Introduction

In aiming for a cleaner environment, the European Union (EU) continues its rigorous policy of reducing pollution levels. Time after time, European refiners face new, more stringent environmental legislation on product quality and refinery emissions. Shell Global Solutions’ gasification technology offers refiners a flexible solution to help meet these challenges. The Shell gasification process (SGP) is a clean and efficient process for converting very heavy residues into syngas. The syngas can be used to produce hydrogen or as a clean fuel for power generation.

The SGP is playing a major role in a residue-upgrading project that is currently under way at the Gdańsk refinery in Poland. This paper describes the current status of the Lotos project and gives details of the integration of the SGP plant with new and existing facilities.

A consortium of companies, technology providers and engineering companies is working together to implement a total site solution (TSS) that will enable the Gdańsk refinery to operate in a more efficient and environmentally friendly manner, thereby increasing its throughput and meeting the growing demand for cleaner refinery products.
1. The Gdańsk refinery

Grupa Lotos SA (LOTOS), formerly Rafineria Gdańska SA, is the second-largest refinery in Poland. It is a coastal hydrocracking and lube oil refinery with a current annual processing capacity of 4.5 million tonnes of crude oil. The existing refinery facilities are a vacuum gasoil hydrocracker and a conventional base oils manufacturing complex together with traditional primary distillation and treating facilities (Figure 1). The main refinery products are gasoline, aircraft fuel, diesel, lube oils, marine oil and modified bitumen.

![Diagram of the existing refinery complex](image)

Figure 1: The existing refinery complex. Also shown are those plant units that are a major concern for the future operation of the refinery – units that have to be revamped or which are supposed to shut down.

Gasoline components are produced in two reformers and an isomerisation unit. Kerosene is treated in a Merox® unit to produce jet fuel. The vacuum gasoil hydrocracker yields gasoil components, which are blended with desulphurised straight-run gasoil for producing diesel oil and industrial gasoil grades. Blending produces bitumen and high-sulphur fuel oil.

2. The threat

In the early 1990s, LOTOS realised that the refinery’s existence was under serious threat if nothing was done to improve its competitiveness and to meet future product-quality and emissions legislation.

A long-term refinery strategy was developed that was based on the predicted changes in economic conditions in Europe for fuel supply and in accordance with the Polish oil sector strategic programme for meeting the emission limits set by the EU. The long-term strategy considers power supply security,
quantity and quality needs for the domestic fuel market, and environmental and social benefits for northern Poland and the Gdańsk region.

The refinery’s diesel and gasoline products will soon have to comply with EU sulphur content directives requiring an intermediate sulphur level of 50 ppm for diesel to be met by 2005 and an ultimate goal of less than 10 ppm by 2009. These low-sulphur diesel specifications will have to be met by both on- and off-road diesel applications.

The sulphur specification for non-marine heavy fuel oil is already 1.0%wt in the EU. Between 2005 and 2010, the sulphur content of bunker fuel oils for non-ocean-going applications will have to be reduced to between 1.0 and 1.5%wt. The combination of more stringent sulphur limits for heavy fuel oils for non-marine and non-ocean-going marine applications implies that most of LOTOS’ high-sulphur fuel oil market will cease to exist and the only outlet for high-sulphur fuel oil will be ocean-going ships. To stay competitive and meet future market demands the refinery will have to produce lighter, higher-value products that meet EU sulphur-content specifications.

In addition, the refinery needs to reduce its overall emissions. Using the surplus vacuum residue as refinery fuel component – after satisfying the base oils and bitumen manufacturing requirements – will not be an acceptable solution.

3. The integration

Over the last five years, Gdańsk refinery has considered various process units and configurations in search of a TSS to meet the following fundamental aims:

- Cost effective hydrogen production (216 t/d) for meeting future product specification
- Power and steam for the refinery use and export (balance to 44 MWe and 72 MWth)
- Produce more high-value products to improve competitiveness
- Eliminate high-sulphur fuel oil production
- Reduce overall refinery emissions to meet EU standards
- Increase refinery throughput from 4.5 to 6 million t/yr to meet future market demands
- Develop solutions integrated with the existing refinery complex
- Integrate and implement the most cost-effective solutions.

