Concept and Operating Results of a Higher-Level Automation System for the new C-Battery at the U. S. Steel Clairton Plant

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KEY WORDS


ABSTRACT

A higher level automation system named COKEMASTER® was installed on the new C-Battery. This system provides an automated and optimized machine scheduling system, smooth and efficient battery heating, continuous management of key operating data including pushing forces and a data interface with the upper level Plant Information and Management System. The lower level control systems, including oven machinery, were fully integrated in an unprecedented architecture. An overview of how this improved the process along with a novel multi-phased testing approach that minimized field commissioning efforts will be presented. This system improves operator workload, plant efficiency, and coke quality.

INTRODUCTION

In 2007 U. S. Steel decided to build a new coke oven battery with new coke oven machinery at Clairton Works near the town of Pittsburgh. The battery was designed by ThyssenKrupp Uhde GmbH /Germany, one of the leaders in coke oven technology and executed by Uhde Cooperation of America (UCA). The battery has 84 large oven chambers (20'-0” high, 52'- 1½” long and 18” wide) and with 112 pushes per day the new battery alone can produce approx. 960,000 tons of coke annually. With this production included, Clairton is now North America's largest coke plant, producing in total about 4.5 million tons annually. The new battery, called "C-Battery" is in pair with the existing same sized B-Battery, so that the new machinery had to be designed to serve both batteries, with one coal- tower in the middle. Two sets of pusher machines, transfer cars, and coal charging cars as well as one
quench locomotive, one quenching car and one pushing emission control system (PECS) have been build. All machines are designed to run in man-less operation, however they are still staffed for safety reasons. The coke from C-Battery is quenched in a new build quenching tower, whereas this tower is also serving the B-Battery. The new battery produces and supplies an additional amount of 28,700 [scfm] raw gas to the existing by-product plant. The ThyssenKrupp Uhde Double Pair Heating Flue System for coke oven gas heating enables accurate distribution of the heating gases and air to be achieved, thus ensures an even distribution of temperature within the coke. It was decided to equip this new plant with “state of the art” automation systems, whereas most of the process control systems for the battery and machinery have been designed and built by company IMS (Integrated Mill Systems Inc.) and the supervisory control system have been designed and build by ThyssenKrupp Uhde GmbH. The C-Battery went into operation in November 2012 and is now in full production for over approx. 1 ½ year.

COKE PLANT AUTOMATION OVERVIEW

The structure of the automation systems installed on C-Battery is as following:

- **Level 0:** Field instruments, sensors and actuators are connected via 4-20 mA to remote I/O stations or, if suitable, connected directly via field bus to distributed PLCs. This is the lowest functional level of automation.
- **Level 1:** The location and performance of the PLC’s are defined by the amount of input/output signals and/or the dedication of signals to specific areas or equipment. Rockwell PLCs are installed in a central control room and are connected to dedicated PC-based operator stations to monitor and control the plant equipment and to keep the process under control. The PLC’s and the Human-Machine-Interface (HMI) on the operator PC’s are serving as an integrated Distributed Control System (DCS).

- **Level 2:** A suite of optimization systems under the brand name COKEMASTER® installed to plan, supervise and optimize the oven machine operation and to automatically adapt the heating of the battery in order to optimize the process. Special coke plant specific measuring and evaluation systems are assisting the optimization models.

- **Level 3:** Process data from the field, calculated data processed by the PLCs as well as important data from the models and assisting systems are transmitted to a Coke-Plant-Management-System (CMS) for reporting and further evaluation by the coke plant management.
The Level 1 system is responsible for sequencing and controlling all machines and equipment within each major subsystem. A modern architecture meets the following criteria:

- **Common Control Platform** for all subsystems
- **System Redundancy** for critical processes
- **Autonomous Operation** of moveable machinery
- Distributed HMI that can be **Viewed from any Location**
- Safe boarding of moveable machinery via **Safety PLC Implementation**

The final solution, shown in the figure below, is comprised of Rockwell ControlLogix PLCs, Drives, and I/O coupled with Schneider’s Citect HMI.

