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THE FIRST COKE MAKING PLANT IN INDONESIA – TECHNOLOGICAL HIGHLIGHTS*

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Abstract
PT. Krakatau-POSCO coke making plant, located in Cilegon, Indonesia, is the results of the know-how and experience of Paul Wurth (PW) in coke making field. The plant has a capacity of 1,321,000 t/y of gross coke achieved by two coke oven batteries with 42 top charging Paul Wurth "Jumbo" ovens each. PW "Jumbo" oven with a useful volume of 78,92 m3 allows decreasing drastically the number of pushing/charging operation per day with a consequent reduction of the diffuse emissions. Gas treatment plant with a capacity of 88000 Nm3/h has been designed in collaboration with DMT GmbH & Co. KG, adopting the latest technologies with specific design know-how. PT. POSCO-Krakatau plant has been successfully commissioned and started-up in October 2013. The present paper will highlight the main technology features applied in PT. Krakatau-POSCO project for both coke oven and gas treatment plants.
Keywords: Coke making; Top charging coke oven; Wet quenching; Coke oven gas treatment; Tar; Sulphur.

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1 INTRODUCTION

PT. Krakatau-POSCO is a Joint Venture Company between PT Krakatau Steel, Indonesia and POSCO, Korea. At the beginning of 2011, consortium formed by Paul Wurth Italia, POSCO Engineering & Construction and PT. Krakatau Engineering was awarded by PT. Krakatau-POSCO the contract for the engineering and supply of 1,321,000 t/y Coke Making Plant and connected By-products Plant. Such project was included within a much larger project concerning the construction of a complete, integrated steel plant able to produce in the first phase 3 Mt/y of steel slabs: the first Integrated Steel Mill in Indonesia. Plant construction started in 2011 and was completed within 33 months.
Coke oven battery and By-products plants were commissioned during 2013 and first coke of first battery was pushed on 8th October 2013.
PT. Krakatau-POSCO coke oven plant can take advantage from PW "Jumbo" oven with oven volume of 78,92 m3 that allows decreasing significantly number of pushing/charging operation with a consequent reduction of diffuse emission. PW "Jumbo" oven is the result of consolidated experience of Paul Wurth Italia in coke making filed and in the coke oven top charging technology from small up to large volume ovens. Figure 1 shows PT. Krakatau-POSCO coke oven battery based on PW "Jumbo" oven technology.
PT. Krakatau-POSCO Gas Treatment Plant project has taken advantage of the combined know how and experience of Paul Wurth Italia and DMT GmbH & Co. KG in the field, a state of the art project that is the outcome of the latest technologies, a specific design know-how together with a fruitful and close cooperation with the customer. Figure 2 shows PT. Krakatau-POSCO GTP installation.

Figure 1 *Krakatau-POSCO Coke Oven Plant*

Figure 2 *Krakatau-POSCO Gas Treatment Plant*

Coke Oven Plant Main Data

Coke production	1,321,000 t/y
Number of batteries	2
Number of ovens for each battery	42
Oven pitch	1650 mm
Oven dimension (hot)	
- Total length	20,9 m
- Useful length	20 m

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- Height	7,6 m
- Effective height	7,175 m
- Width	550 mm
Taper	70 mm
Useful Volume	78,92 m^3
Coking time	24,5 h
Pushing per day	82,3
Set of machines	2 (1 W+1 S)
Coke Wet Quenching type	
COG Heating	
NO_X emission at chimney 7% O2	≤ 150 ppm
SO_X emission at chimney	≤ 300 mg/Nm^3
MG heating	
NO_X emission at chimney 7% O2	≤ 50 ppm
SO_X emission at chimney	≤ 150 mg/Nm^3
Dust Emission at chimney	≤15 mg/Nm^3
Coke moisture (wet quench)	<3%
Coke dust emission at quenching	<15 g/t coke

