

Using modern coke oven technology at the new Hyundai Steel coke plant

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ABSTRACT

Hyundai Steel built a coke oven plant together with ThyssenKrupp Industrial Solutions (formerly ThyssenKrupp Uhde) in Dangjin (South Korea) consisting of 380 large capacity ovens (7.63 m chamber height / 76.2 tons of coal), five sets of oven machines and two separate by-product plants. The plant was taken in operation in three phases during the years 2009-2013 and has an overall annual production of approx. 5 Million tons of coke and produces 290.000 m³ coke oven gas per year. It is worldwide one of the biggest coke plants recently build. The plant is equipped with the latest state of the art technologies. Worth mentioning are the single chamber pressure control system, the extremely low emission quench towers, the total integrated distributed control systems of the battery and by-product site, as well as special analyzers for process control, environmental protection and quality management. A Level-2 framework for production supervision and optimization was implemented and comprises an automatic systems for the control of oven machines, adjustment of battery heating, chamber wall temperature measurement, pushing force evaluation, etc. This framework is also collecting, processing and submitting plant data and results to higher level management systems. The presentation gives an overview, details the technology “in use” and shows the results for production, safety and the environment. Some operation examples are given to allow the audience to evaluate the benefits.

INTRODUCTION

In 2007 Hyundai Steel Company decided to build a new coke oven plant together with ThyssenKrupp Industrial Solutions (formerly ThyssenKrupp Uhde) near the town of Dangjin in South Korea (Republic of Korea). The coke plant consists of 6 batteries with a total of 380 large capacity ovens (7.63 m chamber height / 76.2 tons of coal), five sets of oven machines and two separate by-product plants. The plant was taken in operation in three phases during the years 2009-2013 and has an overall annual production of approx. 5 Million tons of coke and produces 290.000 m³ coke oven gas per year. It is worldwide one of the biggest coke plants recently build. The coke plant was integrated into a new steel plant complex to serve the needs of the blast furnaces and other consumers (Figure1).



Figure 1: Hyundai Steel Industrial Complex – near Dangjin / South Korea

The plant was built in three phases. Phase 1 and Phase 2 consists of 4 (four) batteries with 60 ovens each, means 240 ovens in total and one Gas Refinery Plant. The coke plant is split into two operational blocks. Each block has two batteries, a common coal bunker, a common coke wharf with automated plough feeder, and a (CSQ) low emission quench towers at each end. Between the two operation blocks is a so called Central Control Building, which includes the maintenance facilities, operation offices and the Central Control Room to supervise and control all 4 batteries, the oven machines, all coke making plant units and the coal and coke handling facilities. A conventional quench tower in the middle between the blocks is in stand-by as an emergency system. Each operational block is served by its own set of machines (one pusher machine, one transfer car, one coal charging cars and one quench car) and a shared pushing emission control system (PECS). An additional set of stand by oven machines is located in between the operational blocks if any machine requires maintenance. All machines are designed to run in man-less operation, however they are still staffed for safety reasons. Under normal production with 28.3 hours gross coking time and an average heating flue temperature of 1245 deg.C, the **Coke Oven Plant** (abbrev.: **COP**) of Phase 1 and Phase 2 are designed to produce 3.14 million tons of coke per year and supply 170,000 Nm³/h (approx. 105,000 scf/m) raw gas to a new **Gas Refinery Plant** (abbrev.: **GRP**) located opposite to the batteries. The Gas Refinery Plant has its own instrumentation and control environment and is supervised and controlled from a control room in the Gas Exhauster Building. Phase 1 went into operation in 2009 and Phase 2 in 2010. To increase the production further, Hyundai steel company contracted in 2011 another 2 batteries with 70 ovens each (meaning 140 ovens in total) and a second Gas Refinery Plant. The batteries and the Gas Refinery Plant were designed according to the design of the phase 1 and 2 units. An additional operational block with two batteries (70 ovens each) was built adjacent to the Gas Refinery Plant and battery blocks of Phase 1 and Phase 2. This operation block is similar to the other phases with a coal tower between both batteries, two CSQ-quench towers, two coke wharfs and two sets of machines (one in operation, one in standby). Due to the increase of ovens per battery, the two batteries of Phase 3 are designed to produce 1.79 million tons of coke per year and 97,000 Nm³/h of raw gas under normal production. To refine this amount of gas, an additional Gas Refinery Plant was built on the southern border of the construction space. A separate control building for the Phase 3-Coke Oven Plant (COP) was build close to the batteries. This control building has the same function as the Central Control Building between Phase 1 and Phase 2 (Figure 2).

The following picture (Figure 3) shows an aerial view of all six batteries (numbered 1-6 in “blue” numbers) and the associated Gas Refinery plants (labeled “green” and “yellow”). The picture has been taken at a time when Phase 3 was still under construction. The coal storage area is not an open yard but a hangar with separation walls for each type of coal, also still under construction on

this picture. Since the steel complex is at the coast side and close to a nature reserve, coal erosions from the piles by wind and rain are not acceptable. Therefore the coal yards for both Phases are roof covered. The Phase 3-plant started successfully in 2013 and went to full production shortly after commissioning.

Due to the advanced heating system which includes air stage heating, as well as internal waste gas re-circulation, the NO_x-content in the waste gas of the coke oven batteries is reduced to a minimum. The design fully considers the required limit for NO_x-content in the waste gas of max. 180 ppm at 7% O₂. In order to distribute the heat in a coke battery according to the requirements of the coal charge, the flow of individual combustion media (coke oven gas, mixed gas, combustion air, and waste gas) must be exactly adjusted. Because the calibration of these gas flows is accomplished by careful selection of pressure losses, this system calls for a gas distribution system with precise adjustment and control capabilities.



Figure 3: Aerial View (Phase 3 still under construction)

The gas flows to the coke oven battery are conducted in the direction of battery length, oven length and oven height, which require an adaptable distribution of media. The Hyundai Steel coke oven batteries are using the COMBIFLAME® heating system which consists of special heating flues, equipped with bottom and wall air stage and with internal waste gas re-circulation (Koppers – Re-circulation Heating). It means that the combustion air is fed at three stages (1st at the heating flue sole, 2nd and 3rd about 1/3 and 2/3 of the wall height respectively) into the heating flues (see figure 4).

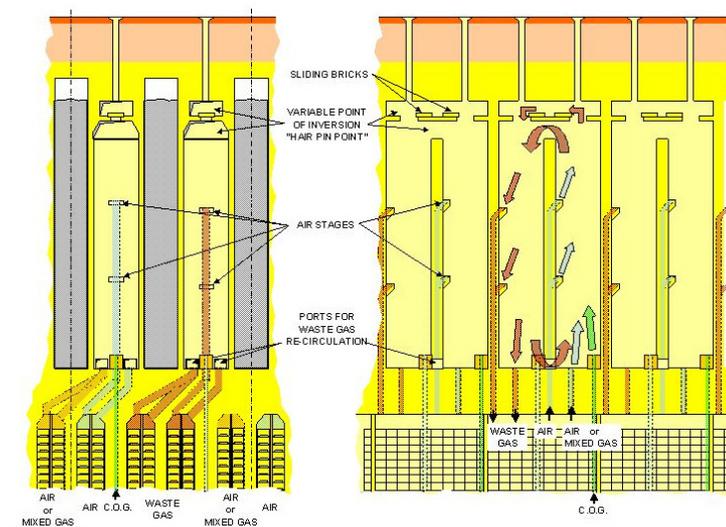


Figure 4: Hyundai Steel Battery Heating System

control system, which reduces and controls the gas pressure in each single oven chamber, the amount of gaseous emissions from the ovens is reduced additionally. The CSQ wet quenching system used in the Hyundai Steel Coke Oven facility is the only wet quenching system which reduces the dust emissions in the quenching vapors to below 15 g per ton of coke. However, spaces for CDQ-plants are still foreseen in the layout of the plant.

This feature alone leads already to a substantial reduction in NO_x formation due to the under-stoichiometric combustion at the heating flue sole. In addition, the waste gas re-circulation at the bottom part of the partition wall of a twin flue recycles waste gas from the down-burning into the up-burning heating flue. Thereby the combustion at the bottom becomes leaner, the flame peak temperature is reduced, and the formation of NO_x is further reduced. Besides this, the flame length can be controlled and optimized which leads to a very uniform temperature profile in the heating flues and in the walls. Both measures in combination lead to a heating system which is unique in coke oven heating and ensures minimal formation of NO_x and optimum temperature distribution.

One of the advantages of the large capacity wide chamber ovens in the Hyundai Steel plant is that the number of pushes per day in relation to the coke production capacity is very low. As most of the emissions from the ovens occur during pushing and charging, this reduces the amount of emissions largely. By applying a single chamber pressure

The Gas Refinery Plants of Phase 1+2 and from Phase 3, besides having to adapt to different gas volumes, are equipped with the same processing units. Therefore, it is sufficient for the general understanding to show the gas flow, the flow of utilities and the flow of refined products of the Gas Refinery Plant in a process flow diagram for Phase 1+2 only (Figure 5).

