

SPECIAL APPLICATIONS

Natural Gas Preheaters

Improving the Efficiency of Gas Turbines

Fuel Preheating -
A Way to Increase Gas Turbine Efficiency

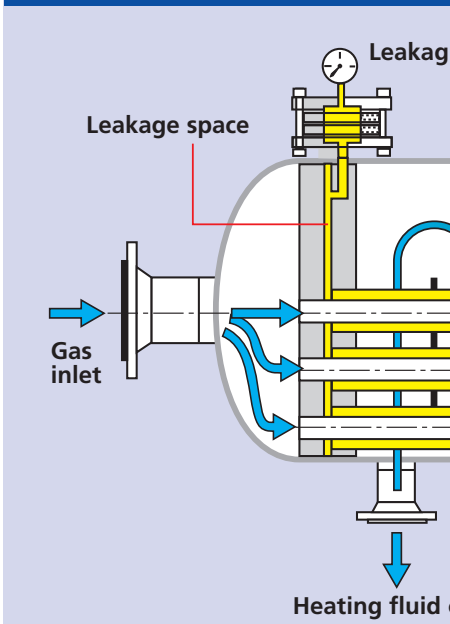
Gas turbines in stationary service are used to power electric generators, gas compressors, and liquid pumps. In comparison to piston machinery they are of straightforward design since there are no mechanical transformation processes; furthermore, they offer an extremely high power density, a long service life and can operate on fuels having different calorific value. In recent years the capacity and efficiency of gas turbines have been increased and harmful exhaust gas emissions could be reduced in order to satisfy the more and more stringent statutory requirements. The higher specific power rating and efficiency increase of more than 40 percent achieved in some cases has primarily been due to higher combustion space temperatures. The double-stage combustion method is another development approach. Other technical innovations have also been attempted such as cutting system-inherent energy requirements through improvements on axial compressors and taking appropriate measures on the required auxiliary drives, as well as for smaller machines the recuperative preheating of the compressed combustion air, or injecting water or steam in the gas turbine process. However, all these efforts in recent years have had their limitations for various reasons, particularly those linked with the materials used, that can only be overcome by realizing sophisticated additional steps or using basically new materials to make sure the service life of the gas turbines is still acceptable. Therefore, preheating the fuel has nowadays been employed in an effort to increase the efficiency of stationary gas turbine drives even further. In this leaflet various fuel preheating possibilities and their effect on the efficiency of gas turbines are discussed.

In aircraft gas turbine construction fuel gas preheating has been known for a long time. It is an indispensable necessity that serves to prevent icing of the fuel lines transporting the kerosene from the tanks located in the wings to the combustion chamber nozzles. Usually, the compressed combustion air produced by the aircraft serves as heat source and a small side stream of it is passed through a heat exchanger thus making sure the fuel is sufficiently preheated even at the low ambient temperatures that prevail at higher cruising altitudes. That the efficiency of the overall process is thus diminished is a natural fact accepted in the interest of meeting aviation safety needs.

In stationary gas turbines operated on natural gas fuel preheating is also necessary to make up for the Joule-Thomson effect that occurs when expanding the natural gas from the pipeline pressure to the combustion chamber pressure. The pressure ratio that is set via the controller and the inlet temperature of the gas from the pipeline can cause the temperature of the natural gas to drop due to the isenthalpic throttling process. This drop in temperature can cause the water vapor dew point to fall and cause icing both inside and outside the gas line.

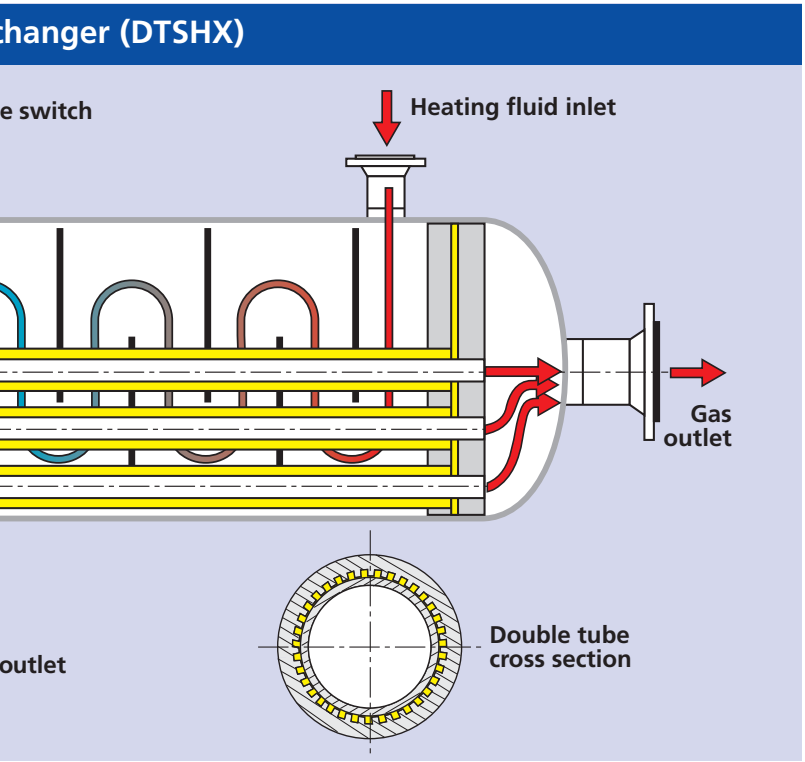
Going below the hydro-carbon dew point of natural gas may at least be equally momentous for the operation of gas turbines. Propane, butane and other higher hydrocarbons present in natural gas will to some extent precipitate in liquid phase at low temperatures and/or pressures. If they are allowed to enter the gas turbine in the form of burning larger drops the turbine blades may suffer a dreaded type of damage caused by what is also referred to as “flashback“.

