Hybrid Combustion Air Conditioning

A New Method to Optimise the Operation of Gas Turbines

In steady-state operation, gas turbines serve to drive electrical generators, gas compressors and fluid pumps. Their advantage relates to simple design, a very high power density, a long service life and the option of operation with various calorific values, advantages not afforded by piston machines. In recent years, it has been possible to increase the output and efficiency of gas turbines and reduce pollutant gas emissions in the waste gases in line with more stringent legislation. However, secondary processes of gas turbines continue to have an important optimisation potential.

The output and effectiveness of gas turbines are greatly dependent on the temperature of the process air at the compressor inlet, owing to the use of an axial-flow compressor. The air density and, consequently, the quantity of air inducted by the axial-flow compressor drop with increasing intake air temperature. The output and the efficiency of the gas turbine drop in proportion with this (*figure 1*).

The inducted air quantity, the output and the efficiency can be increased again by artificial cooling of the intake air in the summertime, and the following methods are already used in practice for this:

- direct adiabatic cooling of the intake air with water:
  - nozzle injection into the air stream using unitary high-pressure blast connections (can hardly be controlled)
  - nozzle admission into the air stream using binary blast connections (additional air consumption)
  - cascading or film humidification with water on fitted cooling devices (max. 65 to 80% relative humidity)
  - direct flow through ice banks.
- indirect cooling of the intake air by waste-heat exchanger, cooled with:
  - absorption refrigerating units
  - adsorption refrigerating units
  - compression refrigerating units.

Refrigerating units are costly investments and are costly to operate. Compression refrigerating units require expensive electrical power to drive them. The drive energy converted to heat and the heat absorbed from the intake air stream must be dissipated to the ambient air. This, in turn, necessitates large recoolers that also consume water and electricity.

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Remarkable optimisation potential

Anti-icing

The risk of icing up of the intake air filter and of the inlet diffuser of the axial-flow compressor occurs in cold regions in the wintertime at high intake air relative humidities. This is counteracted by artificially reducing the relative humidity by air preheating. This process is referred to as anti-icing by specialists. The following methods and heat sources are used for this:

- direct preheating of the intake air by mixing with:
  - warm air from the compressor outlet
  - warm exhaust air of the package of the gas turbine
  - warm exhaust gas (more rarely).
- indirect preheating of the intake air with waste-heat exchangers in the intake air stream with:
  - heat from a combined cycle.

However, intake air preheating, as already mentioned, causes a reduction in the inducted volumetric air flow, output and efficiency of the gas turbine. This reduction is particularly high if warm air from the compressor outlet is used for anti-icing since this air is taken from the process after compression has already occurred and is no longer available for performing work in the gas turbine and the steam process.

Part-load operation

The intake air quantity through the system is reduced with priority on gas turbines for operation at part load. This is done by actuation of the fixed blades at the inlet of the axial-flow compressor. This increases the pressure loss at the suction end and consequently reduces the efficiency of the gas turbine. In addition, the air lost as the result of reduced flow rate is then not available in the downstream steam process of a combined gas and steam process, thus leading to a reduction in the parameters in this sub-process as well.

Secondary cooling circuit

Gas turbines are very effective drives. Nevertheless, (waste) heat that must be dissipated to the environment via separate cooling systems is produced in secondary processes. This includes the (waste) heat of the generator, the waste heat of the lube oil of the bearings and any gearing mechanisms present and, depending on make, other (waste) heat sources. In warmer regions in particular and also as a consequence of global warming, these coolers frequently pose a problem in respect of operation of the gas turbines. The lube oil temperature can no longer be stabilised in the

