Simple Modifications Increase Incinerator Capacity by over 50%

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Abstract

A large (50 MMBTU/hr) waste gas incinerator was in service burning fumes from a network of furnaces. It was built in 1983, but had never achieved its design capacity. This limited production at the facility, and a persistent hammering was a concern even at reduced (maximum 35MMBTU/hr) heat rates. The incinerator's emission performance was adequate, other than a cyclic visible flame out the stack at high rate. A systematic review of the design identified pressure drop in the waste gas inlet, and air-fuel mixing, as bottlenecks. An inexpensive modification brought the unit beyond its design capacity, allowing a dramatic increase in site production.

Introduction

The SGL Carbon Corporation operates facilities worldwide, producing graphite products of all sorts. The Lachute, Quebec, Canada operation fabricates large diameter graphite electrodes for metallurgical processes. Key characteristics of these electrodes are high strength and minimum void space. This maximizes the electrode life in electric arc furnace applications. The fabrication, from the raw materials petroleum pitch and coke, takes place in six major steps:

1. extrusion of mixed raw materials into initial shapes ("green" stock)
2. slow bake of these extrusions to drive off volatiles and begin "annealing"
3. re-impregnation of the stock to fill voids with pitch
4. faster "rebake" to drive off volatiles and continue annealing
5. graphitization with electric current
6. final machining to specific dimensions

This processing takes place sequentially, with each individual electrode tracked meticulously in a comprehensive quality control - and feedback - process.

Steps two and four are accomplished with four natural gas-fired furnaces. The furnace exhaust gases are collected into a large manifold, directing the gases to an incinerator to destroy any residual organics, carbon, H2S, and CO. The incinerator simply burns and heats all residual furnace gases to 800C (or higher) with no scrubbing. It's temperature and stack height create draft on the manifold to provide pressure control for the furnaces.

Batches of electrodes are heated in the furnaces, at controlled rates. The furnace burners are set at tight fuel/air ratio to minimize excess oxygen available, which would combust, the carbon electrodes themselves. The pitch evolves low boilers - volatile compounds - through a certain temperature range. While this range is crossed, the volatiles represent a tremendous heat load to the incinerator. This heat load is the maximum cited earlier.

The incinerator was started up in the early 1980's with a published design capacity of 3200 pph volatiles (48 MM BTU/hr). It never achieved that, though the difficulty of determining mass balance on the system left contractor and SGL with an unresolved proof of performance. The plant simply learned to live with the actual capacity, and the other operating difficulties inherent in what was built. The incinerator performed its role as a pollution control device, and its equally important role generating draft to control furnace and manifold pressure. At high "volatiles" loading, the incinerator draft capability was exceeded and control was lost. This condition evolved at a level of 2200 pph volatiles, establishing the effective maximum heat rate. What's worse, combustion was not completed in the incinerator itself at high rates and pulsing flame was visible exiting the stack at these times. Figure 1 is a photo of the existing incinerator and combustion air blowers. The waste gas feed duct enters from the right of the photo and connects to a flange below the combustion chamber inside the operating enclosure.