The raw coke oven gas evacuated from the gas collecting main of the new batteries will be exhausted from the pusher side of the ovens via the down comer to the condensation plant by one separate gas pipeline for each phase. Before coke oven gas can be used as fuel, it has to be treated. The extent of treatment depends on the particular demands made on the fuel gas and, if coal chemicals are to be simultaneously recovered, on economic considerations. Air and water pollution control regulations have to be observed

accordingly. The first stage of the gas refinery plant is the so-called condensation, consisting of primary gas cooling including preliminary naphthalene and tar removal, tar separation and coal water treatment. During gas cooling water vapor and tar is condensed. Simultaneously naphthalene is condensed to a dew point slightly below the gas temperature. By treating the liquid mixture condensed in the primary gas cooling and separated from the coke oven gas in the down comer at least three products are obtained: Flushing liquor for the use in the gas collecting main spray system, coal water and crude tar. Tar and water separation take place by gravity in a cone type tar separator. For the storage of the crude tar storage tanks with conic bottom are installed. From the storage tank the crude tar is pumped

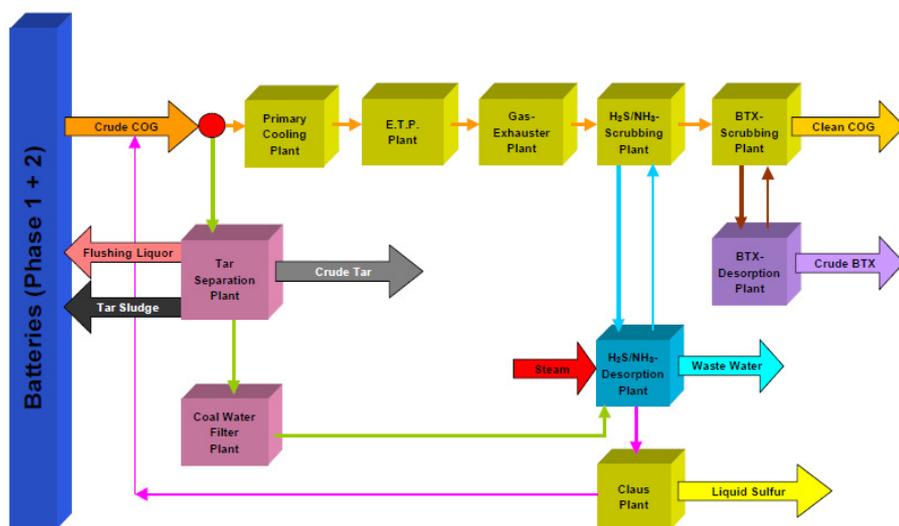


Figure 5: Hyundai Steel Gas Refinery Plant (Phase 1-2) – Process Flow Diagram

to the harbor for ship loading or it can be loaded into tank trucks. To separate remaining tar and water droplets from the coke oven gas, electrostatic tar precipitators (ETP), each equipped with a high voltage unit, is installed downstream of the primary gas cooling. Downstream of the ETP, motor driven gas exhausters are located, which transports the coke oven gas through the gas refinery plant and up to the gas distribution system. Downstream of the gas exhausters, hydrogen sulfide and ammonia is removed from the gas by means of circulating scrubbing water in a combined scrubber, using structured packing as internals. The circulating water is treated in the H₂S/NH₃ desorption plant. The excess ammonia liquor (coal water) mixed with different condensate streams from the plant units is pre-treated in the H₂S/NH₃ distillation plant to such an extent that it can be fed to the biological waste water treatment plant. Before distillation, the pre-cleaning of the coal water is done in a coal water filter plant.

The vapor from the desorption columns is fed to one of two Claus plants where ammonia is destructed and hydrogen sulfide is transformed to elemental sulfur. In the next gas refinery stage BTX is removed by means of regenerated tar based wash oil. The naphthalene content is also reduced to ensure that the dew point cannot be reached in the gas network. For the BTX removal a packed type scrubber is provided. The enriched wash oil is treated in the BTX desorption plant by means of indirect heating and direct stripping. Three products are leaving the distillation unit: regenerated wash oil, crude BTX and steam condensate. For the produced crude BTX storage tanks are provided before pumping to the harbor for ship loading or loading into tank trucks. After the BTX scrubbing plant, the cleaned coke oven gas is fed to the network of the steel works. A part can be sent to the coke oven battery for heating purpose. All treated effluents from the coke plant are taken from the sump of the H₂S/NH₃ desorption column and given to the biological effluent treatment plant (BWWTP) after cooling and intermediate storage in tanks. All equipment is connected to an emission control system, as far as required. The emission control system is fed by nitrogen and drained to the coke oven gas suction main.

Coke Plant Automation Overview

The plant is equipped with the latest available automation technology and equipment. The automation is structured in the classic levels, from Level 0 (Field Level) up to Level 3 (Management Level). The automation design is divided into six basic equipment layers (see Figure 6).

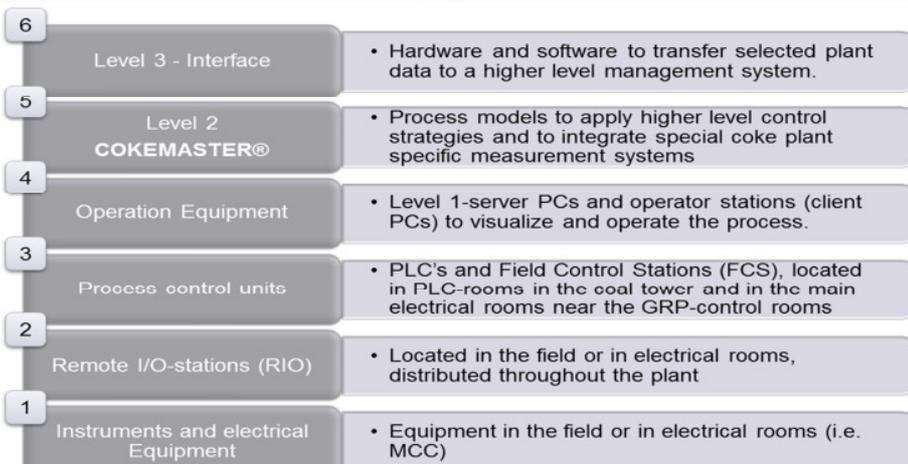


Figure 6: Hierarchy of Automation

The electrical energy is supplied from the 33 kV power station via a transformer into a 6.6 kV switchgear and is distributed to various locations inside the coke oven and gas refinery plant. Some plant units are using high voltage 6.6 kV motors, multiple transformers in various locations are reducing the power from 6.6kV to 460 V, Load Centers in each Phase are redistributing the power to centralized Motor Control Centers (MCC). Intelligent switching technology is used. The 6.6 kV power is redundantly supplied and distributed via the high voltage and low voltage switch-gear in such a way, that the input power can be switched between the two sources. This switching concept is carried on in Load Centers and MCC's

as well. Emergency Generators and Uninterruptible Power Supply units are available to supply power for selected equipment in case of a general power failure. The electrical equipment, the control elements and the instrumentation are generally connected to redundant remote I/O units (RIO) done by standard 4-20mA and 24 DC interfaces. Intelligent subsystems are usually coupled with Profibus or Modbus. The following table gives an overview of the electrical, instrumentation and control system installation as well as field analyzers for process control, process monitoring and alarming (Figure 7).

Electrical equipment		Instrumentation and Control		Automation	
10 pc	Switch houses	22 000 pc	Signals	25 pc	Server PC's
1500 pc	Power switching units	8500 pc	Function diagram	63 pc	Operator Stations
390 pc	Switch panels (0,46 kV, 6,6 kV, 33 kV)	15 000 pc	Measurement Points	16 pc	Backbone Network Switches
45 pc	Package units	1200 pc	Controllers	32 pc	Process- and IT-Bus Switches
5 pc	UPS 80+120kVA	10 pc	Flow Measurements, Gas	71 pc	PLC and Field Control Stations
45 pc	Transformers (Oil & dry)	40 pc	Flow Measurements, Fluids	60 pc	Field-Bus Switches
450 pc	Street Lamps	4 pc	Analyser for Waste Water	250 pc	Field-Bus- Lines (Profibus + Modbus)
85 pc	Cameras (Video)	250 pc	Analyser for CO-Monitoring/Alarming	200 pc	Remote I/O Stations
150 pc	Telephones	10 pc	Analyser for O ₂		
120 pc	Intercommunication systems	4 pc	Analyser for H ₂ S / SO ₂		some numbers are approximations only
50 pc	Butterfly Valves, hydraulic/electric	20 pc	Analyser for H ₂ S Monitoring/ Alarming		
3100 km	Cable for Electric	14 pc	Analyser for Benzene Monitoring/ Alarming		
1000 km	Cable for instrumentation	10 pc	Analyser for pH / Turbidity		
50 km	Fiber optic cable (Profibus)	3 pc	Analyser for Coal Moisture		
20 km	Installation conduit (stainless steel)	3 pc	Analyser for Waste Gas (CO ₂ , SO ₂ , NO _x , CO)		
25 km	Installation tube (stainless steel)	3 pc	Analyser for Waste Gas (Dust)		
10 km	Fire resistant cable protection	6 pc	Analysers for Calorific Value /Wobbe		
		4 pc	Burners for Claus-Plant		

Figure 7: List of Electrical, Instrumentation and Automation Equipment for COP and GRP (Ph.1-3)

All automation equipment is connected via a fiber optic plant network which runs through all plant locations in which relevant

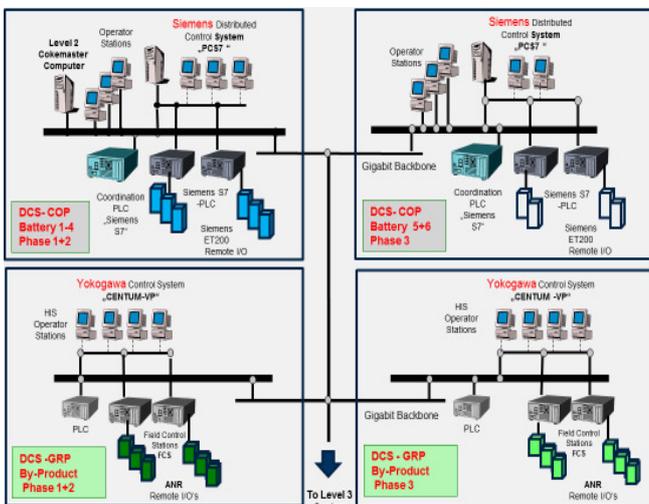


Figure 8: General Set-Up of the Process Control Systems



Figure 9: View into the Control Rooms

equipment is placed. All data are collected and distributed through this network, whereby data source and data target can be flexibly connected with each other using physical connections by patch panels and switches as well as logical connections using a network management system. Through this network all systems are able to communicate with each other.

In the **Coke Oven Plant area (COP)** of Phase 1 and 2 an integrated “state of the art” **Distributed Control System (DCS)** is used on the process control level. Many applications in the COP are sequence control functions, which are best executed by programmable logic controllers (**PLC**), a PLC-based DCS was selected (Siemens S7 with PCS7). On the process control level of Phase 1 and 2 **Gas Refinery Plant (GRP)**, the automation is realized by another DCS system which is specialized on continuous control functions (Yokogawa CENTUM-VP). Both systems, coupled with each other via Modbus, are designed as integrated control systems to realize the control for both, electrical and instrumentation equipment. The control system enables an operation of the plant via operator control stations, located in separate control rooms. Phase 3 again has individual control systems from the same makers (Figure 8). Besides having operator control stations for all major plant units, the four modern control rooms are equipped with large size video screens, including split screen capacity, audio paging systems, Intranet-access, etc. (see Figure 9).