PW "Jumbo" Oven Technology

PW "Jumbo" oven represents worldwide state of the art for top charging coke oven technology and takes advantage on conventional smaller ovens with regards to several aspects such as gas emissions, operation and coke quality.
PW "Jumbo" oven technology, because of combination of long coking time and large coking chamber volume, allows reducing number of pushing per day for a given gross coke production, therefore diffuse emissions related to charging/pushing operation are strongly reduced as well as emissions from oven sealing due to the reduced number of ovens and then of doors (and overall door sealing length) and charging lids.
Reduced number of pushing per day corresponds to reduced thermal stress for refractory bricks due to air cooling and reduced mechanical wear due to pushing operation, therefore an expected longer life-time of battery.
Reduced number of pushing per day, therefore longer push-to-push time, also results in a lower utilization factor for coke oven machine operating on PW "Jumbo" oven batteries, with significant advantages in terms of maintenance cost and life-time of equipment.
Long coking time for Jumbo Oven on its own instead has a positive effect on coke quality in terms of CSR and CRI. Analysis of coke produced in PT. Krakatau-POSCO coke oven batteries shows CSR and CRI to be respectively 70% and 20%.
PW "Jumbo" oven battery is asymmetrical with air and mixed gas entering on pusher side while waste gas discharging on coke side. In addition to cost saving associated (simple reversing winch, single waste gas channel, simple cast iron shapes), such

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asymmetrical configuration contributes to favour gas and air distribution towards coke side, essential for such long ovens and such large taper.

PW “Jumbo” Oven Heating system

PW “Jumbo” oven battery is compound type and can be operated with both coke oven gas and mixed gas with automatic gas changeover. Heating configuration is “twin-flue” type with a total number of 38 heating flues. Coke oven gas under-firing is under-jet type.

A specific optimized heating wall design that includes double level of combustion air staggering and waste gas recirculation allows reducing NOx emissions and achieving proper temperature distribution along the height of heating wall with no hot spots, by means of longer flame, lower flame temperature and dilution of air and gas with waste gas.

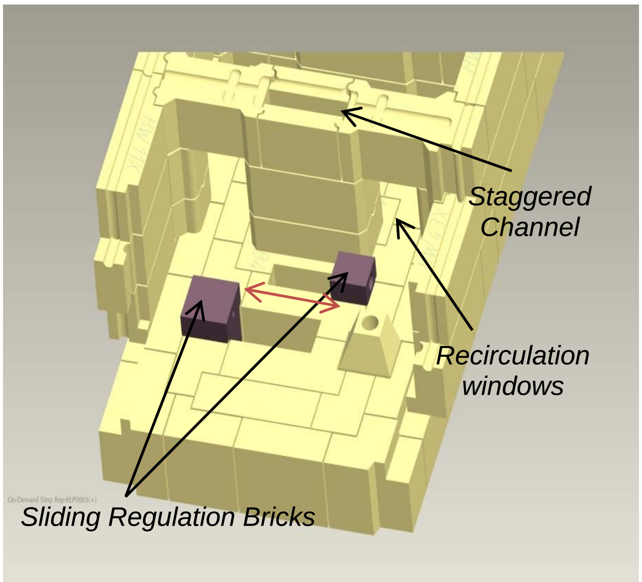

Figure 3 *Heating wall bottom part*

Combination of staggered air distribution and waste gas recirculation is proven to be the best technical solution to minimize NOx emission. In PW “Jumbo” oven heating system waste gas recirculation higher than 60% is achieved. Air and mixed gas supplied to each heating flue are regulated by mean of sliding bricks (as indicated in Figure 3), in addition to nozzle plate installed above sole channels at regenerators inlet and division walls in regenerators that allows fine regulation of flow to each heating flue.

Position of coke oven gas burner has been optimized to provide efficient mixing, to enhance waste gas recirculation and to minimize NOx emission.

Division walls in air regenerators and special design of waste gas box allows separate control of base and staggered air by mean of strips on air inlet box while staggered air to each stage is regulated by mean of sliding bricks. Figure 4 show double air staggering for PW Jumbo oven heating wall and relative regulation bricks.