The entire system nearly exclusively uses Ethernet communications on all levels. Networks are distributed into three categories, shown in the drawing above, to ensure a deterministic flow of critical information without interruption from unscheduled traffic. A combination of fiber, copper, and wireless media is used throughout.

Safety PLCs are used on the moveable machines to replace traditional hard wired circuits, making various functions easier to implement and troubleshoot. Software logic provides mechanisms to allow safe passage (for pedestrians walking past the machines) and safe boarding/de-boarding strategies. Redundant systems are used for applications that required “high availability” of the equipment.
HUMAN-MACHINE INTERFACE (HMI)

The HMI system follows a traditional client-server topology that is enhanced by using multiple servers in key locations; distributed so that local areas can function even when communication to the rest of the system is interrupted. This is particularly important where wireless networks are used to communicate with mobile equipment.

Given that the entire battery facility is spread over a large area and operated by several people in different locations, the entire HMI system is built around the principle that any screen can be viewed from any location. This “View Anywhere” concept not only provides the ability to troubleshoot a given system remotely, but also lets the production staff work together as a unit. Built-in security ensures that only the appropriate user can control any given part of the system.

SUBSYSTEM INTERACTIONS AND COORDINATION

A “Coordinating” PLC (CCO) supervises the entire operation. It is a collection of level one control functions that acts as the central arbiter of the schedule and equipment interlocking. The diagram to the right illustrates the points of functional synchronism between the major subsystems of the C-Battery during each subsystems normal cycle of autonomous operations.

For example, the oven charging sequence requires coordination between the active Coal Charging Car (CCC), the active Pusher Machine (PM), and the PROven® system, ThyssenKrupp Uhde’s system for single oven pressure control of coke oven batteries. The machines are positioned at the “Next Oven to Charge” as determined by the COKEMASTER® system. The coordinated charging effort begins when the CCC indicates that all four telescopes are down and the seals are inflated. At this point the PROven® system is instructed to fully connect the current oven to the collecting main and the pusher machine is requested to prepare for level operation. The CCC is not permitted to charge until the oven is fully connected to the collecting main and the PM is aligned and ready to level. Once both of these systems report “ready” status, the CCO gives permission to the CCC operator to start the feed cycle. The CCO is informed when the cycle begins.
and the status is passed to the PM and PROven® system to ensure that the oven remains fully connected to the collecting main. Coal leveling takes place during the slow feed portion of the oven charging cycle. The CCC indicates to the CCO when slow feed is active and it, in turn, sends a command to the PM to start the leveling process. The CCO permits the CCC to finish the feed cycle by confirming that the leveling process is underway. If the PM fails to report that it is leveling, the CCC is not permitted to feed the remaining coal. The CCC reports when the oven is completely charged with coal and the CCO informs the COKEMASTER® system that the oven has been charged while also commanding the PM to stop the leveling cycle. The PM responds by extending the level bar fully into the oven and finishing with a final sweep in the reverse direction. The charge weight of each hopper is calculated from the load cell measurements when the telescope is raised. This provides more accurate results as the force of the telescope against the top of the oven tends to support some of the weight during the feed process. The oven is considered to be re-sealed after the charge when the lids have been replaced and the chuck door is closed. At this point the PROven® system is issued a message to begin the coking cycle and start with controlling the oven-pressure.

**AUTOMATIC POSITIONING**

The machines are highly automated, including automatic spotting at the ovens. Each machine is propelled by Flux Vector Control VFDs connected to vector duty AC motors equipped with encoder feedback. Coarse travel position feedback is derived from an absolute rotary encoder mounted on a non-driven wheel with backup and cross-check using the transport drive(s) wheel encoder. Machine position is continuously reported to the CO-PLC and shown graphically via a sliding rule across the top of the screen.