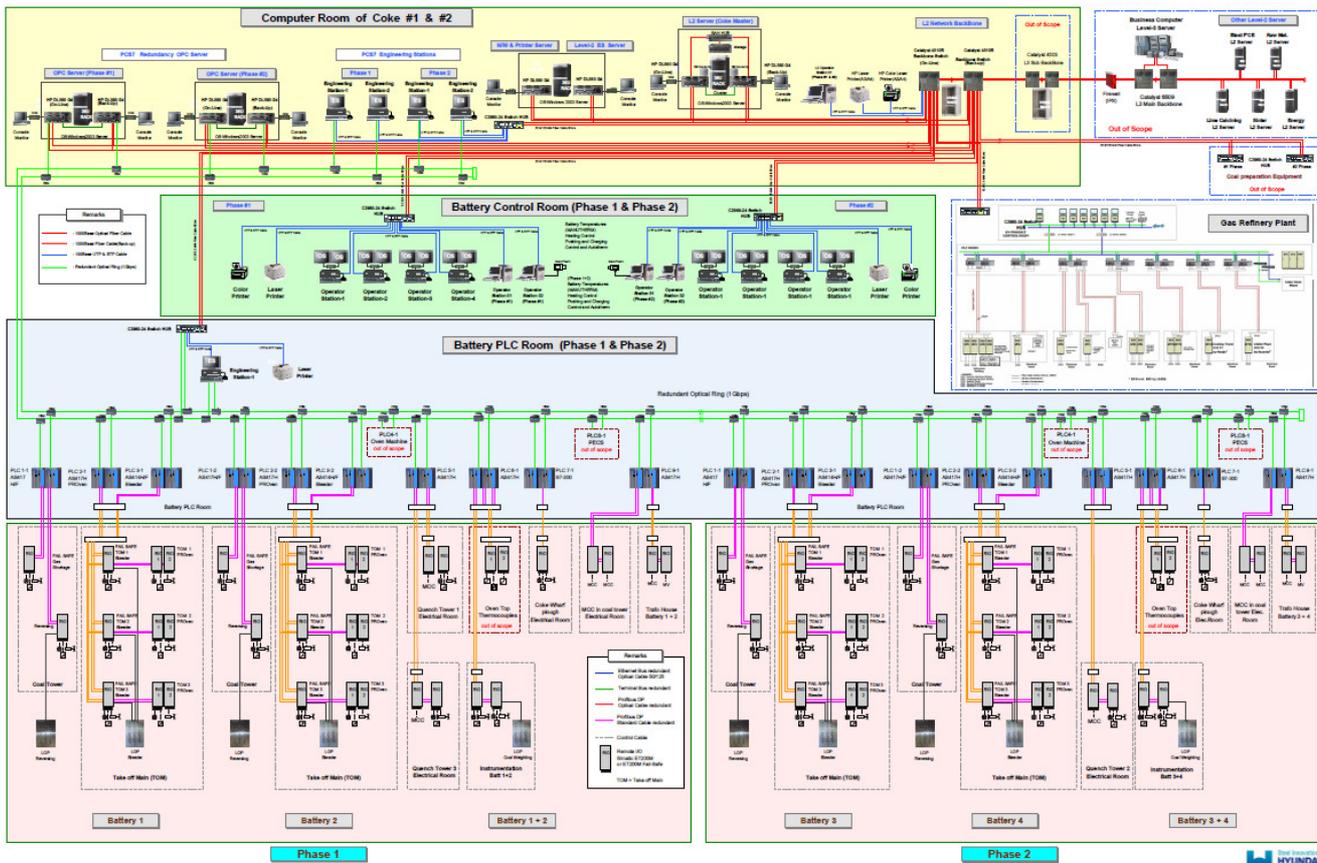


Figure 10: Network and Automation System Configuration COP and GRP – Phase 1 +2 (Ph.1-2)

The complete Network and System Configuration of Phase 1 and Phase 2 for the Coke Oven Plant and the Gas Refinery Plant are shown in Figure 10. The area in pink color shows the COP-Remote I/O level, the blue area shows the COP-PLC-level, the green area shows the COP-operation level and the yellow area shows the system administration level with server and network equipment. In the upper right corner, the interface to the Level 3 systems (Business-Blast Furnace-Raw Material –Lime Calcining-Sinter-and Energy Center Computer) is shown. The area, marked in white color, shows the GRP-DCS-System. The layout for the Phase 3 system is similar except the remote I/O area which is half the size of Phase 1+2 because it handles two batteries only.

SOME SPECIAL AUTOMATION EXAMPLES

Modern instrumentation and control equipment connected to PLC’s or Distributed Control Systems (Level 1) with operation stations on top are standard in modern industry facilities. The Hyundai Steel Coke Plant is using these standards as described above plus additional automation for advanced control and optimization functions. Some of these systems are covered in the successive chapters as following.

PROVEN[®] (PRESSURE REGULATED OVEN) - SYSTEM

Within the nineties a first version of a single oven pressure regulation system (PROven[®]) was developed by the DMT-company (Deutsche Montan Technologie GmbH) in Germany. Since 2002 TKIS has improved the system continuously based on its own practical experience made on more than 2100 oven installations all over the world. As the essential patents, including the name rights, for the system ran out in March 2014 the license contract between DMT and TKIS ended at that time. TKIS decided to continue the successful marketing of the improved PROven technology under the new brand name **EnviBAT[®]** pressure regulation system for the reduction of fugitive emissions at coke plants. Since 2010 it has been accepted as a Best Available Technique (BAT) [Ref. 1]. However, the system at the Hyundai Steel Plant was contracted, licensed and build under the name PROven[®] and therefore still referenced with this name within this paper.

All 380 ovens on all six batteries are equipped with the PROven[®] System. Figure 11, shows the gas collecting main and the gooseneck equipped with the system which had been installed in the Hyundai Steel Plant. The schematic picture on the left side illustrates how the gas flows through the crown tube and fix-cup, the middle picture shows the complete set-up in and above the collection main and the right picture shows the installation on site.

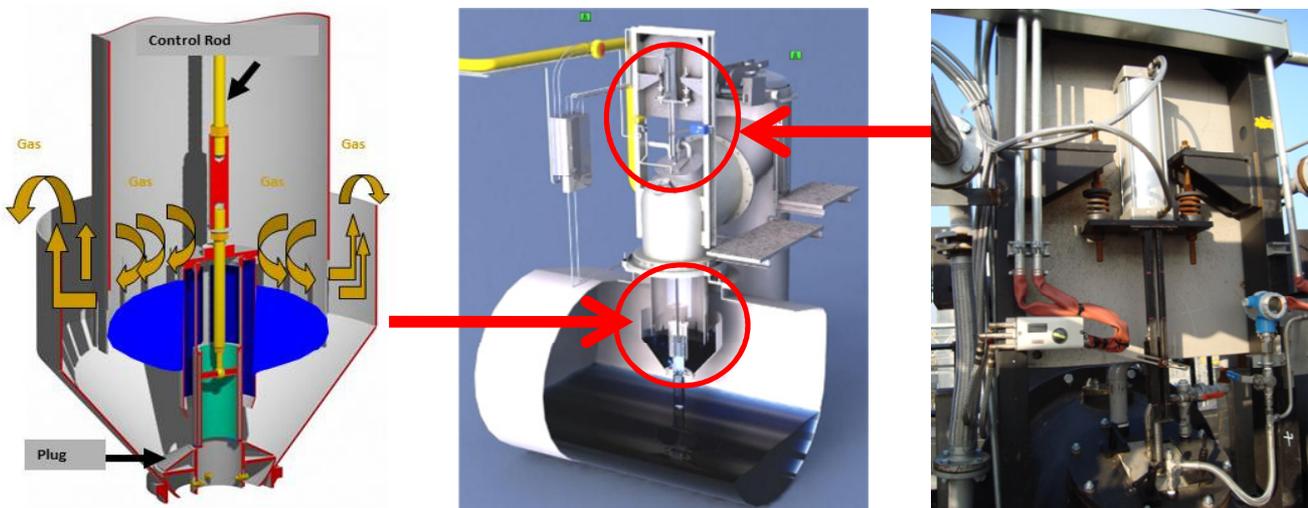


Figure 11: Set-up of PROven[®] System at Hyundai Steel coke making facility

The FixCup (left picture) is installed between the standpipe and the crude gas collecting main. By means of the closure plug equipped with a regulating device and connected to a control rod. In its extension, the standpipe gooseneck terminates in a so-called crown tube, protruding with the crown slots existing therein into the FixCup. Also installed in the standpipe gooseneck are two spraying nozzles which on the one hand provide for cooling the hot crude gas and on the other hand for wetting the gas collecting main to prevent encrustation of tar and other deposits. Furthermore, by way of the quick filling valve, the FixCup can be quickly flooded while a coke oven has been disconnected from the gas collecting main. Mounted in the gooseneck are various apertures and opening ports for connection, assembly and maintenance to install the equipment of the pressure control and/or to clean the gooseneck. The regulation of the oven pressure is done by a variable pressure resistance for the generated crude gas, created by slots in the crown tube. The slots are opened more or less by means of a variable water level in the FixCup. The water level is influenced by the overflow regulation device, which maintains a certain water level within the FixCup depending on the set-point of the oven chamber pressure. The water level in the "Fix-Cup" is directly related to the position of the passage piston of the overflow-regulation device. The drive of the overflow-regulation device is a pneumatic cylinder which is connected with the overflow-regulation device by a rod. The pneumatic cylinder is controlled by a both side working positioner, receiving its information from a control system, which processes the oven pressure measurement. The oven pressure is measured within the gooseneck, from where it is transmitted to the control system. During the carbonizing time the oven pressure will be increased stepwise from approx. +3 mmH₂O (= 0.3 mbar) at the beginning of the carbonizing time, when the amount of generated crude gas and the danger of emissions is on its highest level, to approx. +16 mmH₂O (1.6 mbar) at the end of the carbonizing time, when the amount of generated



Figure 12: Collection Main

crude gas is dropping against zero and therefore the danger of emissions is very low. The final adjustment of the set-points has been done during commissioning after pressure measurements behind the oven doors at oven sole level have been executed. The goal was to adjust the oven pressure in such a way that the lowest possible pressure in the oven can be achieved at all times without creating suction behind the doors at oven sole level. The gas collecting main is located on the battery's pusher side (figure 12). It comprises of 3 sections. Each collecting main section is equipped with two gas bleeders to be able to discharge crude gas directly at the battery in case of an emergency. Water sealed valves form the closure between gas collecting main and the atmosphere. The bleeder valves are pneumatically driven and open automatically at a pre-defined maximum pressure in the gas collecting main. Ignition of the crude gases is effected by an electrical arc system which starts ignition immediately before opening the bleeder valves. The collecting main pressure is controlled by a control valve in each of the off-take mains. The negative pressure provided from the exhauster, is throttled upstream of the control flap so that merely as much crude gas is discharged as is required to maintain the defined pressure in the gas collecting main.

