Thermochemical recuperation (TCR), if successfully developed and commercialized in the near/medium term, will provide increases in furnace thermal efficiency, reduce fuel consumption, and significantly reduce air-pollutant emissions.

Steve Sikirica, Harry Kurek, Dr. Alexsander Kozlov, and Mark Khinkis
Gas Technology Institute, End Use Solutions Section Des Plaines, Ill.

The process of recuperating the energy contained in exhaust gases from high temperature process furnaces, engines, etc., for hydrocarbon fuel reforming and for oxidant preheat is called thermo-chemical recuperation (TCR). If successfully developed and commercialized in the near/medium term, TCR will provide increases in furnace thermal efficiency by 15 to 35% and reduce hydrocarbon fuels consumption by 15 to 60% compared with conventional recuperation/regeneration when usually only combustion air is preheated. TCR will also significantly reduce by 30 to 80% air pollutant emissions (NOx, CO, THC, CO2, etc.).

TCR Advantages

The major advantage for TCR is the opportunity to improve process efficiency. TCR has been extensively studied in Japan, U.S., Ukraine, and Russia. For heating processes, efficiency increases of 20 to 50% have been noted, and for processes using thermal cycles (e.g., internal combustion engines, gas turbines) efficiency increases of 8 to 15% have been noted.

Figure 1 shows a general example to illustrate the concept. At an 1100°F air preheat temperature, and furnace exhaust temperature of 2000°F, 71% of the total heat in the exhaust is recovered. If a reformer is added to make up a TCR system, and the reformed fuel is now at 1100°F also, the amount of total heat recouped increases to 78% or an 8% increase, which can be only achieved using an air preheat temperature of 1450°F.

Recuperative reforming is a technique that recovers sensible heat in the exhaust gas, and uses that heat to transform the hydrocarbon fuel source into a reformed fuel having a higher calorific heat content. The reforming process uses the waste heat plus steam (water vapor) and/or carbon dioxide (CO2) to convert the fuel into a combustible mixture of...
hydrocarbons, hydrogen, and carbon monoxide (CO). The calorific content of the fuel can be increased by up to 28% with the TCR process if the original source fuel is natural gas. When the reformed fuel is combusted in the furnace, fuel economy is improved, system efficiency is increased, and emissions are reduced. In addition, the fuel is preheated during the reforming process, adding sensible heat to the fuel. Because both steam and CO2 can be used in the reforming process, it is advantageous for natural gas-fired systems because both of these gases are major products of combustion and, therefore, are readily available in a preheated state. Further, they can be used in the same ratio as they exist in the combustion products. A schematic for application of a TCR system to an industrial gas-fired furnace is shown in Fig. 2. Similar results were shown by modeling of other metallurgical furnaces including heat treating, carburizing, and sintering. Another example of a TCR application for a low-temperature metallurgical melting furnace using steam reforming is shown in Fig. 3. An example of a TCR application for an oxy-gas glass-melting furnace is represented both in Table 1 and in the Sankey diagram (Fig. 4) using flue gas as the reforming medium together with the flow diagram in Fig. 5. The data in Table 1 show there is a substantial reduction in both natural gas and oxygen consumption.

**TCR Status**

In process heating, GTI has focused on steel industry furnaces and glass and aluminum melting furnaces. GTI designed, built, and tested a bench-scale TCR test facility using a modified radiant tube test rig for both flue gas and steam reforming. A schematic of one configuration for testing and evaluating flue gas reforming is illustrated in Fig. 6, with the physical unit shown in Fig. 7. Potential applications of a highly efficient radiant tube indirect heating system may be evaluated in the near future.

