Root Cause Analysis for Stack Opacity at Tonawanda Coke Corporation

Final Report

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Background

Westbrook Thermal Technology LLC (WTT) was engaged by Harris Beach PLLC (HB) to investigate the causes of high stack opacity at Tonawanda Coke Corporation's (TCC) battery located at 3875 River Road, Tonawanda, New York, and provide an action plan for the facility to undertake to achieve compliance with applicable environmental standards as soon as possible. The purpose of this engagement was to assist in HB's rendering of legal advice and counseling to TCC through the development of a compliance plan.

The current TCC coke battery started operations in 1962, and is a four meter Wilputte design, charging 18.6 tons of coal in each charge, with a total of sixty (60) ovens. The heating system is a hairpin design. The battery is used for foundry coke production and its current operating rate is approximately 18 to 20 ovens per day. Maintenance activities are regularly conducted on the battery and its attendant operations.

There are 6 other Wilputte batteries operating in North America of a similar age, size, and design. Most of these produce blast furnace coke at higher production rates than foundry producers. The significant difference between foundry and blast furnace coke producers is the total coking time and temperature used, with foundry being longer and cooler than blast furnace operations.

WTT understands that in May of 2018, TCC identified a sustained coke oven battery stack draft condition subsequent to a partial collapse of the battery's waste heat stack tunnel roof. This incident resulted in a drop in overall operating temperature, an upset of the combustion system, and other impacts to the operating condition of certain areas of the battery. Based on WTT's understanding, TCC provided malfunction notice of this incident to the New York State Department of Environmental Conservation (NYSDEC) via a May 11, 2018 email from Chuck Lauricella (TCC) to Cheryl Webster (DEC). A more detailed Malfunction Report, developed in accordance with Federal standards applicable to its Title V air operating permit (Permit ID: 9-1464-00113/00031), and consistent with a prior obligation pursuant to a Consent Decree entered amongst TCC, the NYSDEC, the United States Environmental Protection Agency (USEPA), the United States Department of Justice (USDOJ), and the New York State Attorney General's Office, was provided to DEC on May 25, 2018. Activities have been undertaken since that time to address circumstances of elevated opacity above the facility's 20% daily average limitation.

The Root Cause Analysis (RCA) Approach

WTT initiated a Root Cause Analysis (RCA) in late July of 2018 on the TCC coke oven battery. The RCA approach used by WTT is an evidence-based method that first builds a cause map (Cause Map) to identify all possible causes that could contribute to the high stack opacity. After constructing the Cause Map, each possible cause is investigated to determine if evidence exists that these are occurring, either occasionally or on a continuous basis. If any evidence is identified for a specific cause, potential remedies are developed, and priorities assigned by a general estimated level of contribution to stack opacity.

The Cause Map developed as part of this RCA is presented in the attachment to this report. Considering the coke battery at TCC has 60 ovens, the overall RCA process becomes even more detailed since each individual oven can become a smaller, separate RCA target. For example, one cause shown on the map may be "Wall Leakage." This possibility must be reviewed 60 separate times, once for each oven. Several types of data are analyzed in order to determine what specific causes may contribute to opacity from each individual oven. This process is described below.

It is important to note that the Cause Map and RCA process described herein should be not be considered a one-time exercise with a final conclusion. The short-term goal of this exercise is to identify specific areas which need repair or maintenance immediately in order to approach and finally achieve opacity compliance. It is based on recent data which change over time as some ovens are repaired, others continue to wear, and whenever process variables are altered.

As time goes on, new issues will arise which may raise opacity and need to be attended to in a proactive and efficient manner. TCC should adopt the methodology used in this RCA as a foundation for an ongoing Reliability-Centered Maintenance program to ensure the opacity trends do not reach a 20% threshold in the future. In other words, this type of evaluation should continue as a normal part of Operating and Maintenance practice producing an Action Items List being updated regularly as a living document.