After the various options had been evaluated, the best fit with respect to the strategic drivers and return on investment turned out to be the an integrated project in which Shell gasification technology would play an important part.

The LOTOS project centres on the integration of the following new units (see Figure 2):

- A deasphalting unit (ROSETM process) to separate asphaltenes from the vacuum/atmospheric residue feed
• A world-scale hydrocracker to process deasphalted oils (DAO) – primarily to low-sulphur diesel and hydrowax (desulphurised oil)
• A Shell gasification unit to produce hydrogen for the hydrocracker and syngas as a source of clean fuel for the power plant as an integrated gasification combined cycle (IGCC)
• A cogeneration power plant with two gas turbines and two steam-turbine generators that will utilise the syngas not required for the production of hydrogen and the steam generated by the waste heat boilers of the gasification process.

![Simplified block flow diagram of the new units.](image)

Figure 2: A simplified block flow diagram of the new units.

The deasphalting unit is based on KBR’s residual oil supercritical extraction (ROSE) technology, which separates valuable lighter products from the heavy residue using the differing solubilities of the components. A blend of vacuum and atmospheric residue will be the feedstock for the unit. At a nominal throughput of 330 t/hr, the deasphalting unit will produce about 260 t/hr of DAO for the hydrocracking unit and about 68 t/hr of asphaltene for the gasification section. The deasphalting unit will allow processing of various feedstocks from different crude oils.

In the hydrocracker unit, DAO is demetallised and converted to lower-molecular-weight products such as naphtha, kerosene, diesel and hydrowax. The unit, based on Shell Global Solutions licensed technology, will have a nominal throughput of 260 t/hr of DAO using 6.5 t/hr of hydrogen from the gasification section and a catalyst cycle length of one year.

The diesel product will meet 10-ppm sulphur content specifications. Separate kerosene and diesel product fractions will allow flexible operation and the adjustment of product quality to seasonal (for example, winter properties) or special, temporary requirements. The desulphurised and demetallised hydrowax can be sold as a fluid catalytic cracking feedstock for manufacture of 10 ppm sulphur gasoline without further post-treatment or as a low-sulphur component for a fuel oil pool or as gas turbine fuel.
Shell gasification

The SGP is the basis for an IGCC, which produces hydrogen in addition to power. A gas turbine combined cycle is the most efficient way to produce power from the syngas. The refinery steam network can be used for supplying steam to the existing steam turbines. This reduces the investment costs and the overall refinery emission levels by shutting down the heavy-fuel-oil-fired boilers.

The asphaltene stream from the deasphalting unit also contains aromatic compounds and high levels of sulphur and metals. The stream will be fed to three parallel-operating gasification trains with a total input capacity of 68 t/hr. The capacity of each train is such that two trains can produce the hydrogen required for the new and the existing hydrocracker – 8.5 t/hr in total with an additional 0.5 t/hr available in case one of the reformers shuts down. In addition, the gasification section has a desulphurisation unit, a hydrogen production unit, a power block, a cooling water system and a facility for metal oxides (vanadium and nickel) recovery (see Figure 3).

Figure 3: Block Flow Diagram of the IGCC.

The core technology of the SGP is the gasifier and the specially designed syngas effluent cooler. The gasifier is a refractory-lined, low-alloy steel vessel. In the gasifier, the reactants are fed to a single, top-mounted, co-annular burner. This burner is designed to ensure proper atomisation of the highly viscous fuel and intimate mixing with the oxygen. The oxygen necessary for the gasification process is delivered from an air separation unit and is admixed with steam, which serves as moderator.

