
Minimize Downtime and Costly Repairs with the Use of Temperature Tracking

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ABSTRACT

With the onset of a predictive maintenance program using infrared thermography to track temperature, downtime has been prevented due to failure of blast furnace upper assemblies, enabling management to better optimize time during planned outages. By monitoring the temperature, management has been able to change out faulty upper assemblies during planned outages or take preventive measures until they can be replaced. This has not only saved the company a substantial amount of money, but it has also increased the safety of the workplace. By tracking the temperature changes in a spreadsheet, we were able to determine which areas most commonly failed. This information allowed us to review the design and make changes that would increase the life of the upper assembly and decrease the operating temperature. In addition, knowing the condition of the upper assemblies has improved safety for the people working in the area. This kind of program is not limited to upper assemblies. It can be used to monitor the condition of refractory, gas mains, and more. This paper will explain why the program is necessary and describe the many benefits the use of infrared thermography on upper assemblies has provided.

Keywords: steel, blast furnace, upper assembly, refractory, predictive maintenance

INTRODUCTION

U.S. Steel Corporation Gary Works began construction in 1906. We have over 57 production units that span 6½ miles long by 1½ miles wide, which is just over 4,000 acres. Gary Works employs 5,200 people, each of whom has a hand in the production of over 6.5 million tons of steel annually. Gary Works produces flat rolled, carbon steel products such as steel sheet and tin-coated, which we sell to companies such as General Motors, Daimler Chrysler, Ford, Honda, and the food industry. Production of steel begins with the assembly and processing of raw materials. Coal is converted to coke in our coke plant. Coke, iron ore, and flux material in specific weights and sequences are then distributed at the top of the blast furnace, which is essentially a counter-current chemical reaction vessel (Fig.1).