Analysis of Data

Data reviewed for this RCA included the following:

- Hourly Opacity correlated to specific ovens charged
- New oven wall inspection reports with map of location and type of damage
- Waste Gas chemistry and temperature
- Heating flue survey showing condition of air ports and gas nozzles
- Flue temperatures by oven number (by shift and other cross-wall readings)
- Combustion Air inlet pressure (draft) and open area as well as measured flow rates
- Pressure drop across air and Waste gas flues
- Stack draft, waste gas composition, and temperature

1) Hourly opacity correlated to specific oven number charged

This approach typically identifies ovens with wall leakage. A repeated high spike of opacity that lasts for an hour or more is a reliable indicator of wall leakage.

Looking at the most recent 15-30 days of data, most operating ovens were charged 7 to 14 times.

On average, the average opacity spike after charging was 19% and lasted for 10 to 20 minutes. Some ovens had very low spikes while a few of the worst ovens produced an opacity spike of 40% after they were charged.

Ovens were then given a score of 1 to 4 (1=Best, 4=worst) based on their spike average as follows:

- 1 spikes were less than 10% (Best ovens)
- 2 spikes were 10 to 20%
- 3 spike were 20 to 30%
- 4 spikes were 30 to 40% (Worst Contributors)

In some cases, an oven may have exhibited a charging high spike only one time out of 8 charges, with seven looking fairly low. In these cases, other causes were investigated besides wall leakage. TCC should maintain this correlation of spikes for each oven in order to remediate ovens which may be deteriorating.

2) New Oven Inspection Report

While the previous inspection report performed by HeaTeq during the Battery Assessment phase is still applicable, a re-inspection of each oven wall was done in August 2018 by TCC personnel. This most recent inspection was necessary since the battery experienced a prolonged cool down which occurred following the partial waste heat tunnel roof collapse.

A diagram of right and left walls in each coke oven show the location and type of damage observed. Two inspection sheets per oven were completed – one each for the coke side and pusher side.

In general, the types of damage were categorized as follows:

- Jamb patching required
- Spalling of brickwork
- Small holes or cracks (suitable for spray or silica welding)
- Dry gun – tear-out and form (Larger holes or complete end flue, floor to roof)
- Modular End flue requiring "Big Block" shapes
- Other (such as pinion wall problem, bowing, Frames or doors)

A summary chart mapping these categories of repair for each oven is presented in the appendix of this report. Since this is a living document, the status of ovens shown on this report reflects their condition when inspected. As ovens are continuously repaired, this document should be updated.

The 3 categories which are most significant in terms of opacity are the:

- Small holes or cracks (suitable for spray or silica welding)
- Dry gun – tear-out and form with sono tube (Larger holes or complete end flue, floor to roof)
- Modular End flue requiring "Big Block" precast shapes

Based on oven condition after the recent re-inspection, a general score was also give to the ovens for wall condition.

3) Waste Gas Chemistry and Temperature

On each individual oven waste gas flue, a Bacharach Combustion Analyzer was used to determine gas composition, most importantly oxygen (O_2) and carbon monoxide (CO). Waste gas temperature was also recorded along with CO_2 when available

The analyzer used does not measure total hydrocarbons or specific compounds that may be present (such as HAPs) as products of incomplete combustion (PICs). In general, it can be said that CO concentration is typically much higher than these other PICs.

The goal here was to determine if the ovens had sufficient excess air present as shown by the O_2 values. If little or no O_2 is present in the waste gas, this would indicate insufficient air being drawn into that particular oven's air box which would cause incomplete combustion and opacity. Insufficient air could be due to insufficient draft, restricted air flow through the finger bars, or blockage in the air ports/ combustion flues. Each oven sampled in the battery showed adequate amounts of excess O_2 and this possible cause was eliminated from consideration.

Carbon Monoxide (CO) in the waste gas is an indicator of incomplete combustion. Generally speaking, CO levels less than 100 parts per million (PPM) are ideal and 200 PPM still indicates fairly good combustion. All ovens were sampled multiple times, as well as the stack inlet.

Seven (7) of the thirty (30) ovens in service had CO levels between 10 and 200 PPM. The average for the battery was 850 PPM (or 0.085%) One oven registered 5,200 PPM. Ovens with higher CO levels are likely contributing more to stack opacity than the others. Subsequently, the worst ovens were placed high on the maintenance priority list.