Figure 13 shows an example of the HMI (Human-Machine Interface) of the PROven®-system together with a trend plot of the oven pressure control. The HMI consists of multiple operator displays which enables the battery operator to monitor and adjust the system (in automatic mode) and if necessary to operate the system in manual (i.e. in case of emergency). The display in figure 13 is

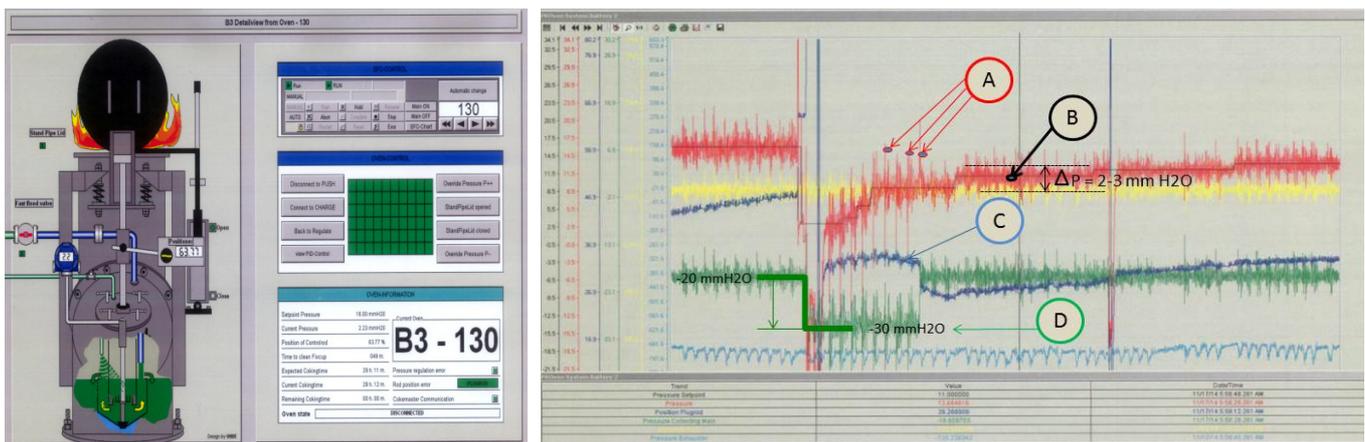


Figure 13: PROven® Operation Display (HMI) and Pressure Control Curve

a representation of the standpipe / gooseneck equipment for one selected oven (Oven 130 of Battery 3). The display is animated and shows the actual operation situation. In this case the oven is disconnected from the gas collection main and the standpipe-lid is open. All process values like oven pressure, water level inside the fix-cup, status of all control elements, last coking time, status messages, etc. are shown. If switched to manual operation, all operation functions like “connect to charge”, “back to regulate”, “close the standpipe lid” etc. can be manually initiated within the proper operation sequence. Some interlocking sequences are still active to avoid harmful operation mistakes. Manual operation without PLC-control and interlocking sequences can only be done from the pneumatic control panel which is located directly in front of the respective standpipe. A trend display for each oven can be selected at the HMI, which shows the main process values in terms of time. The above example shows the control curves of an oven which is approx. 8 hours in its coking cycle. The red curve represents the oven pressure. The oven pressure is raised from end of charging in steps according to the set points, shown as a black curve in the middle of the red curve. The set point of the oven pressure is quickly increased in 8 hours from +3 mmH₂O (right after charging) to +13 mmH₂O in seven steps. Since the raw gas development in the beginning of the coking cycle decreases rapidly, the oven pressure follows in short but big steps. Whenever an oven is charged, the charging peak (created by the sudden development of raw gas) leads to sudden pressure fluctuations in the collection main. These fluctuations are transmitted backwards into each oven of the respective collection main. The PROven® control counteracts these fluctuations, but the peak pressure develops so quickly that the control is not able to completely compensate the peak. These remaining peaks are marked under label “A”. Even so charging peaks from other ovens have an effect to the controlled oven pressure of the PROven®-System, the oven pressure can be kept in a control range of 2-3 mmH₂O (see label “B”). The con-

trolled collection main pressure of minus 20 mmH₂O is increased to minus 30 mmH₂O to add additional suction to each collection main as soon as the first oven on this main is charged (label “D”). Proven-Control compensates the increased suction (-30 mmH₂O) by increasing the position of the control rod (= increasing the water level). The increased water level is reducing the free space of the crown tube slots, which keeps the oven pressure on target (label “C”).

COAL MOISTURE ANALYSERS

A lot of moisture measurement systems are available on the market. Surveys have been made to evaluate different measurement principles whether they are suitable to measure coal moisture or not [Ref. 2]. It is a common understanding between coal moisture measurement specialists that the only reliable method to measure the coal moisture on-line is to use “Microwave with Area Weight Compensation”. Microwaves are a highly accurate way to measure moisture due to the fact that microwaves are highly selective to

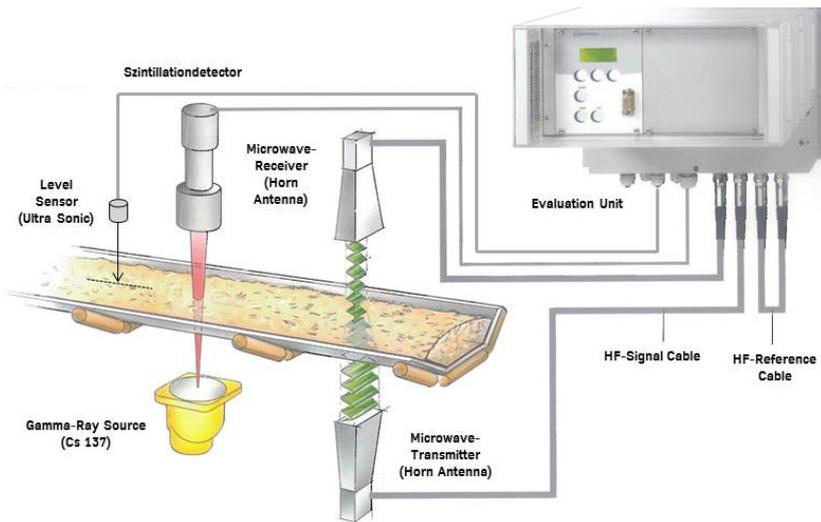


Figure 14: Set-up of the coal moisture measurement system [Ref. 3]

water. Microwaves penetrate the material to be measured. Water molecules are naturally polar, which causes the microwaves to weaken and slow down significantly. The dielectric constant of the material indicates the influence on the microwaves. The dielectric constant of water is 20 times larger in comparison to other materials. This results in a strong interaction of the microwaves with water which are then measure as attenuation and phase shift. To ensure that reflection and resonance do not affect the measurement, multiple frequencies are used and evaluated. Hereby irregular influences of geometry changes, as the layer thickness of the material in spite of a compensation for area weight are nearby eliminated. The phase shift measurement is additionally needed because it is less influenced by several disturbances and results therefore in a better accuracy. Therefore a combination of attenuation and phase-shift further results in a reduction of disturbances, which additionally improves the accuracy. By combining to measure phase shift and attenuation, a precision better than 0.2% can be achieved which is from the measurement “point of view” sufficient to use the moisture value for heating control.

If the bulk density varies, which is the case operating with different coal blends and different grain size distributions, an additional radiometric measuring unit is needed. The layer thickness and bulk density has an impact to the measurement results. It can be largely eliminated by normalizing attenuation and phase shift to the mass per unit area, which is determined by gamma-ray transmission measurements. In this transmission measurement the weakening of the gamma-ray intensity, which depends on the area weight, is measured. As a result, a density-independent moisture signal can be obtained, ensuring the highest possible precision for optimal process control. If at the same time the coal layer thickness is measured close to the gamma-ray source e.g. with an ultrasonic level sensor, the bulk density of the coal can be determined (area weight multiplied with the layer thickness = bulk density). The microwaves are transmitted using a pair of so called horn antennas. One is installed above the belt and the other is below the belt. Due to this transmission geometry a large percentage of the whole volume is measured. This provides a very accurate representation of the moisture content throughout the coal layer. Therefore the moisture inside the full coal layer is measured and not only the surface moisture. The gamma ray source (Nuclide Cs 137) is installed below the belt. It must be as close as possible to the microwave emitting horn antenna so that the same coal portion at the same place and time are referenced with each other (attenuation and phase shift are correlated with area weight in real time). Vertically centered to the gamma ray source is the gamma ray detector (so called Scintillation detector) installed above the belt. The two horn antennas, gamma-ray source and the gamma ray detector are connected with special HF-signal cables to an evaluation unit which correlates and calculates moisture and bulk density in real time. Reference curves obtained from multiple calibration tests (on-line moisture over Lab-moisture) are stored in the evaluation unit for multiple coal consistence or blends. These integrated reference lines ensures reliable compensation of environmental influences. In this way the water content and bulk density of the coal can be very accurately determined.

