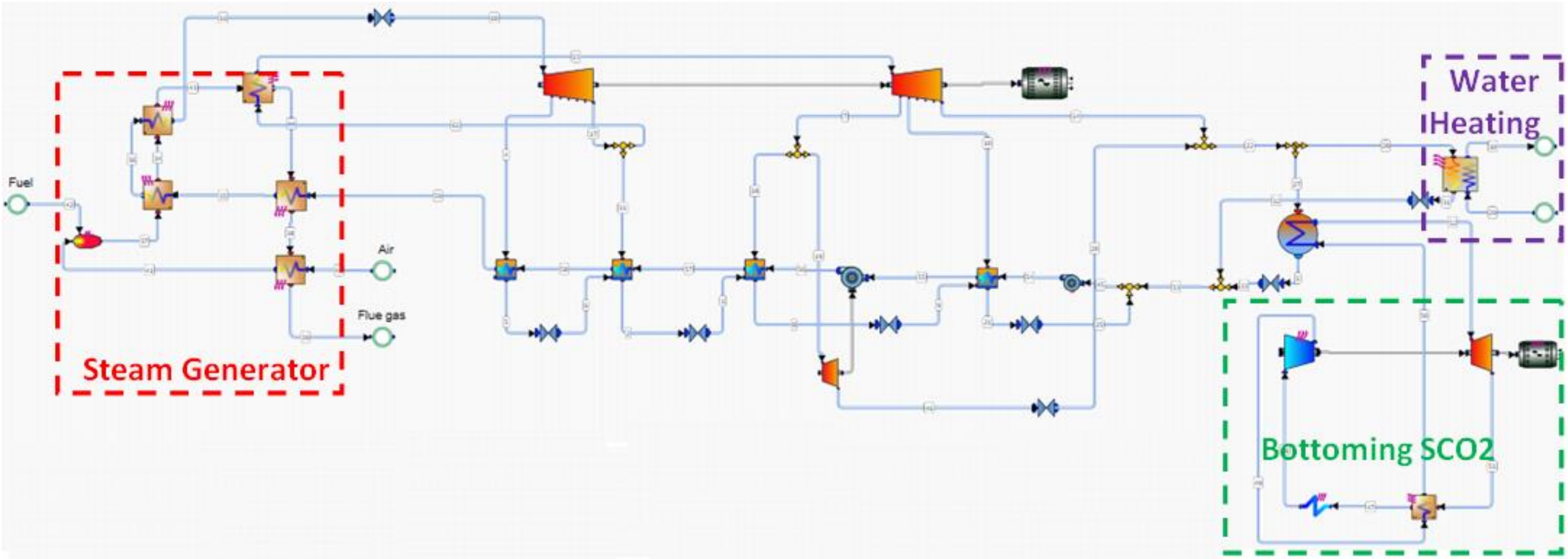
Combined Complex Steam-S-CO2 CHP Plant (Embodiment 1.a)



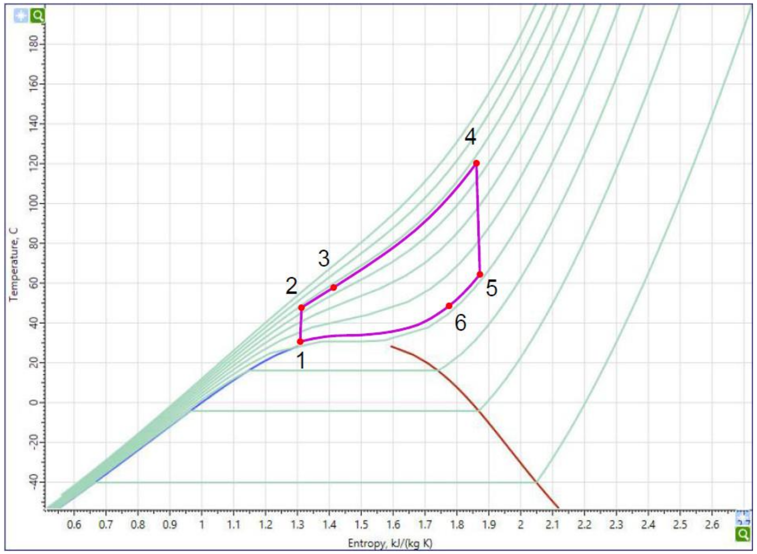
Cycle features:

- high unification degree with the existing steam plants;
- extremely simple bottoming S-CO2 cycle.

