

Combined cycle gas turbine efficiency enhancement using heat pumps for thermal power plants

Andrei Albul, PhD in Thermal Engineering, Deputy Head of Energy efficiency Department at JSC Lores, Moscow, Russian Federation

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Abstract

The paper discusses enhancement of energy efficiency when using natural gas to generate power and heat in combined cycle gas turbine units (CCGT). The combination of CCGTs and heat pumps (HP) is a promising union in the face of growing natural gas prices and technological problems.

Background

Combined cycle gas turbines are the most efficient way of generating power when it comes to burning fossil fuel. Their efficiency goes over 60% and will rise even more in the near future. Japan has a government policy of reaching 65% efficiency¹. As a result, the leading companies on the market, such as Mitsubishi² (MHI) and Siemens are working on reaching this target. This goal is being achieved by raising the GT inlet temperature. However, there are some issues with this.

Over the years, two trends in GT and CCGT building by MHI have developed (fig. 1 and 2).

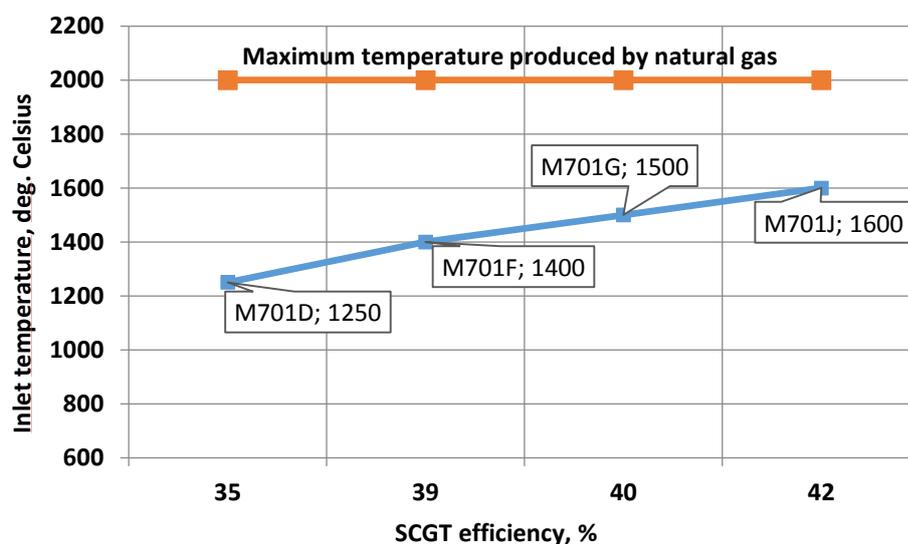


Fig. 1. MHI M701 GT series efficiency development

¹ Japanese Basic Act on Energy: Act No. 71 of June 14, 2002.

² Hada S., Tsukagoshi K., Masada J., Ito E. Test results of the World's First 1,600 °C J-series Gas Turbine. // Mitsubishi Heavy Industries Technical Review. – March 2012 - Vol. 49 No. 1. – P. 18-23.

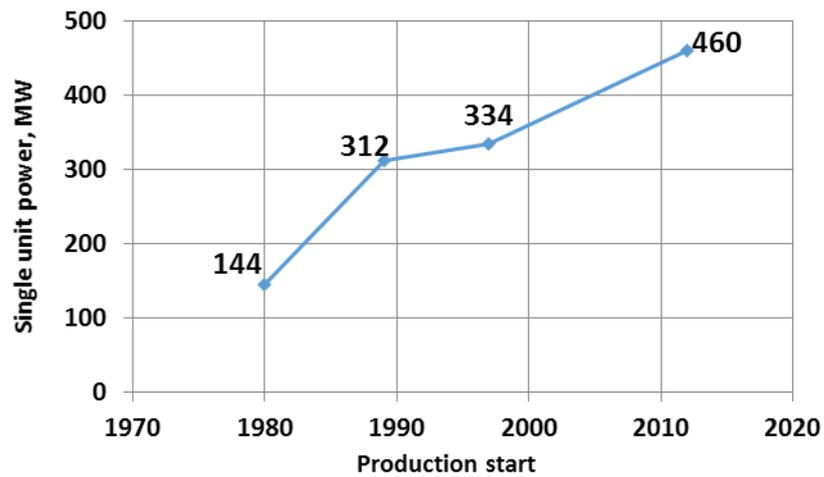


Fig. 2. Single unit power raise since production start

The first is the efficiency rise from inlet temperature increase and the second is the single unit power, which has an economy of scale: the bigger the unit, the bigger its efficiency.