Mapping arrays are used to store the locations of interest along the battery. In the pusher machine, for example, a single dimensional array of 1000 elements that maps the travel length of C-Battery, including the north and south maintenance areas. Each element of the array represents one foot of distance, with element 1000 representing the centerline of B Coal Bunker.
For absolute and precise accuracy, a second position feedback device is used. This is the EUROLASE VEROLINE® P.I. sensor. The system is comprised of a sensing head mounted on the car, and a series of stationary pods that contain a passive RFID transmitter and a positioning magnet. The pods are mounted at specific position targets along the path of travel such as each battery oven location, coal bunkers, etc. As the car passes near a given Veroline® P.I. pod, the RFID tag mounted within the pod provides positive identification. Since each pod is assigned unique identification number, the absolute position of that pod is known. When the car passes through the magnet positioning feedback device centerline, the encoder coarse position feedback is re-calibrated to be equal to the known centerline position of that specific pod. During an automatic positioning cycle, when the car is within range of the pod corresponding to the desired final position, the position feedback for the position regulator is switched from the encoder position feedback to the pod magnetic position feedback.

**PROJECT EXECUTION**

The success of the project depended on a well-timed execution strategy while maintaining strict quality standards through formal documentation and testing. Oven machinery equipment was shipped to Germany to be included with the machine erection prior to coming back to Clairton for final placement and fine tuning.

**System Development:**

A First Engineering Submittal (FES), also referred to as the “Basic Design” of the system, was done early in the project timeline to clearly define the system functional requirements. It included a detailed functional description (from an operator’s perspective), preliminary HMI screens, design standards, equipment lists and arrangement drawings.

The Second Engineering Submittal (SES), also referred to as the “Detailed Design”, described the system in very specific terms. The functional requirements of the project (as introduced in the FES) were finalized, and control techniques were described in sufficient detail to allow software coding to begin. This included a software organization chart and task/program/routine descriptions for each sub-system.
System Testing:

The oven machinery Factory Acceptance Test (FAT) was held in Cleveland, OH. The equipment was staged and wired to represent, to the extent possible, the actual on-machine configuration(s). The electrical cabins were pre-wired with permanent cabling to be easily re-installed at the erection site. Various motors and sensors as well as local control stations were temporarily connected to illustrate system functions. Each PLC contained temporary software that simulated all significant feedback signals pertinent to the test. Actual machine data was used to model the equipment so that each function looked and felt very realistic. Special techniques were also used to keep the simulation code completely separate from the actual program to enhance the validity of the test. A subsequent “main” factory acceptance was done just prior to startup and employed similar techniques.

After the machinery factory test all of the equipment was sent to Germany for installation on the machines. Some of the PLC equipment was retained in Cleveland for the purpose of a final totally integrated factory test. This “Main” factory test included all the systems involved in the battery. The COKEMASTER®, battery PLC’s, machinery PLC’s and HMIs were all setup for this test. Simulation software was written in the machinery and battery PLC’s to support this FAT. The COKEMASTER® provided the oven scheduling information to the battery and machinery systems. A fully automatic machinery simulator was developed that allowed all the machines to operate in a completely autonomous fashion. This allowed the system to be tested continuously for days to verify all the functional requirements were met.
A modular automation framework that mainly serves to optimize the coke plant operation. It is structured as a Level 2 System and is usually suited between a DCS and higher level management systems, in U. S. Steel’s case the CMS. The COKEMASTER® framework for U. S. Steel Clairton contains the following modules:

- **AutoTherm™-G**: automatic coke cake temperature measurement
- **BatControl™**: dynamic heat quantity calculation
- **ManuTherm™**: manual heating flue temperature measurement
- **PushSched™**: dynamic pushing and charging schedule
- **RamForce™**: automatic pushing force measurement

For detailed information to the individual modules, please refer to the publications made during AISTech 2011 or the website of ThyssenKrupp Industrial Solutions (http://www.thyssenkrupp-industrial-solutions.com/en/products-solutions/coke-plant-technologies.html).