Double tube safety heat exc



For that reason the gas turbine manufacturers specify a gas temperature at the combustion chamber inlet that is by approx. 15 kelvin above the hydrocarbon dew point at any operating point.

Double Tube Safety Heat Exchangers -
The Safest Form of Gas Preheating





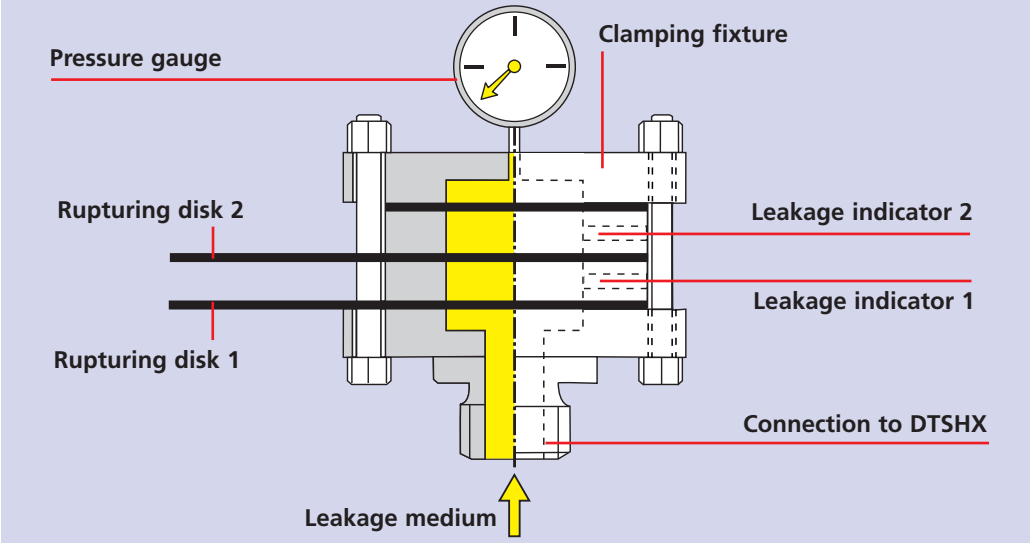
Double tube safety heat exchangers (DTSHX) have mainly been used for the purpose of cooling transformer oil and in the chemical industry.
In these applications it is a necessity that the mixing of the media participating in the transfer of heat is avoided in case leakage occurs in the exchangers.
Since the 1990's DTSHX have to an increasing extent been employed for gas preheating purposes [1].
In double-tube vessels the tube bundle proper is surrounded by another external tube bundle.
The inner and outer tubes with two tube sheets each form a hermetically sealed off leakage space that does not allow media to escape.
After a pressure and leakage test the leakage space remains filled with nitrogen at atmospheric pressure and is closed off reliably by means of a leakage switch.
As a result of thermal influences caused, for example, by temperature changes ranging between - 20°C and 110°C the absolute pressure of the nitrogen in this closed off space varies between appr. 0.89 and 1.35 bar.
This renders additional pressure safeguards unnecessary.
To lower the thermal resistance of the double tube annular space filled with nitrogen each individual internal tube is hydraulically expanded after its installation and thus brought to be in close contact with the inner wall of the respective outer tube.
However, special capillary-like ducts in this inner wall ensure that the ingressing medium can be transferred towards the collecting chambers in the event a leakage occurs. The resulting pressure rise in the leakage space will trip the leakage switch.
Provided a DTSHX is employed it will not be necessary to separate different types of heating circuits hydraulically since the escaping leakage gas is safely prevented from entering the heating fluid circuit.



The Preassembled Leakage Switch
for Added Safety

In the event a DTSHX becomes leaky (i.e. corrosion), the medium that has entered the leakage space can be reliably detected. For the selective detection of heat carrier or natural gas in the leakage space a special leakage switch has been developed and patented [2]. It consists of one or optionally two combined rupturing disks/leakage indicators arranged in a fully enclosed clamping device.
The leakage switch is made of stainless steel grade 1.4571. The standard type of clamping fixture for the leakage switch is designed for a maximum pressure of 160 bar and warrants a safe system operation at this pressure level. In the event of a leakage neither heating fluid nor natural gas is allowed to escape from the leakage space.
The rupturing disks fail successively at 1 bar and 10 bar (+/- 10%).
This design type covers pressure levels acc. to DIN of 16, 25, 40, 63, and 100 bar and acc. to ANSI of 150, 300, 400, and 600 lb/sq in. For higher pressure levels special design variants are available on request.