The inlet temperature has increased by 100 degrees every 10 years. This lead to a fact that the gas turbines are now getting very close to reaching the maximum possible inlet temperature. Natural gas produces a maximum temperature of 2000 degrees Celsius. This means that if the progress in efficiency raise rate remains the same, in a few decades the GTs will reach their maximum efficiency and will face the same problem, which the steam turbines met: they have reached their maximum possible technology level and cannot develop anymore.

In the nearest future, there is still potential for raising the inlet temperature (what MHI or Siemens do) or raising the compression ratio, this is what GE does on its aero derivative GTs – the LM series. These particular turbines, though, are not as effective in combined cycle, since the outlet temperature is very low. There are also quite a lot more options, such as steam injection, recirculation, etc.

However, what these measures have in common is that they are aimed at one thing – getting the maximum effect when producing only power. Combined heat and power generation is thus overlooked.

Figures 3³ and 4 demonstrate that regions with developed district heating networks, such as Russia, have great interest in combined heat and power.

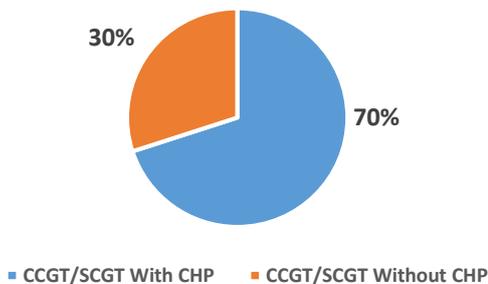


Fig. 3. CHP/non-CHP share by unit number

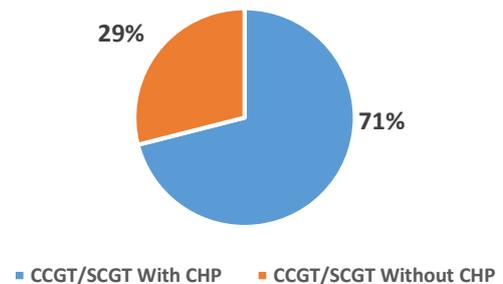


Fig. 4. CHP/non-CHP share by capacity

³ The Energy Market Council - <http://www.np-sr.ru/partnership/index.htm>

During the last five years, when the Russian Government subsidized the construction of new power generation units, the share of cogenerating simple cycle GTs (SCGT) and CCGTs, which were put in commission, was ca. 70% both by unit number and by capacity. The units that produce only electricity have twice as small share.

This is the reason, why for regions with similar circumstances, such that have a great demand in heat, a long heating period, and a developed district heating network, the combined heat and power generation is still the best option.

However, to produce heat, the CCGTs must use steam extraction from the steam turbine unit instead of using that steam to generate power, which lowers the CCGTs units overall efficiency of power generation.

Aims

The aim of this paper is to propose a possible technological solution, which can help the CCGTs maintain their high efficiency without the need to use steam extraction when heat production is required. The combination of CCGT and heat pumps (HP) might be the solution.

Heat supply problems in Russia

Unlike the power sector, heat supply in Russia does not have a market. The Government regulates the tariffs. The current policy that subsidizes electricity costs by raising the price of the heat has resulted in massive construction of boiler facilities. Therefore, instead of efficiently generating power, natural gas heats water, which on all sides is a huge energy waste.

The investors have no interest in construction of large-scale heat pumps, which are a lot more efficient than boilers. This is partly because of the large investments and partly because of the tariff regulation.

The Government is trying to fix this by introducing a heat power market, similar to the power sector. This means that there will be two products: heat power and heat energy. This makes the investment plans easier to achieve and makes combined heat and power production more financially feasible.

Heat pumps

The heat pumps are the most energy efficient way of generating heat when it comes to technology. There are numerous models available from household size to industrial units, big enough to supply a whole city with heat^{4,5}

Their big advantage is the wide spread of low-potential heat sources, starting from ground heat and up to wastewater. Still they require electricity or natural gas for their drive. Electricity is the best option, when nuclear power generation is at hand. If not, natural gas drive is the only reasonable option⁵. In addition, the heat pumps could be used in combination with renewable energy sources or waste management facilities.

