Operating Experience with Two Water/Carbon Steel Heat Pipe Air Heaters

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ABSTRACT

Hudson Products Corporation (HPC) and Babcock & Wilcox (B&W) have been actively developing water/carbon steel heat pipe technology for use in air heaters. As part of this program, the performance of two heat pipe air heaters has been monitored over the past 3-1/3 years. This monitoring has included the detailed examination of individual heat pipes that have been destructively analyzed. Overall, the performance of both air heaters has exceeded the design performance. In addition, the examination of individual heat pipes showed very little internal corrosion and noncondensable gas accumulation. One heat pipe air heater has successfully demonstrated that a compact, staggered tube bundle can be kept free of fouling in one type of fly ash environment. These results demonstrate that water/carbon steel heat pipe technology is viable for combustion air heaters. This paper presents the operating experience gained as part of this ongoing program.

INTRODUCTION

Air heaters are used in most steam generating and process plants to heat the combustion air and improve energy efficiency. Most frequently, the flue gas is the heat source and the air serves as a heat sink to collect and use waste heat from the flue gas stream. As a rule, for each 22°C that the flue gas is cooled by an air heater, the overall boiler efficiency increases approximately 1% [1].

Over the last two decades, heat pipe technology has been introduced in the U.S. as an alternative to rotary regenerative and tubular recuperative air heaters[2]. Heat pipe air heaters (HPAHs) offer many features such as minimal leakage between air and flue gas streams, no moving parts, low maintenance, high thermal efficiency, low pressure drop, and reduced potential for erosion and cold-end corrosion. The majority of HPAH applications in the U.S. utilize organic-based working fluids. Such fluids degrade over time, thereby reducing overall air heater performance and operating life. In addition, organic-based working fluids are generally flammable — an important risk consideration in refinery, petrochemical, and other hydrocarbon processing plant installations.

Water/carbon steel heat pipe air heaters constructed by HPC were first installed in the U.S. in the late 1980s. The thermal performance of those original units degraded to unacceptable levels within one year after startup. After an extensive investigation, a problem related to a proprietary corrosion inhibitor was identified, and HPAHs containing the corrosion inhibitor were replaced. Two HPAHs were replaced in-kind and contained the latest water/ carbon steel based heat pipe technology.

PROGRAM OBJECTIVES

As part of a joint program by HPC and B&W to develop a water/carbon steel heat pipe technology, the performance of the two replacement HPAHs has been monitored over the past 3-1/3 years. The objective was to evaluate and demonstrate HPC's water/carbon steel based heat pipe technology for application to the hydrocarbon processing and electric power industries.

The goals are:

- Monitor individual heat pipe and over all heat pipe air heater performance with time.
- Evaluate several proprietary internal corrosion inhibitor processes.
- Obtain fouling and cleaning experience with a compact, staggered heat pipe arrangement.
- Obtain heat pipe external erosion and internal corrosion data.
- Verify design methods for new or retrofit HPAH applications.

HEAT PIPE AIR HEATER TECHNOLOGY

Original Air Heater Design

The original HPC HPAH design included a proprietary corrosion inhibitor in the water working fluid. Through field failures and an extensive investigation, it was determined that the corrosion inhibitor degraded at high temperature. This resulted in caustic attack of the internal carbon steel tube wall and subsequent generation of noncondensable hydrogen gas. The hydrogen gas filled a significant portion of the heat pipe condenser volume, reducing the available surface area. This reduced overall thermal performance of the air heater with time.

New Air Heater Design

After the problem was identified, steps were taken to develop new technology that would enable the reliable and safe use of water/carbon steel heat pipes in air heater applications. This new technology was used in the construction of two replacement air heaters and included the following design and manufacturing features:

- Modified water chemistry and inner tube wall treatment to control corrosion and hydrogen generation.
- Improved tube cleaning procedure to reduce out-gassing from residual cleaning agents.
- A method to vent accumulated hydrogen inside heat pipes.
- One-piece divider plate with welded perimeter to minimize air leakage.
- Individually removable heat pipes.