Embodiment 1.a

Table 2. Cycle Parameters

	Parameter	Value
Steam part		
1	Live steam pressure, MPa	23.5
2	Live steam temperature, °C	540
3	Back pressure, MPa	0.2
4	Constant net electrical power production, MW	252.3
Bottoming SCO2 part		
5	Compressor outlet pressure, MPa	15
6	Maximum supercritical CO2 temperature , °C	120
7	CO2 cycle lower pressure, MPa	7.7
8	CO2 temperature after the cooler, °C	32



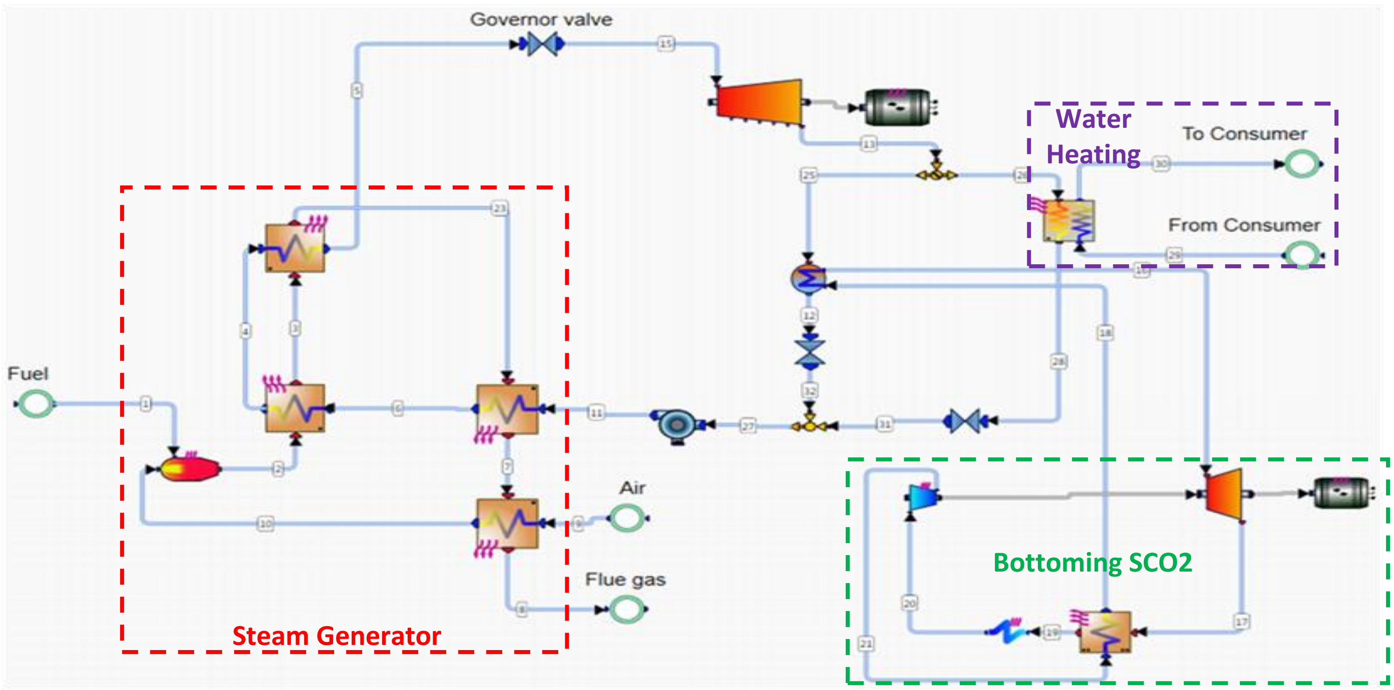
T-S Diagram for Bottoming S-CO2 Cycle (Embodiment 1.a):

1-2 CO2 compression in Compressor
2-3 high pressure CO2 heating in Recuperator
3-4 CO2 heating in Steam Condenser
4-5 expansion in Turbine
5-6 low pressure CO2 cooling in Recuperator
6-1 CO2 cooling in Cooler

Combined Simple Steam-S-CO2 CHP Plant (Embodiment 1.b)

Cycle development - simplification of Embodiment 1.a :

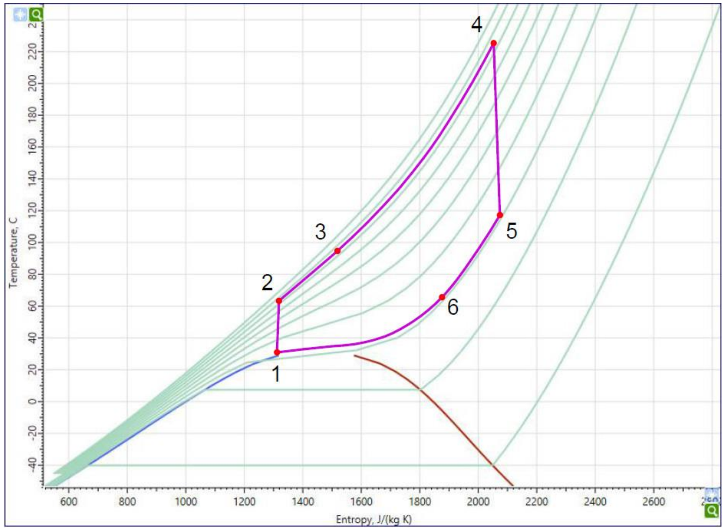
- removing of IP cylinder;
- removing of all steam heat regeneration system.



