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An Update On Shell Licensed Gasification Projects and
Performance of Pernis IGCC plant

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SUMMARY

This paper deals with two aspects of the gasification technologies of Shell Global Solutions. First, it gives a brief review of the status of recent gasification projects that are based upon the licenses of Shell Global Solutions. The Shell Gasification Process (SGP) for liquid feedstocks and the Shell Coal Gasification Process (SCGP) for solid feedstocks are presented briefly.

In the second part of the paper, the Shell Pernis refinery IGCC and hydrogen manufacturing plant on basis of the SGP technology is discussed. The optimal plant lay-out is explained in detail by means of description of four of the major units. Emphasis is put on the power generation units and their integration with the gasification plant. The plant has been running successfully for nearly three years now and is operating at its full capacity. The operators of the refinery are highly satisfied with the multi-functional, high-performing, environment-friendly plant.
1. INTRODUCTION

Gasification is a very versatile process to convert a variety of carbon-containing feedstocks like coal, petroleum coke, lignite, oil distillates, residues and natural gas into synthesis gas. Shell has developed two dedicated gasification technologies, the Shell Gasification Process (SGP) for liquid and gaseous feedstocks and the Shell Coal Gasification Process (SCGP) for solid feedstocks such as coal, lignite and petroleum coke. Both processes are successfully applied commercially. More and more gasification projects select Shell technologies due to their high efficiency, versatile applicability, and excellent performance, in addition to Shell Global Solution’s technological know-how and operational experience. In this paper an overview is presented of recent SGP/SCGP plants that have been built and projects that are in various stages of implementation.

The Shell Pernis refinery IGCC and hydrogen manufacturing plant on basis of the SGP technology has been running successfully for nearly three years. It is an appropriate time to give an update of its current status. This paper describes the optimal lay-out of the plant. Emphasis will be put on the power generation units and their integration with the gasification plant. The performance of the plant will be highlighted in terms of improved reliability and flexibility, optimal energy efficiency, economic benefit, and the emission control.
2. SHELL GASIFICATION PROCESS

Shell originally developed the Shell Gasification Process (SGP) to provide syngas for the chemical industry, e.g. for the production of fertiliser. The syngas can also be used for its combustion value. The utilization of low cost feedstock, feed flexibility and superior environmental performance are important drivers to support further application of this technology for power generation and hydrogen manufacturing in refineries.

In the early years, feeds were usually rather light distillates, but residues became more attractive due to their low values. Necessary adjustments to the process such as the incorporation of the Soot Ash Removal unit extended the technology to the application for the manufacture of syngas from refinery-derived heavy residues like from vacuum distillation, visbreaking and solvent de-asphalting.

The main processing units of a gasification system are the gasification, in which the feedstock is reacted with oxygen and steam to raw syngas, the syngas cooling, sour syngas treatment, and the carbon handling system.

The non-catalytic partial oxidation of hydrocarbons by SGP takes place in the gasifier equipped with a specially designed burner. This design provides for more efficient gas-liquid mixing and a better flame temperature control.

![Diagram of SGP Gasification Plant](image)

**Figure 1** A typical line-up of an SGP Gasification plant for hydrogen production

Figure 1 shows a typical line-up of an SGP gasification plant for hydrogen production. Presently 82 SGP reactors are producing about 62 million Nm³ syngas per day in 26 plants worldwide. This is equivalent to 23,000 tons of residue per day or nearly 8 million tons of residue per year.
3. SHELL COAL GASIFICATION PROCESS

For gasification of solid feedstocks, a dedicated development program has resulted in the commercially proven Shell Coal Gasification Process. The process is characterised by the following features.

- Dry feed of pulverised coal,
- Compact gasifier and other equipment due to the pressurised, entrained flow, oxygen blown concept,
- Slagging, membrane wall gasifier which allows high temperatures because of insulation and protection of wall by solid inert slag layer,
- Multiple, opposed burners resulting in good mixing of coal and blast; large turndown; and large scale-up potential.