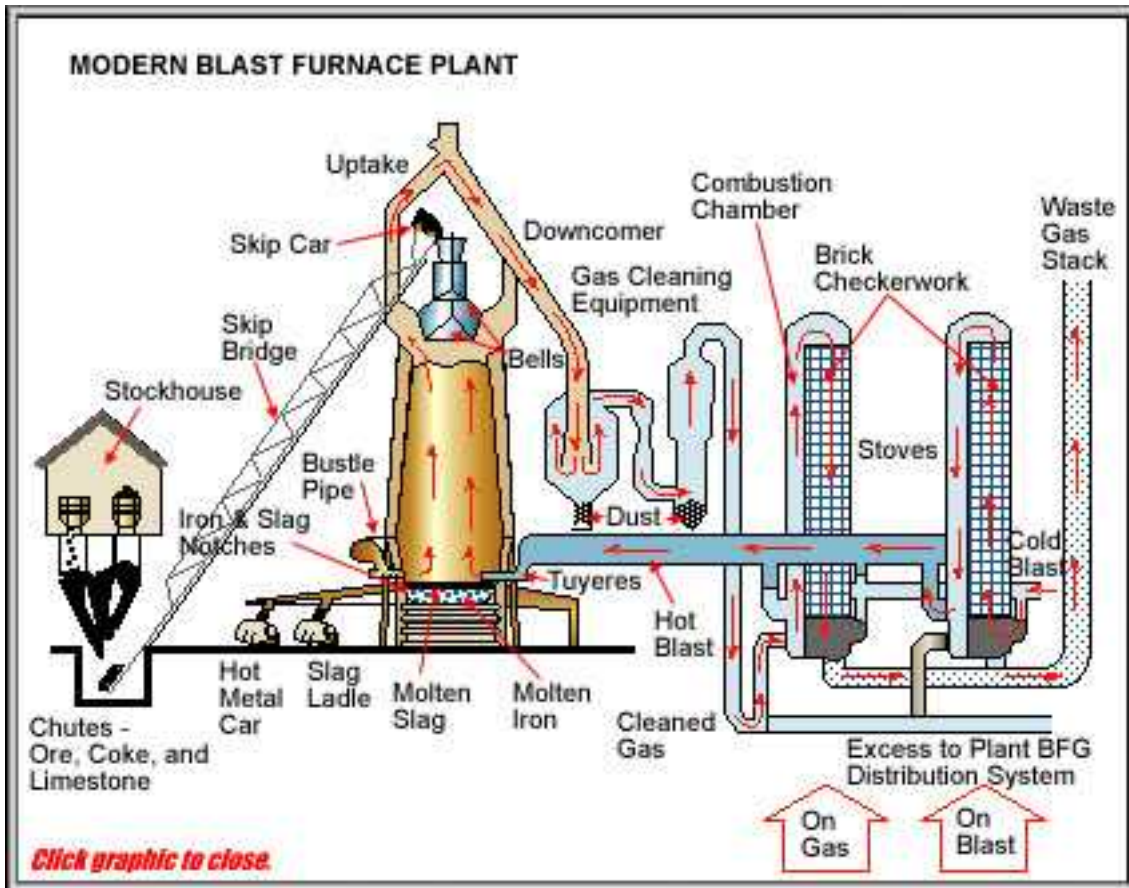


Figure 1. Modern blast furnace plant

Cold blast air is heated in the stoves. It takes about 45,000 to 55,000 cubic feet of air to produce one ton of iron. This heated air, called hot blast, is then discharged into the hot blast main. The hot blast main carries it to the bustle pipe, which encircles the entire furnace. The air leaves the bustle pipe through several openings attached to it, called upper assemblies.

There can be anywhere from 14 to 35 upper assemblies, depending on the size of the furnace. The upper assembly is refractory-lined to help minimize heat loss and protect the steel body of the upper assembly. The hot blast then passes through the blowpipe to the tuyere, which serves as an avenue for hot blast air to enter the furnace. The hot blast air burns the coke present in front of the tuyeres at temperatures above 3700°F. Heat transfer and chemical transfer occur within the furnace. The entire process takes about 4 to 7 hours for the charge to form molten iron and slag.

The molten iron and slag are then removed periodically from the furnace through a casting operation and collected in submarine-shaped refractory lined rail cars to be carried to the steelmaking shops, where it will be converted into steel. The steel is then cast into slabs. Our slabs are 9.1" thick, vary in width from 27" to 100", and vary in length from 17' to 40'. Once cut to customer specifications, the slab is sent to the hot strip mill to be further processed within the plant to meet customer requirements before being shipped.

Here at Gary Works, we have four operating blast furnaces, the largest being #13, which is also the third largest blast furnace in the country (Fig. 2). Of the 6.5 million tons of steel produced here at Gary Works, #13 blast furnace produces over 2.5 million tons. Blast furnace #13 produces approximately 40% of the hot metal needed for Gary Works. High production levels in a blast furnace require high operating temperatures, and high temperatures (over 700°F for upper assemblies at U.S. Steel) can cause problems.



Figure 2. Gary Works blast furnace #13, the third largest in the U.S.

GETTING STARTED

Before the onset of a predictive maintenance program specifically targeting upper assemblies, the only way to know if one was about to catastrophically fail was to wait until it began to glow or just failed. An upper assembly will begin to glow around 1000°F. At this temperature the workplace became very unsafe. Blast furnace #13 produces on average 8,000 tons of steel per day. With such high expectations, it is important that the furnace run with as few unplanned stops as possible. When the program first began, the goal was to locate any area on the upper assembly with a temperature over 700°F and generate a report. Over time it became apparent that was not enough. A spreadsheet was developed to track the temperature changes of each upper assembly (Fig. 3). Because the body of the upper assembly is affected by atmospheric temperature changes and running conditions of the furnace, this information was included in the spreadsheet.

	Report #	T1705	T1773	T1802	T1825	T1840	T1921
Tuyere		20	21	22	23	24	25
U A #	Average	11-Nov-03	2-Dec-03	26-Dec-03	12-Jan-04	23-Jan-04	25-Feb-04
1	729.50			737	671	705	805
2	754.20		674	779	770	769	779
3	658.33	629	743	665	642	625	646
4	732.83	753	733	733	718	741	719
5	634.50	657	650	625	626	643	606
6	783.50	818	749	754	802	780	798
7	765.33	772	780	780	755	761	744
8	881.00	881					
9	694.00	694					
10	651.00	651					
11	658.17	658	680	654	657	602	698
12	607.83	612	611	612	598	604	610
13	690.20		675	702	769	620	685
14	#DIV/0!						
15	#DIV/0!						
16	618.83	603	615	625	612	620	638
17	735.17	731	724	729	756	739	732
18	729.33	745	815	729	718	742	627
19	697.67	695	723	712	688	684	684
20	822.17	818	863	846	824	799	783
21	662.50	1039	607	602	591	535	601
22	807.33	824	783	767	811	786	873
23	743.67	740	709	751	708	723	831
24	721.17	741	721	717	719	719	710
25	635.17	656	658	632	626	608	631
26	692.67	719	726	699	673	649	690
27	842.00	806	850	865	847	822	862
28	815.67	746	819	837	855	794	843
29	628.67	895	583	586	577	553	578
30	974.83	1102	882	918	1030	1162	755
31	723.67	750	724	680	756	692	740
32	573.00	519	575	607	575	583	579
33	793.83	819	780	751	812	797	804
34	840.00	824	845	850	815	835	871
35	624.75			628	627	617	627