The design features and full-load operating conditions of the two replacement HPAHs are given in Tables 1 and 2. The first unit is located on a natural-gas-fired hydrocarbon processing industrial (HPI) train and the second is on a circulating fluidized-bed (CFB) boiler firing agricultural waste.

PERFORMANCE MONITORING

Both HPAHs contain control room instrumentation to monitor air heater performance. In addition, each HPAH is instrumented with many thermocouples to more precisely monitor individual heat pipe performance with time. The major parameters being monitored are:

- Air and flue gas inlet, intermediate, and outlet temperatures.
- Air and flue gas side pressure drops.
- Individual heat pipe condenser and evaporator surface temperatures.
- Air and flue gas effectivenesses and overall heat transfer performance with time.

The thermocouple data obtained for each HPAH include air and flue gas temperature grids and individual heat pipe surface temperatures. Air and flue gas flow rates and pressure drops are obtained via existing plant instrumentation. The data are periodically loaded into a data base from which the individual and overall heat pipe performance can be evaluated in plots or tabular form.

FIELD PERFORMANCE RESULTS

Hydrocarbon Processing Industrial (HPI) Air Heater

This HPAH was brought on-line in August of 1990. Overall performance has remained nearly constant over time with the air heater meeting the design air and gas outlet temperatures (Figure 1). As part of the development program, four proprietary passivation processes designed to prevent internal heat pipe corrosion are included in this air heater. Each respective heat pipe is monitored via thermocouples along the condenser length as shown in Figure 2. A heat pipe that contains little or no noncondensable gas has a near zero temperature difference between Thermocouples 1 and 3, while a heat pipe that contains noncondensable gas has a cold end (T1 is colder than T3). The performance of each tube passivation process with time is shown in

Figure 3. Process C shows the best performance with no detectable noncondensable gas, even in the lowest temperature heat pipes. Processes A, B, and D are about equivalent with noncondensable gas detected in only the low-temperature heat pipes.

Eleven (11) heat pipes (9 - Process A; 2 - Process B) were removed and destructively examined after a 32-month operating time. The results showed little or no internal corrosion for those heat pipes passivated via Process A at either low or high operating temperatures. In addition, little or no noncondensable gas was measured in these heat pipes, and all but one were still at or near their manufactured vacuum of less than -76 cm Hg (Table 3). It was also successfully demonstrated that selected heat pipes could be vented of noncondensable gas and returned to service.

Circulating Fluidized-Bed (CFB) Boiler Air Heater

This HPAH was brought on-line in January of 1993. Overall performance had remained nearly constant over the first year of operation (Figure 4) with the air heater meeting or exceeding the design air and gas outlet temperatures (Figure 5). However, during an inspection of the air heater in February of 1994 (after 57 weeks operating time), severe erosion of the flue gas inlet heat pipes was discovered. Several heat pipes were rendered inoperative due to complete erosion through the tube wall. The concentrated erosion pattern is probably caused by high gas velocities due to inadequate flow conditioning at the inlet transition flue to the air heater. This problem did not exist with the original HPAH after the same operating time. Despite the erosion, the HPAH is still exceeding design performance through its second year, although it is declining with time. There are indications that the erosion may have reached a plateau. It appears as if the first three to four rows of damaged heat pipes are acting as erosion barriers, diffusing the high fly ash velocities. It should be noted that the performance of the replacement HPAH is significantly better than the performance of the original air heater which contained the problem corrosion inhibitor (Figure 4).

The field inspection also found that the sootblowers located within the HPAH are keeping the finned, staggered bundles free of fly ash. This is supported by the gas side pressure drop data that have remained constant over time. In addition, thermocouple data from individual heat pipes show no generation of noncondensable gas in the high-temperature heat pipes and only moderate generation in the low-temperature heat pipes. All the heat pipes in the CFB air heater are passivated via a modified version of Process A, designated Al.