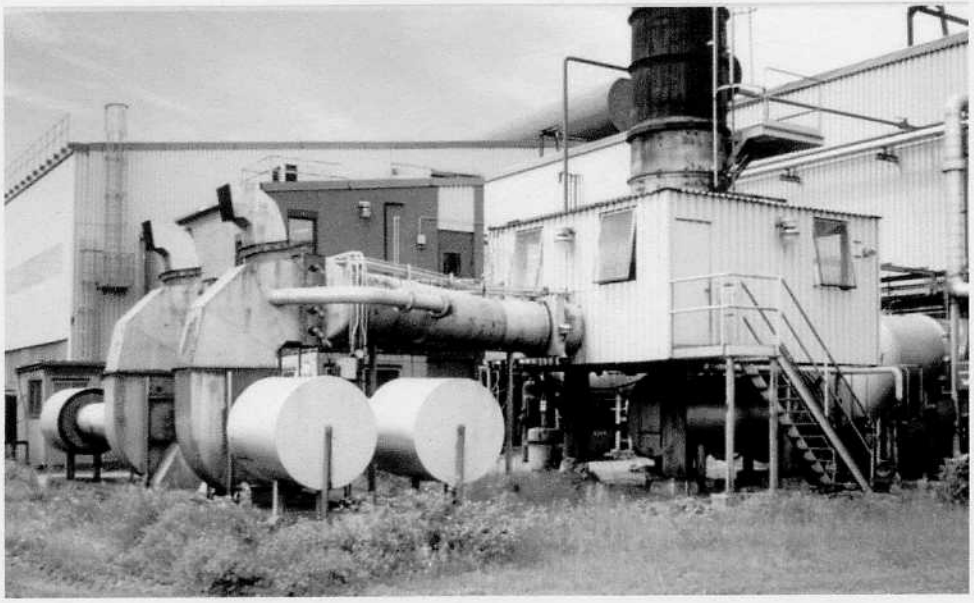

Figure 1

Engineering was performed to systematically evaluate this situation, and identify various solutions to it. Cost estimates on proposed solutions were used to select the actual modification made. This modification was effected. Early results from operations with the modified unit indicate that it has been "debottlenecked" to beyond its design capacity. With this improvement in performance, the site has increased net output, and is experimenting with modified production techniques that will improve both capacity and quality for the products.

Initial Evaluation

Engineering study was performed on the system. As with many incineration systems, the key was to perform a heat and material balance on the system, with which to estimate unit operation requirements. The design requirement is severe - the incinerator requires a "turndown" of nearly 16:1. At minimum gas flow and organics content, the incinerator required 3 MM BTU/hr natural gas to achieve stack temperature. At the design volatiles load, 48 MM BTU/hr are evolved with no supplemental fuel added. The original design addressed this with a hybrid design using natural draft evolved by the stack to exhaust gases from the furnace <u>and</u> deliver combustion air. As heat load increases, the combustion air draft capacity limit is exceeded and a large combustion air fan is turned on manually. This air injection point was designed as an eductor so that the "FD" flow actually increased furnace manifold draft.

This design, while a creative approach to the problem, proved to be the primary problem in meeting capacity goals. An initial study made this determination, and estimated detailed design cost for a variety of possible solutions. The simplest of these was selected for detail work.

Original Process

The furnace and incinerator system were designed and built in the early 1980s by a single contractor. The furnaces must be understood in order to identify the incinerator needs. The four furnaces are gas fired, with a variety of mixing elements that maximize heat distribution into the entire volume. The furnaces are "car bottom" design, with a movable floor onto which batches of electrodes are placed. The facility has five "cars" so that a batch can be prepared while four others are in process. Both 1st and 2nd bake cycles are performed on precisely controlled temperature increase rates, in keeping with quality control standards evolved throughout the company over a decade of evaluation. The first bake is performed very slowly, so that the newly formed carbon mass is allowed to anneal and develop strength. Significant quantities of volatile organics are evolved during each cycle - up to 10% mass loss is experienced from a batch pitch-saturated of electrodes. The 1st bake heats up so slowly that the mass rate of volatiles evolved is less than 200 pph from even the largest batch. Heat rate for the 2nd bake is more rapid, as the electrodes are more structurally stable. Volatiles are evolved during a narrow time period, yielding the 3200 pph rate design specification. In dealing with the facility needs, a total electrode mass in 2nd bake was specified as the new design objective. This mass was presumed to be in two furnaces, on simultaneous heat up so that volatiles evolution periods coincide.

The incinerator consists of the following components:

I. Combustion chamber/stack – carbon steel with brick and castable refractory lining.

II. Burners – two, firing natural gas into the small combustion chamber, each with its own outside air supply

III. Air eduction zone – a spool section mounted below the combustion chamber and designed to add the bulk of the required air for operation. Air injection was via a concentric throat around the outside of the eduction zone.