Embodiment 1.b

Table 3. Cycle Parameters

	Parameter	Value
	Steam part	
1	Live steam pressure, MPa	23.5
2	Live steam temperature, °C	540
3	Pressure at steam turbine outlet, MPa	3
4	Constant net electrical power production, MW	140.4
	Bottoming SCO2 part	
5	Compressor outlet pressure, MPa	25
6	Maximum supercritical CO2 temperature , °C	225
7	CO2 cycle lower pressure, MPa	7.7
8	CO2 temperature after the cooler, °C	32

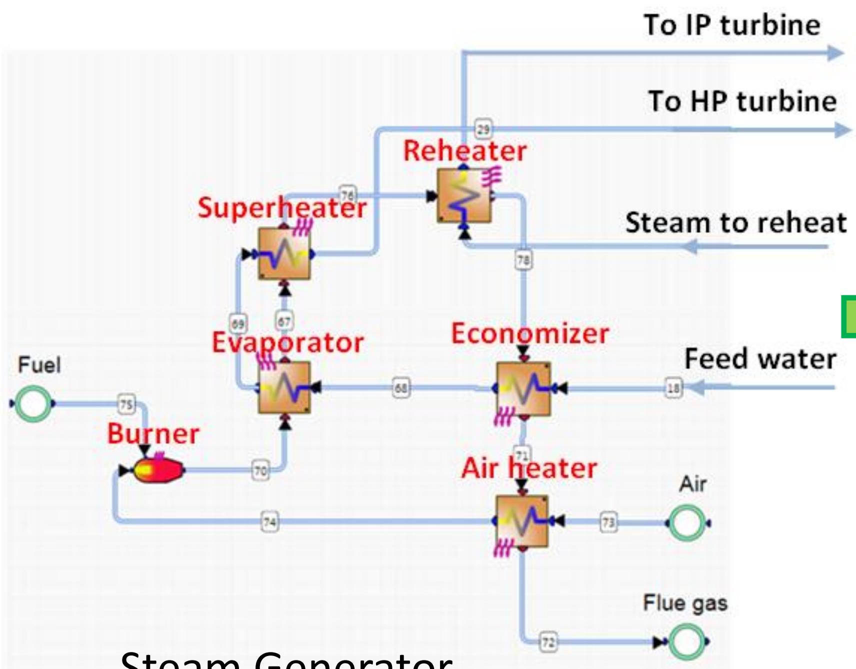


T-S Diagram for Bottoming S-CO2 Cycle (Embodiment 1.b):

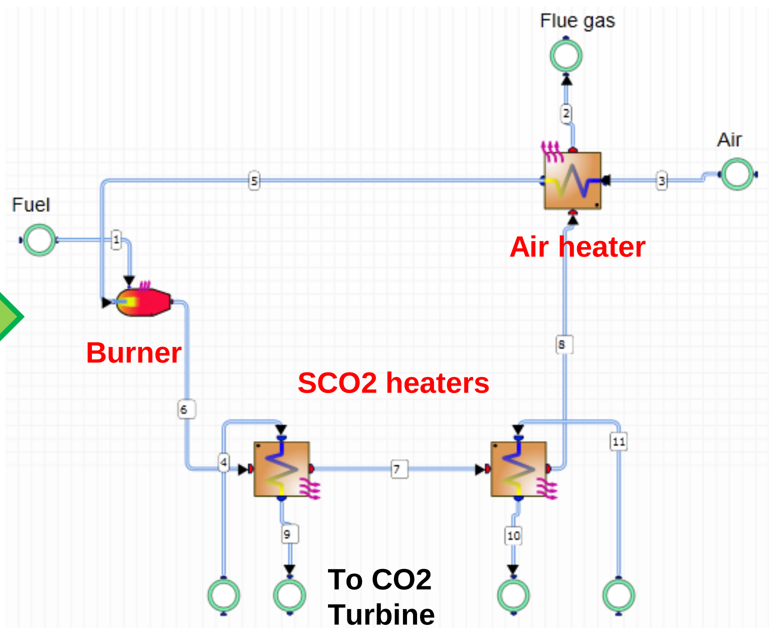
1-2 CO2 compression in Compressor
2-3 high pressure CO2 heating in Recuperator
3-4 CO2 heating in Steam Condenser
4-5 expansion in Turbine
5-6 low pressure CO2 cooling in Recuperator
6-1 CO2 cooling in Cooler

Features of the second concept :

- only the supercritical CO2 fluid is used;
- heat energy is transferred to the CO2 directly in the complex heater.



Steam Generator



Complex Supercritical CO2 Heater

Cascaded Supercritical CO2 CHP Plant (Embodiment 2.a)

Cycle features:

- cascade of supercritical CO2 recompression cycles is used;
- water heating is realized in SCO2 coolers.