SUMMARY

Based upon performance monitoring, testing, and inspection of the two water/carbon steel heat pipe air heaters, the following conclusions can be made:

- Air heater performance can be maintained over time.
- Internal heat pipe corrosion and the resulting generation of noncondensable gas can be effectively minimized or eliminated.
- A compact, staggered finned heat pipe arrangement can operate successfully in one type of fly ash environment.
- Field service (venting of noncondensable gas, removing and replacing heat pipes) can be successfully performed on the new air heater design.

Overall, the results indicate that the water/ carbon steel heat pipe technology is viable.

As part of the development program to improve the technology, we will continue to monitor both HPAHs. Work is planned to obtain additional laboratory and field data on internal passivation methods and corrosion rates. This information will allow for more accurate forecast of heat pipe life and verify the heat pipe air heater design methods.

ABOUT THE AUTHORS

Mr. Russell has been General Manager of Hudson Products Corporation since 1991, and in August of 1996 was named Vice President. Prior to joining Hudson Products, Mr. Russell was Vice President, Engineering for Enstar Engineering Corporation.

Mr. Giammaruti was a Research Engineer at the Babcock & Wilcox Research Center from 1991 to 1996. During this period, he was responsible for the development of McDermott's industrial heat pipe technology, including recommercialization of the product. In 1996, Mr. Giammaruti transferred to Hudson Products Corporation as Technical Coordinator.

REFERENCES

1. *Steam - Its Generation and Use,* 40th Edition, Babcock & Wilcox, Barberton, Ohio, 1992.

2. Guyer, E. C., "Heat Pipe Air Heaters: Status Report," TR-102564, Electric Power Research Institute, Palo Alto, California, June 1993.

Table 1
HEAT PIPE AIR HEATER DESIGN FEATURES

Parameter	HPI		CFB	
Size (m):	2.7 long, 1.3 high, 2.3 deep		15.0 long, 2.8 high, 3.7 deep	
Flow Orientation:	Horizontal, counter-current flue gas and air; 6-degree tilt from horizontal		Horizontal, counter-current, flue gas and air; 6-degree tilt from horizontal	
Heat Pipe Arrangement (cm):	Staggered layout: Longitudinal pitch = 10.2; Transverse pitch = 11.4		Staggered layout: Longitudinal pitch = 10.2; Transverse pitch = 11.4	
Heat Pipe Bundles:	1		3, separated by sootblower cavities	
Number of heat pipes:	144		440	
Working Fluid:	Water		Water	
Tube:	Evaporator	Condenser	Evaporator	Condenser
Material:	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel
Length (m):	1.5	1.2	6.8	7.3
Diameter (cm):	5.1	5.1	5.1	5.1
Fins:	Evaporator	Condenser	Evaporator	Condenser
Rows:	1 to 10	1 to 10	1 to 20	1 to 20
Material:	Carbon Steel	Carbon Steel	Carbon Steel	Aluminum
Height (cm):	1.9	1.9	1.9	1.9
Rows:	11 to 18	11 to 18	N/A	N/A
Material:	Aluminum	Aluminun		
Height (cm):	1.9	1.9		

Table 2
HEAT PIPE AIR HEATER FULL-LOAD OPERATING CONDITIONS

Parameter	HPI	CFB
Temperature (C):		
Gas Inlet	360	260
Gas Outlet	145	160
Air Inlet	15	55
Air Outlet	275	180
Duty (W):	675,000	6,750,000
Operating Time (yr)	3-1/3	2

Table 3
HPI HEAT PIPE INTERNAL PRESSURE MEASUREMENTS

Heat Pipe Number	Passivation Process	Design Operating Temperature (C)	Internal Heat Pipe Pressure Measured at Room Temperature (cm Hg)
1	B	312	< -76
2	A	279	< -76
3	A	247	< -76
4	A	225	< -76
5	A	179	-67.3
6	A	136	-74.2
7	A	120	< -76
8	A	104	-63.5
9	B	89	-32.4
10	A	89	-71.12