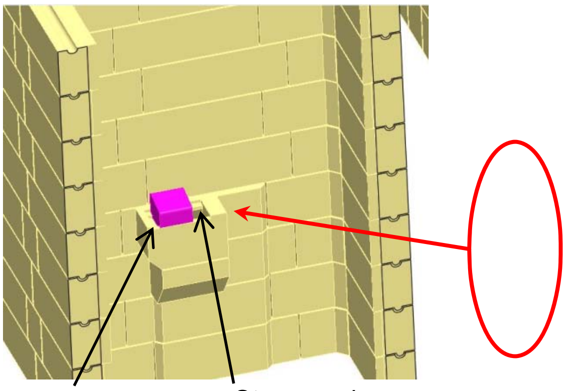

Figure 4 *Heating wall section – Air staggering*

PW "Jumbo" Oven Heating Wall

PW "Jumbo" oven heating wall and bracing system force distribution was optimized with the specific aim to guarantee high mechanical strength even for oven with significant height such as PW "Jumbo" Oven. A Suga Index higher than 12kPa was in fact achieved by an oven pitch of 1650 mm and by increased weight for oven roof. Bracing system, then, gives suitable compression forces to the refractory in order to eliminate tensile stresses in the heating wall and to keep closed the joints between refractory bricks, enhancing battery life.

SUPRACOK

PT. Krakatau-POSCO coke oven plant can take advantage also from SUPRACOK, Paul Wurth Level-2 system for coke oven plants, which provides operators with an advanced, accurate, user friendly support tool, which can be successfully used to improve operation performances and to achieve the following benefits:

- improvement of operation stability, safety and productivity
- constant coke quality
- reduction of fuel consumption
- reduction of environmental emissions
- increase of battery life

SUPRACOK main functions are the followings:

- Thermal control model that calculates the optimum thermal flow to be supplied to the battery, starting from production requirements, coal data and process measurements
- Coking Process Monitoring model that support operators during monitoring of the distillation process, giving proper indications on the pushing permission for each oven
- Scheduling of charging/pushing on the basis of production requirements, taking into account planned and unplanned production delays and possible oven out-of-operation.

Coke Wet Quenching

Wet quenching tower installed in PT. Krakatau-POSCO coke plant is shown in Figure 5.

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Figure 5 *Quenching tower and spraying nozzles*

Quenching technology is based on water spraying nozzles with an optimized quenching water spraying distribution over the coke in quenching car. By such system very low moisture content in coke is currently achieved in PT. Krakatau-POSCO coke plant, less than 3%.
Quenching tower is equipped with two levels of coke dust catching and steam washing water spraying system in between, together with a cleaning system for dust catching baffles with industrial water. By mean of such system, PT. Krakatau-POSCO quenching tower has been proved to achieve dust emission less than 15 g/t coke.
Quenching tower is internally lined with anti-acid clinkers bricks. Settling basin for excess quenching water treatment and coke breeze removal is divided into three basins with coke filters in between. From third pond, filtered water together with make-up water is pumped to quenching water tanks (total capacity to cover two coke quenching without re-filling) by mean of vertical pumps. Settling basin is also equipped with a grab crane system for coke breeze removal.

Gas Treatment Plant Main Data & Process
Main data about PT. Krakatau POSCO gas treatment plant are here below summarized.
PT. Krakatau POSCO Gas Treatment plant has been designed for a total coke oven gas (COG) dry flow of 88,000 Nm3/h, including raw gas production from a 1,321,000 t/y coke oven plant, coal charging gas, tail gas coming back from Claus plant and emission control system gas.
Treated COG quality:

- Tar ≤ 0,02 g/Nm^3
- H_2S ≤ 0,5 g/Nm^3
- NH_3 ≤ 0,04 g/Nm^3
- $C_{10}H_8$ ≤ 0,2 g/Nm^3
- BTX ≤ 5 g/Nm^3

Tar production: approx. 215 t/d
Tar quality: < 4% H2O
Crude BTX production: approx. 55 – 60 t/d
Crude BTX quality: > 95%
Solid Sulphur production: approx. 13 t/d
Solid Sulphur quality: > 99.9%

Short process overview of the installed gas treatment plant is given in Figure 6.

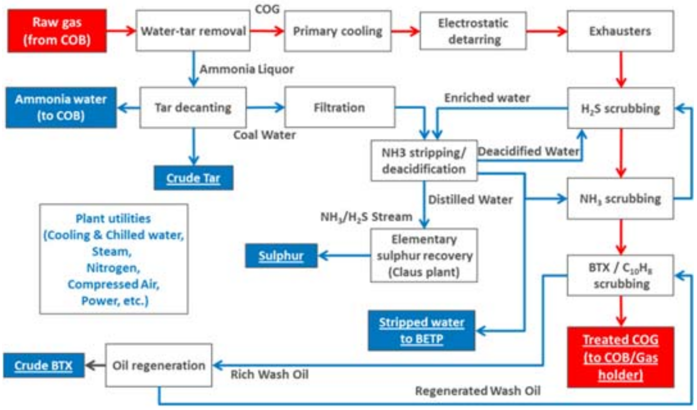

Figure 6 *PT. Krakatau-POSCO Coke Oven Plant and By-products*

Crude gas collected in gas collecting main from coke oven batteries is driven together with flushing ammonia liquor and tar towards the down-comer inside of gas treatment plant where gas and liquid are separated.