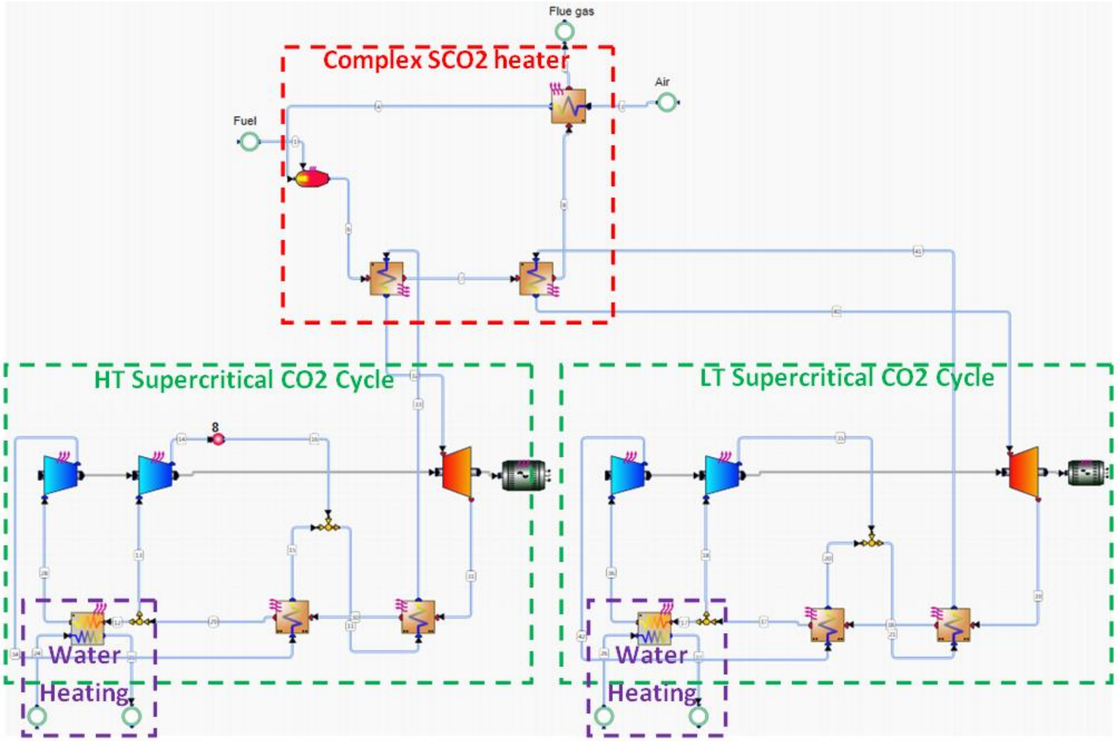
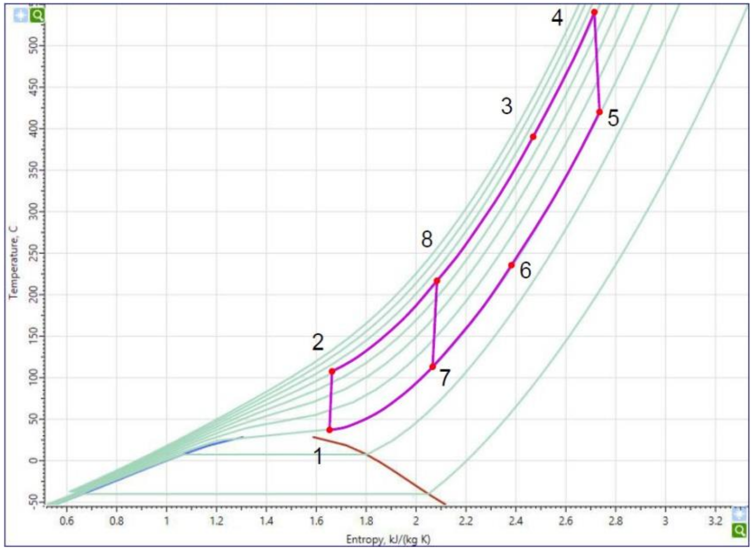
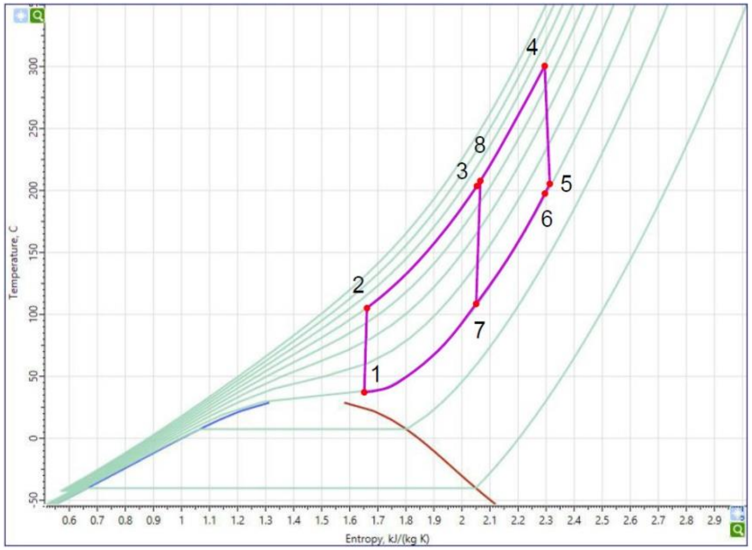