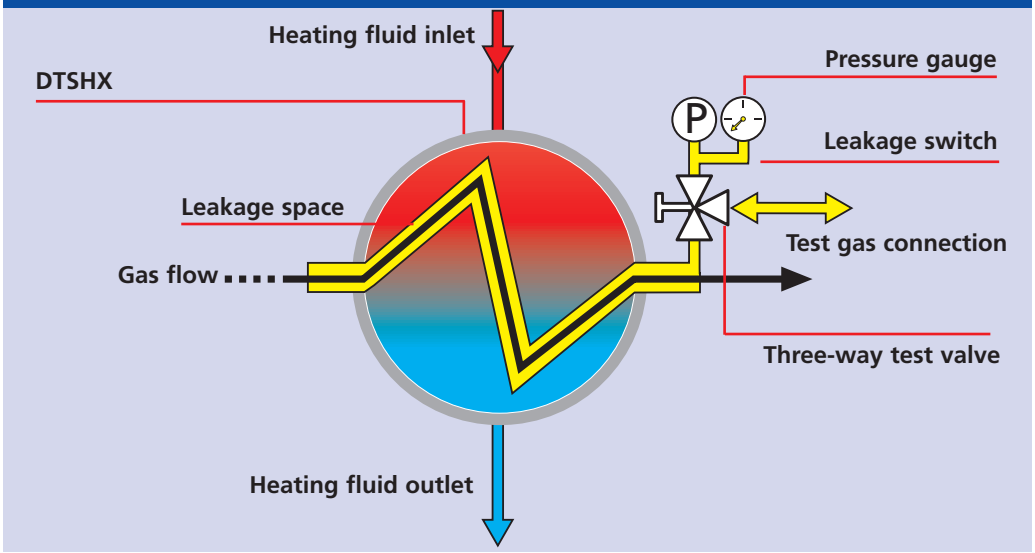
Design of leakage switch



When actuated the rupturing disks will reliably trip the leakage indicators and then remain in this position.
By arranging two similar rupturing disk/leakage indicator systems in series it is possible to have a redundant signal transmission satisfying increased safety requirements.
Feeding of the leakage indicators is intrinsically safe by isolating amplifiers so that the leakage switch can be put to use in all hazardous areas including zone 1 locations. In basic state the break circuit is closed which also enables cabling systems to be monitored for breakage or failures. A leakage signal is transmitted to a manned control room. Since the leakage switch has been designed to detect leaks occurring in only one of the two tube walls both fluids are still safely separated from each other by the additional tube wall of identical pressure resistance which means the defect exchanger may continue to be operated for a limited period until its replacement is scheduled.
To increase safety even further a pressure gauge has been hooked up to the leakage switch and allows the switch to be visually checked locally. To warrant the safe response and operation of the leakage switches individual inspections are performed by independent institutes. As a result of their design the leakage switches need not to be serviced for their entire operating life and functional testing at regular intervals is not required.

Advantages
when Preheating Gas with DTSHX

Repeat pressure testing of DTSHX via the interspace



Since the prescribed repeat pressure testing can be performed with the unit remaining in place and operation may continue for a limited time period in the event of leaks, a gas preheating system via a DTSHX can be a single-line design without bypass. Due to the excellent availability of the plant this will yield especially high savings.

Integrating DTSHX units in gas preheating facilities offers benefits in terms of cost reductions of about 1/3 versus conventional exchanger designs since the heating fluid pressure enables a cost-effective shell-side design, the heating fluid side needs no special safeguard and there is no need to separate the pressure spaces hydraulically.

Furthermore, there are substantial savings in plant operation due to the fact that the exchangers require neither maintenance nor an electric drive unit for an intermediate recirculation pump.

Statutory requirements call for repeat pressure tests to be carried out in gas technological plants on a regular basis over a period of ten years. A DTSHX can be inspected or checked via the interspace. For such tests it does not need to be removed from the installation and, if desired, can even continue in operation. This as well enables considerable cuts in cost.