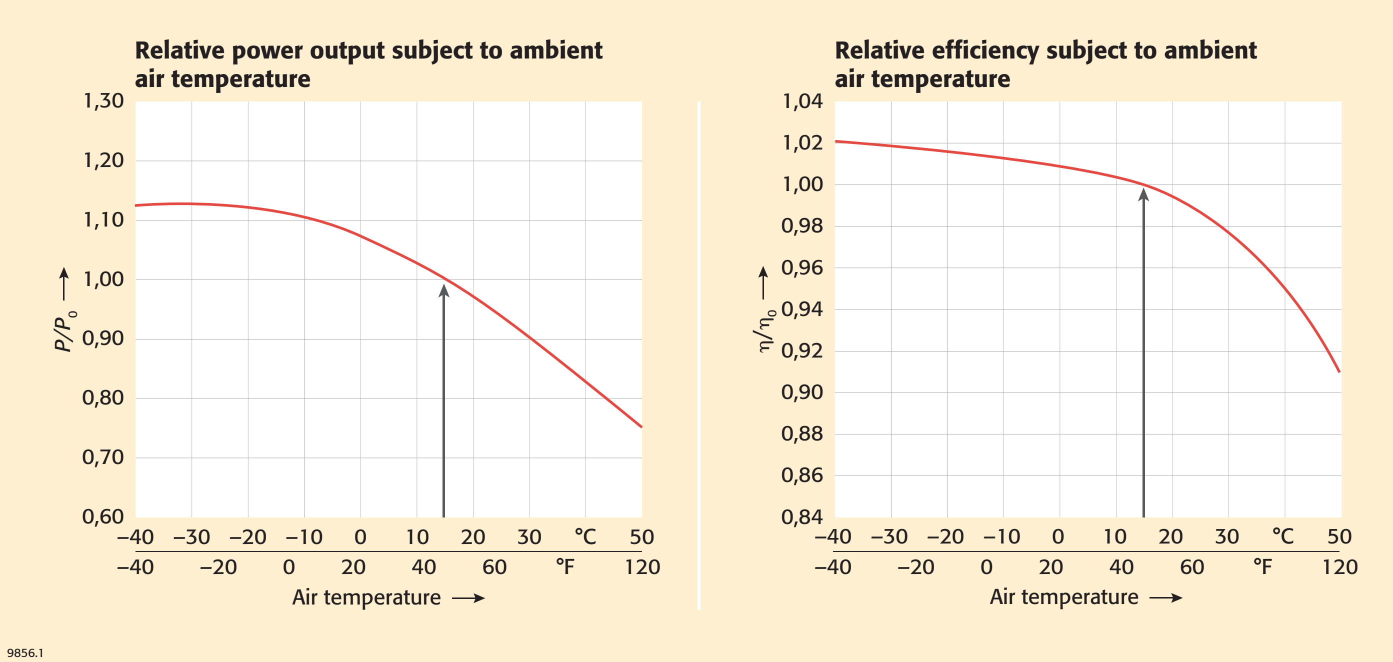

Figure 1. Example of the dependence of output and efficiency of a gas turbine on ambient temperature

summertime and the gas turbine output must be reduced. In rare cases, it is also necessary to completely discontinue operation temporarily. The lube oil ages more quickly and other lube oil grades may need to be used.

Fuel preheating

Fuel preheating is required on steady-state gas turbines operated with natural gas so as to compensate for the Joule-Thomson effect when reducing the pressure of the natural gas from pipeline pressure to combustion chamber pressure. The temperature reduction of the natural gas occurring in the isenthalpic restriction process may also be so great – depending on pressure ratio on regulator and inlet temperature of the gas from the pipeline – that there is a risk of the temperature dropping below the water vapour dew point and consequently, icing up inside and outside the gas pipe.

The effects on gas turbines can be at least just as far-reaching if the actual temperature drops below the carbon dew point in the natural gas. Propane, butane and other higher hydrocarbons contained in natural gas are precipitated to a certain extent in liquid phase at low temperatures and/or low pressures. If this liquid phase enters the gas turbine, burning in the form of large droplets, this may cause the dreaded damage to the turbine blades, also known as flashback.

Gas turbine manufacturers consequently demand a gas temperature at the combustion chamber inlet that is around 15 K above the hydrocarbon or water vapour dew point at every operating point. This combustion gas preheating is performed in gas pressure reducing stations in a separate heating building with a not insignificant fuel gas consumption from the turbine's own fuel.

Moreover, in power stations, the fuel gas is heated further, directly upstream of the gas turbine, temporarily up to temperatures as high as approximately 200 °C. This preheating is performed with heat from the combined cycle. This results in a saving in fuel gas corresponding to the heat equivalent and an almost proportional increase in efficiency of combined cycle.