⁴ Zogg M. History of Heat Pumps. Swiss Contributions and International Milestones. - Oberburg: Process and Energy Engineering CH-3414, Switzerland. 2008. – 114 p.

⁵ McDonough M.J., Lafaille S. Natural-Gas-Engine-Driven Heat Pumps. // HPAC Engineering. – Aug.1. – 2012.

A fossil fuel station in particular has great potential for low-grade heat sources that have a stable temperature over the year.

Therefore, it is reasonable to combine the two best available technologies (CCGTs and HPs) to get a technology, that is suitable for regions with developed district heating and that will not decrease the CCGTs efficiency.

Combination of CCGTs and HPs

The result could be the scheme displayed on Fig. 5.

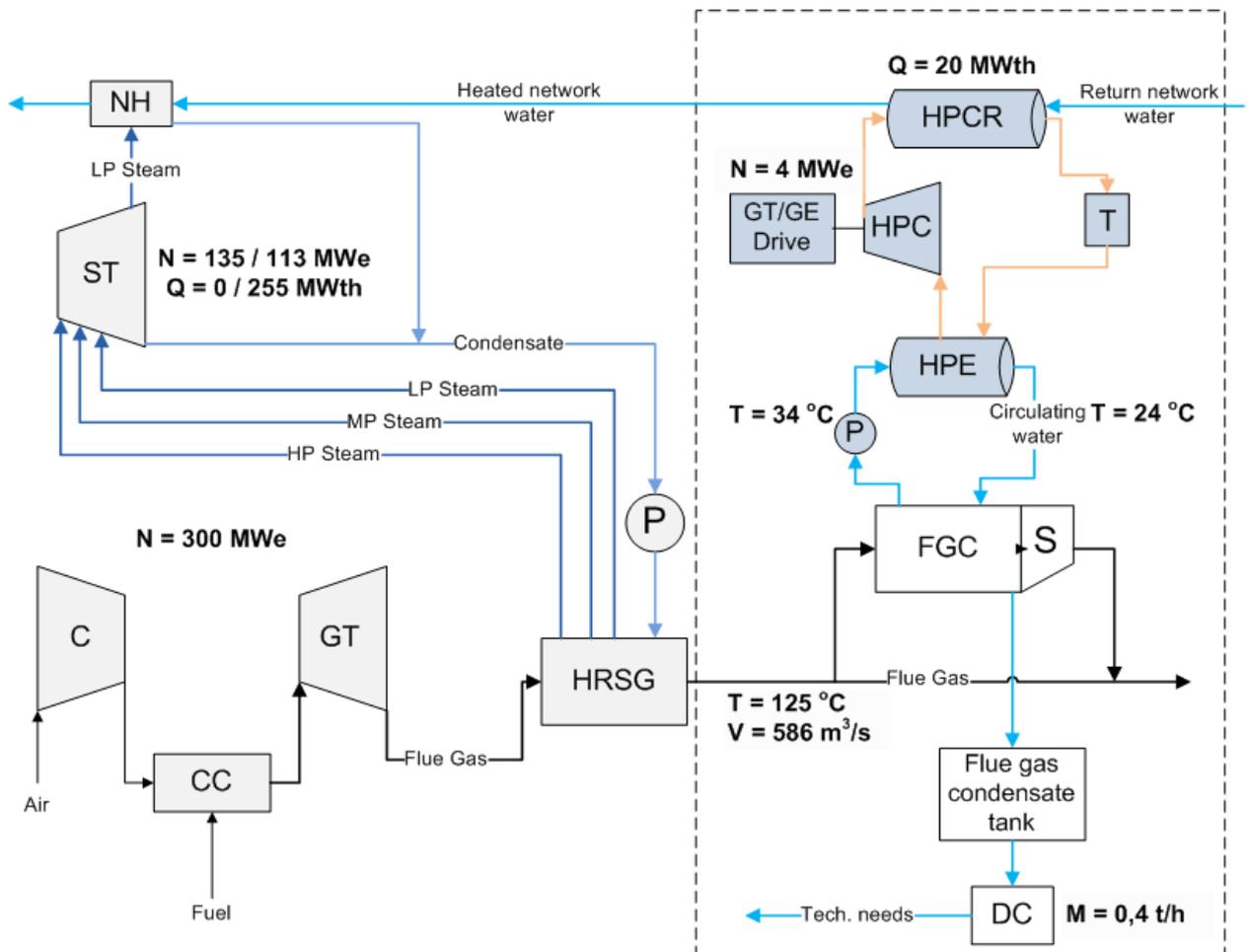


Fig. 5. The combination of CCGT and an HP.