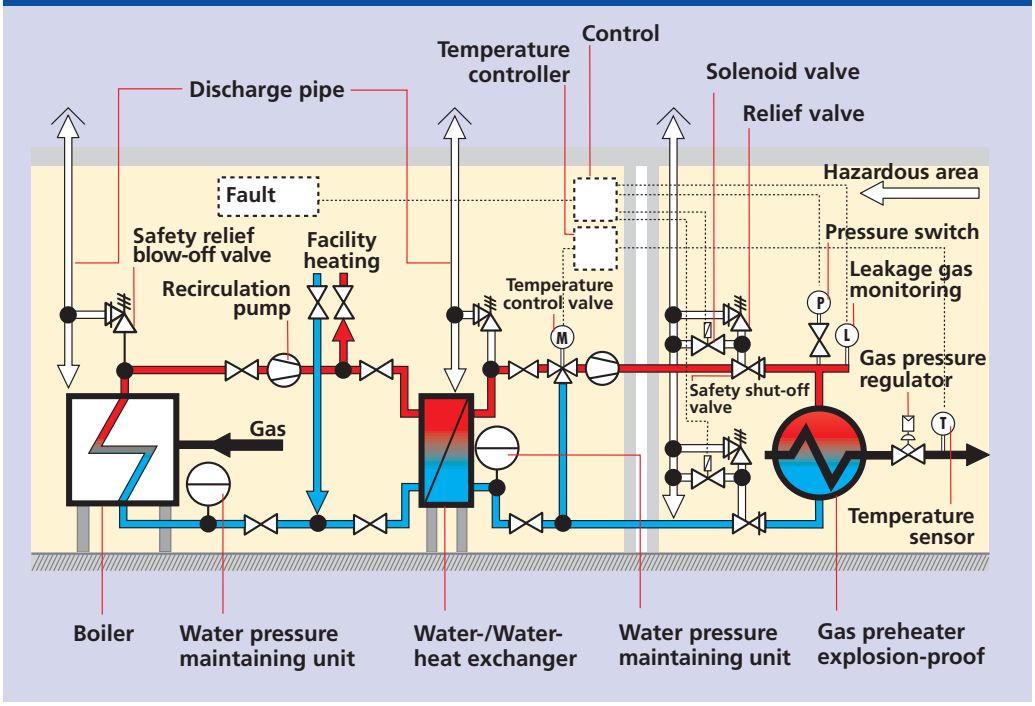
Gas Preheating
in Gas Pressure Regulating Stations

Gas pressure regulating stations as used in gas supply systems are employed for the conditioning of fuel gas to meet gas turbine requirements. Gas preheating is performed with the help of heat exchangers that are heated either directly or indirectly through a carrier fluid with heat being transferred by free or forced convection.
Safeguarding these gas preheaters against leakage is achieved on the basis of standards prescribed by the gas supply industry.
There are various ways to protect the adjacent heating systems against damage caused by leaky heat exchangers [3]. The most common design method is to make the heat exchanger shell tight to pressure and arrange safety shut-off valves on the hot water connections.

If leaks occur as a result of poor tube fabrication or pores in the existing weld seams, they are usually less severe.
Leakage gas that ingresses in the heat carrier fluid must by all means be detected as quickly as possible to prevent any carryover into the heat carrier circuit. Level probes in vertically arranged heat exchangers or special gas collecting domes located downstream of horizontal vessels are well-known technical solutions to this problem.

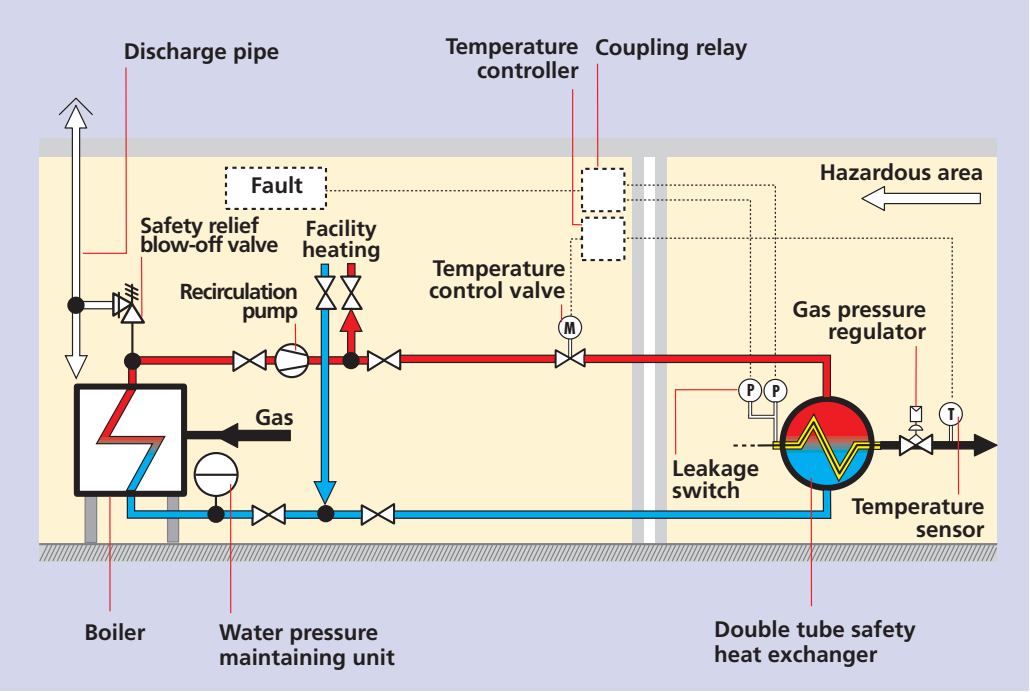
Nevertheless, such a safety arrangement also has its weak points:
The safety shut-off valves must be checked on a regular basis and readjusted as necessary. In the event of internally dirty valves through which the entire hot water flow passes these valves must be disassembled and thoroughly cleaned.
With regard to the water circuit a pressure of only about 1.3 bar is permissible so that special recirculation pumps and bigger expansion vessels (by approx. 60%) are required.

