COMPRESSOR STATION FUEL GAS SUPERHEATING USING LUBE OIL WASTE HEAT

Katie T. Sell
Proposals Engineer
Heatric
46 Holton Road
Holton Heath
Poole, Dorset
BH16 6LT
England

Tel: +44 1202 627000
katie.sell@heatric.com

Paul R. Langston
Senior Proposals Engineer
Heatric
46 Holton Road
Holton Heath
Poole, Dorset
BH16 6LT
England

Tel: +44 1202 627000
paul.langston@heatric.com

René H. Mitchell
Principal Machinery Engineer
National Grid Transco
Asset Engineering
NGT House
Warwick Technology Park
Gallows Hill, Warwick
CV34 6DA, England

Tel: +44 1926 655511
rene.mitchell@ngtuk.com

HEATRIC

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ABSTRACT

Compressor station gas turbine engines require protection from fuel gas liquid drop-out caused by the Joule-Thomson effect when natural gas is let down from transportation line pressure to the burner supply pressure. Indeed, gas turbine manufacturers specify a minimum gas superheat, which requires fuel gas heating at pipeline temperatures experienced in Northern Europe.

Conventionally, fuel gas superheating is achieved through the use of either electric or gas fired water bath heaters, which require maintenance, and an external heat source. Meanwhile, waste heat from the turbo-compressor lube oil system is released to atmosphere, typically by air-cooled heat exchangers. Hence, there is an obvious opportunity to protect the gas turbine engine, whilst reducing the amount of heat rejected to the environment.

Mechanical integrity is a key operational requirement when combining fuel gas superheating with lube oil cooling in a single heat exchanger. Fuel gas at high pressure must not enter the low pressure lube oil system. High integrity Printed Circuit Heat Exchangers (PCHEs) are ideally suited to this application, as they are diffusion bonded and fully welded heat exchangers.

Used extensively in offshore high pressure gas compression trains in the North Sea, PCHEs have demonstrated that they are low maintenance items that are ideal for use in remote unmanned applications, such as those required by gas compression stations. PCHEs are highly compact, reducing space and structural requirements. This allows the exchanger to be installed underneath the compressor, minimizing the visual impact of the heat exchanger. In addition, safety and pressure relief requirements are significantly reduced, as PCHEs do not have a failure mode analogous to tube rupture in shell and tube heat exchangers.

National Grid Transco have realised the opportunities of PCHEs, and operated them successfully over many years in many of their compression stations throughout the United Kingdom.

INTRODUCTION

As natural gas travels along a pipeline it loses pressure due to friction effects. To maintain the required rate of gas supply, compressor stations are required at intermittent points along the pipeline. Although many types of compressor and drives can be used to maintain pipeline pressure, for large-scale, long distance natural gas transmission, gas turbine compressor sets are typically employed[1, 2].

An important design consideration in the specification of gas turbine engine systems is the required protection from fuel gas liquid drop-out. This is caused by the Joule-Thomson effect when natural gas is let down from transport line pressure to the burner supply pressure, and is overcome by superheating the fuel gas. Failure to observe this requirement can lead to severe damage to the hot gas path components within the engine, which can be extremely expensive, requiring equipment replacement.

Gas turbine manufacturers normally specify a required level of fuel gas superheat. For example, GE specify a minimum superheat of 28°C (50F) above the dew point of the gas supplied to their turbines[3].

Elsewhere on the gas turbine compressor train, the lube oil system releases unwanted heat to atmosphere, typically by air-cooled heat exchangers. Combining the two duties of heating the fuel gas and cooling the lube oil has the potential to significantly reduce heat losses and operational expenditure. However, a heat exchanger employed in this service must be highly reliable, as maintaining a constant supply of gas is very important in the gas supply industry. Disruptions in supply have immediate consequences for many consumers[4], and regular losses of gas supply can lead to angry customers and ultimately loss of business or company reputation.

The various options available for superheating fuel gas before entry into the gas turbine are described in this paper. Advantages and disadvantages of various options are outlined, with the option of a Printed Circuit Heat Exchanger (PCHE) considered in detail.

ELECTRICAL & GAS FIRED SUPERHEATING

Water bath heaters are the most common heat exchanger type used for superheating fuel gas, and can be obtained from many equipment suppliers. These can be either gas or electric fired units that, as their name suggests, use water as a heat transfer medium to superheat the fuel gas.

Although proven reliable, water bath heaters require a utility supply and regular maintenance to keep them in good working order. There is an operating cost associated with the gas or electricity required to heat the water bath, and the addition of anti-freeze and anti-corrosion agents to the heating medium to protect the vessel integrity.

As water bath heaters are relatively large items, they need to be located some distance from the gas turbine. At start-up, when the gas between the heater and the turbine is cold, liquid slugging may occur due to the distance between the water bath heater and the gas turbine. As heating of the process fluid is not instantaneous, the only method of reducing the volume of cold gas entering the turbine is by heating the water bath before start up. Moreover, during normal operation the water bath must sufficiently overheat the fuel gas to overcome pipework heat losses between the heater and the gas turbine, and still maintain the minimum specified fuel gas superheat at the turbine inlet. Therefore energy is unnecessarily wasted in the water bath heating medium.