Three measurement systems were installed in all three coal towers of Phase 1-3 and adopted to the very special coke plant environment. The set-up of the installation is shown in Figure 14. Besides the equipment mentioned in the set-up description, some more items are needed to make the system work. The measurement works best, if the surface of the coal is straight and flat. Therefore it is mandatory to put some flattening equipment in front of the measurement set-up. The next picture shows the equipment to

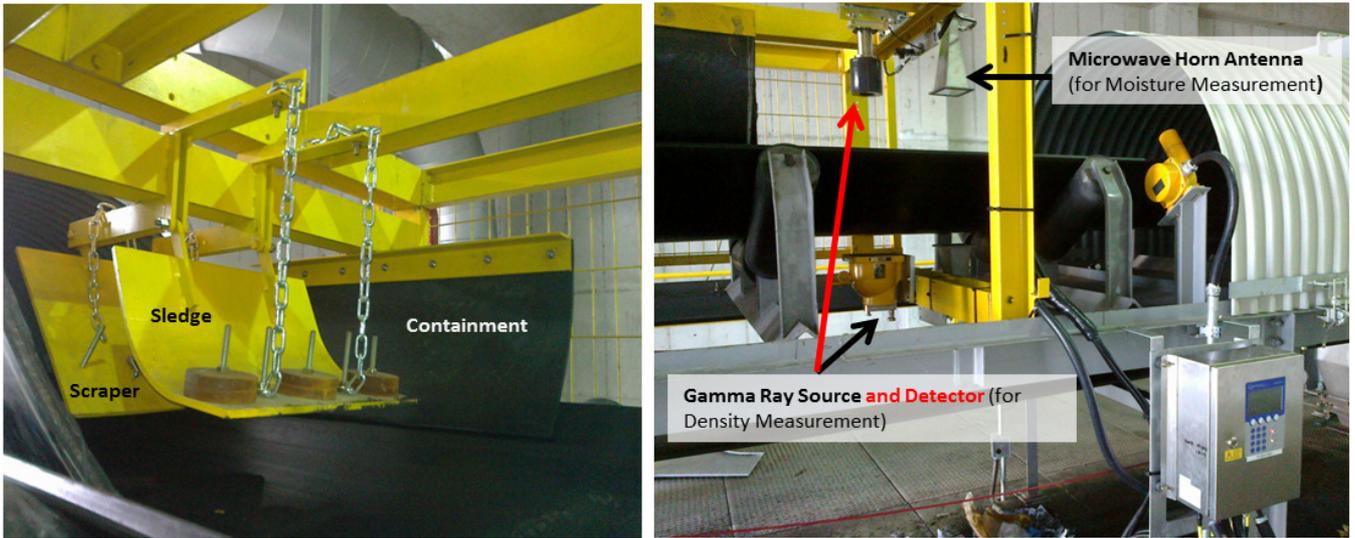


Figure 15: Mechanical set-up on site

flatten the coal surface in two steps. First a heavy steel plate works as a scraper. The maximum excursion of the scraper is limited by chains to avoid that the scraper comes into contact with the rubber belt. Weights can be added to the scraper to set the scraping

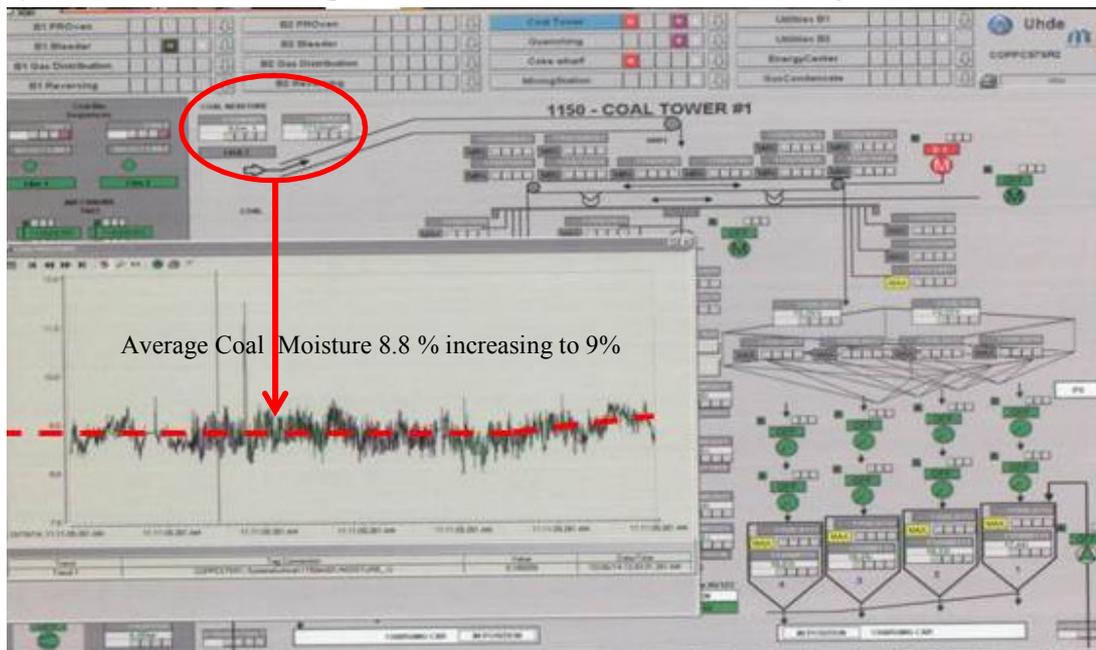


Figure 16: A coal tower operation display overlaid by a 6 day “coal moisture trend plot”

force and adjust the paving path. Second a sledge, also limited in his movement by chains, levels the remaining bumps. If the coal level on the belt is very high or piles of coal are approaching, the scraper or the sledge may spill coal from the belt. Therefore containments made from rubber-belt material were placed on each side of the belt. (see Figure 15). A flat coal surface is mandatory for getting reliable signals. Figure 16 shows an operation display for the coal tower from the COP-DCS with coal moisture measuring results in a trend display over 6 days taken in October 2014. The signal fluctuation due to disturbances (inconsistencies) is approx. +/- 0.2 % around the actual value. The average coal moisture in the first 4 days is approx. 8.8 % and it is increasing to 9 % in the following days.

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CSQ - QUENCH TOWER

The CSQ wet quenching system (Coke Stabilization Quenching) is the only wet quenching system ever built - which reduces the dust emissions in the quenching vapors to below 15 g per ton of coke.

The coke is mainly quenched by the water entering at the bottom of the coke box of the quenching car as well as by the rising vapor. By flooding the coke box from the bottom, the coke is quickly cooled down creating steam which catapults the coke high up into the shaft. As the coke falls down the small loose breeze coke particles are separating from the lumps, which has a stabilizing effect to the coke. Furthermore the quick cooling down of the coke reducing the development of unwanted gas emissions.

The CSQ towers in the Hyundai Steel Coke Plant are approx. 70 m high and made of a reinforced concrete structure which is lined by red bricks, same as the conventional quenching tower. Different from the stand-by emergency quenching tower which is located

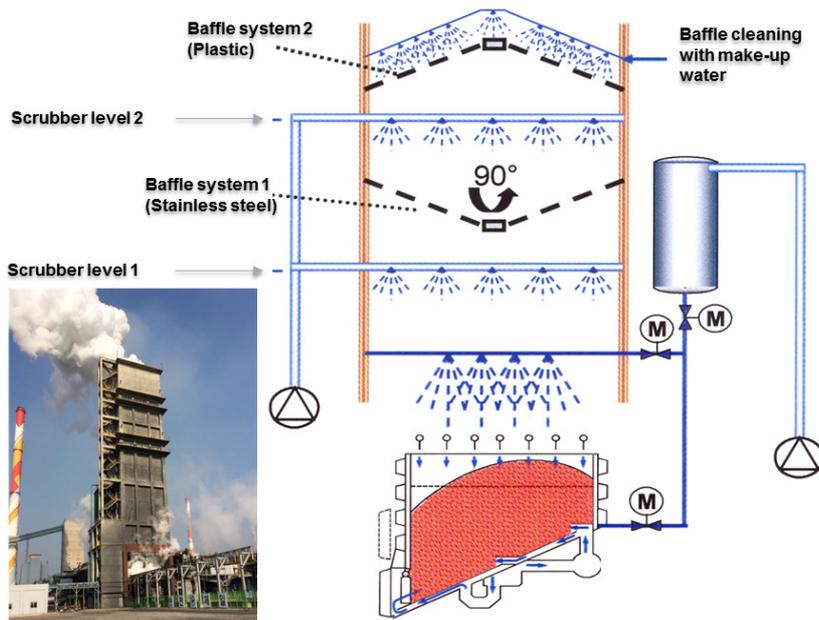


Figure 17: CSQ-Quench Tower in principle and "as build"

between Phase 1 and Phase 2, the square section as well as the height of the stack needs to be larger than in case of the conventional tower, in order to accommodate the second set of emission control facilities and vapor spray system. The quenching process and equipment of the CSQ towers is the same as for the conventional quenching tower. However, two stages of baffle plates fastened on supporting structures of Bongossi wood are separating the dust from the quenching vapor. The baffle plates are arranged louver-like in a roof type pattern. The baffles of the lower stage are made of stainless steel, the baffles of the upper stage are of special plastic material. Further, two stages of vapor spraying system arranged below each stage of baffle plates. The piping is made of stainless steel and contains nozzles to spray the water on the rising vapors. By the water spray nozzles, located below the dust catching louvers, the rising vapors are cooled and dust particles are washed down. The water for spraying of the vapors is extracted from the clean water basin of the quench water treatment plant. Dust particles not washed down by spraying are largely removed by the baffle plates installed above. Further, the arrangement of the louvers is designed to ensure an equal distribution of the vapors over the full section of the quench tower stack. By this system, the required limitation of dust in the quenching vapor is achieved.

AUTOTHERM™ (AUTOMATIC CHAMBER-WALL TEMPERATURE MEASUREMENT)

The AutoTherm™ System is a coke chamber wall temperature measurement system via air cooled fibre optic cables and attached pyrometers mounted on the "cold" rear end ram beam of the pusher car. The temperatures of the walls are measured when the ram passes through the oven. They are converted and evaluated to enable the supervision of the temperature and heat distribution of the battery in longitudinal, transversal and vertical direction. This can be performed by checking cross wall temperatures, longitudinal battery temperatures, vertical heat distribution, temperature development in terms of time, wall-heating checks etc.