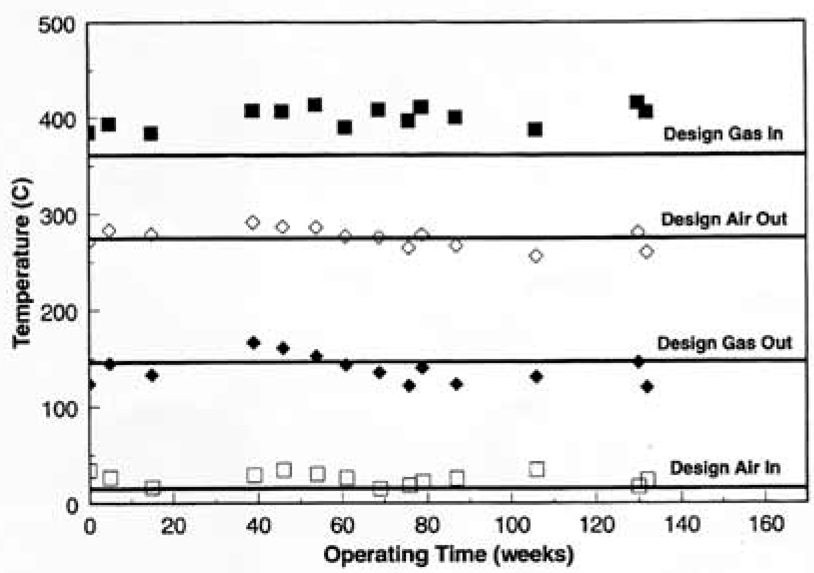

Figure 1. Operating Temperatures Measured for the Replacement HPI Air Heater

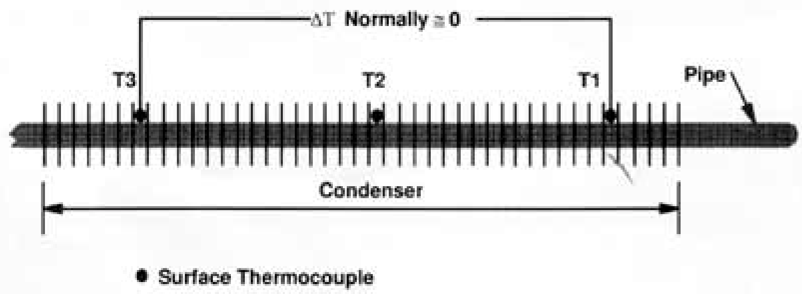

Figure 2. Thermocouples on Selected Heat Pipes in the HPI Air Heater

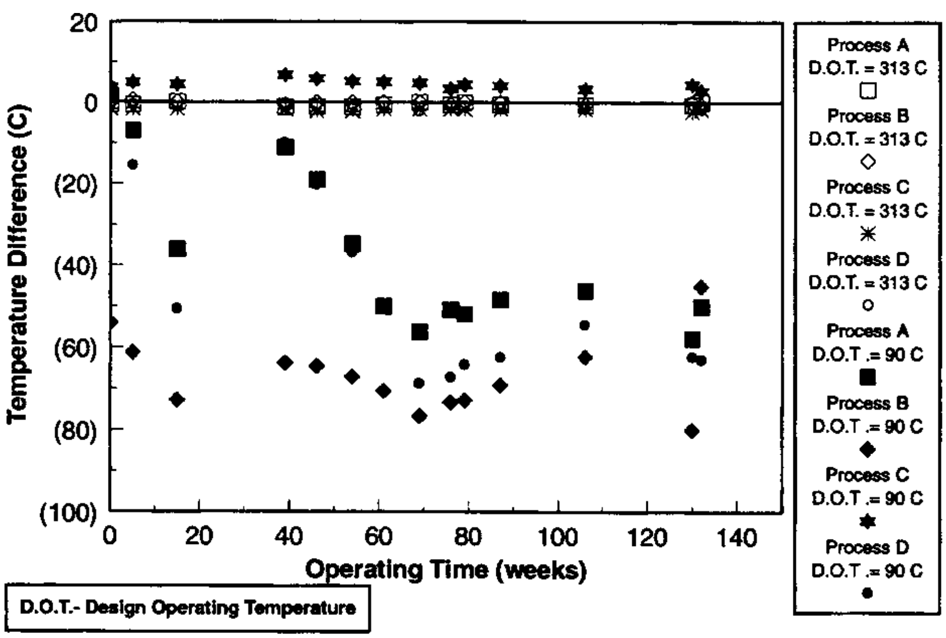