Connection between secondary cooling, fuel preheating, anti-icing and air humidification

A new system that performs the following tasks with few known and tried-and-tested components has been developed for conditioning the intake air on gas turbines:

- recooling of the secondary cooling circuit (lube oil and generator)
- fuel preheating
- combustion air conditioning of the gas turbine:
  - indirect preheating of the intake air in the event of the risk of sub-zero temperatures
  - direct humidification of the intake air in the case of positive ambient temperature
  - indirect preheating of the intake air in order to achieve part-load operation.

This involves interconnecting the (waste) heat sources of generator and lube oil etc. with a safety heat exchanger to be installed in the fuel line and hybrid coolers to be installed in the intake air by the closed secondary cooling circuit to form a system of hybrid combustion air conditioning (*figure 2*).

Hybrid cooler

Hybrid coolers have been used for recooling to date. They are operated only dry up to outside temperatures of approximately 7 to 18 °C depending on design. Recooling is then performed via a finned tube matrix. If the outside temperature is beyond these limits, it is humidified externally so that a water film wets the entire matrix with secondary water. Partial evaporation of the wetting water results in indirect additional cooling. The excess water is caught in a sump beneath the cooler and fed back to the wetting circuit until the permitted concentration is reached and automatic blow-down/desludging occurs. Wetting is performed with excess water so as to reliably flush out contamination from the ambient air and in order to avoid drying of the fins during wetting. Air is circulated with variable-speed fans. Hybrid coolers thus feature economical use of water and electrical power. Cooler elements derived from the sector of hybrid cooler construction are now also used for combustion air conditioning and are installed directly in the intake air stream.

Air washing relieves the load on the downstream air filters in humidification mode, thus leading to a far longer service life of the filter elements.

The hybrid heat exchangers are designed on the basis of the permitted additional pressure loss in the air-intake, e.g. 100 Pa. This means that they are so generously dimensioned that cooling of the intermediate cooling circuit is performed with very slight temperature differences between the air and the cooling water.

A relative humidity of around 98 to 99% is achieved at the inlet of the gas turbine in humidification mode with no appreciable discharge of droplets. Humidification mode is possible as of an outside air temperature between 5 and 8 °C. The thermal output and the air temperature at the outlet of the hybrid coolers can be controlled to a certain extent on the basis of the quantity of wetting water approximately from 30 to 100%. No other humidification method can be controlled as well or is as effective.

As-rolled aluminium are electrophoretically coated and are therefore insensitive to corrosion and consequently afford a long service life.

Copper is used as the pipe material. Fully demineralised water should be used to wet the hybrid coolers. Desludging that is then required far less frequently is controlled as a function of the measured conductivity in the secondary water circuit, thus contributing towards economical use of additional water.