Leaving the down-comer, gas is directed to the primary gas coolers (PGC) where coke oven gas (COG) is cooled down within two indirect cooling stages using respectively cooling water and chilled water. Additional tar and in particular naphthalene condensation takes place over the external surface of heat exchange tubes; for such reason, continuously operated cleaning system based on spraying of light tar emulsion coming from tar separation plant removes naphthalene sticking on the cooling tubes to guarantee long operation period between two intensive PGC cleaning.

Tar rich ammonia water leaving the down-comer is directed to tar separation plant that includes solid pre-separators where solid and heavy tar particles are separated and vertical tar decanters with conical bottom. Flushing liquor is returned to battery gas collecting mains for flushing of raw gas from coke ovens, while excess coal water is pumped via a buffer tank to the gravel filter plant for final tar removal required by ammonia still plant. Production crude tar is extracted from tar decanter bottom and pumped to storage tanks. Tar emulsion is spilled at different levels of tar decanter close to water-tar interface in order to achieve the right light tar content required by PGC continuous flushing system.

Coming from the primary gas coolers, cooled COG is supplied to electrostatic tar precipitators (ETP) for reducing tar content upstream gas exhausters. COG leaving ETP is then compressed by gas exhausters driven by electric motors providing required suction of raw gas from coke oven batteries and required head for the downstream gas treatment plant and clean COG downstream network.

After leaving the gas exhausters COG is supplied to a scrubbing system with integrated final and internal cooling stages for reducing H_2S and NH_3 concentration down to the required levels. Such cooling stages, operated indirectly with chilled water, secure the temperatures required to guarantee performance of the scrubber system. Scrubbing liquor for the H_2S/NH_3 removal consists of stripped (low NH_3 content) and deacidified water (low H_2S, high NH_3 content) returning from the distillation plant.

As final gas cleaning stage, COG is supplied to BTX-Naphthalene scrubber in order to reduce BTX and naphthalene content of COG by means of special tar based wash oil. Enriched wash oil is then regenerated in a stripping plant where crude BTX is produced as by-product.

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Enriched scrubbing liquor coming from the H_2S and NH_3 scrubbers is regenerated in a distillation plant consisting of deacidifiers and ammonia stills by stripping H_2S and NH_3 by mean of steam, together with CO_2 and HCN absorbed during scrubbing process. Excess coal water, coming from gravel filter plant, is stripped under the presence of caustic soda (NaOH) within ammonia stripper to remove fixed NH_3 compounds. Excess stripped water flow (consisting in coal water and stripping steam) with reduced free and fixed NH_3 content is led to the biological effluent treatment plant (BETP).

Vapours leaving distillation plant, mainly consisting of H_2S, NH_3, HCN, CO_2 and hydrocarbons, is supplied to a combined NH_3 cracking/elementary sulphur plant (Claus Plant) for Sulphur recovery. In the process, NH_3/HCN are cracked down into N_2, while H_2S content is converted to liquid Sulphur, and then solidified in small pastilles; tail gas from Claus Plants is returned to the crude gas mains upstream primary gas coolers.

GTP Technological Highlights

Primary Gas Coolers (PGC)

PT. Krakatau POSCO plant includes 5 PGCs with nominal dry COG capacity of 22,000 Nm3/h, 4-working and 1-stand-by. Figure 7 shows primary gas coolers.

PGCs are equipped with several bundles of horizontal heat exchange tubes grouped into two independent circuits, upper circuit supplied with cooling water and lower circuit supplied with chilled water. Such heat exchange surface have been optimized in order to achieve very low COG outlet temperature (<20°C) and then low naphthalene content in COG (<0,5 mg/Nm3) with a low ratio surface/gas flow, in combination with a special and reliable system for continuous cleaning of tubes through tar emulsion spraying system via perforated pipes at multiple levels that allows very long period of regular operation between two intensive PGC cleaning performed with both tar emulsion and steam.