Table 4. Cycle Parameters

	Parameter	HT cycle	LT cycle
1	Live CO2 temperature, °C	540	300
2	Maximum cycle pressure, MPa	21	20
3	Lower cycle pressure, MPa	7.7	7.7
4	CO2 temperature at LT recuperator outlet, °C	115	110
5	Temperature at CO2 cooler (water heater) outlet, °C	37	37
6	Net electrical power production, MW	297.7	13.9
7	Hot water temperature, °C	100	

Embodiment 2.a



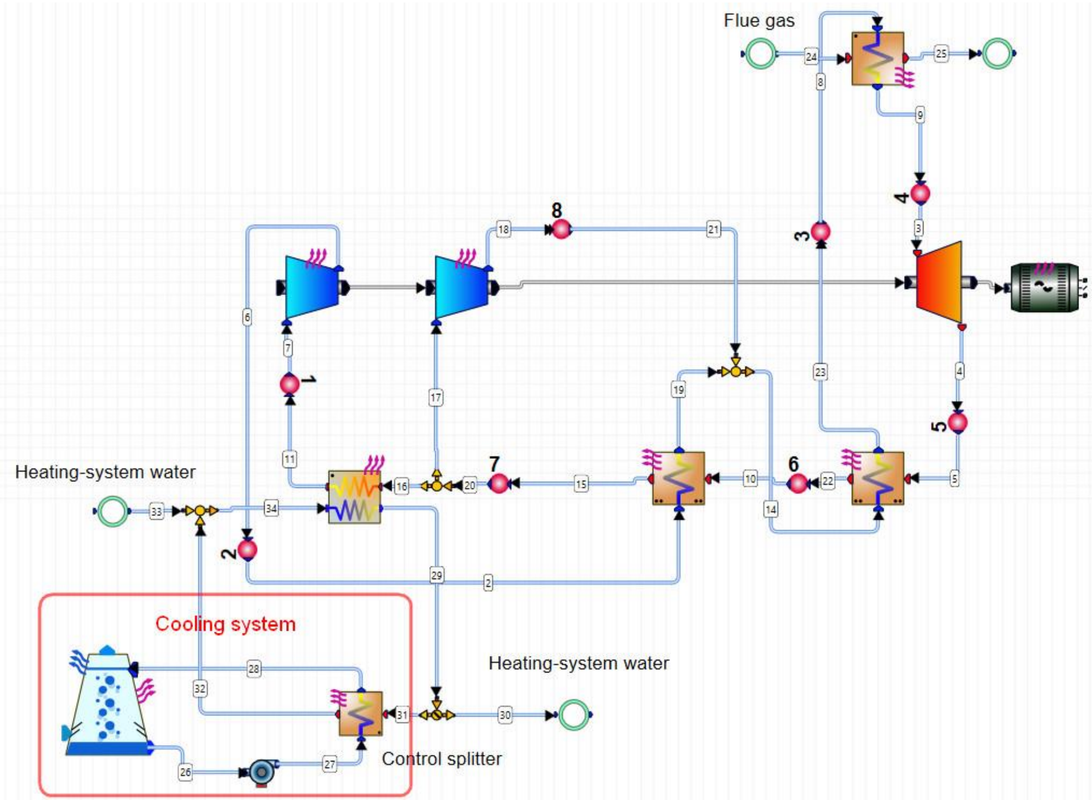


T-S Diagrams for High and Low Pressure Recompression S-CO2 Cycles (Embodiment 2.a):

1-2 CO2 compression in Main Compressor
2-3 CO2 heating in low temperature and high temperature Recuperators
3-4 CO2 heating in Complex SCO2 Heater
4-5 expansion in Turbine
5-6 low pressure CO2 cooling in high temperature Recuperator
6-7 CO2 cooling in low temperature Recuperator
7-8 CO2 compression in Recompressor
6-1 CO2 cooling in Cooler

Heat load adjustment

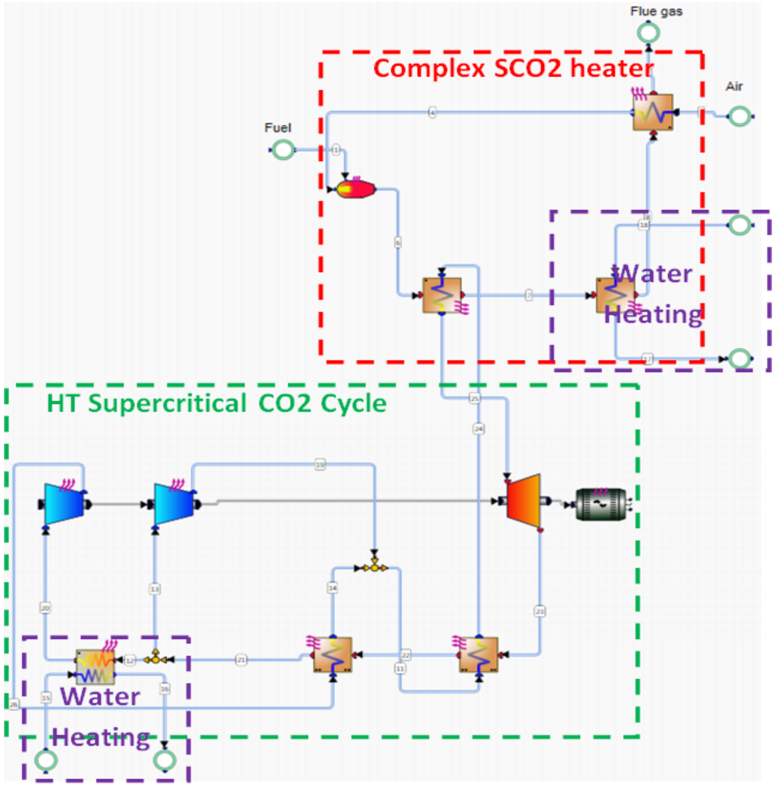
- For heat load adjustment the control splitter is used.
- The unclaimed by consumers heat is rejected in the cooling tower.



