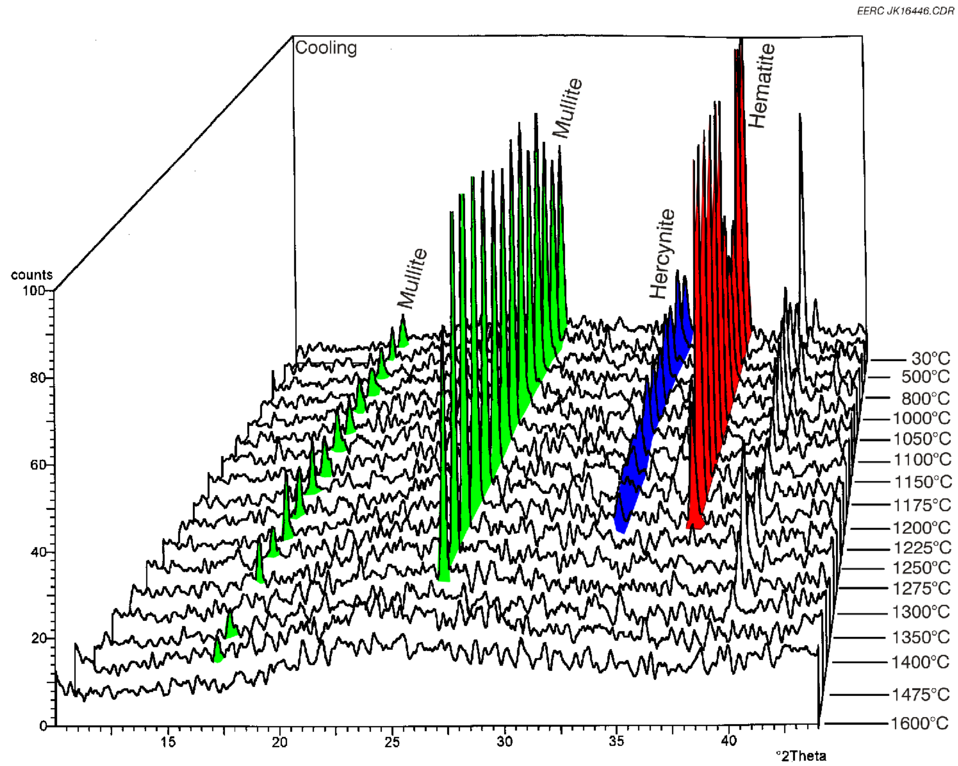

Figure 3-69. X-ray diffractograms for the eastern Kentucky slag tap sample measured while cooling from the melting point.

4.0 CONCLUSIONS AND OBSERVATIONS

The objective of the proposed work was to improve the performance of a high-temperature heat exchanger, as well as to develop methods for reducing corrosion of brick and castable refractory in slagging coal-fired combustion systems. Specific technical issues of interest included the effects of coatings on heat transfer in an RAH heat exchanger panel, the general impact of firing a lower-iron bituminous coal on the operation of the RAH panel and SFS, and the development of ways to treat brick and castable refractories to increase their resistance to slag corrosion. Specific conclusions and recommendations concerning fuel characteristics, SFS operation, CAH performance, and RAH panel performance as a result of firing the Illinois No. 6 and eastern Kentucky bituminous coals are discussed here along with those developed based on analytical, laboratory, and bench-scale work to develop methods to prevent excessive corrosion of the heat exchanger components.

4.1 Fuel Characteristics

A comparison of the two bituminous coals fired in the SFS shows that the Illinois No. 6 coal contained twice the moisture (4.4–5.1 wt% versus 2.3–2.5 wt%), four times the sulfur (3.6–3.7 wt% versus 0.8–1.0 wt%), and nearly three times the ash (11.2–11.3 wt% versus

3.9–4.7 wt%). As a result of these fuel characteristics, the heating value of the Kentucky coal was 21%–26% greater than that of the Illinois No. 6 coal, 13,861–14,120 Btu/lb (32,210–32,812 kJ/kg) versus 11,257–11,328 Btu/lb (26,159–26,324 kJ/kg) on an as-fired basis. Therefore, the Kentucky coal was an easier fuel to fire and had fewer operational impacts on the SFS.

Coal ash analyses determined that the Kentucky coal ash contained significantly less silica, more alumina, and somewhat less iron and calcium. These differences in ash composition resulted in ash fusion temperatures that were significantly higher (100° to 200°F, 56° to 111°C) for the Kentucky coal ash. As a result, slag properties caused slag screen plugging which forced an SFS shutdown. Limestone injection was effectively used to mitigate this problem during a subsequent test.

4.2 SFS Performance

When the Illinois No. 6 bituminous coal was fired, the total furnace firing rate (main plus auxiliary burners) ranged from 2.9 to 3.0 MMBtu/hr (3.0 to 3.1 × 10^6 kJ/hr). The main burner firing rate ranged from 2.1 to 2.25 MMBtu/hr (2.2 to 2.3 × 10^6 kJ/hr), accounting for 73% to 77% of the total energy input. The resulting flue gas temperature near the furnace wall/RAH panel was 2775° to 2840°F (1524° to 1560°C).