As a point of reference, the stack gas CO concentration (which is an average of all the ovens) measured daily in August typically ranged from 300 to 500 PPM (0.03% to 0.05%) with a few days better and a few worse.

For individual ovens, CO concentrations are likely to change significantly over the coking cycle if wall leakage is occurring. Walls with low leakage rates are likely to have a steadier CO rate since fuel delivery and air rate are more consistent. For ovens with low apparent wall leakage and high CO content, it is likely that fuel gas is flooding and/or air ports in the heating flues are blocked. In this case, poor air or gas distribution may occur among and between the 14 fired flues per wall. This can lead to poor mixing of fuel and air. TCC should regularly test waste compositions to identify ovens that may have declining performance. Taking cross-wall temperatures in each of the heating walls periodically provides valuable feedback relative to the local distribution of air/fuel ratios as well.

Another possible cause of high CO for ovens with relatively tight walls can be the use of natural gas as a supplemental fuel. When significant amounts of natural gas are mixed with COG, the combustion air requirements for that mixture also change and some process stability can be sacrificed. For example, one cubic foot of COG typically requires approximately 5 cubic feet of air (without allowing for excess air). Pure natural gas will require double that amount of air per cubic foot of gas. Since gas flow rates and air flow rates cannot easily or automatically be changed (they have fixed orifices and openings), the air/fuel ratio will subsequently change instead. While not as significant as other causes of opacity, this variable gas mixture can still contribute to the problem.

Regarding waste gas temperature, no ovens were found to have an unusually low temperature and only two ovens were above 500F. These two were also flagged for additional testing.

4) Heating Flue Inspection Report

TCC began assessments of the battery in late June and undertook a comprehensive inspection of heating flues which it completed it on August 10th of 2018. The condition of all 1,708 flues were observed and documented in order develop a maintenance priority list. On average, gas nozzle or air-port obstructions were found on between 4 and 7 flues per wall (out of 28).

A program to free up the gas and air pathways on each wall began in early August 2018. At this writing, more than half of the oven walls have been worked on and brought back toward proper working condition. The schedule for completing this work is late September 2018. Beyond this milestone, TCC should return to inspecting gas nozzles and air-ports on a regular basis, and specifically when opacity trends increase. As stated in the previous section, walls with poor distribution may cause opacity increases. Some specific ovens with gas or air-port blockage can also be identified by measuring waste gas composition exiting the oven.

Another method of verifying whether significant blockage exists in a wall is the differential pressure (DP) measured across the inlet air box and waste gas flues. Baseline DP values were taken by Westbrook Thermal on approximately half of the ovens. A few showed high DPs and subsequent low air flow into the flues. TCC had also previously measured air flow into each air box with a hand held device. This should be re-done periodically to refine the process of identifying ovens that need minor maintenance or air box adjustments as time goes on.

Additional Testing and Inspection

Some potential causes of opacity could not be fully evaluated and may be occurring on some level. These include short-circuiting air within the regenerator below the floor level, either through small leaks in brickwork or across the mushroom valves if there is not a tight seal. These possibilities are not as easy to diagnose as the others causes described above. Instead, identification of short-circuits below the floor involve the removal of brickwork for visual inspection. This can worsen opacity while the inspection takes place since the regenerators are now open to the waste gas flues.

After the immediate maintenance items are worked down in order of priority, the level of average opacity improvement achieved should provide some indication of whether or not short-circuiting below the floor is occurring.

Findings of the Root Cause Analysis

The RCA identified approximately forty-eight (48) potential causes which could contribute, in some measure, to stack opacity. Some of these are a consequence of the waste heat tunnel failure. It is not likely all of these causes occur simultaneously or on all ovens.

Five (5) ***Primary Causes*** show strong evidence of contributing to opacity. These include:

- Wall leaks - Small holes or cracks in walls just beyond the end flues
- Wall leaks - Larger holes in the end flue area of some oven walls
- Heating Flues - Blocked or missing gas nozzles
- Heating Flues - Plugged air ports
- Dirty goosenecks, collector main and dampers (ovens are not fully dampered open)

TCC has implemented a repair program that has focused on these major causes.