The following schema shows the interconnection between the individual COKEMASTER® models implemented in Clairton. Manual heating flue temperature measurements with ManuTherm™ (hand held pyrometer with internal data storage) can be used as an input to the Heat Quantity Calculation (HQC) inside BatControl™. Also and preferable, AutoTherm™-G is used as continuous temperature feedback for HQC, because it is an automatic measurement system. With each push of a carbonized oven an indication of the temperature profile of the coke cake from the respective oven is given. This information is evaluated by automatic calculation tasks and provided for the downstream processes as the average battery temperature, so called "Mean Battery Temperature" (MBT). The system design is described in detail in chapter "**COKEMASTER® - AutoTherm™-G**".

The dynamic pushing and charging schedule PushSched™ is tightly interlocked with the coordination PLC (CCO). The entire production is based on the coordination of the pushing and charging and the Pusher Machines (PM) and Coal Charging Cars (CCC) are interlocked to the calculated oven position and timestamps from this scheduling system. With this interaction to the operation and the feedback from the production, another important input parameter for BatControl™, the expected coking time, can be calculated. So the heat quantity model receives the necessary performance information from of the process, generated by PushSched™, to react in advance to the production demands. Please refer to the chapter "**COKEMASTER® - PushSched™**" for more details.

For the optimum heating of the C-Battery several additional parameters from the process are considered to support the use of under-firing gas pressure control. To make pressure control work, two additional controllers were installed in the C-Battery heating system.

1. **Extended Wobbe control**, which reacts on fluctuations of the calorific value in the under-firing Coke Oven Gas (COG).
2. **Extended O₂ control**, to guarantee to any time an optimum combustion in the heating flues which prevents stack emissions.

The benefits of BatControl™ and its extensions can be found in the respective chapters. **"COKEMASTER® - BatControl™ and Wobbe- & O₂-Control"**.
To monitor the oven condition and the adjustment of the pusher ram, RamForce™, a system to record the force of the pusher ram while traveling thru the ovens, was installed on C-Battery as a Coke-Oven-Maintenance tool. Operation Examples are shown in the chapter “COKEMASTER® - RamForce™”.

COKEMASTER® - AUTOTHERM™-G

The temperature distribution within the battery block and the “Mean battery temperature” (MBT) is an important process parameter for keeping up with the production target and getting the best possible coke quality. Traditionally, manual measured heating flue temperatures are used, in case of C-Battery, these measurements are done with handheld pyrometers as part of the ManuTherm™-System. A much more sophisticated way to achieve a temperature feedback from the battery are measurements done with an automated system. U. S. Steel decided to use a system which measures the coke temperature called AutoTherm™-G.

Three optical lenses are located in three different heights, looking onto the coke surface thru slots in the guide. The optical lenses are connected to fiber optic cables which transmit the light intensity from the measuring point to the opto-electronic receiver and amplifier, both arranged in a protection box near the coke guide on the car.

The fiber optics are protected against dust and isolated against heat by special protection hoses. The purging air is cleaned by an air filter and is constantly supplied through an oil and water free compressor located on the machine as well. The system setup is shown in Figure 1. The temperatures of the coke surface are measured when the coke passes through the guide. When the coke mass is travelling through the coke guide during pushing, the temperature values are averaged for a certain wall span (width of heating flue) by a designated PLC, so that 32 measuring values in correspondence to the heating flues are available for each coke mass measurement and measuring point. The values so determined together with the pushed oven number are transmitted to the COKEMASTER® server for further evaluation, which is done by a special application software, called MARCO (ManuTherm, AutoTherm, RamForce for Coke Ovens).

One challenge was to synchronize and to assign the temperature data to the coke cake position inside the guide in relation to the heating flues. The temperature data, measured “on-line” on the coke surface while the coke moves thru the guide, are evaluated by the AutoTherm™-PLC on the Coke Transfer Pyrometer Box