HBT:	2045	2069	2052	2046	2059	2041
WIND:	187	176	176	194	186	187
HOLE CASTING:	2 & 1	3	3	1 & 3	3	1 & 2
TIME:	10:00AM	1:30PM	9:30AM	10:30AM	7:30 AM	10:45AM
HBP:	51.54	54.23		52.72	54.71	55.01

Green:	Replaced T, C &/or BP
Yellow:	Hot Spot on PeepCap
Blue:	Leak found on PeepCap
Grey:	BlowStock Hot
Red:	UA Replaced
Tan:	Over 800F
Periwinkle:	Over 900F
Aqua/Dots:	Over 1000F
White/Dots:	Lance/Fan on UA

Figure 3. Blast furnace #13 upper assembly temperatures

DESIGN

The basic function of an upper assembly is to transport hot blast air at temperatures up to 2100°F and wind volume up to 200K scfm (standard cubic feet per minute) from the bustle pipe to the tuyere. In order to handle the high temperature and wind, the upper assemblies are lined with a castable refractory material that is designed to handle temperatures as high as 2800°F. A ceramic fiber gasket in a stainless steel casing is placed between the upper assembly flange and the bustle pipe flange. The upper assembly used at #13 blast furnace has two gimbal expansion joints. One is located at the top of the upper assembly, just below the upper flange, and one is at the bottom, just above the angled flange that ties the upper assembly to the blowpipe (Fig. 4).



Figure 4. Blast furnace gimbal expansion joint

The gimbal expansion joint is designed in such a way as to allow for some rotation to compensate for the movement of the bustle pipe. This rotation, however, has at times caused the overlapping vacuum-formed insulation – a colloidal silica binder – within the gimbal joint to be compressed to a point that it cannot regain its original shape (Fig. 5). The over-compressing of insulation creates a gap between the refractory and the upper assembly shell. This insulation gap then allows hot air to heat up the upper assembly shell, and the insulation begins to break down, leaving behind a sand-like material.

Hot air can also get under the ceramic fiber gasket and cause the bustle pipe flange and the upper assembly flange to develop hot spots (Fig. 6). Once this occurs, no repairs can be made to the upper assembly while the furnace is operating. The furnace must be taken off-line, the upper assembly completely removed and replaced with a new one, and the old one sent out of the plant for repairs. Removing and replacing the upper assembly can take anywhere from 3 to 6 hours. Lost production time, along with the repairs, can be very costly.



Figure 5. Overlapping vacuum formed insulation



Figure 6. Ceramic fiber gasket

TEMPERATURE TRACKING

At the start of the program, the upper assemblies were scanned once a month. As the number of hot spots found rose, and the maximum temperature of the hot spots climbed, the frequency was changed to once a week. With each person receiving the report having different names for the areas on the upper assembly, a standard list was put together and distributed to ensure everyone would know exactly where the hot spots were located.

After each scan the temperatures are recorded on a spreadsheet using a color-coding system, making it easier to track which upper assemblies have the highest maximum temperature. Graphs are also used to track the upper assemblies' hot spot progression (Fig. 7). Because the hot spot seemed to move around the upper assembly, a numbering system was developed (Fig. 8).