Secondary Causes showing some contribution to opacity include:

- Variable Btu in fuel gas value as a result of:
    - Low coke production / low COG volume and BTU
    - Natural gas injection on manual (no mixing station)
    - Dampers need maintenance (Ovens cannot be completely dampered off the main or back on the main)
- Cold End Flues from:
    - Poor flue gas distribution (Related to low gas rate & removed sputniks)
    - Doors off too long for maintenance (occasionally occurs)
- Air pathways abnormal below floor level in some ovens
    - Holes in air boxes
    - Short-circuiting through brick work or,
    - Leaky mushroom valves

Immediate Action Items

In order to restore stack opacity to compliant levels as quickly as possible and ensure that compliance will be maintained, a detailed list of battery repairs, ranked in order of priority and method, have been developed as part of this report.

1. Complete the Heating Flue Maintenance Program

Currently, over 70 % of the oven walls have undergone initial flue maintenance as recommended in the Preliminary Report. The current plan shows these maintenance activities will be substantially complete by September 22, 2018.

2. Complete the Wall Repair Program

Repair of the most critical wall leaks will be substantially complete by October 13, 2018.

There are approximately 30 ovens currently out of service at this writing, primarily due to leaks between ovens and flues in ends walls requiring repair. Repairing and returning some of these ovens to service should provide sufficient coke oven gas volume and quality for heating the battery. Currently, natural gas supplements the COG supply and contributes somewhat to opacity in the stack.

With respect to repair sequence, WTT has produced an oven health ranking from 1 to 4 with 1 being best and 4 being worst. This ranking is presented in Table 1 below as sorted by oven number. Table 2 has sorted this list by the oven health ranking such that ovens with a ranking of 1 are at the top of the totem pole – those the ovens in the best condition. Ovens with a rank of 4 (highlighted in red) are the worst ovens and next in line to be repaired. After the 4s are complete, the number 3's can be repaired, followed by 2s and so on. This type of list should be a living document whereby TCC continually updates the repair needs of each oven and factors into the ranking the actual oven's opacity signature after charging, waste gas chemistry, and other variables like WTT has done in this case.

Table 1 - Ranking Sorted by Oven Number

		as of 9/8/18	Type of Repair Required						
	Oven	In Service	Jamb	Spalling	Small Hole Patch	Dry Gun End Flue	Modular End Flue	Other	Overall Ranking
1	61	no	no	no	no	no	no	Yes	
2	62	yes	yes	yes	yes	no	no	no	1
3	63	yes	yes	no	no	no	no	no	3
4	64	yes	yes	no	no	no	no	no	3
5	65	no	yes	yes	yes	no	no	no	4
6	66	no	no	no	no	yes	no	no	3
7	67	yes	no	yes	no	no	no	no	3
8	68	yes	no	no	no	no	no	no	1
9	69	no	yes	no	yes	no	no	no	1
10	71	no					yes		
11	72	no					yes		
12	73	no					yes		
13	74	no					yes		
14	75	no	yes	yes	no	yes	no	no	
15	76	no							
16	77	yes	no	no	no	no	no	no	1
17	78	yes	yes	yes	no	no	no	no	2
18	79	no							
19	81	no							
20	82	no	no	no	no	no	no	yes	3
21	83	yes	yes	no	yes	no	no	no	3
22	84	yes							3
23	85	no							2
24	86	no	yes	no	yes	yes	no	no	2
25	87	yes	yes	yes	no	no	no	no	4
26	88	yes	no	no	no	no	no	no	4
27	89	no	yes	yes	yes	yes	no	no	
28	91	yes	no	no	no	no	no	no	2
29	92	yes	no	no	no	no	no	no	3
30	93	no	yes	no	no	yes	no	no	
31	94	no							
32	95	no	yes	yes	no	yes	no	no	4
33	96	yes	yes	no	no	no	no	no	3
34	97	no	no	no	yes	no	no	no	4
35	98	yes	no	no	no	no	no	no	1
36	99	yes	no	no	no	no	no	no	1
37	101	no	yes	yes	yes	no	no	no	
38	102	no	no	no	yes	no	no	no	
39	103	no							1
40	104	yes	no	no	no	no	no	no	1
41	105	yes							
42	106	yes	no	no	yes	no	no	no	2
43	107	yes	no	no	no	no	no	no	2
44	108	yes	no	no	no	no	no	no	1
45	109	yes	no	no	no	no	no	no	1
46	111	no	no	no	yes	yes	no	no	
47	112	no							
48	113	no	no	no	no	no	no	no	1
49	114	no	yes	no	no	no	no	no	1
50	115	no							
51	116	no	no	no	no	yes	no	Yes	1
52	117	no	yes	no	yes	yes	no	no	
53	118	no	yes	no	yes	yes	no	no	
54	119	no	no	no	yes	yes	no	no	
55	121	no	?	?	?	?	?	?	3
56	122	yes	?	?	?	?	?	?	2
57	123	no							
58	124	no							
59	125	yes	yes	no	no	no	no	no	2
60	126	yes	yes	no	no	no	no	no	3