When the eastern Kentucky bituminous coal was fired, the total furnace firing rate (main plus auxiliary burners) ranged from 2.7 to 2.9 MMBtu/hr (2.8 to 3.0 × 10^6 kJ/hr). The main burner firing rate ranged from 2.1 to 2.27 MMBtu/hr (2.2 to 2.3 × 10^6 kJ/hr), accounting for 76% to 82% of the total energy input. The resulting flue gas temperature near the furnace wall/RAH panel was 2740° to 2830°F (1505° to 1555°C). A lower auxiliary burner firing rate was required to maintain desired slag screen temperatures, possibly the result of the lower moisture content of the eastern Kentucky coal. Operating problems encountered during the February test were related to slag screen plugging and high differential pressure.

The slag tap never plugged, and slag flow through the slag tap was not a problem during either of the three test periods. Reducing the number of tubes in the slag screen and the use of limestone to modify the Kentucky coal slag successfully mitigated the slag screen plugging and differential pressure control problems experienced when we first attempted to fire the eastern Kentucky coal in the SFS.

Inspection of the furnace refractory after the January, February, and April tests indicated that the new high-density refractory was in excellent condition. The only area showing any deterioration was below the RAH panel where slag from the panel was dripping onto the high-density refractory below. The only observed change in the high-density liner as a function of operation is that the color appears to get a little darker with each test, indicating slag penetration into the refractory. This change in appearance may indicate the potential for a failure of the high-density furnace liner if the refractory chemistry is sufficiently modified. Therefore, further work is definitely needed relative to the selection and performance of refractory materials to be used in the commercial HITAF.

The coatings applied to specific areas of the high-density refractory surface to improve its slag corrosion resistance prior to the January test were not evident upon furnace inspection following the test. Apparently the coatings were eroded from or absorbed into the surface of the high-density refractory. The two coatings tested in the slagging furnace were selected based on bench-scale observations. Based on the pilot-scale observations, further bench-scale development work is necessary before additional coating tests occur in the pilot-scale slagging furnace.

In order to modify the slag chemistry and reduce its ash fusion temperature, control slag screen differential pressure, and avoid plugging problems when firing the eastern Kentucky coal, a feed system was set up to add −40-mesh (−370-μm) limestone to the coal at the point it entered the primary air stream. The effectiveness of the limestone addition was evaluated for limestone feed rates ranging from 0.25 to 2 lb/hr (113 to 908 g/hr). Ultimately, slag screen differential pressure was stabilized and effectively controlled at 0.5 in. W.C. (0.9 mmHg) using a limestone feed rate of 0.5 lb/hr (227 g/hr).

Baghouse temperature ranged from 330° to 367°F (166° to 186°C) during the 4 weeks of operation. The 36 bags (total filtration area of 565 ft^2 [52.5 m^2]) used in the baghouse were a 22-oz/yd^2 (747 g/m^2) woven glass with a PTFE membrane. The filter face velocities ranged from 2.4 to 3.0 ft/min (0.74 to 0.91 m/min). Calculated particulate emissions from the pulse-jet baghouse were as low as 0.0014 lb/MMBtu while effectively using on-line cleaning to control differential pressure in the range of <2 to 6 in. W.C. (<3.7 to 11.2 mmHg).

Further work characterizing fly ash generated by the HITAF concept is necessary in order to properly select the type of particulate control technology (electrostatic precipitator, fabric filter, or hybrid system) to be used as well as to prepare detailed system designs and the approach to operation. Based on the SFS pulse-jet baghouse experience to date, there are questions yet to be answered concerning the appropriate filter face velocity, fabric type, and approach to cleaning that will effectively achieve performance objectives relative to particulate emissions and the control of differential pressure for all fuel types.

4.3 CAH Performance

The CAH tube bank was installed and initially evaluated during a shakedown test completed in October 1997. Through April 1999 the CAH tube bank has experienced twelve heatup/cooldown cycles as a result of 1716 hours of coal/lignite (731 hours) and natural gas (985 hours representing SFS heatup/cooldown and refractory curing) firing in the SFS.

Clean tube surface temperatures were nominally 1565°F (852°C), with the surface temperature decreasing to 1340°F (982°C) as ash deposits developed and adjustments were made to the process air flow rate during the tests in January, February, and April 1999.

When coal firing (Illinois No. 6 or eastern Kentucky) began, surface temperatures initially decreased at a rate of nominally 5°F/hr (3°C/hr) for 10 (eastern Kentucky) to 20 hours (Illinois No. 6). After nearly 40 hours of coal firing, there was no further decrease in tube surface temperature for either fuel.

On the basis of CAH data developed during this test series, it appears that the addition of the fins to the air-cooled tubes improved heat recovery during the coal-fired test periods. The fins appear to have reduced the rate of heat-transfer degradation as ash deposits developed and helped to maintain a higher heat-transfer rate once the deposits had formed. However, no improvement in heat recovery was observed during the initial natural gas-fired periods with clean tube surfaces.