Alternatively, direct electrical heating of the fuel gas is often employed. The main advantage of direct electrical heating over water bath heaters is the instantaneous heat source available to heat the process fluid. However, there are still operating cost and maintenance requirement considerations with this method of heating.

Trace electrical heating of the fuel gas feed line has also been used for fuel gas superheating. Whilst simplistic in concept, this heating method is not used extensively due to reliability concerns, and maintenance difficulties.

LUBE OIL WASTE HEAT REJECTION

Heat generated in the gas turbine compressor set must be rejected from the lube oil system to maintain efficient operation and longevity of the equipment. The most convenient method of rejecting this waste heat is via an air cooled heat exchanger.

Even though air cooler exchangers in this service are not large items, they must be located remotely from the gas turbine compressor, outside the protective soundproof enclosure, in order to reject heat to the environment.

SUPERHEATING USING LUBE OIL WASTE

There is an obvious opportunity to combine fuel gas superheating with lube oil heat rejection, as combining these services will improve the overall thermal efficiency of the compression station. However, a key design and operational requirement when combining fuel gas superheating with lube oil cooling in a single heat exchanger is to ensure complete isolation of the process streams. Fuel gas at high pressure must not enter the low pressure lube oil system.

Small shell and tube type heat exchangers have been applied to this service, although operational experience has highlighted concerns over tube pitting failures.

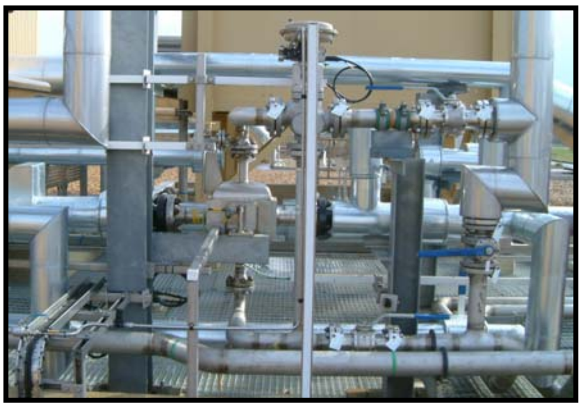

Figure 1: An 80kW PCHE in Fuel Gas Superheating Service.

Despite the combination of fuel gas pressure and lube oil temperature precluding the use of most plate-type compact heat exchangers in this service, PCHEs can easily handle the operating conditions. They have operated on 16 compression station projects globally, with 25 exchangers currently installed. A typical arrangement is shown in Fig. 1.

PRINTED CIRCUIT HEAT EXCHANGERS (PCHEs)

Printed circuit heat exchangers (PCHEs) are high integrity compact plate-type exchangers. They are constructed from flat stainless steel metal plates, into which fluid flow channels are chemically milled. This is similar to the way in which electronic printed circuits are produced – leading to the name 'Printed Circuit' heat exchangers. These milled plates are stacked and diffusion bonded together to form a solid block containing precisely engineered fluid flow passages. Diffusion bonding is a 'solid state joining process' where metal surfaces are pressed together at high temperatures, promoting grain growth between the surfaces. This growth creates a bond between the plate with the strength and ductility of the parent material[5, 6]. Fluid headers and nozzles are welded to the core in order to direct the process fluids to the appropriate flow passages.

PCHEs are highly compact heat exchangers, and are up to 85% smaller than the equivalent shell and tube exchangers. The heat exchange surface area is large per unit volume, and high effectiveness counter flow contact and high heat transfer coefficients are common.

Design temperatures of over 500 barg and extreme temperature of –200°C to 800°C are easily within the capability of PCHEs.

PCHEs are not susceptible to hazards commonly associated with shell and tube heat exchangers such as flow induced tube vibration and tube rupture. Therefore, overpressure relief systems can be substantially reduced, and in some cases they have been eliminated. This is illustrated by considering typical passage geometries of 2mm diameter semi-circular channels in a PCHE, and 25mm diameter tubes in a shell and tube exchanger. Under 'tube rupture' conditions, the volumetric discharge rate is proportional to the area of the 'tube'. The area of the semi-circular PCHE channel is $\frac{1}{2}\,\pi d^2/4$, which equals 1.6 mm^2. In contrast, the area of the tube is $\pi d^2/4$, which equals 490 mm^2. The flow from a tube is 300 times larger than that from a PCHE channel.

In comparison with shell and tube exchangers, PCHEs also have relatively low inventories, enhancing the safety benefits of the compact technology.

APPLICATION OF COMPACT PCHE TECHNOLOGY TO COMPRESSOR STATIONS

In the early 1990's, National Grid Transco (then British Gas) realised the advantages of combining fuel gas superheating with lube oil heat rejection. Essentially, heat from the lube oil that was previously lost to the environment could be recovered into the fuel gas. The resulting saving in electric power to the air cooler fan, and the electrical fuel gas superheater, will more than offset the cost of the fuel gas / lube oil heat exchanger.