Optical lens located at the coke guide

Inhomogeneous coke surface

Oven 72 upper pyrometer

Figure 1 – AutoTherm™-G Setup

Figure 2 - Installation

Figure 3-1: Raw data from AutoTherm™ PLC

Figure 3-2: Temperature profiles of multiple measurements
The location of the coke inside the guide can only be calculated by using the ram position while the pusher ram moves thru the oven-chamber. But the ram position is gathered by a PLC on the Pusher Machine (PM) only. This means, two different signal sources from two different PLC’s, have to be connected with a high performance connection in order to allow a data exchange in “real time”. Another challenge was the evaluation of the temperature raw data. Figure 3-1 shows the temperature raw data in terms of time during one push. Due to the inhomogeneous temperature of the coke with hotter and colder spots inside the coke surface structure, the measured temperatures are fluctuating in a wide range. This may lead to the conclusion, that the measuring system is not suitable for detecting heating problems. But this is not the case. Due to sophisticated filter and averaging methods, an acceptable temperature profile can be calculated (see orange curve in Figure 3-2). In Figure 3-2, a comparison of multiple temperature profiles from various ovens is shown. Temperatures, displayed for multiple ovens, are sharing the same behavior. This means they follow similar profiles and show good comparability between each other as well as a clear and visible correlation between the coke temperature profile and the heating flue temperature profile. This proves that the measurement system is functioning properly and can be used to supervise and evaluate the temperature distribution in each oven and to calculate the “Mean Battery Temperature” (MBT), for the C-Battery.

Figure 4 shows an example how to detect irregularities in the heating process with AutoTherm™-G System coke temperature measurements. The evaluation system provides at any time an overview of the heat distribution of the complete battery, using a “mosaic” - graph. In this graph, each “mosaic stone” represents one heating flue. The color of the mosaic stone represents the coke cake temperature at the respective heating flue position. Different colors are assigned to different temperature ranges. With the mosaic graph, weak spots can be identified quickly and then further investigated. In this example, the temperatures of the upper pyrometer are recorded as a top view thru the battery block. It is obvious that in the area of heating flue 6-10 extreme low temperatures (“Blue” mosaic blocks) have been measured in longitudinal direction of the battery for nearly all ovens. Looking to the individual temperature profiles, this temperature fault through is also visible (see Figure 5). The temperature drop is so steep, that it seems doubtful to be the result of a heating problem within the heating flues. A graduated temperature transfer takes place between each heating flue and the wall and some equalization will take place in the transfer process, so that a “cold” heating flue will never show such a deep temperature drop in the coke cake. Further investigations have found out that it was not a temperature problem but an undercharging between charging hole 1 and 2. This leads to a valley in the coke line. In other words, in the level of the upper pyrometer there was simply no coke to be measured between charging hole 1 and 2. No coke cake, no temperatures!

This example shows the benefit but also the limitations of the measuring system. Irregularities in the coke cake temperature profile can be easily detected but also can be easily misinterpreted. However, an experienced operator should be able to distinguish between both troubles causes and will draw the right conclusions.
In the dynamic pushing and charging schedule application, named PushSched™, all relevant production data, which means information received from the CCO and calculated values from the dynamic pushing and charging schedule are displayed in an operator interface client application as the human machine interface (HMI). This application is available for standard Microsoft Windows environments and comes with the newest usability techniques, such as docking of tabs, auto sizing of all forms to the aspect ratio and size of the window. On Unix based systems and on some automation systems (i.e. Siemens SIMATIC WinCC) this application can be implemented as Microsoft .Net User Control.

PushSched™ is connected via an OPC connection to the CCO where all oven machine information is available and the cross-battery interlocking is implemented. This interface is used for receiving and sending data from/to the machines.

Most important data-exchange:

Sending direction (COKEMASTER to CCO):
- Push Oven No.
- Push Timestamp
- Charge Oven No.
- Charge Timestamp

Receiving direction (CCO to COKEMASTER):
- Last Pushing Oven No.
- Last Pushing Timestamp
- Last Leveling Oven No.
- Last Leveling Timestamp
- Last Leveling StrokeCount
- Last Charging Oven No.
- Last Charging Timestamp
- Last Charging CoalWeight

