Liquid fuel oil commonly used to fire process heaters and boilers can be especially difficult to burn, yielding elevated emissions and inefficient operation. To develop a liquid-fired system that lowers emissions while consuming less energy, a team of burner engineers compared the inherent differences between gas and oil firing and studied the typical applications for oil burners. From the analysis, the team developed a breakthrough atomisation technology that controls emissions, reduces steam consumption and dramatically improves residual oil combustion.

Challenges of oil firing
When compared to gas-fired burners, oil-fired burners typically have higher flame luminosity and flame heights (Figure 1), excessive soot and particulate emissions, and less uniform heat flux distribution in the furnace. Oil-fired burners also have an inherent problem of producing NOx levels that can be an order of magnitude higher than gas-fired burners. As an example, approximately 86 mg/MJ of NOx (equivalent to 142 ppm) are attributed to fuel NOx for oil that contains 0.47% weight nitrogen.

Because oil fuels must be atomised before they can be injected into a burner, liquid-fuel burner designs vary distinctly from gas-fired burner designs. Furthermore, the successful combustion of liquid fuels depends on the atomiser design and fuel/atomising medium (steam, air or mechanical) conditions.

Adequate atomisation is particularly challenging for heavy fuel oils. No. 6 oil, which is most commonly used in oil-fired burners, must be preheated before the oil can be supplied to the burner and fired in a furnace. When preheated between approximately 60 - 100 ºC, the viscosity of No. 6 oil is decreased to a level that allows for atomisation and injection into the burner. Therefore, a maximum viscosity of about 200 SSU is commonly recommended for use in a standard oil gun.

New oil gun development
Considering the array of liquid-fuel properties and applications, the team of research, development and commercialisation engineers embarked on a program to determine the optimal ways to burn.

I.P. Chung, A. Patel, P. Singh, C. Strupp and C.E. Baukal, John Zink Company, LLC, USA, discuss the advances the company has made in atomisation technology.

Table 1. Particulate emissions from HERO atomiser

<table>
<thead>
<tr>
<th>Oil flow rate (kg/min)</th>
<th>Air temp (ºC)</th>
<th>Box temp (ºC)</th>
<th>O₂ level (%)</th>
<th>Oil p (kg/cm²)</th>
<th>Particulate Emissions (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>232</td>
<td>867</td>
<td>3.9</td>
<td>2.11</td>
<td>47.5</td>
</tr>
<tr>
<td>0.35</td>
<td>236</td>
<td>846</td>
<td>4</td>
<td>2.81</td>
<td>51</td>
</tr>
</tbody>
</table>

Figure 1 (Above). Typical gas and oil-burner flames.

Figure 2. HERO: high efficiency residual oil gun.
fuel oils. The team’s objective was to develop a process to combust fuel oils at maximum efficiency with minimum smoke and pollutant emissions. First, the engineers used a series of spray tests to analyse droplet size measurements in a pilot-scale spray research laboratory. Then, the engineers conducted full scale combustion tests in the company’s combustion research facility to determine flame length and quality, NOx and particulate emissions, steam consumption and turndown ratio. From the test results, the team developed and patented HERO4,5, a high efficiency residual oil gun (Figure 2).

Employing a patented phased atomisation technique, which distributes the oil spray into paired phases, HERO™ lowers combustion emissions and operating costs while improving combustion performance6,7. In a primary entrainment zone, steam energy is added to the oil to form a pre-mixed emulsion. This emulsion is then introduced into a secondary zone where the balance of steam energy works to efficiently atomise the liquid fuel into a mist of fine particles. HERO’s phased-atomisation technique reduces the viscosity and heats the fuel oil. The new oil gun produces a spray with a median liquid droplet size that is approximately 50% the size of droplets formed by conventional atomisation techniques, which significantly improves liquid-fuel combustion performance. The new oil gun can be retrofitted to an existing burner element or specified as an integral component of a John Zink burner system (Figure 2).

As shown in Figure 4, the new oil gun uses nearly 50% less steam compared to a conventional oil gun with a firing rate from 1 to 4.5 x 10⁶ kcal/hr. HERO steam consumption ranges between 0.1 to 0.2 kg steam/kg of oil, as compared to 0.3 to 0.4 kg steam/kg of oil for a typical oil gun. Figure 4 also shows NOx emissions of the new oil gun range between 150 - 200 ppm in a furnace firing between 1 and 4.5 x 10⁶ kcal/hr as compared to 260 - 300 ppm produced by a conventional oil gun under similar conditions.

The engineers also studied particulate emissions from the new oil gun. Table 1 shows at an oil pressure of 2.1 kg/cm², the emissions are 47.5 mg/m², while at an oil pressure of 2.8 kg/cm², the emissions are reduced to 31 mg/m². These values are lower than the current European regulation of 50 mg/m².

The engineers observed that the flame length in a typical burner featuring the new oil gun was 1.5 m/10⁶ kcal/hr using No. 6 oil, and 2.4 m/10⁶ kcal/hr using No. 2 oil. Table 2 illustrates a performance comparison of different oil guns. As shown in the Table, the new oil gun displays superior performance with respect to NOx emission, steam consumption and flame length.

In brief, studies show the new oil gun provides operators with the following advantages:

- Lower operating cost resulting from lower steam consumption (0.17 kg steam/kg oil).
- Shorter flame length (1.5 - 2.4 m/10⁶ kcal/hr).
- Up to 30% less NOx emissions.
- Lower particulate emissions.
- Good turndown ratio (4:1).
- Reduced potential for plugging of oil ports.
- Easy retrofit.
- Clean burning for less furnace maintenance and longer life.