Performance of tar separation plant together with light tar quality, controlled light tar content in tar emulsion and tar emulsion distribution over the tubes are also key factors for achieving good performance of PGC unit in terms of stable COG outlet temperature, pressure drops and COG distribution between the different PGC in operation and for extending time period between two intensive PGC cleaning.

Figure 7 *PT. Krakatau-POSCO Coke Oven Plant and By-products*

Tar Separation and Coal Water Filtration

PT. Krakatau POSCO plant includes 2 solid pre-separators and 2 vertical tar decanter, 1 working and 1-stand-by. Figure 8 shows tar separation plant installation.

Solid pre-separators with rotating sieve drum and chain scraper driven by electrical motors prevent large and solid particles to enter tar decanter producing a tar sludge that is collected, transported and then mixed with the coal.
Tar decanters installed in PT. Krakatau POSCO coke plant are vertical type with conical bottom and no movable parts inside, equipped with heating jacket with hot decanted water flowing around conical bottom to maintain crude tar temperature and an adjustable level for ammonia water inlet for optimization of tar and water quality through adjustable residence time.
Very low tar particles content in flushing liquor can be achieved (total suspended solids <200 mg/l) as well as very low water content in crude tar (<4%).
Tar storage tanks are equipped with conical bottom with indirect heating steam coil and deep-in pipe for incoming production and recirculation tar; in fact, additional heating of tar in storage tanks is provided by tar recirculation through steam heat exchangers. Such installation allows a final de-watering of crude tar with resulting very low water content.
Chart reported in Figure 8 below shows low level of water content in crude tar from tar storage plant achieved in PT. Krakatau POSCO plant

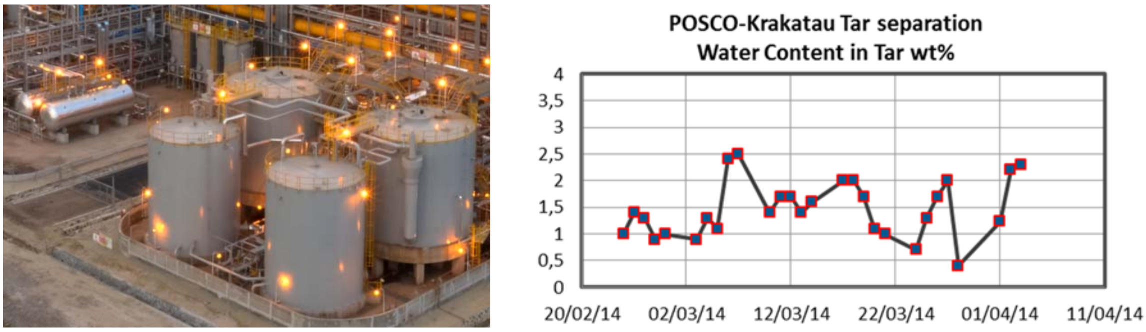

Figure 8 *Water content in crude tar in PT.Krakatau-POSCO Plant and Tar Separation Plant*

Tar separation unit is also equipped with automatic system for spillage of tar emulsion at three different levels of vertical tar decanter across water-tar interface based on tar emulsion density control.
Excess coal water is discharged through a dedicated overflow inside vertical decanter and by gravity into two large buffer tanks also connected to suction of flushing liquor pumps as additional flushing liquor buffer for emergency.
Coal water filtration, key process for downstream coal water treatment efficiency and operation, is achieved by 3 filters, 2 working and 1 regenerating by back-flushing. Filters are equipped with a bed of gravels of variable size to guarantee high efficiency filtration (down to 10-20 mg/l suspended solids in filtered water) and water discharge system that minimize gravel dust carry-over. Easy and quick bed regeneration is performed through clean water back-flushing together with air flushing.