There is a cyclic refresh of the HMI-Client application which brings the operators in the Control Room in the position to have nearly a real-time view to the operation outside. The example in Figure 6 shows a typical pushing and charging schedule where the information for pushing is shown in the yellow colored section, for leveling in green, for charging in blue and coking time information in light orange. The last pushed oven, in this example oven #28, is marked by the red rectangle (item no. 1). The information at the bottom (marked with item no. 2a-2c) shows additionally the last push oven, the last level oven and the last charge oven. The bar graphs in the column “Coking Progress” shows the coking progress of the respective oven. Ovens to be operated next, which have reached the scheduled coking time, are displayed as dark green going into dark red color if the target coking time is exceeded (item no. 3). Ovens which are freshly charged are colored yellow, going to light green for ovens in the normal coking process (item no. 4). These colors are configurable and can be stored as general or as user-dependent parameter. Each oven operation is recorded and any significant deviation to the target coking time is marked (item no. 5). Rules can be set to highlight inconstancy in the coke plant production at a glance.

The PushSched™ application is the scheduling tool for all changes in the production process. Implemented assistance functions support the operation personal to guarantee an efficient and balanced oven operation. Immediately after a machine operation is executed the system automatically recognizes this action and considers it for the next update of the schedule. PushSched™ can handle normal production planning as well as all types of special operation (i.e. compensation of breakdown, decreased production, special handling of ovens for repair, ovens with extended coking times, etc.). A re-calculation can be triggered and remade any time when there is a change in production, any operating trouble or any special need to do so. Several strategies are available to handle a loss of production. The loss can be accepted or made up for by increasing production with shortening the coking time in a careful and secure manner for keeping best heating performance and production. The main criteria are to treat the Battery and oven machinery gently to achieve long service lifetimes while keeping up with the scheduled production. The dynamic pushing and charging schedule is closely interlocked with the ThyssenKrupp Uhde GmbH PROven® system to handle the automatic disconnection from the collection main for pushing and reconnection to the collection main for charging.
Additionally the calculated expected coking time is used as set point for the different pressure steps over the coking process and is used for the coking time based interlocking (oven carbonized / oven not carbonized).

In the rare and unpredictable case of communication lost between the COKEMASTER system and the CCO, a buffer of 20 operations for pushing and charging is implemented. After the communication disturbance is resolved, a process for buffer synchronization is triggered, the dynamic pushing and charging schedule system will be updated with the latest machine actions (ovens operated during the outage), followed by a new schedule calculation to update the buffer in the CCO and to bring the system back into full automatic mode.

In addition to this, there is a function in the CCO to drive the machines in Manual Mode. If this mode is selected, the buffer in the CCO is deleted and respectively one pushing target and respectively one charging target can be inserted manually.

Figure 7 illustrates the interconnection between the COKEMASTER® Client application and the subsystems. From the COKEMASTER® - PushSched™ Report (left side) the required information is forwarded to the CCO and from there to the machines and to PROven®.