Natural gas preheating plant without double tube safety heat exchanger



Commonly used form of safeguarding the hot water circuit of gas preheating systems including safety shut-off valves and explosion-proof heat exchanger shell as well as hydraulic isolation of the heater system

Natural gas preheating plant with double tube safety heat exchanger



Simplified plant design due to the use of DTSHX. There is no need to separate the heating circuits hydraulically; expensive safety valves can be omitted.

The safety shut-off valves operating without auxiliary energy can only be actuated through the level control system located in the domes of the heat exchanger via solenoid valves arranged in parallel with the pressure relief valves. This means the principle of having valves not requiring auxiliary energy for actuation is no longer applicable.

Since the gas preheating process is interrupted as a result of the safety shut-off valves being actuated the gas pressure regulator located downstream of the heat exchanger may freeze up externally and possibly suffer internal clogging due to gas hydrates. As a consequence, the pressure in the downstream gas network may rise inadmissibly causing the respective safety blow-off valve (not shown) to open. For that reason gas preheaters of this type are usually of redundant design.

The piloting units and solenoid valves arranged in parallel emit a gas/water mixture when actuated which has to be safely discharged to the atmosphere and disposed of via the sewer system.

If antifreezing agents are used these have to be properly collected.
If the pressure in the heat exchanger falls the safety shut-off valves will open again which may have unforeseeable and unintended consequences.

If the preheaters are fed from district heating water networks or with condensate in power plants care must be taken to rule out leakage gas carryover in these circuits due to the operation of heat exchangers.

This will make recirculation pumps, pressure maintaining units and safety blow-off valves necessary. Moreover, space requirements are higher, the efficiency of the heat exchanger deteriorates and economic drawbacks are inevitably encountered. A gas preheating system configuration as outlined above will necessitate substantial capital investments and significant operating and maintenance expenses on a constant basis.

Using DTSHXs in systems like this will eliminate expenditure as described here – refer to the above diagram.

Gas Preheating - Using Waste Heat

In addition to the benefits outlined above the double-tube exchanger technology offers new opportunities in fuel gas preheating applications [4]. On the basis of a patented process DTSHXs enable the exploitation of the thermal potential of heat carriers previously considered impracticable for safety reasons, due to high expenses associated with intermediate circuits, or additional temperature gradients arising on intermediate heat exchangers [5].

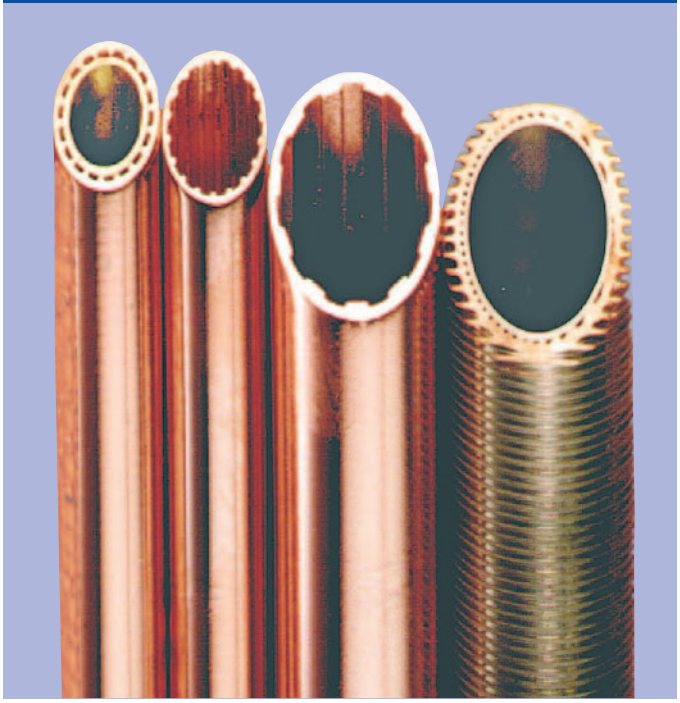
In gas turbine installations and in particular in combined-cycle gas & steam turbine plants (G&S plants) large volumes of waste heat of low potential are available that normally are released into the environment via secondary cooling circuits. Secondary cooling circuits require capital, operating and maintenance costs and reduce the plant's net efficiency. Moreover, such circuits require a cooling medium, as well as outside air or surface water of appropriate temperature and purity.