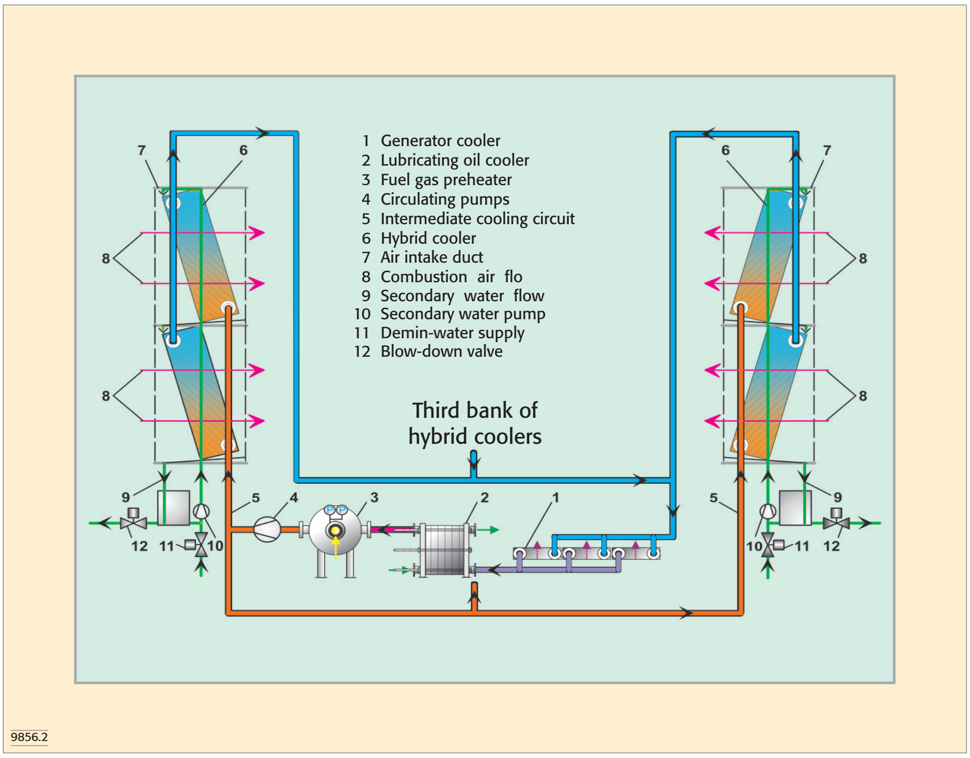

Figure 2. Schematic of a hybrid combustion air conditioning system for gas turbines

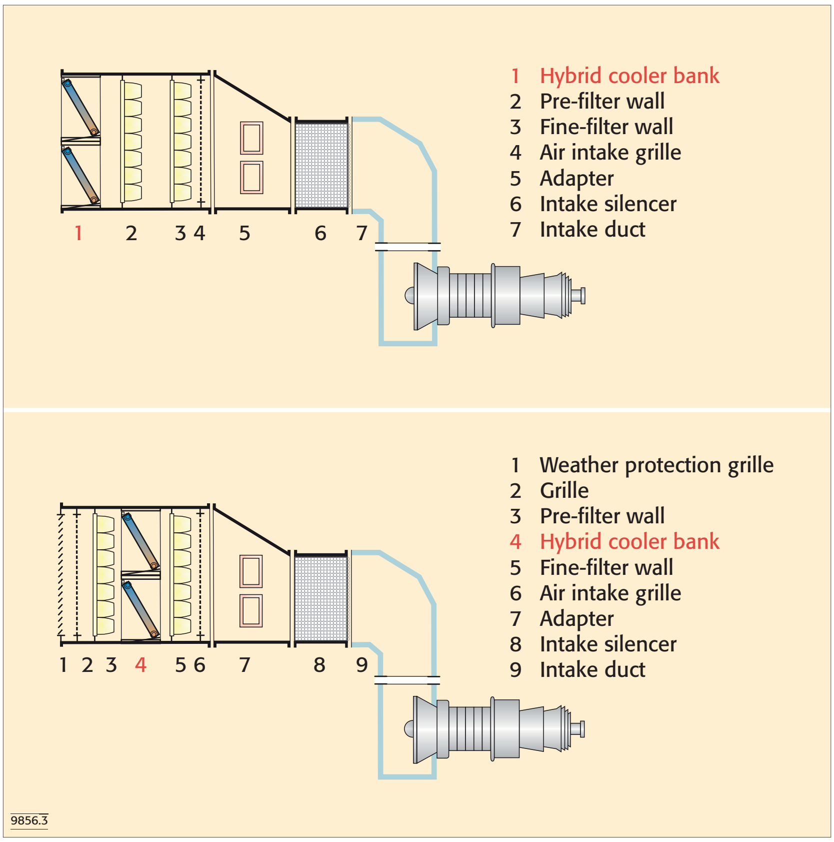

Figure 3. Options for arrangement of hybrid cooler elements in the intake tract of a gas turbine