Single Supercritical CO2 CHP Plant (Embodiment 2.b)

Cycle development - simplification of Embodiment 2.a :

- the second supercritical CO2 cycle (LT) was substituted by an additional water heater;
- water heating is realized in SCO2 cooler and directly in the complex heater.



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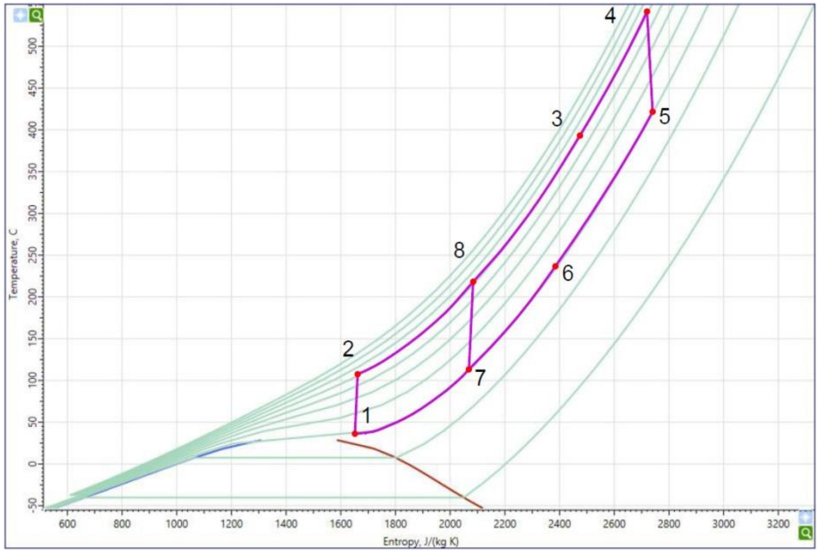
Embodiment 2.b



T-S Diagrams for Recompression S-CO2 Cycle (Embodiment 2.b):

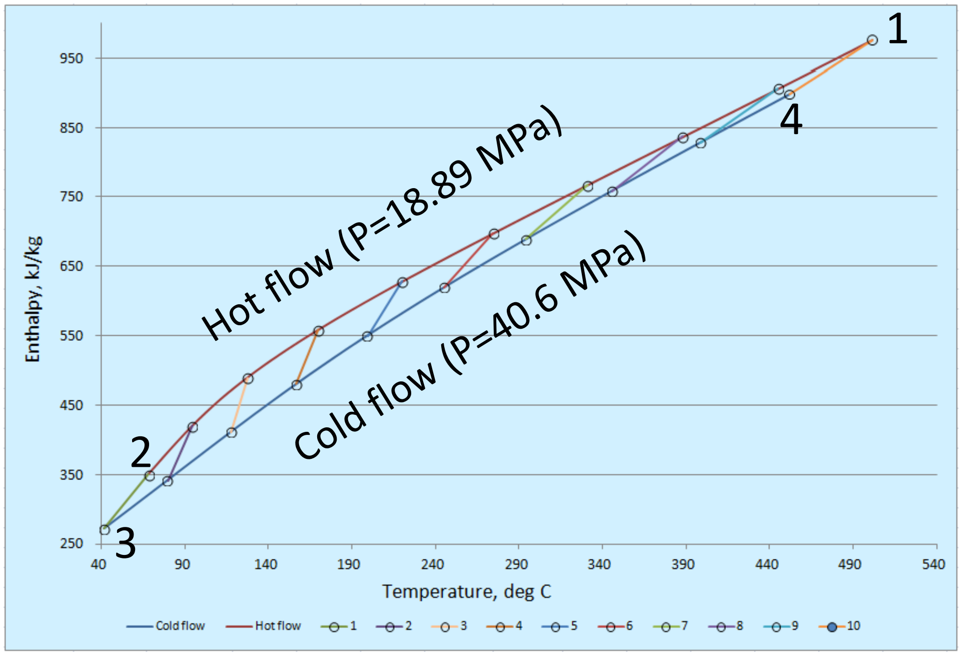
1-2 CO2 compression in Main Compressor
2-3 CO2 heating in low temperature and high temperature Recuperators
3-4 CO2 heating in Complex SCO2 Heater
4-5 expansion in Turbine
5-6 low pressure CO2 cooling in high temperature Recuperator
6-7 CO2 cooling in low temperature Recuperator
7-8 CO2 compression in Recompressor
6-1 CO2 cooling in Cooler