Although there is capital cost involved in procuring a combined fuel gas / lube oil heat exchanger, a crude cash flow calculation indicates that due to the direct saving in electrical power this can be recovered in as little as 18 months.

As indicated in Fig. 2, during start up a small electric heater is required to ensure cold gas does not enter the gas turbine, before the lube oil reaches operating temperature. However, a smaller air cooler is required on the lube oil outlet line to control the lube oil supply temperature.

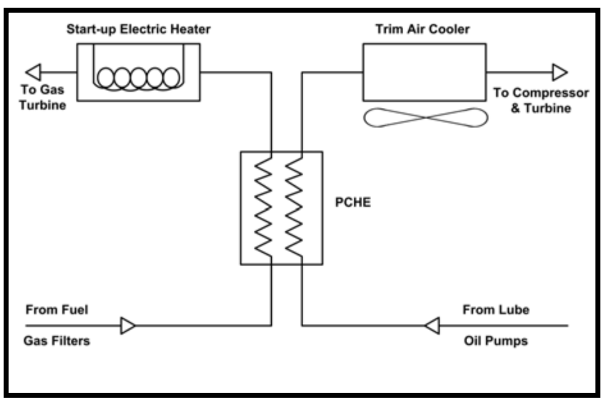

Figure 2: Flow Diagram of Fuel Gas Superheater / Lube Oil Exchanger

A major concern when combining the two services is the possibility of inter-stream leakage. This would result in high pressure fuel gas entering the lube oil system, causing contamination and system over-pressure.

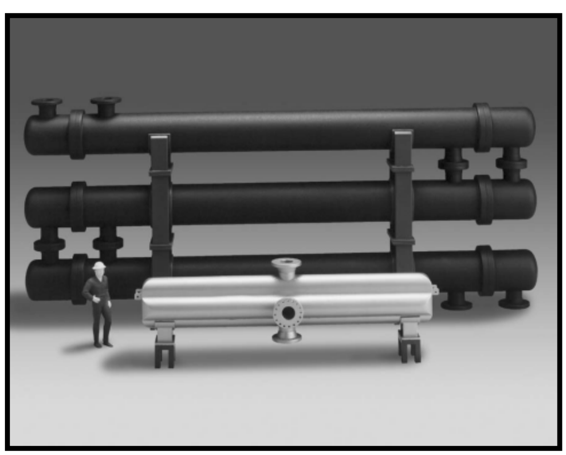

Figure 3: The relative size of a PCHE versus a Shell & Tube Exchanger

The compact nature of PCHEs, as shown in Fig. 3, results in a very low fluid inventory, and small overall size. In fact, the PCHEs are small enough to be installed beneath the compressor in the pipework, without any foundations or structural support. Hence they are installed in close proximity to both the gas turbine fuel supply and the compressor lube oil system. This results in a very small volume of gas between the fuel gas superheater and the gas turbine inlet, greatly reducing the possibility of cold gas entering the turbine.

Due to their stainless steel construction, without the need for gaskets or braze material, both sides of the PCHE are fully corrosion resistant. Hence, there is no risk of contamination of the fuel gas, or the lube oil, from the PCHE. There is also a very low maintenance requirement, making them highly suited to remote applications.

As they contain small passages (approximately 2mm diameter semi-circles), PCHEs are best suited to relatively clean process fluids, or systems fitted with strainers. However, in this application the filtering requirements for the lube oil and the fuel gas streams are far more stringent than those of the heat exchanger[(3)].

ENVIRONMENTAL CONSIDERATIONS FOR COMPRESSOR STATIONS

Within Europe, Environmental Impact Assessments are increasingly required for new industrial installations, to limit the impact of industry on the environment as far as is practical[(7)].

Such an assessment will be required for a compressor station, and, although the fuel gas superheater is relatively small, the equipment choice will have an environmental impact.

Compact technology, such as PCHEs, will lessen the visual impact of the installation, as the overall size can be reduced, therefore reducing the visual impact on the landscape, and the amount of civil engineering required.

Using hot lube oil to heat the fuel gas has an environmental as well as an economic benefit, as there are no combustion products produced by the equipment, and a reduction in electricity utility consumption. There can also be a reduction in noise, by the elimination of gas burners compared with some other exchanger types.

CONCLUSION

Water bath heaters, or directly heated electric heaters are normally used to superheat the fuel gas entering gas turbine combustors in compression stations, to protect the engine from liquid drop-out. Alternatively a high integrity heat exchanger can use waste heat in the compressor lube oil to superheat the fuel gas. PCHEs are an ideal candidate for such duties.

The energy savings resulting in the direct reduction in electrical power more than offset the capital cost in procuring the fuel gas / lube oil heat exchanger. There are also associated environmental benefits associated with the lack of emissions from using a PCHE in this service.

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HEATRIC

46 Holton Road, Holton Heath, Poole, Dorset, BH16 6LT, UK

Tel: +44 1202 627000 Fax: +44 1202 632299 email: info@heatric.com www.heatric.com