Table 2 - Ranking Totem Poled by Ranking - Best to Worst

	Oven	In Service (as of 9/8/18)	Jamb	Spalling	Small Hole Patch	Dry Gun End Flue	Modular End Flue	Other	Overall Ranking
			Type of Repair Required						
1	62	yes	yes	yes	yes	no	no	no	1
2	68	yes	no	no	no	no	no	no	1
3	69	no	yes	no	yes	no	no	no	1
4	77	yes	no	no	no	no	no	no	1
5	98	yes	no	no	no	no	no	no	1
6	99	yes	no	no	no	no	no	no	1
7	103	no							1
8	104	yes	no	no	no	no	no	no	1
9	108	yes	no	no	no	no	no	no	1
10	109	yes	no	no	no	no	no	no	1
11	113	no	no	no	no	no	no	no	1
12	114	no	yes	no	no	no	no	no	1
13	116	no	no	no	no	yes	no	Yes	1
14	78	yes	yes	yes	no	no	no	no	2
15	85	no							2
16	86	no	yes	no	yes	yes	no	no	2
17	91	yes	no	no	no	no	no	no	2
18	106	yes	no	no	yes	no	no	no	2
19	107	yes	no	no	no	no	no	no	2
20	122	yes	?	?	?	?	?	?	2
21	125	yes	yes	no	no	no	no	no	2
22	63	yes	yes	no	no	no	no	no	3
23	64	yes	yes	no	no	no	no	no	3
24	66	no	no	no	no	yes	no	no	3
25	67	yes	no	yes	no	no	no	no	3
26	82	no	no	no	no	no	no	yes	3
27	83	yes	yes	no	yes	no	no	no	3
28	84	yes							3
29	92	yes	no	no	no	no	no	no	3
30	96	yes	yes	no	no	no	no	no	3
31	121	no	?	?	?	?	?	?	3
32	126	yes	yes	no	no	no	no	no	3
33	65	no	yes	yes	yes	no	no	no	4
34	87	yes	yes	yes	no	no	no	no	4
35	88	yes	no	no	no	no	no	no	4
36	95	no	yes	yes	no	yes	no	no	4
37	97	no	no	no	yes	no	no	no	4
38	61	no	no	no	no	no	no	Yes	
39	71	no					yes		
40	72	no					yes		
41	73	no					yes		
42	74	no					yes		
43	75	no	yes	yes	no	yes	no	no	
44	76	no							
45	79	no							
46	81	no							
47	89	no	yes	yes	yes	yes	no	no	
48	93	no	yes	no	no	yes	no	no	
49	94	no							
50	101	no	yes	yes	yes	no	no	no	
51	102	no	no	no	yes	no	no	no	
52	105	yes							
53	111	no	no	no	yes	yes	no	no	
54	112	no							
55	115	no							
56	117	no	yes	no	yes	yes	no	no	
57	118	no	yes	no	yes	yes	no	no	
58	119	no	no	no	yes	yes	no	no	
59	123	no							
60	124	no							

In Service 25

3. Complete Cleaning of Goosenecks, collector main and crossover piping

This activity is forecasted to be complete by September 22, 2018. It is currently about 65% complete.