In a G&S power plant there are the following waste heat sources sorted by their temperature levels:

- Exhaust air from the turbine package
- Generator cooling with air or hydrogen
- Sealing oil for generator cooling
- Lube oil
- Transformer oil
- Exhaust steam / Blow-out
- Condensate
- Rotor / stationary vane cooling air
- Waste gas

On the other hand, due to its almost constantly low temperature level natural gas conveyed through underground piping systems can be directly heated up in a DTSHX so that such low-temperature heat sources can be favorably put to use. Provided the appropriate type of heat source is selected an exactly even heat balance may be achieved in the most favorable case and the traditionally required cooling system as well as external heat sources for gas preheating can be dispensed with altogether.

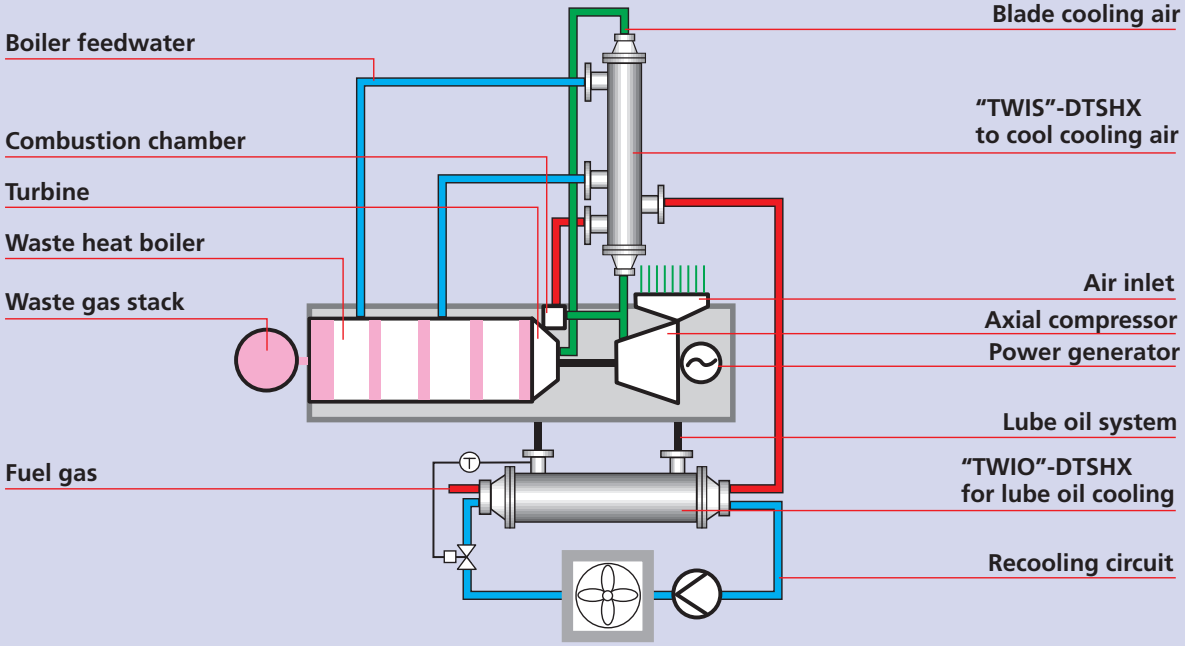
Various double-tube design versions



Double tubes for DTSHX can be fabricated in numerous shapes, diameters, and material grades, even different material combinations may be used for the inner and outer tubes. Therefore, there are virtually no limits to the use of double tube safety heat exchangers. The following DTSHX design versions can be made available for the respective heat sources:

- High-finned DTSHX tube bundles for installation in the cooling ducts of the turbine package, the generator or waste gas pipe
- DTSHX condensers for the exhaust steam from the steam turbine or blow-out. As condenser the natural gas preheater can also operate with vacuum in the shell space
- Low-finned DTSHX tube bundles for lube oil, seal oil or transformer oil cooling
- In the shell space DTSHX tube bundles tight to the gas pressure to cool the gas turbine cooling air
- Plain tube DTSHX tube bundles for installation in high-temperature waste gas lines.

Gas turbine with DTSHX for lube oil and cooling air cooling



Making use of a skillfully designed gas preheating system with several DTSHX being arranged in parallel and/or series additional effects and high fuel gas temperatures can be attained.

A good example of this is reflected by the above technical diagram showing a G&S power plant.
By using two special types of DTSHX cooling of lube oil and cooling air is to a great extent done with the help of fuel gas. In this case the lube oil cooler is a "TWIO" ("two in one") unit while a "TWIS" ("two in series") unit has been used for the cooling of cooling air.
The fuel gas may reach temperatures of up to 200°C. A reduced volume of the residual heat of the lube oil would be discharged via the secondary cooling circuit that uses the cooling air for feedwater preheating purposes.

It has been shown that especially with so-called aeroderivates and with gas turbines of high specific power a completely even heat balance is achieved when cooling lube oil by means of fuel gas. It is no longer necessary in this case to use a secondary cooling circuit for additional lube oil cooling.