The light intensity radiated from the oven wall is detected by a fiber optic cable at each measuring point. This measuring point consists of a housing thermally insulated against radiation and heat conducted by the ram head. The housing accommodates the fiber optic cable holder, air routing system for an optimum cooling effect, fiber optic cable and compressed air feed connection.

The fiber optic cable is permanently attached in relation to the ram. Compressed air is allowed to pass along the fiber optic cable protecting it against overheating and dirt, and clearing the passage between light the guide housing as it blows out into the oven chamber (see figure 18).

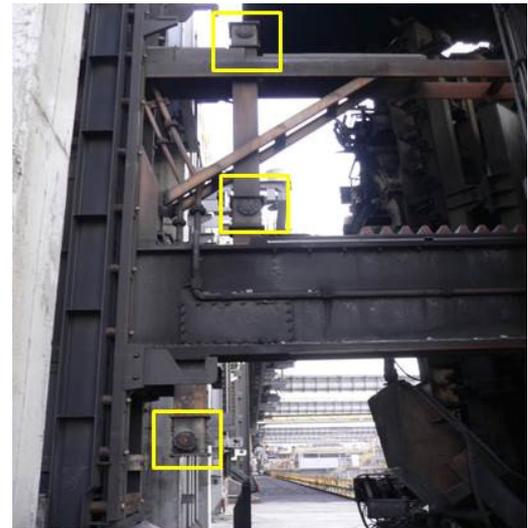
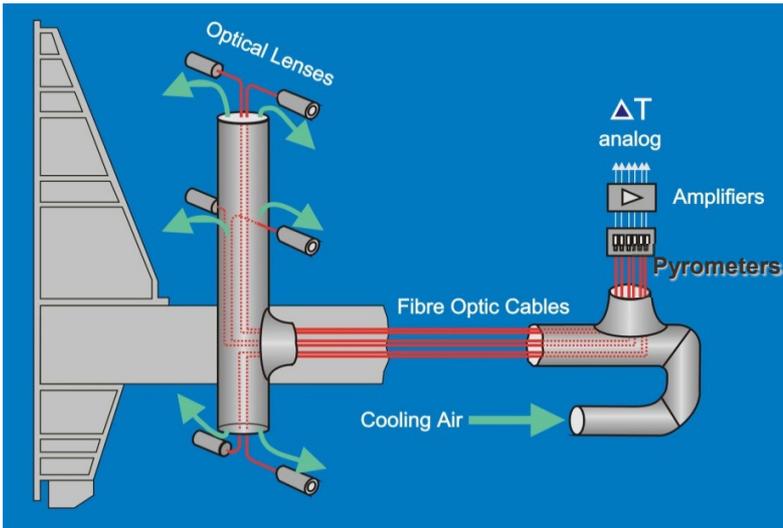


Figure 18: AutoTherm™ in principle and “as build”

Several hundred data points (raw data) are measured by each pyrometer during one push process, transmitted to a PLC in the pusher machine’s electrical room and correlated with the related distance information from the ram drive system. The raw values are compressed to build one average temperature value per heating flue for each pyrometer. These values (in total 6 x no. of heating

flues) together with the oven number of the respective push and the time of pushing and the leveling are temporarily saved in the storage medium of the designated AutoTherm™-PLC station on the pusher machine. The values so determined are transmitted via fiber optics from the pusher machine to the COKEMASTER®-Server which receives the data and stores those data in a database. Whenever desired, the operator may select and evaluate temperature data from the archive by using a comprehensive menu system which is integrated in the COKEMASTER® HMI, available on all COKEMASTER® client PC’s. Automatic alarms will be generated if threshold values are exceeded. The operator is able to check at regular intervals or in case of an alert the temperature distribution within the battery block to detect maladjustments of the under firing system which may lead to under-coking of the coal in specific areas of the coke mass resulting in bad coke quality and pollution during pushing.

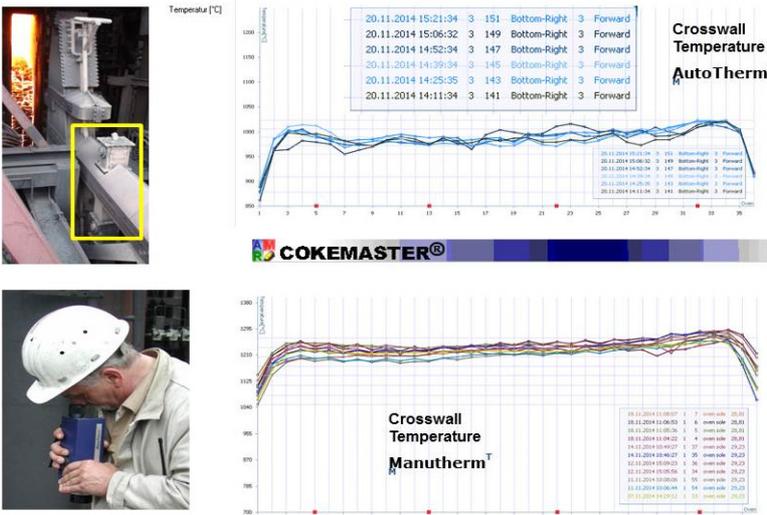


Figure 19: Comparing Wall Temperature with Heating Flue Temperature

Besides alerting to problems in the crosswall, the vertical temperature distribution is especially important in high oven chambers. This is achieved by a long flame over the full height of the flue. The flame is influenced by the gas and air distribution to the heating flue which has to be properly adjusted. Changes in the air distribution (i.e. changes in the stack draft) without proper counter-measures may have disturbing influences to the length of the flame (=vertical heat distribution) and ultimately may lead to uneven coking, to roof carbon, and worst of all ultimately to “sticker ovens”. AutoTherm™ is able to quickly detect vertical heating problems while taking temperatures in three levels of the oven chamber during each push. Detection of these problems helps to improve the heating system which leads to better environmental protection, higher coke quality, higher production efficiency (=gas/energy savings) and less stress to the brickwork (= longer service life of the battery).

A comparison between manual measured heating flue temperatures (measured with a pyrometer system with integrated data storage device, named ManuTherm™) and chamber wall temperatures (measured by AutoTherm™) are shown in figure 19. The “Crosswall Temperatures”, measured by AutoTherm™ are a collection of multiple wall temperature curves taken by the measuring head close to the oven sole (Bottom-right lens) of different oven chambers.

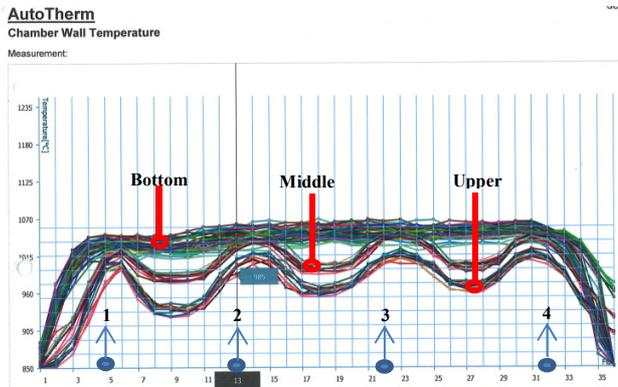


Figure 20: Temperature in three (3) levels of oven walls

walls are looking good, but the “Middle” and the “Upper” part of the wall are showing big temperature drops between the charging holes (1-4). Since multiple readings from different ovens are showing the same profile in each level, the readings can be considered as valid and the heating team were able to re-evaluate the situation based on these findings and took the necessary actions. Such insight can only be gained by looking over the wall in all directions and not only at the heating walls temperatures at heating flue base. Besides heating evaluation of single walls or ovens, the oven wall temperatures from AutoTherm™ can be condensed to provide a mean battery temperature, which can be used as an input for battery heating control.

RAMFORCE™ (AUTOMATIC MONITORING OF THE PUSHING FORCE)

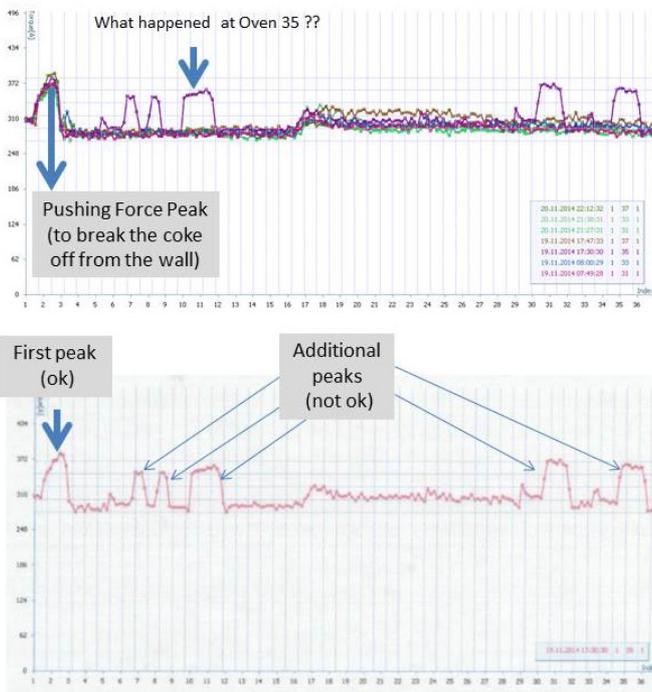


Figure 21: Pushing force on an oven having pushing trouble

AutoTherm™ are a collection of multiple heating wall temperature curves manually taken by an operator through the inspection holes at the oven top. (at heating flue bottom) of different heating walls. The heating flue temperatures are approx. 200 deg. C higher than the oven wall temperatures which is due to the heat transfer gradient between the flames and the coke mass. However the progression and shape of the temperatures between wall and flue are so similar, that it is obvious that both measurement systems can be used for evaluating the heating performance. AutoTherm™ is even superior against the flue measurements, because it takes readings in three levels of the walls so that heating disturbances over the height of the walls can be detected. A very rare and extreme example, but an example which shows the value of the AutoTherm™ system. (Ref. to figure 20) Shortly after first coke of battery 6, the coking times, the wall temperatures and the charging level of the coal were still not adjusted and in disorder. The temperatures at the “Bottom” of the oven