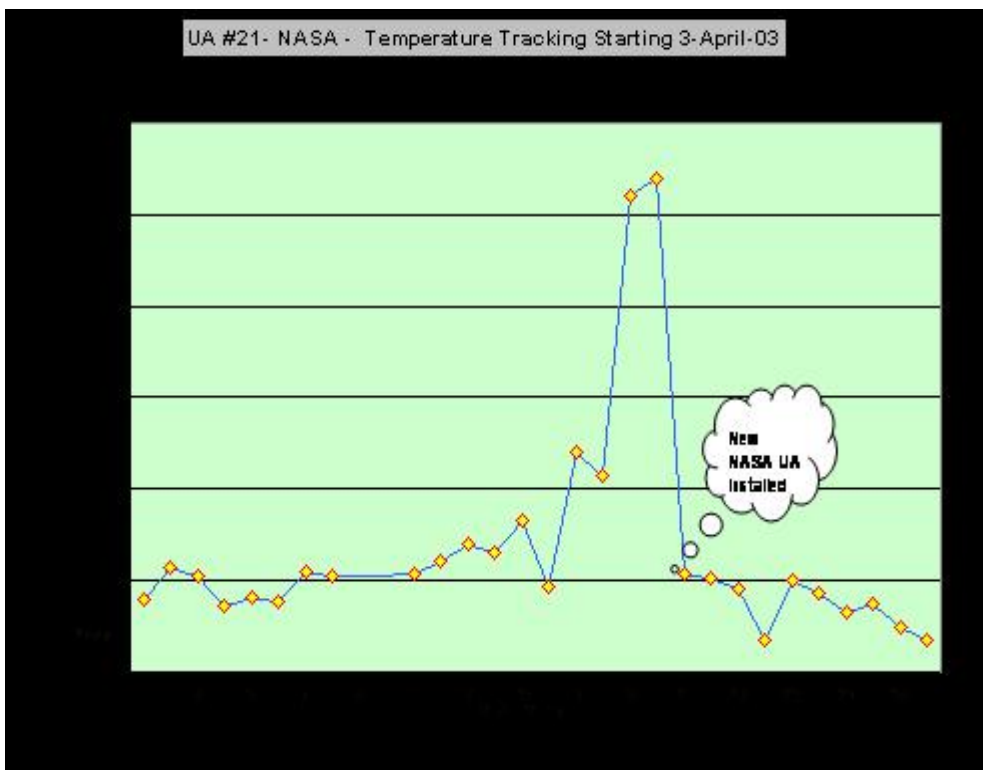


Figure 7. Temperature tracking of upper assembly hot spot progression

REPORT #	DATE	ASSEMBLY #						
		18	19	21	22	23	24	25
1046	1/9/2003	2	6	1		6		2,6
1042	1/3/2003	2	6	1		1,6	3	2
1038	12/26/2002			1		6		4
1034	12/18/2002			1		6		2
1030	12/11/2002	2	6	1		6		2
1022	12/2/2002	2	6	1		6		2
1017	11/25/2002	2	6	1		4		2
987	11/4/2002		6	1		4		2
982	10/30/2002	2	6	1		4		2
967	10/22/2002		6	1		4,FLB		2
958	10/15/2002		6	1		1,4,FLB		2
952	10/8/2002		6	1		4,FLB		2
944	10/1/2002		6	1		FLB		2
932	9/24/2002		6	1		4,FLB		2
925	9/19/2002			1		1,4,FLB		2
913	9/9/2002		6	1		1,10		1,2
911	9/6/2002		6	1		1,10		1,2
908	9/5/2002			1		1,4		2
902	8/29/2002			1				
897	8/27/2002			1				
895	8/22/2002		6	1				2
887	8/12/2002			1	5			2,3
875	7/25/2002			1	5			3
850	7/9/2002		6	1	FUF			6,2,3
843	7/2/2002		6	1	FUF			6,2,3
836	6/26/2002		6	1	FUF			6,2,3
832	6/19/2002		6	1	FUF			6
821	6/13/2002	1	6	1	FUF			2,9
810	6/3/2002		6	1	10			6,2,3
803	5/28/2002			1	1,10			6
802	5/23/2002				10			6,2,9
795	5/16/2002							6
781	5/1/2002		3,10		4			4,2,3

- | | |
|-----------------------------------|--|
| 1 = Left Side Below Upper Bellow | 8 = Right Side Below Lower Flange |
| 2 = Right Side Below Upper Bellow | 9 = Left Side Above & Below Lower Bellow |
| 3 = Left Side Below Lower Bellow | 10 = Right Side Above & Below Lower Bellow |
| 4 = Right Side Below Lower Bellow | 11 = Left Side Above & Below Upper Bellow |
| 5 = Left Side Below Upper Flange | 12 = Right Side Above & Below Upper Bellow |
| 6 = Right Side Below Upper Flange | 13 = Front View Above Upper Flange |
| 7 = Left Side Below Lower Flange | FUF = Front Upper Flange |
| | FLB = Front Lower Bellow |

Figure 8. Upper assembly temperature tracking using location numbering system

From the numbering system, certain patterns have been noticed. Hot spots found on the lower and upper bellow of the upper assembly would appear and disappear, due to the rotation of the upper assembly and change in operating conditions. But those found on the upper flange remained constant and only increased in size and temperature over time. For example, an upper assembly could have a temperature of 800°F on the lower bellow one week and then be under 700°F the next week. However, if the upper flange had a temperature of 800°F, it would either remain this hot for a few weeks, or the temperature would increase with each scan. Eventually, the upper flange area would begin to glow. At this point, the upper assembly would be removed from service as soon as possible.