Legend: C – GT compressor. CC – GT combustion chamber. GT – Gas turbine. HRSG – Heat recovery steam generator. ST – Steam turbine. FGC – Flue gas cooler. S – Separator. P – Condensate/water pump. HPE – Heat pump evaporator. HPC – Heat pump compressor. T – Throttle. GT/GE Drive – Gas turbine/engine drive. HPCR – Heat pump condenser. DC – Decarb unit. NH – Network heater.

The scheme includes a 435 MW CCGT by Mitsubishi. The M701F4 300 MW gas turbine is the base. The three-pressure heat recovery steam generator produces steam for the ST unit.

The idea is to use the flue gas in the CCGT as a heat source for the heat pump. The HP can produce 20 MWth of heat; it is gas driven (by a small gas turbine or a combustion engine) and has a coefficient of performance (COP) of five. A Swiss company Friothersm produces similar HPs. Their COPs typically range from four to six depending on the conditions and models. The

heat pumps heat the district heating water, and can work both in summer and in winter. They can also operate on 4-th generation cooling agents with minimum Global Warming Potential (GWP) without severe loss of efficiency⁶.

Theoretically, a part of the water that the flue gas has could be captured. After some minor processing, this water could be sent to feed the needs of the CCGTs steam turbine or the needs of the heating network.

There are a number of benefits with this solution:

- No steam extraction is required – thus the efficiency of the CCGT does not drop while heat for the district heating network is produced.
- The deep cooling of the flue gas could bring some valuable water.
- No electricity is required, since natural gas is already available at the site.

There are drawbacks as well:

- The scheme is very sophisticated. The components have to match each other perfectly.
- The second potential problem is the possibility of water condensation from flue gas. Unlike the conventional boilers, which have an air-fuel ratio around 1–1.2, the ratio for GTs is much higher, typically around 4 to 6. That means that there is a lot more air in the flue gas rather than water. Therefore, this has to be tested and experimentally confirmed.
- There still has to be supplementary steam extraction since the heat pump has issues with load control.
- There is still some loss of efficiency for the GT since there is additional aerodynamic drag in the cycle from the flue gas cooler.

The efficiency of the CCGT before the heat pump installation:

$$\eta^{CCGT} = \frac{N_{GT} + N_{ST}}{Q} = \frac{300 + 135}{845} \cdot 100\% = 51.5\%$$

Legend:

N_{GT} – electric capacity of the gas turbine, MW;

N_{ST} – electric capacity of the steam turbine, MW;

Q – fuel input of the CCGT, MW.

The total system efficiency of CCGT+HP:

$$\eta^{CCGT+HP} = \frac{N_{GT} + N_{ST} + Q_{HP}}{Q + Q_{GD}} = \frac{300 + 135 + 20}{845 + 10} \cdot 100\% = 53.2\%$$

Legend:

Q_{HP} – electric capacity of the gas turbine, MW;

Q_{GD} – fuel input of the heat pump, MW.

The total efficiency raise from the unit is ca. 1.7% without the need to use the steam from the ST unit for district heating needs.

⁶ Sultanguzin I.A., Potapova A.A., Govorin A.V., Albul A.V. Comparison of high temperature heat pumps on 4-th generation refrigerants. // VIII Minsk International Seminar "Heat Pipes, Heat Pumps, Refrigerators, Power Sources", Minsk, Belarus, 12-15 September, 2011, Vol. 1. – P. 225- 230.

Conclusions

Combined cycle gas turbine units are very effective when generating power only. For regions with developed district heating networks combined heat and power generation is the best option. To produce heat on a CCGT unit there has to be steam extraction from the steam turbine, which brings down the total power generating efficiency of the unit. The proposed combination of the CCGT and the heat pump could solve the issue by using the waste heat from the flue gas.