The performance of the automatic heating control function of the BatControl™ system is displayed in Figure 8 over a period of 7 days. The black curve is the so called “expected Coking Time (eCT), which is an average of individual coking times of the next i.e. 45 ovens to be pushed. Therefore the expected coking time is a look into the future production. The target Coking Time (CT-black line) is scheduled to be approx. 18:30 hours, but due to commissioning work and other delays, in this case the production is fluctuating between 18:00 hours minimum and 27 hours maximum (refer to time period A, B, C). If the coking time increases (i.e. due to a delay in production), the heat input to the battery has to be decreased. If the coking time is decreased (i.e. to speed up the production), the heat input to the battery has to be increased. The heat to the C-Battery is provided by manipulating and controlling the under-firing Gas Pressure (GP - blue curve). If the pushing schedule program detects a delay in production, a new expected coking time development in the future is calculated and the pushing schedule relays it to the heat control system. The heating calculation determines a new heat demand for the battery and in this case the system will decrease the under-firing gas pressure. The same procedure applies to a speed up of production. Therefore each increase or decrease of production (see black arrows) is automatically followed by a variation of the under-firing gas pressure (see blue arrows). It is obvious that a sudden unscheduled increase or
decrease of production will have a direct influence of the coke temperature. Ovens in a delay have extended coking times which leads to over-carbonization and higher coke end temperatures after pushing. Making up for production too fast will result in low coke temperatures, because the heat transfer from the heating flues to the coke cake is slow and needs time and can’t keep up with the sudden heat demand. This interrelation leads to a certain fluctuation of the coke temperature (brown curve). Since the coke temperature is measured on the surface of the coke cake during pushing (by AutoTherm™), a too hot coke is a permanent loss of energy in the battery. The lost heat is no longer available in the battery brickwork, so ovens which are pushed too fast to make up for production are maybe not well carbonized and can produce pollution during the pushing sequence. The heating control system may compensate some of the lost heat automatically, but is limited by the time delay of the slow heat transfer. As the speed-up of production start in period “C” the heat input (gas pressure) is increased immediately. The first ovens are over-carbonized and have enough heat accumulated during the delay, therefore the decrease of temperatures starts with a time delay (green arrow) when the buffered heat has been pushed out and wasted. As the coking time decreases further (from 27:00 hours to 18:00 hours), the coke temperature drops from 1060 degC (=1940 degF) to 975 degC (=1787degF). This happens because the balance of heat supply, heat transfer and heat loss (by decreased coking time) came out of sync. Therefore a fluctuation of production will always lead to a fluctuation of coke temperatures and it is the goal of any automation to keep this fluctuation as small as possible. The red stepped curve is the manually measured heating flue temperature. The heating wall temperatures are not so good for controlling the heat, because they are sampled not so frequently and therefore they are not so reactive to production changes. But it is interesting to see that the heating flue temperatures are not so much fluctuating as the coke temperature. They are more or less in a narrow band around the orange dotted line. This shows that the control is on target and the automatic adaption of the under-firing gas pressure by the BatControl™ system has been done well in advance to keep up with heat demands.

**COKEMASTER® - WOBBE & O2-CONTROL**

The under-firing pressure is only one out of multiple heating parameters which influences the burning of the gas. The heat input is a multiplication of gas-volume and calorific value, whereas the gas volume is a direct function of the gas pressure. A measure for the calorific value is the Wobbe-Index. If the Wobbe (=gas composition) is very stable, the production demand is the only influencing factor for the gas pressure controller. But if the Wobbe is not stable, the fluctuation of the Wobbe must be compensated as well. This can be done by cascading a Wobbe control on top of the under-firing gas control. Wobbe fluctuations are compensated by adapting the gas pressure to maintain under all circumstances a constant energy supply to the battery while having a complete “smokeless” burning of the gas. To reach this goal, the waste gas pressure must additionally be adjusted to the changes in the under-firing gas pressure to suck enough oxygen thru the heating system for getting an optimal burning result. For the given production demand and the given gas quality, the heating control system BatControl™ calculates the optimal oxygen content for best “smokeless” burning results. Best burning results can only be achieved with a gas to air ratio (Lambda) of 1.2, which means 20 %
for the basic heating requirements of the production but corrected for Wobbe fluctuations. As can be seen, the Wobbe fluctuations are perfectly compensated by the gas pressure controller (black arrows). Whenever the Wobbe goes up, the gas pressure will be reduced accordingly and vice versa to maintain a balanced energy input. The green curve is the controlled chimney suction counted as a negative value from the top (-15 mmH2O) to the bottom (-60 mmH2O) of the graph. The chimney suction works in the same direction as the gas pressure (blue arrow). Whenever the gas pressure increases (=more gas to burn) the chimney suction is increased accordingly to bring in more air to the heating system. In the example in Figure 9, the heating control has increased the gas pressure to 105 mmH2O (blue arrows) and at the same time the chimney suction is raised to -38 mmH2O (green arrows). To avoid incomplete combustion and smoking of the chimney under all circumstances, a special safety mechanism has been developed. The chimney suction is automatically increased as soon as the oxygen in the waste gas goes below 4% (see red and orange markings). With these special features of the C-Battery automation system, the combustion in the heating system and the heat demand of C-Battery is well controlled.