The product of the partial oxidation at 1300°C and 65 bar is a raw syngas containing particles of soot and ash. The raw gas is cooled to below 400°C in the syngas effluent cooler and the heat recovered is used to produce high-pressure steam at about 95 bar. The raw gas is then passed through an economiser before reaching the soot quench for particulate removal. After passing through a cooler and a scrubber at about 40°C, the gas has a residual soot content of less than 1 mg/m³. This is suitable for feeding to the desulphurisation unit, which uses the Rectisol® process, where carbonyl sulphide and hydrogen cyanide are removed. The hydrogen sulphide removed from the syngas will be processed in the refinery’s Claus and tail-gas treatment plants to produce pure sulphur. Metal carbonyls are removed from the syngas to avoid problems with the gas turbine injectors.
Most of the desulphurised syngas will be used to manufacture hydrogen. A carbon monoxide shift, carbon dioxide removal and methanation produce the pure hydrogen, which is fed to a common hydrogen network. The excess desulphurised syngas will be fed as a clean fuel to the gas turbines of the power block to produce electricity for the refinery. A small amount of power will be sold to the public grid.

Steam production will be in line with the net demand of the integrated refinery complex. It will cover the process needs of the gasification section, the power block and the existing refinery facilities. The remainder will be used in a steam turbine for production of additional electricity.

The partial oxidation reaction of asphaltenes produces some soot, which is removed from the system together with metal ashes as soot–water slurry. In a Soot Ash Removal Unit, soot and ash are removed from the slurry using an optimised filtration method that produces a hard filter cake with about 20%wt solids and clear water. The filter cake undergoes controlled oxidation in a multiple hearth furnace that produces a metal oxide ash with a minimum of residual soot and high metal concentrations – with vanadium oxide typically at about 65%.

Wastewater from the gasification section will, after pre-treatment by steam stripping, be sent for further treatment to the existing wastewater treatment plants in the refinery.

4. Outlook – fit for 2010 and beyond

Integrated with a deasphalting unit and a hydrocracker, the Shell gasifier with power block is the optimum solution for the Gdańsk refinery as the residue-upgrading units will convert the residue into low-sulphur finished products and feedstock for the low-sulphur gasoline market – heavy fuel oils will no longer be manufactured. Based on proven technology, this is the state-of-the-art integration of gasification that will convert the refinery’s ‘bottom-of-the-barrel’ products into valuable products.

The gasification section and power block (IGCC) will generate steam and power efficiently, and the gas treatment units will remove components harmful to health and environment. As a result, the airborne emissions of the refinery will be significantly reduced and will comply with the future requirements of the EU directives.

Currently, the basis of design is being developed and the concept for integrating the new units into the existing refinery complex is finalised. The next phase will be the definition of the project, which will lead to the final investment decision. The first units are expected to start up by the end of 2007.

By implementing the Lotos world-scale residue-upgrading project, the key strategic drivers of both the refinery and the community will be satisfied:

- Enhance the financial performance of the refinery
- Eliminate the high-sulphur fuel oil exports
- Replace obsolete utility facilities
- Meet future product specifications
- Improve the environmental performance of the refinery
- Secure or even expand employment and business opportunities in the region.
The refinery will be able to process high-sulphur crude oil into gasoline and diesel that will meet the highest EU environmental standards. The upgrade will also expand the refinery’s capacity from 4 to 6 million t/yr. The production of high-sulphur fuel oil will cease.

The new SGP with integrated power block will result in a dramatic improvement in emission levels and help the refinery to comply with the new EU standards. Refinery sulphur dioxide emissions will be reduced by 80 to 90% through the replacement of high-sulphur fuels with desulphurised syngas as feedstock for utility generation. National sulphur dioxide emissions will also be reduced, as power generated externally using high-sulphur fuels will be replaced by power co-generated in the refinery with clean fuels.

This total site solution will help to increase the profitability of the Gdańsk refinery and will help it to maintain its position in a very demanding and competitive market.