Pre-heat technologies

ProHeat Systems is a British design and professional engineering consultancy specialising in energy conservation for critical infrastructure. Here, Stefan Romocki looks at fast responding pre-heat technology for dynamic and responsive gas distribution networks.

With the last coal-fired power plants in the UK mandated to close as soon as 2022, renewable sources are anticipated to provide 34 per cent of electricity by 2020. Their inherent intermittency has raised the necessity to transition from large scale power production plants to decentralised and largely gas-fired on-demand production.

Gas will play a central role in reshaping the energy landscape, as it is readily storable within gas networks and easily converted to meet periods of high electricity demand. Additionally, there has been a rise in the adoption of residential and industrial scale CHP in a move towards local generation of heat and power.

For gas distribution networks, the growing gas-electric interface and unpredictability of real-time load balancing will represent new operational stresses. One key asset impacted by growing inter-day and inter-hour load variability will be pre-heat infrastructure. The gas distribution industry relies on preheating to avoid freezing. When gas is transferred from high pressure networks to lower pressure networks, preheaters are used to prevent subsequent freezing, overcoming a thermodynamic principle called the Joule Thompson effect.

A key challenge to ensuring effective and efficient use of energy in pre-heating processes is matching heat supplied with increasingly variable, unstable hourly gas demand.

Current preheat infrastructure installed in the UK is one-third comprised of water bath heaters originally installed in the 1970s and 1980s, with the balance using more modern and efficient modular boiler houses. While Water Bath Heaters (WBH) have been in use on UK gas networks for more than 40 years, they waste a significant amount of energy and typically have efficiencies well below acceptable modern standards of performance.

Over the past two decades more than 500 water bath heater sites have been upgraded to more efficient Modular Boiler and Modular Condensing Boiler Houses (BH). Boiler houses also boost combustion efficiency by maintaining low water temperatures (below 55°C and more preferably below 30°C) to extract heat from exhaust gases. Both WBHs and BHs rely on the difference in temperature between warmer water and cooler natural gas to transfer energy.

One technical challenge for systems that use liquid water as an indirect heat transfer media is achieving a controlled heat transfer to match changes in demand. While it is relatively simple to transfer energy from a concentrated heat source, such as a flame, into water with little energy loss, it is far more complex to control heat transfer in exact amounts from a dilute energy source such as warm water to process gas. The challenge is that liquid water has limited ability to absorb and transfer energy which in turn requires a relatively large mass of water to be used to ensure peak heat demands can be met. Thermal lag, or system inertia, reflects the time required for a heating system to adapt to a change in demand. Systems with high inertia are more difficult to control as the heat required often arrives late and when heat is no longer needed the energy already stored in the system results in a temperature over-shoot. The combination of a high-thermal inertia with lower operating temperatures lengthens the time required to transfer heat, which can lead to considerable lag in system response, as highlighted in figure 1.

The figure illustrates the disturbance of a constant control temperature established overnight with a quick change in morning gas loads, followed by a temperature drop and response overshoot. The most practical way for a conventional water based technology to satisfy heat demand with rapidly changing loads is to increase the margin of safety available for a sudden change in flow with a higher operating temperature (set point). In turn, slow response and overcompensation for demand periods leads to more energy being stored in the system, which ultimately results in using more fuel than necessary and over-heating. In a Strategic Heat Study undertaken by SGN & ProHeat Systems across eight UK pressure reduction stations, results illustrated consistent overheating, representing up to 30 per cent of annual fuel consumption.

Network efficiency and flexibility is aligned with preheat equipment capable of matching energy required with energy delivered, dynamically and in real-time. Since 2014, fourteen dual-phase Immersion Tube Thermosyphon Heaters have been installed in preheat applications across three UK gas distribution networks. These new systems use low-pressure steam to concentrate and control heat so that just the right amount is used exactly when it’s needed.

Figure 2 illustrates the energy carrying capacity of steam under a partial vacuum. Steam holds a significant amount of energy on a unit mass basis (between 2,250 and 2,400 kilojoules per kilogram). Since most of the energy content of steam is stored as
latent heat absorbed during phase change, large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute for optimising gas preheating applications. Under vacuum, water can change to steam at temperatures below 50°C. By comparison, a process using hot water at 50°C is limited to transferring between 84 and 200 kilojoules per kilogram.

This subtle difference of relying on phase change rather than a difference in temperature to transfer heat enables heat transfer rates 10-25 times higher than that of water, with less fluid in the system.

The two-phase Loop thermosyphon used in the new preheater design offers significant advantages in optimising heat transfer, including rapid response, a lower store of energy in the system and higher overall heat transfer efficiency. Thermosyphons are increasingly being used in cutting-edge energy management applications, ranging from temperature control of satellites and avionics to the world’s most efficient solar collectors. Practical advantages include simplicity of design, long asset life and low maintenance requirements.

As shown in the cross section diagram (left) of the Immersion Tube Thermosyphon Heater, there are no moving parts within the system as steam and water travel under the influence of natural convection and gravity.

Significantly, application of thermosyphons for heat transfer offers new potential for adaptive responses from rapid changes in energy demands in preheat applications. The figures in figure 3 highlight a comparison of temperature control achieved by a 930kW Immersion Tube Thermosyphon Heater and a 1.2 MW water bath heater operating on a same site, with similar changes in gas flows one year earlier.

The thermosyphon heater was able to adapt easily to changes in process gas flow while maintaining a constant station exit temperature, while the water bath experienced significant under and overshoots from the 5°C set-point. Losses related to over-heating of gas were quantified by comparing fuel consumptions of each technology relative to that of an ideal preheater (defined by the ability to maintain a steady 1°C outstation temperature). As the main function of the heater is to maintain a gas temperature above freezing, any fuel used to warm process gas beyond 1°C offers no additional benefits. The table above compares annualised results of fuel use and emissions associated with over-heating losses for the two preheat technologies.

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<thead>
<tr>
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<th>Overheating losses (% of fuel consumed)</th>
<th>Additional CO2 (mT/year)</th>
<th>Additional Fuel (£/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITTH 930 kW</td>
<td>1.3</td>
<td>2,900</td>
<td>430</td>
</tr>
<tr>
<td>WBH 1.2 MW</td>
<td>25</td>
<td>96,200</td>
<td>14,400</td>
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The UK’s gas networks are an essential component in the development of a smart, low carbon energy system that is responsive and dynamic. As renewable sources of power generation are increasingly integrated within UK power networks, traditional gas infrastructure will face new stresses to simultaneously satisfy peak daily gas and peak hourly power demands. The increase in gas-power system interdependencies will intensify variations in hourly gas demand, posing new operational stresses on assets such as pre-heat.

The introduction of two-phase thermosyphons offers one example of an innovative solution to a complex problem, and represents an exciting opportunity for a new generation of fast responding pre-heat technologies that provide increased network flexibility while maintaining high standards of efficiency.