**COKEMASTER® - RAMFORCE™**

RamForce™ is part of the COKEMASTER®-Framework and is a tool to monitor the pushing performance and to support the maintenance of the oven. The pushing force is a good indicator for the oven conditions (i.e. heating and wall alignment) as well as pusher machine ram condition (i.e. ram alignment and straightness). The current consumption of the frequency controlled ram drive motor is a
rect indication of the forces during the pushing progress. The Amperage values from the frequency converter are recorded by the AutoTherm PLC and correlated to the travel path of the ram. The recording starts as soon as the ram move out of its home position. This allows conclusions about all travel related forces as well as conclusions of mechanical performance of the ram drive system.

During the commissioning of the C-Battery, the pushing sequence for the coke oven battery was altered. This led for a short period of time to ovens with extended coking times. How these ovens behaved while pushing was monitored by RamForce™ and evaluated by the persons responsible for operation as shown in Figure 10.

The pushing force curves above the red line shows the ovens on extended coking time (33-42 hours) with ~30Amps higher maximum pushing force in comparison to ovens with normal coking times (approx. 19 hours). This is caused by a structural change of the coke in the ovens with longer coking time. Due to the over-heating of the coke cake, the coke granulation becomes smaller and smaller which leads to a disintegration of the coke cake stability. This means the coke start to lean closer to the oven chamber walls which creates additional friction during pushing. This leads to the effect that the coke cake needs additional force to be pushed out smoothly.

CONCLUSION

The coke plant process control level system from IMS in combination with ThyssenKrupp Uhde’s online process optimisation system is a powerful software solution for the automation of the C-Battery in U. S. Steel’s Clairton coke plant. All systems from coke plant operation level up to the coke plant managemeent have been successfully taken into operation already before or shortly after the start of production (first coke) and have fully met the requirements of the operation. With its sophisticated automation systems the C-Battery is up to this date the most modern coke plant in the USA.

ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Explanation</th>
<th>Abbreviation</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>CCC</td>
<td>Coal Charge Car</td>
<td>OPC</td>
<td>OLE for process control</td>
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<tr>
<td>CCO</td>
<td>Coordinating PLC</td>
<td>OVN</td>
<td>Oven number</td>
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<tr>
<td>CHGTM</td>
<td>Charging time</td>
<td>PAU</td>
<td>Pause time between pushes</td>
</tr>
<tr>
<td>CMS</td>
<td>Coke Plant Management System</td>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>COKTM</td>
<td>Coking time</td>
<td>PECS</td>
<td>Pushing and Emissions Control System</td>
</tr>
<tr>
<td>CTC</td>
<td>Coal Transfer Car</td>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
<tr>
<td>CWT</td>
<td>Charging weight</td>
<td>PM</td>
<td>Pusher Machine</td>
</tr>
<tr>
<td>degC…degF</td>
<td>degree Celsius ….degree Fahrenheit</td>
<td>PROven®</td>
<td>Pressure Regulated Ovens</td>
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<td>FAT</td>
<td>Factory Acceptance Test</td>
<td>PTIME</td>
<td>Pushing time</td>
</tr>
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<td>FES</td>
<td>First Engineering Submittal</td>
<td>QC</td>
<td>Quench Car</td>
</tr>
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<td>HMI</td>
<td>Human Machine Interface</td>
<td>RFID</td>
<td>Radio Frequency Identification</td>
</tr>
<tr>
<td>HQC</td>
<td>Herat Quantity Calculation</td>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/Output (used for electrical signals)</td>
<td>SES</td>
<td>Second Engineering Submittal</td>
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<tr>
<td>ma….mA</td>
<td>milliampere (1/1000 Ampere)</td>
<td>WT</td>
<td>Coal moisture</td>
</tr>
<tr>
<td>MBT</td>
<td>Mean Battery Temperature</td>
<td>VFD</td>
<td>Variable Frequency Drive</td>
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<tr>
<td>O2</td>
<td>Oxygen</td>
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</table>

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