The outlet system for raw coke oven gas can cause back pressure on the oven chamber due to restrictions in the gas path. Excessive pressure on the oven can cause leakage into the flue system, leading to stack opacity.

The crossover mains have demonstrated restrictions due to buildup. Some ovens cannot be fully dampered off of the main due to tar/pitch buildup in the collector main. These issues can serve to restrict raw coke oven gas flow from the oven or prevent proper dampering protocol. Cleaning procedures can include use of steam lances, high pressure water blasting or injecting coal tar distillate. Manual cleaning of the goosenecks is also done.

4. Implement a Formal Repair/Sign-off Process

After refractory repairs on an oven have been completed, it is important for TCC to consider other environmental performance factors prior to charging the oven and returning it to service. This is due to multiple trades and operating/maintenance personnel that could be working on other parts of the oven, such as door replacement, damper cleaning, and so on.

To this end, WTT recommends that one dedicated manager be responsible for determining the oven's readiness for service. This process would require that manager to verify specific aspects of the repairs done by multiple groups and complete a formal readiness checklist. The manager may also provide his or her own reasons for holding an oven out of service and document these reasons. In addition, the manager would ensure that pre-charging activities have been done properly, such as time allowed for refractory cure-out.

An example of a pre-charging checklist is shown below:

Readiness Checklist

Post Oven Maintenance

Oven Number

Date:

1 - Refractory

Inspect wall repairs

List repairs made

	Item	Pusher Side	Coke Side	Completed (Yes/No)	Observed By:
a	Hole repair				
b	Spalling				
c	Silica Weld				
d	Jamb Patch				
e	Spray or dry gun ends				

Item	Completed (Yes/No)	Observed By:
2 - Inspect floor/corbel area during coking cycle. Flood/grout as needed.		

3 - Heating Wall

	Item	Completed (Yes/No)	Observed By:
a	Nozzles - replaced or plugged nozzles cleaned.		
b	Air ports - cleaned		
c	Sputniks — in place. Cleaned &/or replaced		

4 - Raw gas outlet

Item	Completed (Yes/No)	Observed By:
Gooseneck/standpipe cleaned		
Collector Main Damper - Clean		
Downcomer functiona		
Pan clean, swing ok		
Aspirating steam valve — Operational open/close		

5 - Above items checked, then

Item	Completed (Yes/No)	Observed By:
Silica dust		
Hold oven empty with doors on for 12 hours, then charge.		
Take crosswall temperatures, 3 hours after charge.		

Item	Completed (Yes/No)	Observed By:
6- Observe flues immediately after charge for leakage from oven chamber.		

Oven Ready For Service

Manager's Approval

Date:

5. Additional Recommendations:

- Continue the correlation of opacity spikes to specific ovens charged. Develop a summary report on a weekly basis and create a totem pole of the most chronic or severe contributors of opacity spikes. Ensure these conditions are factored into maintenance priorities.

- Utilize silica welding as appropriate for small holes and cracks where refractory temperature is above 1,300 F.

- Review the existing training program for all personnel with special emphasis on a Continuous Environmental Training Awareness Plan (CETAP)

- Install a natural gas mixing station to ensure a consistent (and lower) heating value of the combined COG and NG

- Consider a slightly higher VM coal blend to help with gas production while coke production is low.

- Consider the best combination of coking cycle with ovens in service. For example, keeping the best 30 in service on 36 hour cycles would mean 20 ovens per day. The shorter coking time will facilitate developing carbon on the oven walls which helps seal the walls. This may produce a better opacity level than having more ovens on longer cycles. As more repairs are made, this may not be an issue.

- As repairs proceed, slowly raise the collector main back pressure, as this will also promote wall sealing. This should not be done to the detriment of the opacity levels.