G&S power plants are frequently designed to operate on two types of fuel. Aside from gaseous fuel they are also capable of using liquid fuels. In this way, peak prices for gas can be circumvented and the availability of the G&S power plant ensured without having to rely exclusively on the gas supply. To achieve a constantly reliable lube oil cooling under any operational condition both the gaseous and the liquid fuel are used for cooling with an extremely compact "TWIO" design version. It is to be noted here that at the same temperature spread liquid fuels usually are capable of absorbing higher thermal volumes than gaseous fuels.

Benefits of Preheating Gas
with Waste Heat

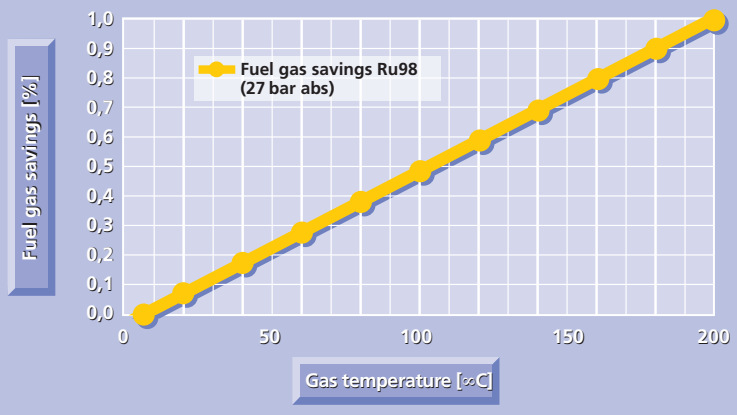
An external fuel preheating step accomplishes what really happens during the combustion process proper. Part of the fuel is used to preheat the fuel until it has reached the combustion temperature. An external recuperative fuel pre-heating by means of waste heat taken from the main process reduces the fuel consumption of a gas turbine as a function of gas composition, gas pressure and gas temperature. With the power output remaining almost constant a fuel preheating process will thus increase the overall efficiency of the gas turbine plant.

Depending on the relevant application several million cubic meters of fuel gas may thus be saved annually which translates into an efficiency improvement of more than 0.5% as can be seen from the examples shown here.

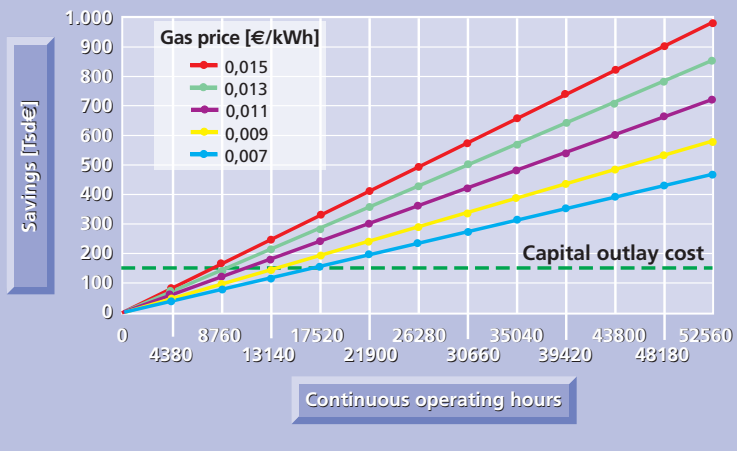
The higher the initial degree of efficiency, the greater is the gain in efficiency that can be achieved. Taking solely the achievable fuel savings the installation of a DTSHX fuel preheater in a retrofit will pay back in less than 3 to max. 4.5 operating years, depending on applicable fuel prices.

Moreover, for new installations a higher power output as well as significant capital cost reductions may be achieved as a result of an improved generator or transformer cooling effect, the omission or scaling down of the conventional cooling system and combination with a gas regulating system usually arranged separately upstream of a gas turbine.

Fuel gas savings using waste heat for gas preheating



Operating cost cuttings using lube oil for fuel gas preheating



Possible efficiency improvement when preheating fuels with a double tube safety heat exchanger

Plant	Electric power output (MW)	DTSHX	Gas heat-up (°C)	Annual operating time (h/a)	Consumed gas reduction (Nm³/a)	Efficiency increase (%)
GuD	89	Lube oil/ fuel gas	from 5 to 70	8.000	414.000	0,18
GT	105	Waste gas/ fuel gas	from 5 to 200	8.000	2.359.000	0,54

References:

[1] Triesch, F.: Zwei Varianten der Absicherung von Erdgas-Vorwärmanlagen nach DVGW-Merkblatt G 499, gwf Gas – Erdgas, 135(1994), 11, 636-640

[2] DE P 43 31 314

[3] DVGW-Merkblatt G 499: Erdgas-Vorwärmung in Gasanlagen, published by DVGW Deutscher Verein des Gas- und Wasserfaches e.V. 03/94

[4] Triesch, F.: Rekuperative Brennstoffvorwärmung – Erhöhte Wirtschaftlichkeit von Gasturbinen, BWK, 53(2001), 10, 60-62

[5] DE 197 05 216 A1.