The most common problem areas were above and below the two gimbal expansion joints and the upper flange of the upper assembly connecting to the bustle pipe flange. The information collected and stored in the spreadsheets helped Research and Development make changes to the design of the upper assembly.

DESIGN CHANGES

While changing an upper assembly as a result of temperatures exceeding 1100°F on the upper flange, it was discovered that the flange gasket had been partially destroyed (Fig. 9).



Figure 9. Partially destroyed upper assembly flange gasket

This is believed to be the result of the gasket not being rated to handle the high temperatures coming from the bustle pipe to the upper assembly. Even though changing the upper assembly and installing the properly rated gasket did lower the temperature in this area, it did not completely solve the problem. For example, upper assembly #30 had been changed four times in just less two years because of the same problem. Within weeks of installation the upper flange area was already exceeding the trigger temperature. A field inspection of the last failed upper assembly #30 was performed, and the following discrepancies were found: the flange gasket was sitting 2" from the front edge of the upper assembly, overlapping the bolt holes; and a burn pattern was clearly visible (Fig. 10). In addition, the flange gasket was sitting 4¾" from the back edge of the upper assembly, and no burn marks were noted (Fig. 11).

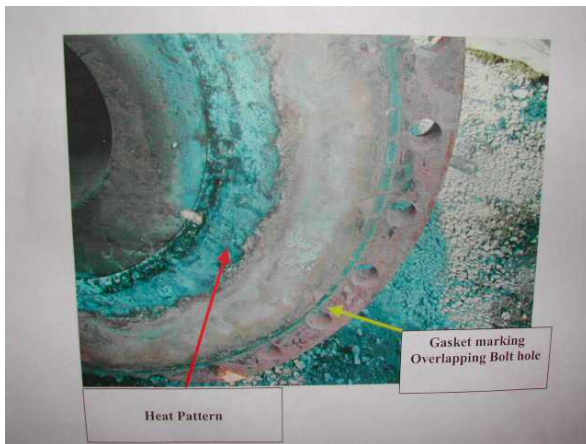


Figure 10. Burn pattern on flange gasket



Figure 11. Flange gasket showing no burn marks

While observing the installation of the new upper assembly, it was noted that positive positioning of the gasket could not be obtained. Because the gasket was smaller than the flange area, it could shift out of position during the bolting process, which would explain the burn pattern on the failed upper assembly. Recommendations were made to develop a gasket that requires the bolts to pass through it, thereby preventing it from moving out of position. It was also noted during a visual inspection of the bustle pipe flange that there was a 1/16" gap between the ceramic and the material. It took 1½ gallons of grout to fill the void. The recommendation was made to install grout nipples in the bustle pipe flange in order to add more grout, if needed, and monitor the area to see if the added grout would rectify the problem, instead of changing the upper assembly. This procedure was tried on a different upper assembly with the same problem and lowered the temperature on the upper flange from 1077°F to 649°F.

Another change was made to the insulating material within the gimbal expansion joint. The original design allowed for an overlap of refractory material (Fig. 5). The concern was that while installing the plug in the expansion joint, the material could move, causing a gap at the overlap. Or it could slip down and leave a gap, thus allowing air to pass through the body of the upper assembly. It would be like putting your sock in your shoe and then trying to put your foot in the sock. New cylinder and bowl gaskets were designed that consisted of silica/glasswool fibers enclosed in a high-temperature cloth. The cylinder gasket was then stitched to the bowl gasket using high temperature thread. The new design was a custom-fit sleeve, resembling a toeless sock, that could better handle the rotation of the gimbal expansion joint and high temperatures (Fig. 12, 13).



Figure 12. Close-up view of new cylinder and bowl gasket design



Figure 13. Another view of new cylinder and bowl gasket design

This refractory is similar to that used by NASA in the space shuttle, resulting in lower shell temperatures on the upper assembly. While these changes have improved the condition of the upper assembly, they still do not meet our intended goal. As a result of infrared thermography and temperature tracking, a completely new upper assembly is currently being developed for the 2005 rebuild of #13 blast furnace.