IV. Waste gas injector – extension of the waste gas duct, delivering the waste upward into the air eduction zone

V. Burner air blower(s) – delivering combustion air directly to the two burners, to assure stability

VI. Main air blower(s) – delivering air to the Air Eduction Zone when needed

VII. Control system – instrumentation for flame safety and to allow operator control of air addition and stack temperature.

A photo of the waste gas feed duct and the entry duct into the Air Eduction Zone is shown in Figure 2 below. The waste gas duct enters from the left of the photo. The combustion air flows through the duct on the upper right side of the photo. The Air Eduction Zone is the vertical cylinder where the air and waste gas ducts meet.

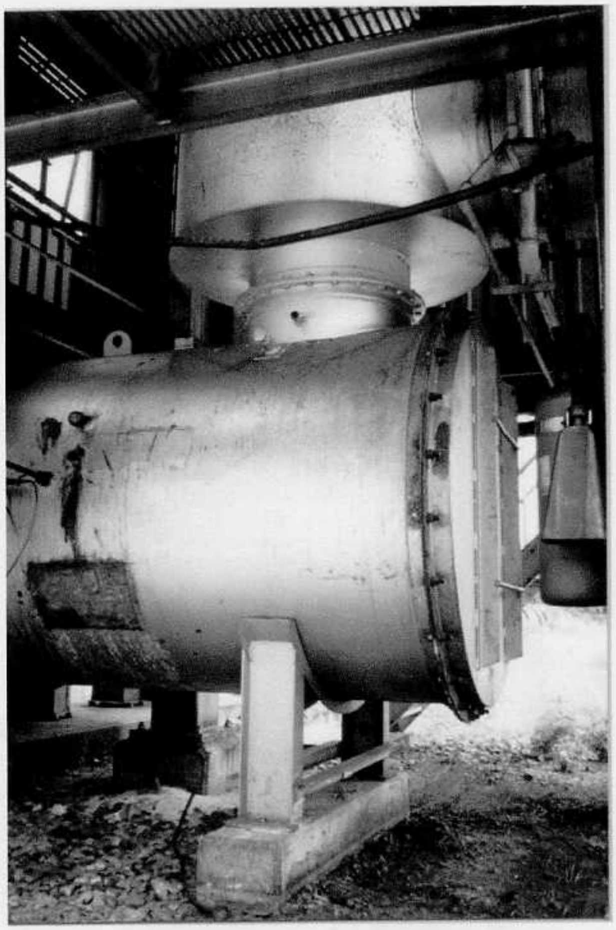

Figure 2

The existing design handled the waste gas and combustion air in a novel way. The main combustion air supply was via centrifugal blower, with air fed into a plenum surrounding the Waste Gas Injector duct. Air from the plenum flowed upward through an annular gap formed by the top and bottom ends of the duct. This design acted to draw a slight vacuum on the waste gas, helping to propel it upwards into the combustion zone. Unfortunately, this design also allowed the air stream to hug the wall of the duct, while the hydrocarbon laden waste gas flowed up the center of the duct. The result was that air and waste gas remained poorly mixed through most of the length of the stack, accounting for the presence of flame at the stack tip even with (theoretically) excess oxygen available for combustion.

As a side effect, the cross sectional area of the Waste Gas Injector was too small to permit full waste flow. The original designer may have counted on more help from the air eductor design than was achieved. In fact the pressure drop in the waste gas injector exceeded the vacuum "boost" generated by that design. At any rate, the plant operators were forced to limit production. High production would have generated enough waste gas to create a positive pressure in the waste gas duct, which would have led to venting waste gas to atmosphere. Figure 3 is a schematic of the old waste gas / air mixing arrangement.