Together with the chamber wall temperatures (AutoTherm™), measured while the pusher ram pushes the coke out of an oven, simultaneously the torque needed for this action is measured on the ram drive motor. These values are measured while the pusher ram pushes the coke out of an oven. The torque is provided from the frequency converter unit which controls the motor speed and motor torque and is converted in the COKEMASTER® system into a pushing force. The system is called RamForce™ and provides excellent information about the mechanical maintenance situation of the ram drive system and the coking condition of the coke cake. If the ram force increases over a period of time, a mechanical or a heating problem can be assumed and calls for attention and further evaluation for trouble shooting. RamForce™ graphics can be called up on the COKEMASTER® HMI by the operators for process control and as a trouble-shooting tool. The plant managers select RamForce™ data from a long term archive for process monitoring, optimisation and historical surveys. Figure 21 shows multiple pushing force curves which all show the same profile that means a pushing force peak in the beginning to break the coke loose from the wall and get the coke cake moving. After this initial peak, the pushing force is much lower, just enough to keep the coke cake moving along the length of the oven. As soon as the pusher ram shoe enters the oven, a new but smaller peak develops. This support shoe slides over the oven sole and put additional friction onto the bricks which have to be counteracted by the ram drive, leading to an increase of the pushing force needed. This is the normal situation during

each pushing. However, oven (Oven no. 35) stands out of the regular profile with multiple pushing peaks along the pushing path. The first peak repeats itself multiple times during one push. Reason: The pushing was stopped several times and resumed again as the ram travelled through the oven. Mechanical problems on the coke guide required these stops. With each restart, the pusher drive system has to regain the force to get the coke cake moving again. Five additional peaks indicate that the pusher ram stopped and restarted five times after the initial “break off peak”. This example shows that the pushing force measurement is a useful tool to detect and document operational problems during pushing.

PUSHSCHED™ (AUTOMATIC SCHEDULE AND CONTROL OF OVEN MACHINES)

Process control and monitoring of coking plant operation also includes the preparation of a pushing schedule and screen display of the oven machines operation performance. For this purpose the Hyundai Steel automation includes a very advanced pushing and charging schedule program called PushSched™ as part of the COKEMASTER® system suite. Pushing and charging times for each oven are calculated and optimized, transferred to the oven machines and signalled to operators. The actual data of the pushing and charging operation is feed back to the scheduling system to update the calculation (see figure 22).

That means that PushSched™ can handle normal production planning as well as all types of special operation (i.e. compensation of breakdown or decreased production). A re-calculation can be triggered and remade anytime when there is a change in production data or there is any operating trouble. Several strategies are available to handle a loss of production. The loss can be accepted or made up by increasing production with shortening the coking time in a careful and secure manner for keeping best heating performance and production. Therefore changes in the schedule will automatically influence the calculated nominal heat within the BatControl™ heating control model. The pushing and charging schedule can be calculated for several days in advance in a special simulation mode for advanced production planning. The system is interlocked with the PROven® system to handle the disconnection from the collection main for pushing and reconnection to the collection main for charging. Figure 22 shows the main function and operation system philosophy as well as the operation displays. The top display is called “Oven Status”, showing for each oven the next push / charge-times, last push / charge times, time in cycle as bar graphs with multiple colours, charging weight, etc. The display in the middle is the calculated schedule which shows the pushing and charging cycles in chronological order for the next five days in advance. The bottom display shows the pushing and charging history as a report (on screen or paper).

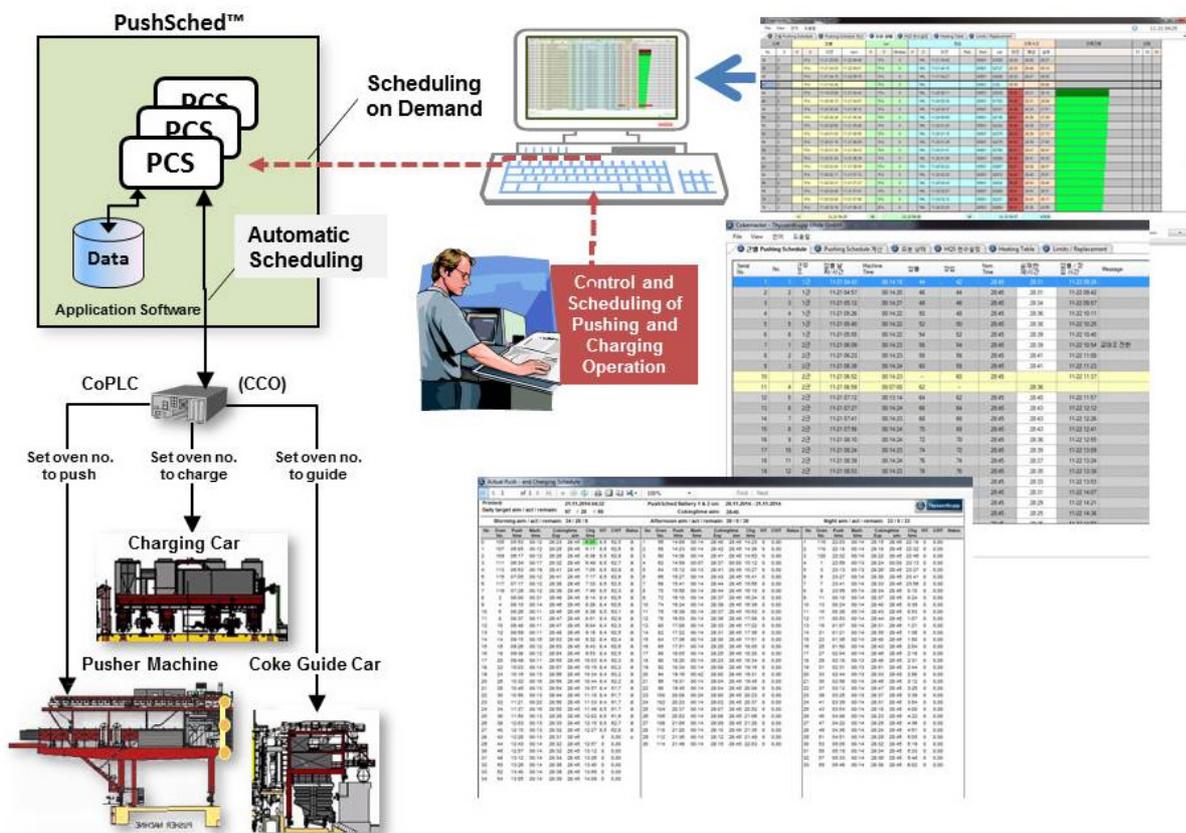


Figure 22: Pushing Schedule sequence and control

BATCONTROL™ (AUTOMATIC CONTROL OF THE BATTERY HEATING)

BatControl™ is a theoretical calculation model which determines the required energy for heating the battery. The model is dynamically updated by the actual production performance (adapting to delays, “speed up”, lost production, etc.) and the actual heating performance (adaptions based on actual heating flue, coke or wall temperatures which are outside of the target range). The energy requirements determined by the BatControl™ model are the set point for the heating system. The energy required for the battery heating is in this case controlled by changing the heating time (varying a pause time between reversals).

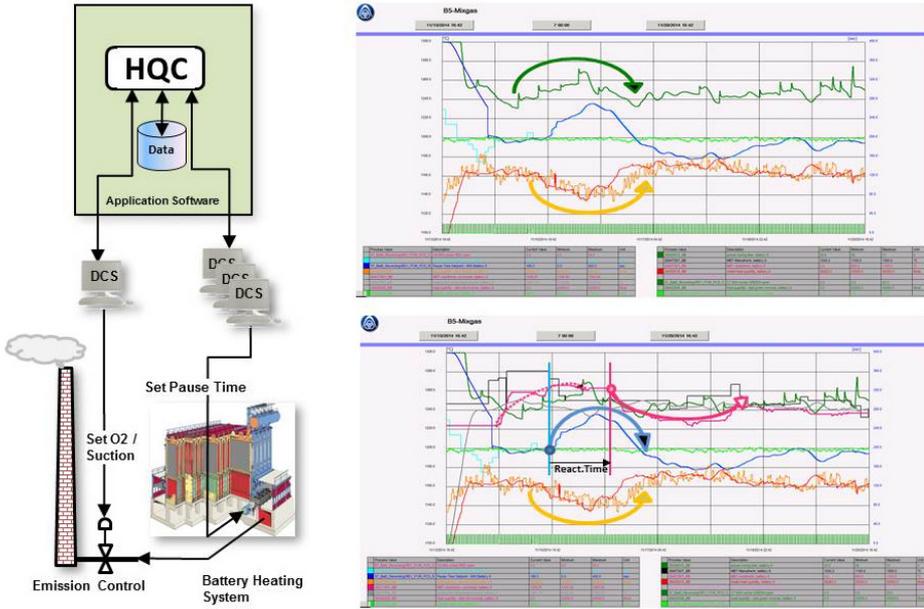


Figure 23: BatControl™ – Automatic monitoring and control of the battery heating

Figure 23 is a trend graph of the heating control results. Whenever the coking time changes (green arrow), the energy quantity control reacts by creating a new set point for the energy input (orange arrow), mainly by changing the pause time (blue arrow). In the example given, the pause time is increased from approx. 200 seconds to approx. 275 seconds by the model to match a declining energy demand (red curve) due to a general increase in the coking time (green curve) from 28.9 hours to 30.1 hours. The rise of the Mean Battery Temperature, measured by AutoTherm™ (pink dotted arrow), also requires a reduction of heat, which lowers the energy set point even further. The total reduction of energy (orange curve) leads to a reduction of the “Mean Battery Temperature” (pink arrow). However this happens with a time delay due to the reaction time needed to bring the energy from the heating flue to the coke.