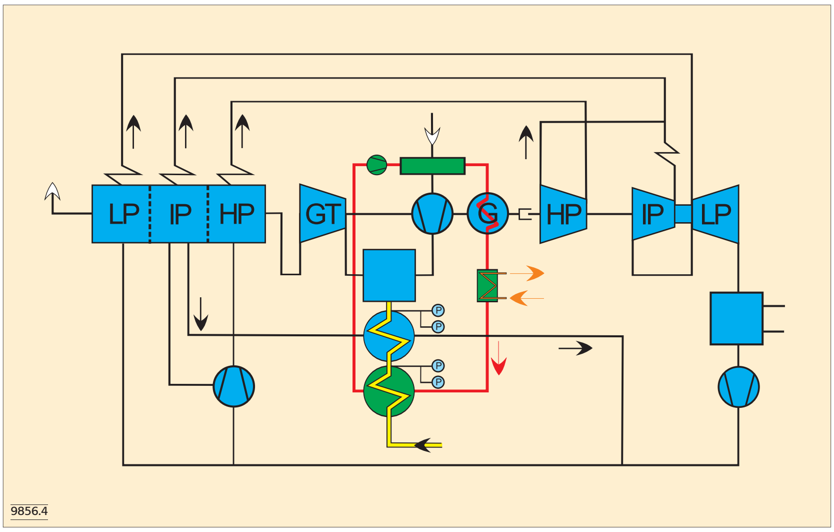

Figure 4. Integration of a hybrid combustion air conditioning system in a gas and steam process

Arrangement of the hybrid cooler elements in the air intake of the gas turbine

In desert regions subject to permanent sand contamination of the intake air, the hybrid cooler elements should be arranged between the prefilters and fine filters of the gas turbine (*figure 3*).

Fuel preheating
Fuel preheating with the (waste) heat of the gas turbine is practical if the fuel itself has adequately low temperatures. This will be the case with natural gas that is taken from a pipeline at high pressure and that cools down substantially when reduced to combustion pressure as the result of the Joule-Thomson effect.

The use of safety heat exchangers for fuel preheating means that there is absolute certainty that the fuel is unable to enter the intermediate cooling circuit in the event of any fuel leakage. Any fuel leakage is signalled by a fail-safe leakage switch. Safety heat exchangers require no maintenance and can also be operated for a limited period after any leakage event owing to the pressure-resistant design.

The benefits of hybrid combustion air conditioning

Benefits
Process-engineering coupling of recooling for secondary processes, fuel preheating and combustion air conditioning result in interesting options for gas turbine construction overall:

- Very effective recooling of the generator, the lube oil and other (waste) heat sources without additional demand for fan power or secondary water, universally at any outside air condition; conventional recooling might be left out.
- Boosting output and efficiency of the gas turbine for long parts of the year due to combustion air humidification to approximately 98 to 99% relative humidity. This means that combustion air humidification can also be used in moderate climatic zones and achieves operating times > 5,000 h/a. The use of fully demineralised water alone produces additional electrical power in this case (water to electricity).
- Boosting output and efficiency of the gas turbine in the case of anti-icing due to the use of (waste) heat.
- Boosting the efficiency of combined cycle system in part-load operation, resulting from artificial combustion air preheating with (waste) heat. This makes part-load operation of gas and steam system efficient.
- Prefiltering of the intake air in the hybrid cooler in the case of pre-humidification – this greatly prolongs the service life of the downstream air filter elements.
- Reduction in installation space required by gas turbine installation owing to the fact that there is no recooler in the secondary cooling circuit.
- Fuel saving due to fuel preheating with (waste) heat – an additional fuel saving of approximately 0.1% per 20 K gas preheating, no need for the conventional heating boiler installation.
- Use of the fuel for indirect intake air cooling – the natural low temperature of natural gas is the cheapest refrigeration energy available.
- Reduction in NO_x emissions in the case of combustion air humidification.
- Online compressor washing, fogging or wet compression in the case of negative temperatures.

In the case of new installations, savings are possible with the invest-

Figure 5. Air intake with hybrid combustion air conditioning and three-stage air filtration

ment by comparison with conventional solutions. The substantial benefits achieved when operating the installation must also be considered. The method of combustion air conditioning thus represents an important advance in the sector of gas turbine construction (*figure 4*).

Reference plant on the gas turbines at Potsdam South CHP station

The German utility Energie und Wasser Potsdam has been operating a combined cycle system as a CHP plant using two Siemens SGT-600 (previously ABB/Alstom GT10B) gas turbines at its southern site since 1996.