Figure 3. Performance of Tube Passivation Processes

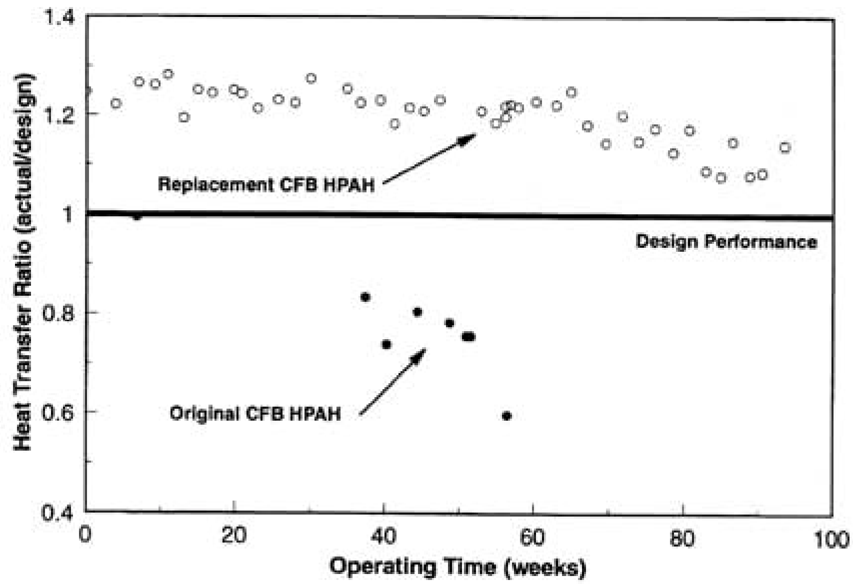

Figure 4. Performance of the Original and Replacement CFB Air Heater with Time

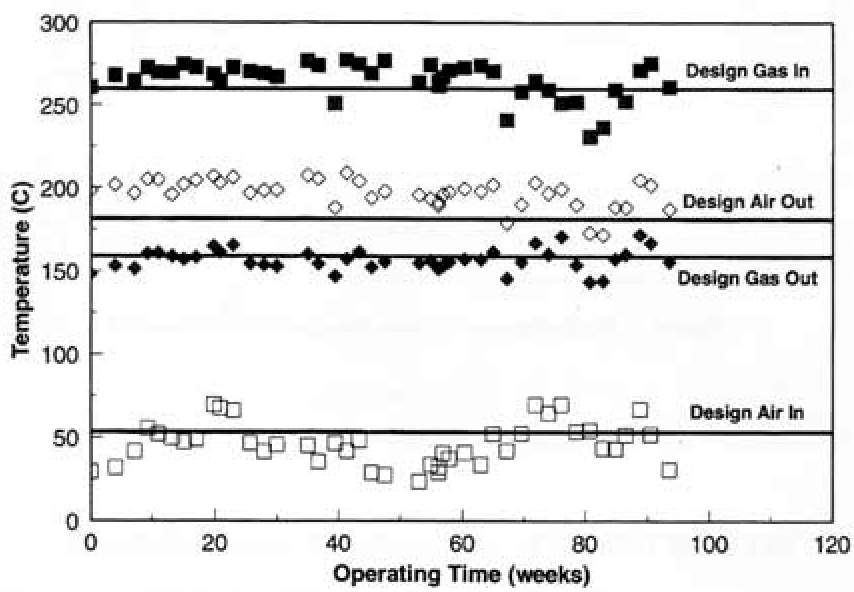

Figure 5. Operating Temperatures Measured for the Replacement CFB Air Heater