Figure 24 shows a heating control trend over 30 days. Hyundai’s maintenance strategy requires scheduled maintenance days with operation breaks of 4-8 hours once every month. In this time, the pushing and charging is stopped completely and most of the plant power is shut down to clean and repair all systems safely. The operation breaks require a reduction of the battery heating. The orange curve in figure 24 shows the energy input to the battery in Mega-calorie (Mcal). The steep reduction of the energy input during maintenance days can be clearly seen (blue dotted circle). Between the two maintenance days in figure 24, the automatic control of the battery heating counteracts all fluctuations in the production and respective thermal response by setting the pause time accordingly. Please follow the blue curve in the centre of the trend, which works opposed to the orange/ red energy curves and its response is able to keep the battery temperature in a proper control range. In the control range of the temperatures, marked in pink background color, the mean battery temperature, measured by AutoTherm™ (pink curve) as well as the mean battery temperatures,



Figure 24: BatControl™ – Automatic heating control over a period of 30 days

calculated by heating flue temperatures (black curve) are showing a good correlation to each other. To make both temperatures measured at different places in the brickwork comparable to each other, the heating flue temperatures are extrapolated by the heat transfer rate to oven wall temperatures. It is reasonable to conclude that the BatControl™ heating model is able to keep the quantity of heating energy under control, ensures less energy consumption and a quick and automatic response to operation troubles which holds the battery temperatures in balance, reducing heating problems and pushing emissions.

PRODUCTION DATA, OPERATION AND MAINTENANCE

Production data & Coke Quality (Hyundai-Steel Company. Dangjin)



2013	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Phase 1. (1,000 ton)	117	104	118	109	113	106	112	106	105	112	113	111	1,325
Phase 2. (1,000 ton)	117	104	118	109	111	105	111	106	106	113	113	109	1,323
Phase 3. (1,000 ton)	-	-	-	-	-	-	11	39	67	100	127	124	468
DI (%)	88.7	88.0	88.4	88.4	88.0	87.9	88.0	87.9	87.8	88.0	88.2	89.0	88.2
CSR (%)	68.6	70.0	69.3	69.0	69.7	69.3	67.4	70.1	68.3	67.0	68.1	66.5	68.6

2014	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Phase 1. (1,000 ton)	110	100	109	105	109	104	109	108	108	113	109	110	1,293
Phase 2. (1,000 ton)	110	99	107	107	106	105	109	108	108	112	107	109	1,287
Phase 3. (1,000 ton)	131	115	134	127	133	129	130	130	123	128	126	131	1,537
Total													4,117
DI (%)	89.3	89.3	88.9	88.4	88.1	88.4	88.4	88.3	88.2	88.3	87.8	88.3	88.5
CSR (%)	67.9	67.0	66.5	67.4	70.2	71.1	67.9	67.2	71.6	70.7	70.1	70.2	68.9

Figure 25: Production Data and Coke Quality (Year 2013-2014)

In May 2014, the last performance tests for the coke oven batteries of Phase 3 have been conducted. The guaranteed coal throughput for both batteries of 6920 tons of coal per day (dry) has been exceeded by reaching an average throughput of 6940 tons of coal per day (dry). With a coke yield of 75% this would amount for nearly 1.9 million tons of coke per year for Phase 3 alone. The table in figure 25 shows operation data based on “lump coke” from the coke oven plant over a period of two years (from 2013 until 2014). Phase 3 went into production in July 2013 so the first year under continuous production was 2014. For this year the annual coke production of Phase 3 has totalled at 1.537 million tons which nearly reached the design capacity (1.540 million tons). There-

fore the total coke production for all three phases balanced at 4.1 million tons of “lump coke” for the year 2014 which is approx. 97% of the nominal production (4.240 million tons).

	European range ^a	Australian BHP Port Kembla ^b	American range ^c	Japan range ^d
Mean size (mm)	47-70	50	50	45-60
M ₄₀ (+60 mm)	>78->88	85	n.a.	n.a.
M ₁₀ (+60 mm)	<5-<8	6.5	n.a.	n.a.
I ₄₀	53-55	n.a.	n.a.	n.a.
I ₂₀	>77.5	n.a.	n.a.	n.a.
DII50/15	n.a.	84.4	n.a.	83-85
ASTM stability	n.a.	63.6	60	n.a.
CSR	>60	74.1	61	50-65
CRI	20-30	17.7	23	n.a.

Figure 26: Quality Parameters of Coke [Ref. 4]

As a reference, main quality parameters commonly used in the evaluation of blast furnace coke are shown in figure 26. The table includes the typical value range of each coke property for coke plants in different parts of the world. The coke quality of the Hyundai Steel Coking Plant is shown in figure 25 on a monthly base by the two key parameters **C**oke **S**trength after **R**eaction (CSR) and **D**rum **I**ndex (DI). The CSR-value averaged at 68.6 and 68.9% with top values in September 2014 at 71.6%. A CSR of 60 and higher is regarded as a good value for blast furnace operation and higher than the standard range in most countries (compare the CSR ranges in figure 26). Since Hyundai Steel has high

capacity Blast Furnaces in operation, this higher CSR value is appreciated by the blast furnace operators. Because in general, with increased blast furnace capacity the CSR has to be increased as well.

The drum index which evaluates the mechanic abrasion of coke lumps when tumbling in a rotating drum is another indication for the coke strength. The **Drum Index (DI)** in figure 25 refers to the Japanese standard JIS K2151 - DI150/15. The monthly averages show only very small fluctuations in a range between 88 and 89 % over the year, which are very good values if compared with Australian and Japanese standard ranges (compare the ranges in figure 26). Unfortunately, the different drum tests (JIS K2151, MICUM, AST Tumbler, etc.), which are used in different regions of the world can't be easily compared with each other. This is the reason why standard ranges for the DI 150/15 drum index in European and American countries are not available and thus the values from Hyundai Steel can't be evaluated against drum indexes from European or US-Plants.

A balance of consumption and production data is shown in the mass flow diagram shown in figure 27. The diagram is a snap-shot

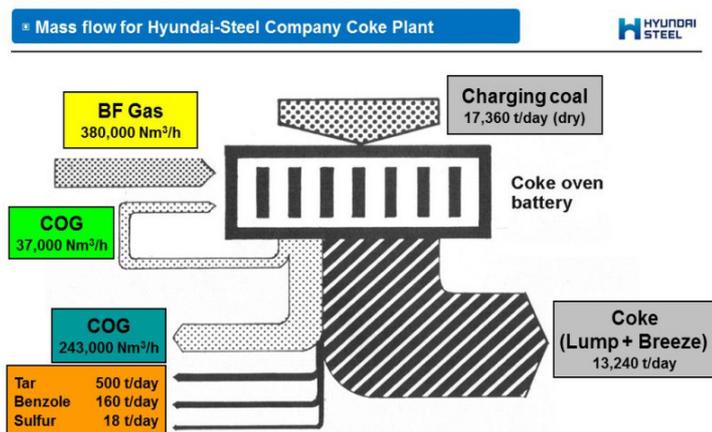


Figure 27: Mass Flow Diagram

of actual production data, collected and evaluated for a period in January 2015. At that time, the plant had a coke production of 13,240 tons per day which is approx. 98% of the nominal production. The coking process theoretically would produce 264,000 Nm³/h of raw gas (based on 98% nominal production). Figure 27 shows a mass flow of gas coming out of the battery block and separates into two flow streams. One is the cleaned COG-flow which is returned to the battery block for heating, the second is the cleaned COG-flow which leaves the plant for other consumers in the steel plant. Both COG-flows together totals to 280,000 Nm³/h which is 16,000 Nm³/h more than the design value for 98% nominal production rate. The reason for this difference is the additional tail-gas which is produced in two Claus-plants and inserted into the raw gas network. This “pumps” up the raw gas balance. The coke yield estimated to be 75% in the design phase was actually 76.3 % at that point of time.

Hyundai Steel has a unique and very efficient maintenance philosophy. For each Phase one maintenance day per month is scheduled. During this maintenance day, the production is completely stopped for approx. 8 hours to check, repair or replace equipment and to clean the equipment and the environment. The loss of production during the maintenance break is accepted in the interest of higher plant availability, smoother production and well groomed facilities all around the year. During the maintenance break, the heating of the battery is automatically adjusted by the battery heating control system and additionally manually by adjusting the “Shut-Off”-cocks in order to cut the gas supply to individual walls if needed. Besides the maintenance day, some other standard operation and test procedures are scheduled in regular intervals. Some examples: Usually the batteries are heated with Mix Gas (= Blast Furnace Gas enriched with some small amount of COG). To test the equipment and to practice the operation procedures, the heating is switched to COG-heating once per month for a period of one day. Also the bleeders (flare stacks) on the collection mains are tested for safe and proper operation, including an ignition test. And the oxygen content in the waste gas is constantly supervised and readjusted in order to optimise the heating adjustment.

With well trained and well educated operators and maintenance personnel, with state of the art equipment and facilities, with a high level of automation, with a process department concentrated on continuous improvements and optimisation and last not least with highly motivated people the Hyundai Steel Coke Oven Plant has become one of the most modern and best operated plant worldwide.

Abbreviation	Explanation	Abbreviation	Explanation
AC	Alternating Current	GRP	Gas Refinery Plant
BF-Gas	Blast Furnace Gas	I/O	Input/Output (used for electrical signals)
CCC	Coal Charge Car	ma...mA	milliampere (1/1000 Ampere)
CCO	Coordinating PLC	MCC	Motor Control Center
CDQ	Coke Dry Quenching	O ₂	Oxygen
COG	Coke Oven Gas	OPC	OLE for process control
COP	Coke Oven Plant	PC	Personal Computer

CSQ	Coke S tabilization Q uenching	PCS	Pushing Charging Schedule (Program Name)
CSR	C oke S trength after R eaction	PECS	Pushing and Emissions Control System
DC	Direct Current"	PLC	Programmable Logic Controller
DCS	Distributed Control System	PM	Pusher Machine
degC...degF	degree Celsiusdegree Fahrenheit	PROven [®]	Pressure Regulated Ovens = EnviBAT [®]
DI	Drum Index	QC	Quench Car
FCS	Field Control Station	RIO	Remote I/O unit (to collect process signals)
HF-signal	High Frequency Radio Signal		
HMI	Human Machine Interface	VFD	Variable Frequency Drive
<i>All physical units are based on metric system, if not shown otherwise.</i>			

ACKNOWLEDGEMENTS

We wish to thank Hyundai Steel for their support during installation, commissioning and operation of the coke plant automation system and for supporting us to compile this presentation for the AISTech 2015. We also like to thank Matt Kraeuter from ThyssenKrupp Industrial Solutions - USA, Inc. for his continues support.

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