Electrostatic Tar Precipitators

Removal of tar fog downstream primary gas cooler is achieved by mean of 2 electrostatic tar precipitators (ETP), 1 working and 1 stand-by, equipped with honeycomb collecting electrodes that guarantee tar fog removal efficiency higher than 99,9% and tar concentration in COG of less than 20 mg/Nm3 upstream gas exhauster and scrubbers, preserving then efficiency and operation of all downstream units including distillation plant. Compared to Venturi scrubbers, ETP is a stand-alone equipment with no ancillary equipment and simple control and very low pressure drops (<50 mmWC). Intensive cleaning of honeycomb collecting electrodes is performed by spraying hot ammonia liquor from top in addition to ammonia liquor

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supplied in the bottom part and steaming; sloped bottom guarantees constant drain of the condensates and ammonia water avoiding any risk of clogging.

Gas Exhausters & COG loop

Suction in crude coke oven gas main is achieved by mean of 2 gas exhausters, 1 working and 1 stand-by, each specified for 100,000 Nm3/h and driven by around 1,200 kW electrical motor.

Raw gas main suction control is performed by a butterfly control valve located at gas exhauster suction (PIC control in front of PGCs) while exhauster surge protection in case of reduced gas production is guaranteed by total inlet flow control performed by recirculation of a fraction of compressed COG from downstream gas exhauster to PGC inlet where compressed recirculation gas is cooled together with incoming raw gas. Among several advantages, such cold by-pass configuration allows larger cooling flexibility than configuration with COG recirculation from downstream BTX scrubber to gas exhauster inlet with recirculated gas cooling performed, instead, in the final cooling stage of H2S scrubber.

COG pressure in COG network at coke oven plant battery limits is controlled at around 650 mmWC by mean of a butterfly control valve (for a gas holder pressure maintained at around 450-500 mmWC), therefore gas exhauster provides required head to achieve such pressure and compensate pressure drops through all scrubbers and piping from gas treatment plant and coke plant battery limit where mentioned control valve is located. Gas exhauster system is also equipped with hot by-pass line across exhauster needed during start.

NH_3/H_2S and $C_{10}H_8$ (Naphthalene) - BTX Scrubbers

PT. Krakatau POSCO plant includes 1 H_2S scrubber, 1 NH_3 scrubber, 1 Flexi scrubber that can be operated as both H_2S and NH_3 scrubber and 1 BTX scrubber located downstream gas exhauster. Figure 9 shows PT. Krakatau POSCO scrubbing plant installation.

H_2S absorption is performed in combination with NH_3 absorption from COG by pre-enriched water coming from NH_3 scrubber and deacidified water from distillation plant at high free NH_3 concentration. NH_3 absorption is instead performed by stripped water coming back from distillation plant at low free NH_3 concentration.

BTX and $C_{10}H_8$ scrubbing is performed by tar based wash oil supplied after cooling from oil regeneration/BTX recovery plant

All scrubbers are equipped with several stages of expanded metal packing as gas-liquid mass transfer contact area, with a surface area of around 50 m2/m3 resulting in low pressure drops and no risk of clogging. Scrubber are equipped also with a high efficiency liquid distribution trays that allow to optimize liquid distribution over the whole section of expanded metal packing, enhancing wetted surface and improving then scrubbing efficiency.

All scrubbers are equipped with a demister made of ceramic rings on top part to catch droplets carried over by COG. H_2S/NH_3 scrubbers are also equipped with hot ammonia liquor sprayers on top of scrubber and steam nozzles at several levels for packing cleaning and hot ammonia liquor sprayers on the bottom stages of packings of only H_2S and Flexi Scrubber for flushing of any naphthalene deposits in metal packing that might occur during final cooling of compressed COG. BTX scrubber cleaning is performed instead by steaming.

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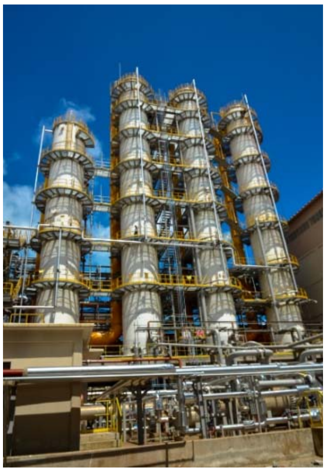

Figure 9 *H2S, Flexi, NH3 and C10H8-BTX scrubber (from right to left)*

BTX Recovery Plant

Enriched wash oil is regenerated in stripping columns with medium pressure steam equipped with special design trays. Enriched wash oil is pre-heated by welded plate type enriched oil/stripped oil and oil/steam heat exchangers; compact welded plate type heat exchangers are also used for condensation and final cooling of BTX/water mixture from stripper before final separation.