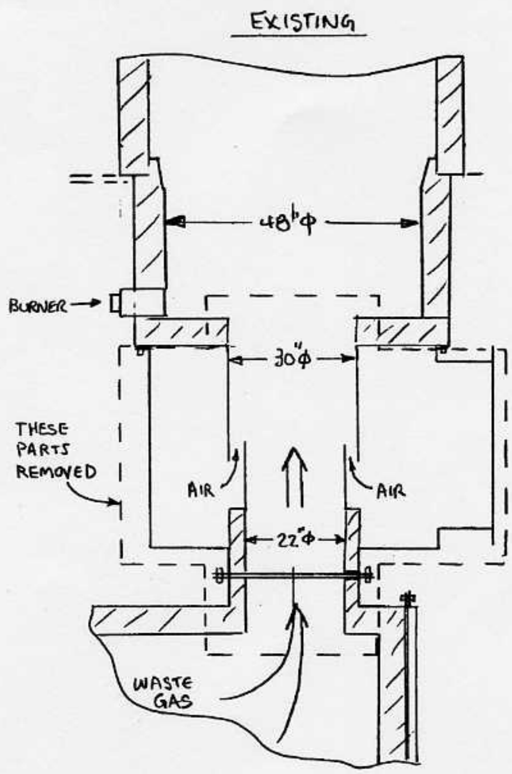

Figure 3

A simple control scheme is in place, with a set of thermocouples halfway up the stack performing all control functions. At low volatiles loading, supplemental natural gas fuel flow is controlled by temperature set point of 800°C. As volatiles load increase, gas shuts off and combustion air dampers open up - again controlled by stack temperature. Set point for this is 1000°C. Once natural draft is used up (and the dampers are wide open), the operator energizes a main air blower, the dampers close, then continue to control stack temperature. This transition is a critical, but very predictable, step. With the blower on, draft is increased. Operation with the existing design was literally shaky. A rapid pulsation was evident throughout the system. This appeared to be caused by intermittent combustion of surging waste gas flows in the incinerator. This pulsation was increasingly violent as rate increased. Flame exit the stack was also evident at these high rates, pulsing in step with the pressure surges below.

The operators and the E & C firm spent several years and made minor modifications, in an attempt to achieve design capacity, in the first several years after start up. These efforts were not able to substantially increase actual capacity, and were focused on controller tuning and minor modifications to the eductor design. Not much data was available at the time with respect to material balance, and so the two parties simply agreed to disagree, while SGL lived with actual performance of the incinerator. This had constrained site production for many years. Only recently had business demands driven the facility to seek a capacity increase. A new (or second) incinerator was not justified, but the level of modification cost that emerged as feasible was readily approved.

Design Assessment

Capacity requirements were defined by furnace(s) 2nd bake charge. This criterion is directly useful in production planning, and clear to operators at all levels. Translating that into heat and material balance was not a major issue, given the volumes of data developed by SGL as a whole since the plant started up. This data is a welcome outgrowth from quality control efforts. Combustion gas flows from each furnace are quantifiable. These then combine into fuel and/or combustion air requirements. Maximum combustion gas, and combustion air flows were estimated from an array of case studies. These were then used to estimate pressure drops (and stack draft) to evaluate the system pressure profile. This analysis highlighted several portions of the unit, and identified areas for modification.

Primary revisions to the incinerator were replacement of the Waste Gas Injector and Air Eduction Zone. The Waste Gas Injector diameter was increased to the maximum size permitted by the geometry of the waste gas feed duct. Lower pressure drop in this portion of the assembly improved system draft at all times, especially furnace "volatiles" periods. This allowed operations to increase production rates to the desired level without creating a positive waste gas duct pressure. The air eduction design was abandoned and combustion air is now added to the waste gas by a grid of nozzles around the perimeter of the injector. These are perpendicular, though slightly tangential, to the waste gas flow. Figure 4 is a diagram of the improved waste gas / air mixing arrangement.