The typical syngas product consists of 25-30 % of hydrogen and 60-65 % of carbon monoxide. High-pressure steam is produced in the gasification and heat recovery section and can be used, e.g., to generate electricity in the IGCC application, thus increasing the efficiency of the whole process. Other by-products are: inert slag, elemental sulfur, and relatively small amounts of clean water effluent. As an alternative to discharge the effluent water, it may be evaporated to give a zero water discharge and salts as a by-products. The slag and sulfur can readily marketed.

The process can handle a wide variety of solid feedstocks, ranging from lignite, brown coal, sub-bituminous coal, bituminous coal, anthracite, to petroleum coke. Coal types can be switched during operation. Over the wide range of coal properties processed, the SCGP process has proven to be insensitive to the size, condition, or other physical properties of the raw coal.

Figure 2 shows a typical SCGP line-up gasification plant.

![Figure 2](image)

**Figure 2** A typical line-up of an SCGP Gasification plant
Shell's operational experience with coal gasification started with a 6 t/d pilot plant in Amsterdam, followed by a 150 t/d unit in Harburg, Germany. A third unit in Houston with a capacity of 250-400 t/d fully demonstrated the capability of the Shell gasifier to process a wide range of solid fuels from lignite to anthracite and to petroleum coke. These experiences have lead to the successful design, construction and operation of the 2000 t/d coal gasification unit of the Demkolec plant. Various SCGP plants are at different stages of implementation, which are briefly reviewed below.

4. OVERVIEW OF RECENT PROJECTS

4.1. The Shell Pernis Refinery, The Netherlands

In the recent major revamp of the Shell Pernis refinery, a hydrogen plant was built based on SGP gasification of heavy residue oil to supply the hydrocracker with hydrogen and, in conjunction with a new power plant, to produce power and steam. The gasification takes place in three parallel trains with a total capacity of 1650 t/d residue. Feedstocks are vacuum flashed cracked residue from the thermal cracking unit and a mixture of straight-run vacuum residue and propane asphalt. The gasification capacity is sufficient to make the required hydrogen in addition to supplying a clean fuel for the gas turbines of the IGCC power plant. The SGP plant provides an outlet for heavy refinery residues, particularly those that are high in sulfur and ash. Therefore, the flexibility of the refinery has been significantly enhanced. The refinery as a whole is able to process a heavier crude diet with a higher sulfur and ash content while at the same time producing more white products and reducing refinery emissions.

4.2 Shell MDS, Malaysia

The Shell MDS plant at Bintulu, Malaysia represents the first commercial size gas-to-liquid plant world-wide. It uses the SGP technology for the partial oxidation of 100 MMSCFD of natural gas to syngas. This syngas is then converted to 12,000 bbl/day of high-quality distillate fuels and specialty products. The plant operated successfully from the start-up in 1993, but suffered from a severe explosion of the oxygen plant late 1997. After thorough investigations of the cause of this event, the plant was rebuilt and restarted in May 2000 in record time.

4.3 IOCL Pet coke Gasification, India

In 1999 Shell Global Solutions was selected to provide the license and a basic design package for a gasification plant to produce clean syngas for power generation and Hydrogen for a grass-roots refinery of Indian Oil Corp. Ltd. at Paradip, Orissa State, India. The feedstock for the gasifiers will be delayed coke. The configuration to use the syngas for both power generation and hydrogen manufacture is similar to that of the Pernis project. The sour syngas from the gasifiers is desulphurised using a COS hydrolysis step followed by H₂S absorption using the Shell Sulfinol process. Part of the sweet syngas is sent to gas turbines, the remainder is used for hydrogen manufacture. The syngas is shifted applying high temperature shift catalysts. The bulk of the CO₂ is removed by a MDEA wash and final purification is done with a PSA unit. The hydrogen will have a purity exceeding 99.5 %v. The project is nearing the final investment decision.
4.4 Sulcis ICGCC, Italy

Shell Global Solutions has been selected to provide a license and a process basic design package for the gasification unit for the Sulcis IGCC project in Sardinia, Italy. This project will have a power generation capacity of 450 MWe. The project is supported by the Government of Italy and the EU. The ATI Sulcis consortium is developing the project, which will be realized under project financing. The IGCC plant will use at least 50% Sulcis coal from the local mine as the gasification feed. The Sulcis coal is characterized by its high ash content and high sulfur content. Shell Global Solutions was requested to provide the SCGP technology, whose high efficiency meets the project requirement. The engineering, procurement, and construction phase of the project is expected to start in early 2001.