The following operating states were examined in a survey, to determine the cost-effectiveness of retrofitting a plant for hybrid combustion air conditioning (HCAC) to prevent icing, increase output and improve efficiency:

- fuel gas preheating using waste heat
- anti-icing using waste heat > 300 h/a
- increase in output using adiabatic air humidification > 5,205 h/a
- reduction in output using waste heat > 780 h/a.

Ultimately, a return on investment in approximately 2.2 to 2.5 years

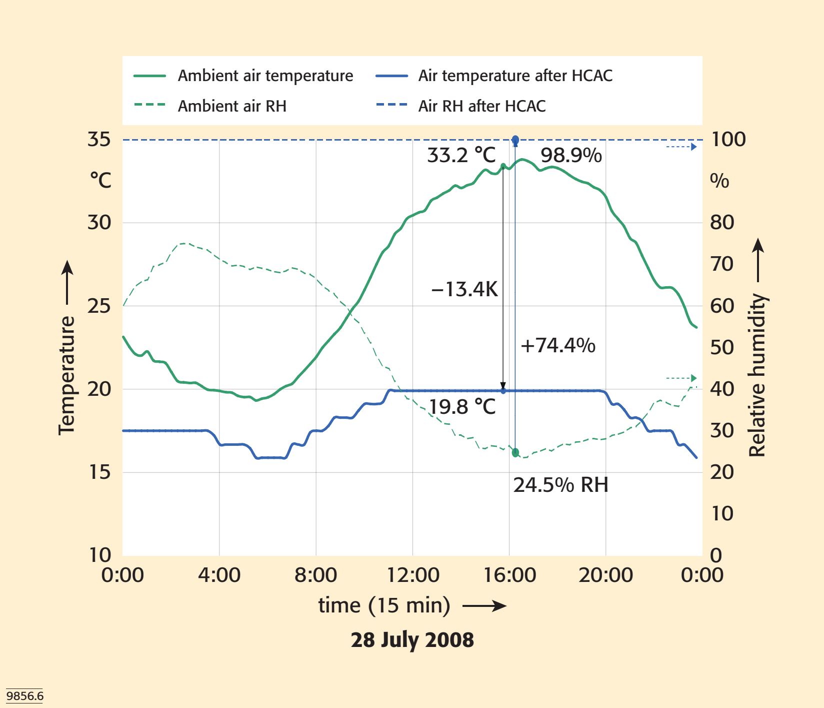

Figure 6. Reducing the intake air temperature

was determined. The first hybrid combustion air conditioning system was installed on gas turbine 1 on this basis in 2007. This measure was associated with the erection of a completely new filter enclosure with three-stage air filtration, in which the hybrid cooling elements were a crucial component. Initial operating experience was positive, so an identical system was installed on gas turbine 2 (*figure 5*) as early as 2008.

Anti-icing using cooling water

The hybrid coolers were integrated into the cooling system for the purposes of anti-icing. This is sufficient to preheat combustion air in critical air states upstream of the turbine from –5 to +5 °C and at a relative

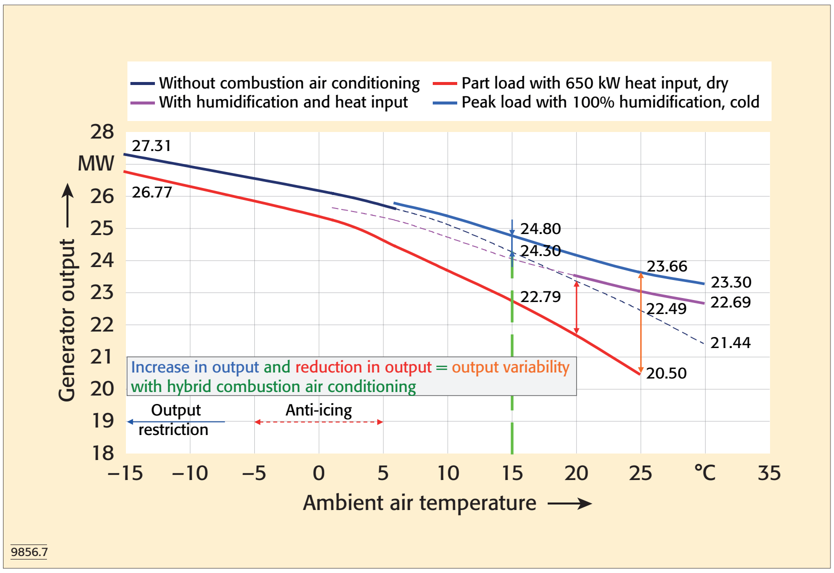

Figure 7. Output variability by means of hybrid combustion air conditioning on an SGT-600