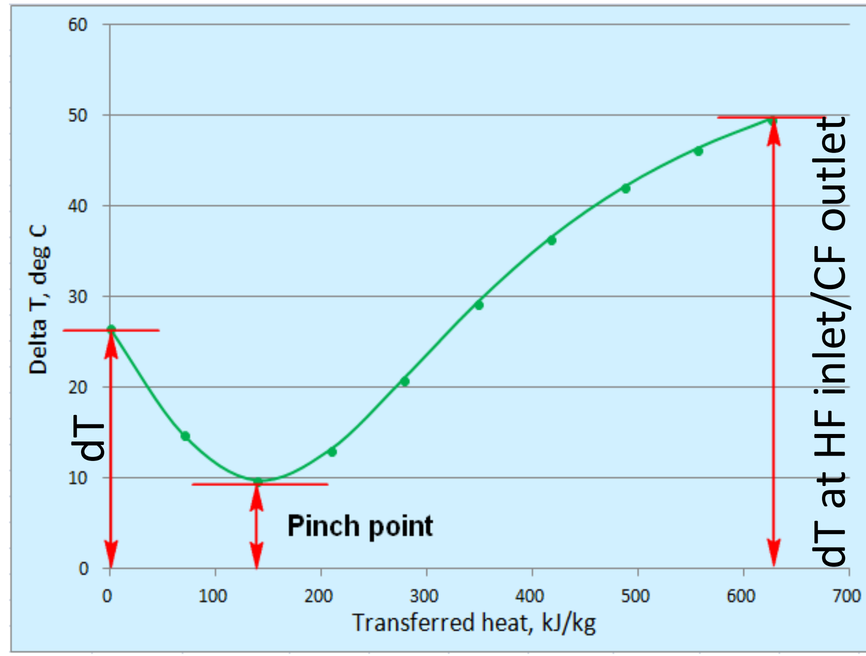
Table 5. Cycle Parameters

	Parameter	HT cycle
1	Live CO2 temperature, °C	540
2	Maximum cycle pressure, MPa	21
3	Lower cycle pressure, MPa	7.7
4	CO2 temperature at LT recuperator outlet, °C	115
5	Temperature at CO2 cooler (water heater) outlet, °C	37
6	Net electrical power production, MW	297.7
7	Hot water temperature, °C	100

Definition of SCO2 heat exchangers parameters

Because of variability of the SCO2 specific heat the pinch point can occurs in any region of heat exchanger.





Heat transfer process in high pressure CO2 heat exchanger:

1 – hot flow inlet; 2 – hot flow outlet;

3 – cold flow inlet; 4 – cold flow outlet.

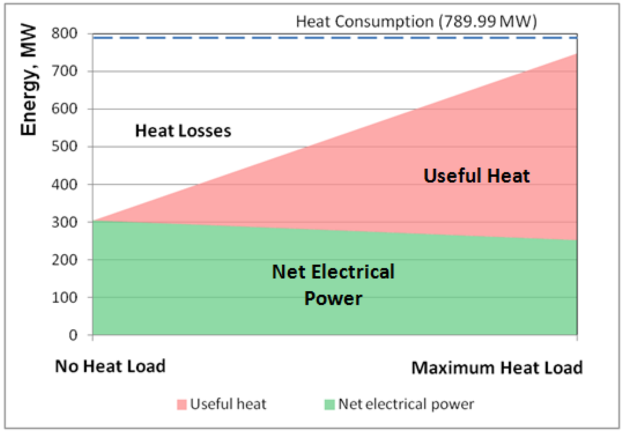
Temperature differences along heat exchanger

4. Comparison of proposed CHP systems with typical steam cogeneration cycle

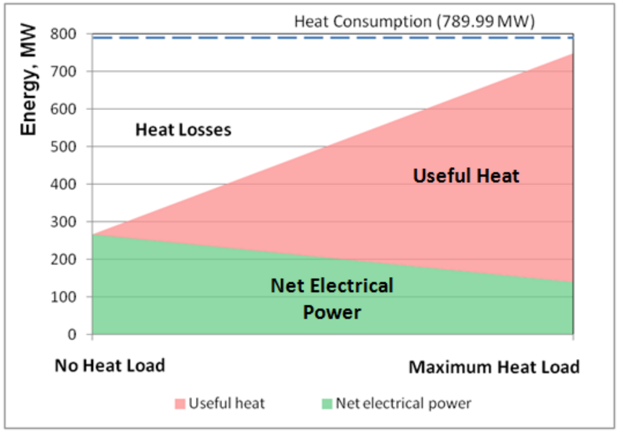
Table7. Calculated Performances of the Considered CHP Plants