BTX stripper pressure is maintained by pressure control on BTX fume line between condenser and cooler discharging to gas exhauster suction while top temperature is controlled by BTX reflux flow.

An integrated pitch column is also installed for disposal of high molecular compounds, processing also naphthalene fraction from BTX stripper.

Distillation Plant

PT. Krakatau POSCO distillation plant included 2 Deacidifiers, 1 working and 1 stand-by, and 2 Ammonia Stills, 1 working and 1 stand-by.

Ammonia stills function as combined stripper for free and fixed NH3 from coal water. Fixed NH_3 is stripped out in the lower part of ammonia still after decomposition of fixed NH_3 salts by caustic soda solution (48% NaOH).

All columns are made of titanium material and equipped with high efficiency titanium valve trays that allow reducing steam/liquid ratio, leading to low steam consumption, with large margins on column flooding and low pressure drops.

PW/DMT solution foresees the use of top vapour condenser to condense most of water from H2S/NH3 vapors in order to reduce volumes and improve downstream vapor treatment unit efficiency.

Distillation plant is equipped with spiral type heat exchangers for heat recovery and cooling of deacidified and stripped water before recirculation to scrubbers. Permanent heat exchangers cleaning system via hot ammonia liquor is installed.

Claus Plant

H2S/NH3 vapors from distillation plant are treated in the downstream Claus plant. Under the top pressure of the deacidifier and ammonia stripping system, the H2S/NH3-vapours are supplied to the burner of the catalytic oven reactor. Vapours are burnt in a special burner under sub-stoichiometric combustion conditions and a certain ratio of H2S is burned to SO2 without any COG support; NH3/HCN are cracked by Nickel based catalyst within catalytic oven reactor. Downstream of the catalytic bed secondary air is supplied to adjust the stoichiometric ratio of H2S/SO2

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for the reaction in the following Claus reactor. Hot process gas leaves the oven reactor and flow through the waste heat boiler system where process gas is indirectly cooled down by generating steam from boiler feed water. Parameters of the produced steam can be selected in a certain range. During cooling down of the process gas within boiler, first Sulphur is condensed that after separation is directed to the Sulphur sealing pot.
In the downstream 2-stages Claus reactors, H2S/SO2 vapors are converted into elementary Sulphur over a catalytic bed. Process gas downstream each Claus reactor is cooled down in Sulphur condenser where produced sulphur is separated and LP steam is produced from boiler feed water. Upstream second Claus reactor, gas is re-heated by mean of HP steam.
High conversion of H2S into elementary Sulphur is achieved, minimizing the additional H2S load to H2S scrubber coming from tail gas recirculation back to PGC inlet. In addition, because of such tail gas recirculation, no emissions to the environment are guaranteed.
Claus plant is also equipped with boiler feed water system including water degasification by steam and chemicals.
Bright yellow Sulphur, purity 99,8% is produced. Liquid Sulphur is then solidified in a Sulphur solidification unit to produce small Sulphur pastilles for easy storage and transport (see Figure 10 below)

Figure 10 *Claus Plant installation in PT.Krakatau POSCO Plant and bright yellow sulphur pastilles*

Emission Control System

Process and storage tanks, including tar decanters, are connected to an emission control system that supplies a constant flow of nitrogen maintaining tanks to a slightly constant positive pressure, compensating any level variation and discharging nitrogen together with noxious gases and vapors produced inside tanks (aromatic hydrocarbons, ammonia, hydrogen sulphide, etc.) to the suction of coke oven gas exhauster downstream electrostatic tar precipitators. Tanks are grouped together in different independent loops to avoid any possible product contamination.

Conclusion

Technological highlights for coke plant, in particular for PW “Jumbo” Oven battery, and for gas treatment plant designed and built within PT. Krakatau-POSCO steel making plant installation in Cilegon, Indonesia, have been presented. Coke oven plant as well as gas treatment plant was accordingly commissioned, tuned with performance guarantees correctly fulfilled and finally handed over to PT. Krakatau-POSCO. Currently, the plant is in its normal operation, in terms of performance, operability and maintenance, meeting the company's needs for the equipment.