Innovative Gas Conditioning Methods
for Stationary Gas Turbines

Making use of DTSHXs in gas preheating applications not only opens up new opportunities but at the same time creates new requirements linked with the technological configuration of the gas conditioning units serving stationary gas turbines.

The gas pressure regulating station preceding every power plant operating on gas serves to remove the liquid and solid constituents of the gas coming from the pipeline, measure the gas flow for settlement purposes with the gas supplier, preheat and reduce the fuel gas pressure. The outlet temperature of the conditioned fuel gas depends on the water and hydrocarbon dew points of the gas mixture and must exceed these considerably to rule out that the gas turbine suffers damage as outlined earlier.

It has been generally accepted practice hitherto to view and design gas pressure regulating stations for gas turbine plants as entirely separate units. Accordingly, the plant design allows for distances of several hundred meters between the gas pressure regulating station and the gas turbine. The gas turbine manufacturers even prefer such distances with a view to having available a substantial buffer volume in the line section between pressure regulators of the gas pressure regulating station and the gas turbine flow controllers.

In this way excessive hunting of the series-arranged controllers can be avoided.

Gas pressure regulating stations are designed to satisfy the entire gas demand of a power plant. Aside from the gas turbines there may be other gas consumers like additional boilers and burners. The number of gas regulating sections is determined to ensure maximum plant availability and very rarely is identical with the number of gas turbines. The gas pressure regulating station has a separate heat supply for preheating purposes that is independent of the power plant. This may either be an enclosed boiler plant or directly fired heaters arranged outdoors.

Inside the power plant a gas line designed for the nominal fuel gas pressure of the respective gas turbine is installed. In this way, a clearly defined interface exists where certain gas pa-rameters in terms of pressure, temperature and moisture must be made available as required by the turbine.

To improve the efficiency of the plant, properly adjust the wobbe index of the fuel gas or safely prevent flashbacks the temperature of the fuel gas is further increased to a very high level immediately ahead of the gas turbine.

This additional heating step is called superheating and depends on the relevant gas turbine operating mode; specific superheating parameters are either prescribed or even implemented by the gas turbine manufacturer. Moreover, the fuel gas is filtered, its flow again measured and controlled before the gas enters the respective turbine. The last few meters of the gas line immediately ahead of the turbine are made of stainless steel to make sure the fuel gas cannot be contaminated by corrosion products from the pipe.

In the interest of keeping capital and operational expenses to a minimum and in view of the novel and already discussed opportunities linked with the utilization of power plant waste heat for gas preheating purposes with DTSHX units it is undoubtedly recommendable to optimize the overall gas conditioning process.

To this effect, gas conditioning should be optimized for the individual gas turbine. It would be most desirable to combine into a single unit all functions of the upstream gas pressure regulating station and all fuel gas specific functional groups arranged immediately ahead of the turbine:

- Gas filtering
- Gas measurement
- Gas preheating
- Gas pressure regulation
- Gas overpressure protection
- Gas superheating
- Gas measurement
- Gas filtering
- Gas flow control
- Gas flow isolation

For this purpose the following requirements set by gas suppliers, gas turbine manufacturers and Operator/Owner as well as applicable standards and rules have to be satisfied:

- clearly defined interface with the gas supplier
- Explosion and fire protection
- Control quality regarding gas pressure/gas flow/gas turbine output
- Control quality regarding gas temperature/wobbe index/dew point
- Protection against liquid and solid gas constituents
- Availability
- Series production-oriented, compact and preassembled design
- Low capital investment, operating and maintenance expenses

When all these requirements are met it should be possible to develop modern and compact gas conditioning systems for gas turbine power plants making use of DTSHX units. This is certainly to be seen as a major step forward in gas turbine construction.

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Special Applications

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Sales:

Mr Jürgen Venter
Phone +49(0)67 51/93 03-1 70
e-mail: Juergen.Venter@geagroup.com

Project Execution:

Mr Stefan Krolla
Phone +49(0)67 51/93 03-1 71
e-mail: Stefan.Krolla@geagroup.com

Mr Lothar Barth
Phone +49(0)67 51/93 03-1 72
e-mail: Lothar.Barth@geagroup.com

Representatives Germany:

Mr Ulrich Schieritz
Sales Office Area West
Phone +49(0)23 61/65 92 66
e-mail: schieritz@gmx.de

Ms Gisela Müller
Secretary Sales Office Area West
Phone +49(0)23 4/94342-333
e-mail: Gisela.Mueller@geagroup.com

Mr Gustav-Lothar Krueger
Sales Office Area South-West
Phone +49(0)1 71/540 88 06
e-mail: LotharKrueger@gmx.com

Mr Franz Bauer
Sales Office Area South
Phone +49(0)82 54/26 50
e-mail: Franz.Bauer@geagroup.com

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Process Equipment
GEA Renzmann & Grünewald GmbH

Industriestraße 6, D-55569 Monzingen ·
Phone +49(0) 67 51/93 03-0 · Fax +49(0) 67 51/93 03-1 00 ·
Petra.Shurtleff@geagroup.com · www.renzmann.com

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