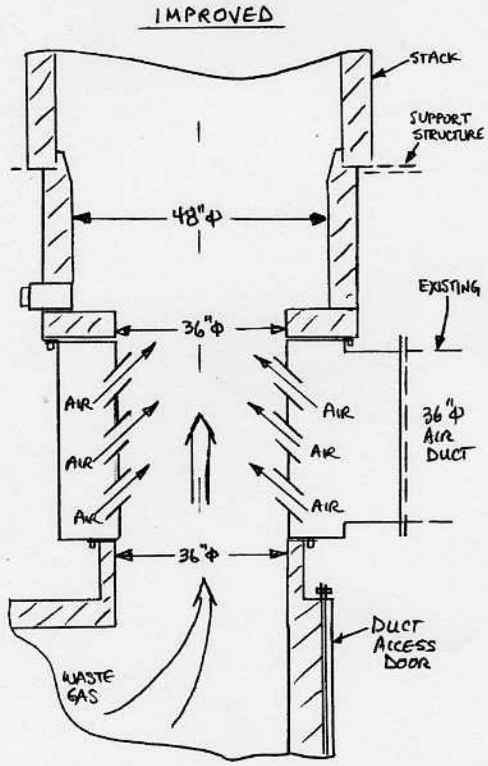

Figure 4

Figure 5 shows the new Air Eduction Zone installed between the waste gas duct and the combustion chamber above.

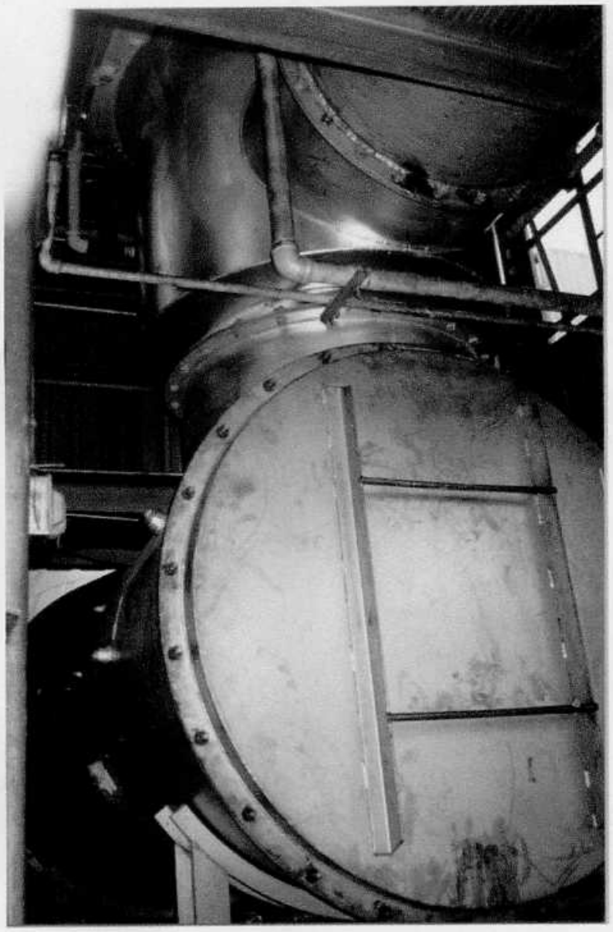

Figure 5

The waste gas hydrocarbon content is low during most phases of plant operation. Minimal fuel gas firing is used except at the start of a production cycle when waste gas flow rates are low and or very cool. At low rates, fuel gas flow is controlled by stack temperature. As inlet gas becomes richer in volatiles, the gas shuts off and combustion air opens. Stack temperature is controlled (quenched) by modulating the main combustion air flow, while keeping fuel gas rates at low "flame stability" or pilot levels.