CONCLUSION

Temperature tracking through the use of infrared thermography has proven invaluable within our industry, with more and more applications being found every day

Since the inception of this program, we have not catastrophically lost an upper assembly in almost 3 years, resulting in increased safety, lower operating costs, and increased production. The savings to the company, by preventing just one catastrophic failure of an upper assembly, is easily over \$100,000. It is our hope that the new design changes will help increase the daily productivity of blast furnace #13 and reduce spending due to failure of upper assemblies. We have recently expanded this program to our coke plant (Fig. 14). By tracking the skin temperature of the coke plant gas main, we can determine if blockage is present, and if so, to what level. Temperature tracking is also being used to determine the condition of our hot metal sub ladles.

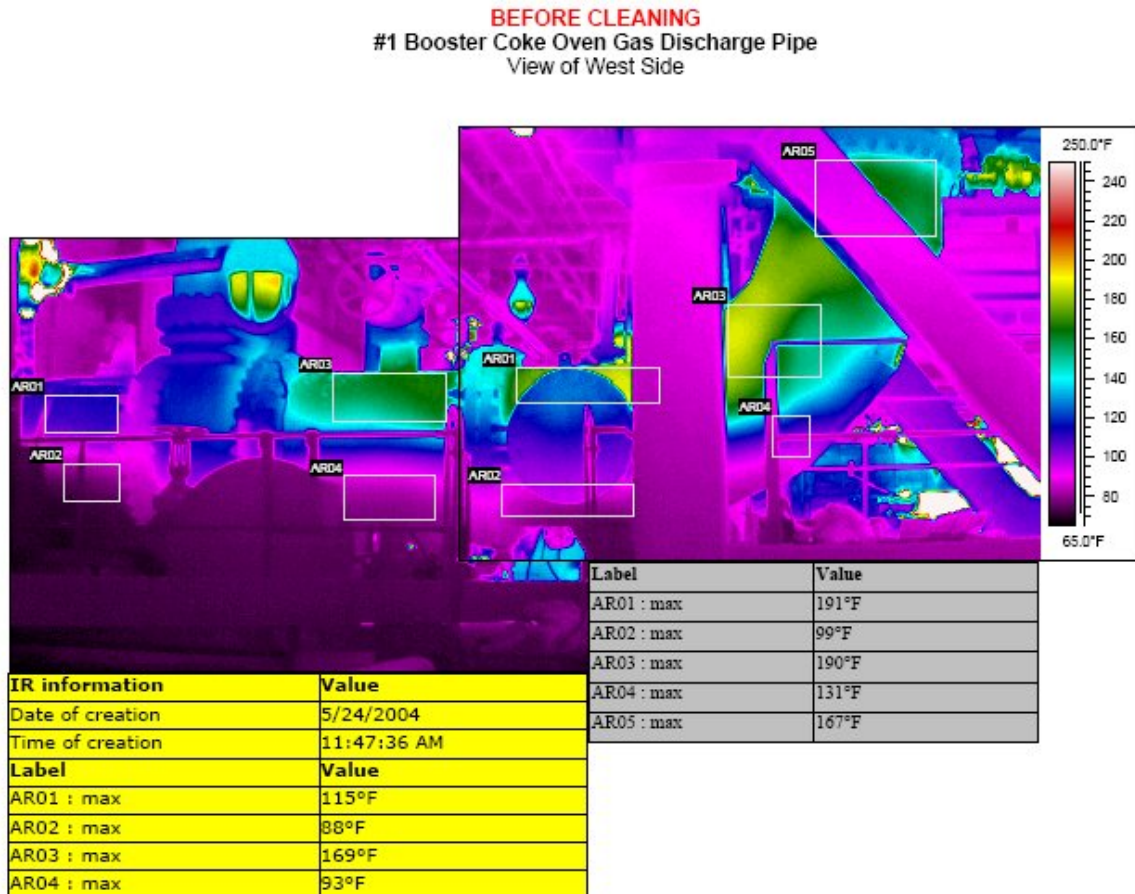


Figure 14. Coke plant thermal image collage of #1 booster coke pump discharge pipe before cleaning (view of west side)

This information is then used for scheduling routine maintenance. We have only scratched the surface with regard to what infrared thermography can do to improve working conditions and productivity within our plant. We can't wait to see what the next year will bring