Parameter	**Embodiment 1.a**		**Embodiment 1.b**		**Embodiment 2.a**		**Embodiment 2.b**		**T-250/300**	
	HL 0%	HL 100%	HL 0%	HL 100%	HL 0%	HL 100%	HL 0%	HL 100%	HL 0%	HL 100%
Heat consumption, MW	789.998									
Net electrical power, MW	304.416	252.283	266.685	140.4	311.56	311.56	297.66	297.66	300	250
Useful heat, MW	-	494.627	-	607.627	-	421.011	-	436.166	-	384.100
Electrical efficiency	38.53%	31.93%	33.76%	17.77%	39.44%	39.44%	37.68%	37.68%	37.97%	31.65%
Heat utilization factor	0.385	0.945	0.338	0.947	0.394	0.927	0.364	0.929	0.380	0.803
Potential of Useful heat, MW	-	-	-	-	421.011	-	436.166	-	-	-

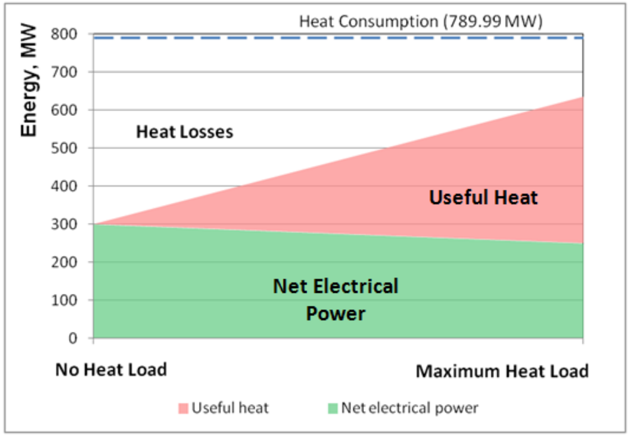
Comparison of proposed CHP systems with typical steam cogeneration cycle



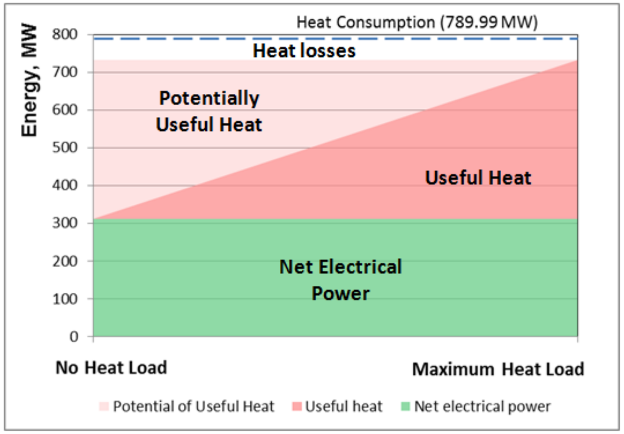
1.a



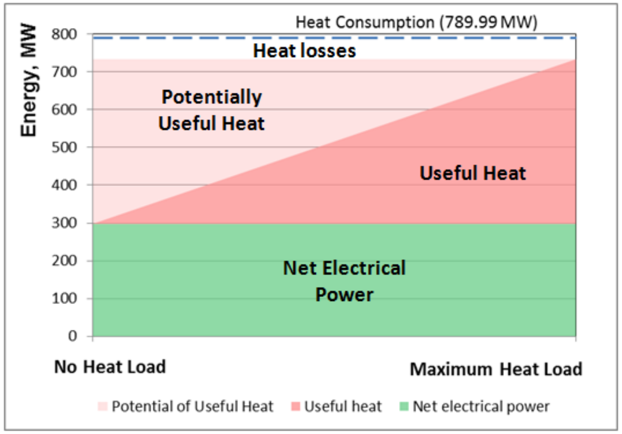
1.b



T-250/300-23.5



2.a



2.b

5. Conclusions

1. Taking into consideration high efficiency of fuel energy utilization of CHP plants and the high potential of the supercritical CO2 technology the latter should be also considered as the base of future CHP plants.

2. In order to accommodate supercritical CO2 technology to CHP conception numerous configurations and approaches were considered and two most interesting concepts were selected and analyzed.

3. The obvious advantages of the "Steam Rankine cycle CHP plant with bottoming supercritical CO2 cycle" conception are that some energy equipment remains the same and the bottoming SCO2 cycle is extremely simple.

4. The obvious advantage of the "CHP plant with single supercritical CO2 working fluid" concept is that a single working fluid is used.

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Conclusions

5. In terms of electrical efficiency almost all the embodiments with the supercritical CO_2 beats T-250/300-23.5 unit except for the embodiment “Combined Simple Steam-SCO_2 CHP Plant”. The Cascaded Supercritical CO_2 CHP Plant was found to have the best electrical efficiency.

6. The electrical power production depends on the heat load of the plant for the first proposed concept and does not depend on it for the second.

7. In terms of Heat Utilization Factor the best embodiment is the “Combined Simple Steam-SCO_2 CHP Plant” but taking into account that the electrical power is more valuable than the heat the “Cascaded Supercritical CO_2 CHP Plant” is preferable.

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