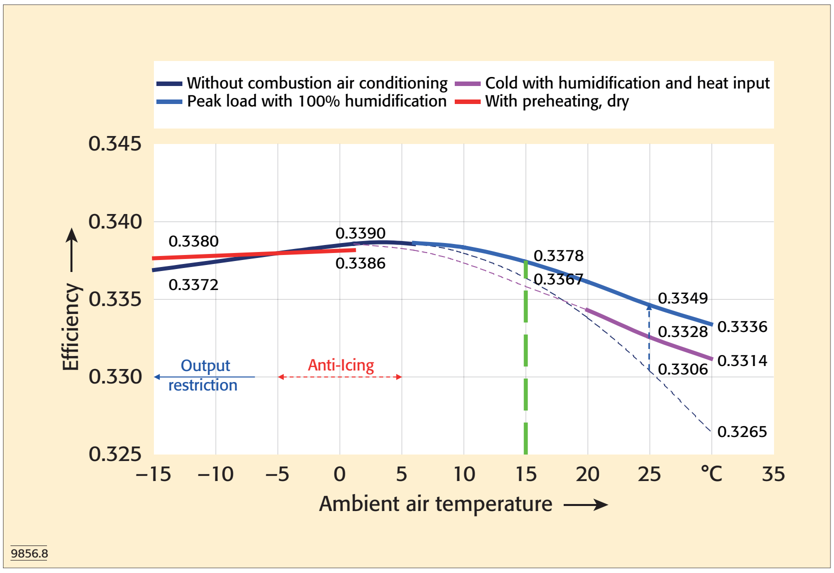

Figure 8. Increasing efficiency of an SGT-600 by hybrid combustion air conditioning

humidity > 80% into a non-critical range. The dry cooler fans are now operated at a lower speed.

Artificial reduction in output using waste heat

A combined cycle system operating in combined heat and power is predominantly heat-led, but is nowadays also subject to market demands for electrical energy. It is possible to reduce gas turbine output artificially by preheating air using waste heat. The elimination of throttling losses and the waste heat input produce higher part-load combined cycle efficiency.

Increase in output using adiabatic air humidification

The possibility exists of operating the gas turbine with intake air humidification from approximately March to November. The associated natural cooling of the intake air stabilises the gas turbine output. In the hot months, intake air temperatures < 20 °C were measured consistently at ambient air temperatures of up to 34 °C (*figure 6*).

As a result, output variability and efficiency rose across a wide operating range. At an ambient air temperature of 25 °C, the output of an SGT-600 gas turbine can be varied from 20.5 MW to about 23.7 MW, i.e. by approximately 3.2 MW, if required, thus artificially reducing the standard output of 22.5 MW by around –2 MW (–9.1%) by means of air preheating, or increasing it by approximately +1.2 MW (+5.3%) by air humidification (*figure 7*). Intake air humidification increases the efficiency of the gas turbine by about 0.43% absolute at 25 °C (*figure 8*). A maximum of 1.75 t of completely demineralised water evaporates per hour in air humidification.

Complete replacement of the filter enclosures with hybrid combustion air conditioning and three-stage air filtration facilitated:

- reliable anti-icing operation
- reduction in intake pressure loss
- high output variability
- no filter flushing requirement
- considerably longer filter life
- reduction in NO_x emissions
- relief of the recooling system in both summer and winter.

Alternatively, the combustion air can be conditioned in stackable airtainers, which combine three-stage air filtration and hybrid combustion air conditioning within the dimensions of a standardised unit. Compared to a filter enclosure with two-stage air filtration, an airtainer conditioning system is amortised in less than two years.

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