The CAH ash deposition rate was a factor of 3 greater when the Illinois No. 6 coal was fired, 0.03 lb/MMBtu (13.3 g/10^6 kJ) versus 0.01 lb/MMBtu (5.9 g/10^6 kJ) when the eastern Kentucky coal was fired. As a result, heat recovery from the CAH tube bank was significantly greater when the eastern Kentucky coal was fired, consistent with the Kentucky coal's lower ash content and higher heating value. However, these data do not address the potential for improved heat recovery for either fuel type as a function of an effective sootblowing system.

CAH tube bank plugging was not a problem when the Illinois No. 6 or eastern Kentucky coal were fired. The deposits that formed were limited to the leading and trailing edges of the tubes. However, when the Illinois No. 6 coal was fired, deposits did bridge the area between the tubes in the direction of the flue gas flow.

In addition to greater mass, deposit strength was greater when the Illinois No. 6 coal was fired. The strength of the Illinois No. 6 deposits was indicated by the fact that the deposits generally remained intact when the CAH tube bank was removed from the duct. Also, the deposits were generally removed intact from the tube surfaces. In contrast, following the eastern Kentucky coal test, the ash deposits from the cooled tubes could not be removed intact from the tube surfaces.

Characterization of the eastern Kentucky ash deposits showed that essentially all of the deposits were composed of complex silicates, except for a thin powder layer adjacent to the tube, which contained approximately 15% sulfate material. The deposits were dominated by larger particles enriched in silica (about 50% silica) and iron and depleted in alumina and calcia. Because all alkali and alkaline earth species were present in very low concentrations, limited deposit sintering at the temperatures of the CAH was observed.

4.4 RAH Performance

Initial shakedown and testing of the RAH panel took place in December 1997. Through April 1999, the RAH panel has experienced ten heatup/cooldown cycles as a result of 1485 hours of coal/lignite (684 hours) and natural gas (801 hours representing SFS heatup/cooldown and refractory curing) firing in the SFS. The new ceramic tiles that were installed in January 1999 were exposed to three heating and cooling cycles and 480 hours of slagging furnace operation: 181 hours of natural gas firing (including heatup and cooldown) and 299 hours of coal firing.

The hairline cracks found in new RAH ceramic tiles are believed to result from stresses encountered during tile fabrication, the actual casting/cooling process, and the machining of the tiles. These stresses and the resulting cracks could be reduced if the tiles could be formed in near net shapes, eliminating the need for machining.

Exposure of the RAH ceramic tiles to slag during coal firing in January darkened the tiles as a result of the residual slag layer on the surface. No additional tile color change was evident following the February and April tests.

Following the April test, cracks were evident in four of the five tiles. In general, none of the cracks indicated the potential for a near-term tile failure. However, the combination of cracks in the small and larger upper tiles could be problematic with further heating and cooling cycles. Heatup/cooldown cycles are believed to contribute significantly to the RAH panel ceramic tile/brick cracking and the propagation of cracks formed during tile fabrication.

Overall, the condition of the ceramic tiles deteriorated somewhat with each test, with the small lower tile showing the greatest degree of erosion/corrosion. This is believed to result from the combination of its higher surface temperature and the greater quantity of slag flowing over its surface relative to the other tiles.

The highest RAH heat recovery rate was observed in February 1999 (eastern Kentucky coal), with fuel quality believed to be the reason for the lower heat recovery rate in January (Illinois No. 6 coal). Overall, the data indicate that the heat recovery rate for the RAH panel is decreasing with each week of operation since the slagging furnace high-density refractory was replaced in late 1998 and the RAH panel was reassembled in January 1999.

Possible contributing factors to the degradation of RAH panel performance relative to heat transfer from the furnace to the RAH tubes include 1) changes to the ceramic tiles on the flame-side surface as a result of slag coating and/or erosion/corrosion of the ceramic tile surfaces and 2) changes in the reflectivity or emissivity characteristics of the high-density furnace refractory as a result of slag adsorption/absorption and the darkening of the furnace liner.

Based on the RAH heat-transfer data obtained during the three test periods completed, no conclusion can be drawn concerning the use or nonuse of a coating on the cavity side of the RAH ceramic tiles to improve cavity-side heat transfer.

Increasing heat exchanger efficiencies and material lifetimes demonstrates to coal-burning utilities that coal-fired options exist and it may not be necessary to switch to natural gas firing or purchase CO_2 credits if CO_2 emission restrictions are legislated. Instead, existing coal-burning boilers can be repowered with an indirectly fired turbine combined cycle to increase efficiency by up to 50% and reduce CO_2 emissions by as much as 40%.

4.5 Bench and Laboratory Corrosion Testing

Bench-scale testing with the DSAF showed that a new sintered chrome–alumina refractory brick material prepared by Kyocera is at least 70% more resistant to flowing slag corrosion than the fusion cast alumina material currently in use in the RAH. In addition, the corrosion channel was much narrower than for the fusion cast material, so actual service lifetime may be substantially better than indicated by the 70% reduction figure. Also, TCLP tests showed that the slag flowing over the Kyocera material does not absorb enough chromia to become a disposal