The refractory in the combustion zone and stack was in good shape overall due to good operating and maintenance practices at the plant. Review of the lining design revealed that an increase in flue gas temperature could easily be tolerated. By increasing the stack operating temperature, a net increase in draft at the stack base could be achieved, effectively increasing waste gas capacity as measured by waste duct pressure. The higher temperature would also result in better destruction of the waste hydrocarbons. The lower stack flow also reduced pressure drop in the stack itself, improving overall draft performance. A revision to the operating procedures to allow this change was authorized. Use of this increased temperature has proven to be unnecessary to meet initial capacity goals for the modified incinerator - but will allow for further, future debottlenecking.

Improved air / waste gas mixing was needed to take full advantage of the stack combustion volume. The original design introduced the combustion air supply in a layer along the wall of the Air Eduction Zone. This part of the system was removed and replaced with a new air plenum with a series of separate air injection nozzles directing the air more directly into the waste gas stream. This resulted in much quicker mixing of the waste hydrocarbons with the oxygen needed for their combustion. The new air injectors were fabricated of 304 stainless to tolerate the expected temperatures and were sized to for an air pressure drop compatible with the existing air blowers and dampers. If future changes should lead to richer waste gas, more quench air would be needed. This can easily be handled by simply cutting a few holes through the wall where the air injection pipes are mounted. All needed waste/air mixing necessary for good combustion are already in place. In fact, to ease installation and to handle thermal expansion as the incinerator heats up, the top of the plenum's inside shell was sealed to the plenum floor with a simple slip joint. Part of the combustion air leaks from the plenum into the combustion chamber at this point, but performance is unaffected due to the excellent mixing below.

Modified Incinerator

Shutdown planning was a crucial component of the actual modification project. To shut down the incinerator, all four furnace schedules needed to be synchronized so that they too could be shutdown. Staging this required a month to align. Once shutdown, site production was basically off for the duration, and the design and work planning focused on minimizing the duration of this shutdown. Three days proved to be necessary, with significant prefabrication successful at keeping this to a minimum. This was the first incinerator shutdown in several years, and reliability was a secondary consideration in the design. The modification was fairly simple, and no rotating equipment was involved, so reliability was not compromised in any way.

System testing was also very hard to schedule. The "hole" in production from the shutdown left a shortfall to make up. Production demands increased at the same time, so scheduling was all the more difficult. When a two furnace, simultaneous 2nd bake was finally executed, the unit performed with excellent draft performance, essentially validating capacity. Linkage "slop" in the combustion air controller, combined with a too-rapid set point change, upset the operation in the middle of the test, but the unit recovered and completed the test with no further difficulty. The incinerator was opened and inspected following this, to evaluate some troubling symptoms after the upset. Some displaced refractory had partially blinded the waste gas injector. This was removed - and the offending manway liner was mortared in place - to put the unit back on line. Procedures were modified to prevent recurrence. Subsequent operation has been solid and the plant is steadily increasing the frequency and volume of 2nd bake procedures.

Emissions performance was also a focus. The unit had been evaluated for PM, semi-volatile organics, and H_2S emissions several years prior to the study. The revised incinerator actually operates with lower emissions of these, in analogous circumstances. This fits with the design intent to improve combustion by improving air/fuel mixing.

As measured by 2nd bake charge size, the capacity of the incinerator was nearly doubled by this change. Translating that into site capacity is not so simple. The scheduling convenience the change has made has already begun to increase production. As the operators and planners work with the improved unit, site capacity will continue to increase. The improved draft provided by the incinerator has also made several procedural modifications possible. These will continue, within quality protocols, as the site strives to stay competitive - and superior to the competition.

Further debottlenecking means have been identified as part of this project. The stack temperature increase remains available, with the potential to improve net waste gas flow by 15%. A larger diameter stack has also been evaluated, as the pressure drop in the stack itself is now the single largest consumer of the draft generated. A rebuilt stack could also be lined to operate at even higher temperatures, increasing draft further. Even oxygen injection has been considered as a means to improve system capacity. These can be implemented as justified, prioritized by cost effectiveness, as and if the site demands further improvements in output.