Figure 8 shows initial experimental

---

**Table 1 — Parameters of oxy-fired high-temperature glass melter with natural gas/flue gas reforming**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Without reformer (baseline)</th>
<th>With reformer</th>
<th>Increase (+) or decrease (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate, scfh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas consumption</td>
<td>26,000</td>
<td>21,754</td>
<td>-16%</td>
</tr>
<tr>
<td>Oxygen consumption</td>
<td>59,000</td>
<td>45,824</td>
<td>-16%</td>
</tr>
<tr>
<td>Flue gas</td>
<td>85,000</td>
<td>67,578</td>
<td>-20%</td>
</tr>
<tr>
<td>Fuel to burners</td>
<td>26,000</td>
<td>44,280</td>
<td>+70%</td>
</tr>
<tr>
<td>Heat balance components, MMBtu/hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat input</td>
<td>25.5</td>
<td>21.3</td>
<td>-17%</td>
</tr>
<tr>
<td>Useful heat</td>
<td>13.3</td>
<td>13.3</td>
<td>-</td>
</tr>
<tr>
<td>Heat losses through walls</td>
<td>5.0</td>
<td>5.0</td>
<td>-</td>
</tr>
<tr>
<td>Heat losses with flue gas</td>
<td>7.2</td>
<td>2.7</td>
<td>-63%</td>
</tr>
<tr>
<td>Heat losses in reformer*</td>
<td>—</td>
<td>0.3</td>
<td>nil</td>
</tr>
<tr>
<td>Thermal efficiency, %</td>
<td>52.0</td>
<td>62.2</td>
<td>+10%</td>
</tr>
</tbody>
</table>

* Assumed heat losses in fuel reformer = 5% of heat load

---

**Fig. 3 — TCR system applied to a low-temperature melter with natural gas/steam reforming (51% efficiency).**

**Fig. 4 — Sankey diagram for oxy-fired high-temperature glass melter with natural gas/flue gas reforming.**

**Fig. 5 — TCR system applied to an oxy-fired high-temperature glass melter with natural gas/flue gas reforming (62% efficiency).**
results by GTI regarding TCR chemical efficiencies (increase in heating value not including increase in thermal energy) for varying reforming temperatures and flue gas/natural gas ratios. At a reforming temperature of 1150°F (620°C) and a flue gas/natural gas ratio of 2.5, the reformed fuel heating value is about 10% higher than that of natural gas.

GTI is also currently developing reciprocating engine applications, with initial work funded by the Utilization Technology Development (NFP), a consortium of natural gas distribution companies (NYSERDA) and the California Energy Commission (CEC). In the project, a bench-scale recuperative reformer will be built and tested for operating on a 50 kWe research engine.

The design basis will be established for scale-up of the technology. Various arrangements will be studied for applying TCR to lean-burn and stoichio-

---

Visit our new Global Community Website for the best in information and networking:

www.asminternational.org

WIN up to $10,000 in ASM products and services. Enter the $35,000 ASM “Everything Material” Sweepstakes.

FREE 30-Day Trial Membership featuring the best of ASM’s online features.

FREE Access to selected ASM Handbook content through October 1 (a $250 value).

ASM’s new site represents a huge leap forward in terms of performance, design and content.

- Find what you need with improved navigation and searching
- Access high-quality content from our Handbooks and other leading sources
- Customize your own ASM access experience
- Interact with materials scientists and engineers worldwide

Sweepstakes runs from July 30 through September 30, 2007
metric versions of a Cummins QSK19 gas engine including a demonstration for 500 hours on a 331 kW engine at Cummins Technical Center in Columbus, Ind.

**Future Plans**

GTI intends to continue collaborative efforts with industry and government. More work is needed to gain a more complete understanding of TCR operational parameters and control and to design practical and cost-effective TCR Systems. Dave Rue, R&D Manager – Process Heating states: “We expect TCR to become a significant option for industry to consider in the future when addressing energy efficiency, and that GTI will play a major role in helping bring the technology to the market.”

**Literature**


Demonstration Industrial Heating Furnace with ThermoChemical Recuperation, Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine.


For more information: Steve Sikirica is Institute Engineer, Gas Technology Institute, End Use Solutions Section, 1700 South Mount Prospect Rd., Des Plaines, IL 60018; tel: 847-768-0859; fax: 847-768-0600; e-mail: steve.sikirica@gastechnology.org; Web site: www.gastechnology.org.

**Fig. 7** — Actual lab-scale TCR test unit at GTI Combustion Laboratory using a modified heat-treat furnace having one burner simulating a furnace process and a second burner simulating a reformed fuel burner.

**Fig. 8** — Chemical efficiency of natural gas reforming with flue gases: DHHV (fuel higher heating value increase due to reforming); HHV (natural gas higher heating value).