**Field proven**

John Zink Company installed the new oil gun in several existing oil burners that were either not functioning properly or not meeting emission requirements. Comparative field data obtained from two cases at one site in Korea indicates enhanced field performance using the new oil gun.

Unit H-1101 was originally fitted with 24 combination oil and gas McGill model NCR-14 burners. The engineers retrofitted 12 of the 24 burners with HERO oil guns. Table 3 presents the results before and after the new oil guns were installed in the unit.

For the next case, the engineers retrofitted the original 10 combination oil and gas John Zink model LNC burners in Unit H-40501 with HERO atomisers. Table 4 shows the results before and after the new oil guns were installed in the unit.

Case No. 1 of Unit H-1101 indicates a significant reduction in steam consumption with only 50% of the burners modified with the new oil guns. Case No. 2, retrofitting every burner in Unit H-40501, shows the steam consumption is 67% less with the new oil guns. Before retrofit, the unit operated with partial oil firing, forcing the balance of the load to gas firing. Improved flame performance with the new oil gun allowed the heater to operate with 100% oil fir-
ing, while meeting furnace load requirements, an unexpected economic advantage for the customer.

Based on the success of the two cases, the refinery in Korea decided to retrofit an additional eight heaters with the new oil guns. The performance to date has been excellent; field reports suggest the new oil gun provides the following:

- An average of 38% less steam usage.
- Up to 30% reduction in flame length.
- Lower flue gas temperature in the furnace arch.
- An average of 15% less NOx emissions.

Studies show and field tests prove HERO oil guns provide significant performance improvements and dramatically lower emissions compared to conventional oil gun technology, while consuming less energy to atomise the liquid fuel.

References


Table 2. Performance comparison of different oil guns

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
<th>JZ Hero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil pressure (kg/cm²)</td>
<td>5.63</td>
<td>4.22</td>
<td>6.26</td>
<td>5.49</td>
<td>5.63</td>
</tr>
<tr>
<td>Steam differential (kg/cm²)</td>
<td>1</td>
<td>2.11</td>
<td>1.34</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>Furnace temp (°C)</td>
<td>775</td>
<td>738</td>
<td>760</td>
<td>748</td>
<td>793</td>
</tr>
<tr>
<td>NOx(3%O₂) (ppm)</td>
<td>269</td>
<td>238</td>
<td>287</td>
<td>252</td>
<td>200</td>
</tr>
<tr>
<td>NOx (3% O₂) (ppm)</td>
<td>202</td>
<td>248</td>
<td>287</td>
<td>257</td>
<td>179</td>
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<tr>
<td>750 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam/fuel ratio</td>
<td>0.263</td>
<td>0.216</td>
<td>0.271</td>
<td>0.218</td>
<td>0.145</td>
</tr>
<tr>
<td>Flame length (m)</td>
<td>4.42</td>
<td>4.88</td>
<td>4.27</td>
<td>5.33</td>
<td>3.05</td>
</tr>
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</table>

Table 3. Field results before and after HERO retrofit in Unit H-1101

<table>
<thead>
<tr>
<th>Fuels fired</th>
<th>Gas/oil</th>
<th>Gas/oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel oil supply pressure (kg/cm²)</td>
<td>6.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Automising steam pressure (kg/cm²)</td>
<td>7.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Excess O₂ in stack (%)</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Steam/oil ratio (kg)</td>
<td>0.37</td>
<td>0.28</td>
</tr>
<tr>
<td>Flame quality</td>
<td>Smokey</td>
<td>Clean</td>
</tr>
<tr>
<td>Flue gas temperature at arch (°C)</td>
<td>804</td>
<td>774</td>
</tr>
</tbody>
</table>

All data based on 0.4% (wt) fuel bound N².

Table 4. Field results before and after HERO retrofit in Unit H-40501

<table>
<thead>
<tr>
<th>Fuels fired</th>
<th>Before retrofit</th>
<th>After retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel oil supply pressure (kg/cm²)</td>
<td>6.5</td>
<td>7.2</td>
</tr>
<tr>
<td>Automising steam pressure (kg/cm²)</td>
<td>8.4</td>
<td>10.2</td>
</tr>
<tr>
<td>Excess O₂ in stack (%)</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Steam/oil ratio (kg)</td>
<td>0.68</td>
<td>0.23</td>
</tr>
<tr>
<td>Flame quality</td>
<td>Smokey</td>
<td>Clean</td>
</tr>
<tr>
<td>Flue gas temperature at arch (°C)</td>
<td>810</td>
<td>793</td>
</tr>
</tbody>
</table>

For more information please contact:

www.johnzink.com

In the USA:
John Zink Company, LLC
World Headquarters
11920 East Apache
Tulsa, Oklahoma 74116
UNITED STATES OF AMERICA
800-421-9242 or 918-234-1800
Fax: 918-234-2700

In Europe:
John Zink International Luxembourg S.a.r.l
Zone Industrielle Riedgen
L-3401 Dudelange
LUXEMBOURG
+352-518991
Fax: +352-518611

In Asia-Pacific:
John Zink Asia-Pacific, a division of Koch Asia-Pacific, Inc.
7th Floor, KSS Gotanda Bldg.
21-8 Nishi-Gotanda 1-chome, Shinagawa-ku
Tokyo, 141-8538
JAPAN
+81-3-5435-8551
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Europe
+352-518991
+44-1932-769830
+39-02-6698-1232
+33-1-4119-4100

Asia-Pacific
+81-3-5435-8551
+65-732-7555
+61-2-8833-4600

Americas
+1-918-234-1800
+1-800-755-4252

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