4.5 AGIP Refinery IGCC, Italy

For an AGIP refinery in Italy, the basic design is being prepared for an SGP complex which will process high-viscous bottom tar from a visbreaking unit and produce clean syngas for a power generation unit, where it will be co-fired with natural gas. This gasification plant will consist of the gasifier and syngas cooling system including the steam generation in an effluent boiler, the syngas scrubbing, and water handling system. The Soot Ash Recovery Unit, which has been demonstrated successfully in the Pernis refinery, will be an integral part of the plant. The project teams of Shell and AGIP are working closely together to complete the project following a fast-track execution schedule.

4.6 Dong Ting fertiliser plant, China

Shell Coal Gasification Process will be applied in the Dong Ting fertiliser plant, Hunan Province, China. The plant will gasify 2,000 ton/day coal to syngas to manufacture hydrogen for ammonia synthesis. The coal will replace naphtha as the feedstock, resulting in significant cost savings for the plant. A joint venture between Shell and Sinopec will be set up by the end of the year after approval by the government authorities to construct and operate the plant. The plant is expected to be ready for start-up in 2003.

5. PERFORMANCE OF PERNIS IGCC PLANT

5.1 Plant Lay-out

As an integral part of the major refinery upgrading project, the Per+, the SGP-based residue-oil gasifying IGCC plant in the Pernis refinery fulfils a number of functions:
- supplying high-purity hydrogen for the new hydrocracking unit;
- generating electricity for the refinery internal use and export;
- generating medium-pressure and low-pressure steam for the refinery utility system;
- conversion of vacuum flashed cracked residue in an environmentally friendly manner.
Figure 3. Block diagram of IGCC plant at Pernis refinery based on SGP technology

Besides the endeavours to meet the general requirements of high reliability and flexibility of the supply of the products, as well as the optimization of the energy efficiency, careful considerations of many specific aspects of each unit and their integration have resulted in an optimized lay-out of the plant. Figure 3 shows blocks of the major units and essential streams that cross the battery limit of the plant. The Shell Gasification Hydrogen Process (SGHP) stands central in the IGCC plant. In what follows, each major unit of the IGCC plant will be described in some details.

Gasification plant (SGHP)

A vacuum flashed cracked residue is gasified at a pressure of 64 bar in three SGP reactors each with a capacity of 550 ton feed intake per day. Oxygen is supplied at 70 bar over the fence from an Air Products plant. The high-level heat at the gasifier outlet with a temperature of 1300 °C is recovered with a waste heat exchanger (WHE) producing saturated high pressure steam. After the removal of soot and ash from the raw syngas by means of a water wash, the sulphur in the syngas, available as H2S, is removed by washing with methanol. At this point the syngas can either be directed to the gas turbines or to the hydrogen manufacturing plant. The clean syngas is shifted in both high-temperature and low-temperature shift reactors to increase the H2-to-CO ratio. The hydrogen stream is purified in the CO2 removal and methanation units. The syngas for power generation is routed to the fuel-mixing unit for the gas turbines. In this fuel mixing unit natural gas is added as a back up for pressure control reasons. LPG can be added in case there is surplus in the refinery. The total out going stream of the fuel mixing station is heated up to 80 °C.

Gas Turbine Generation Facilities (GT)

Based on the previous operation experiences of the gas turbines, two General Electric MS 6541 B generator sets were selected in the project. The gas turbines have a power output of 43 MWe (ISO) each. They are equipped with three-stage air inlet filtration and inlet guide vane control. The gas turbines have dual fuel gas nozzle combustors and parallel gas control systems for natural gas as well as mixed syngas, as required by the wide variation in fuel gas properties. No liquid fuel
firing is included. Steam injection facilities were installed to keep thermal NOx emission within the strict legislation of 65 g/GJ (as NO2 at 15 % O2 in dry flue gas). Both hardware and software modifications of the standard gas turbines were needed to meet the requirements of the refinery. The modifications were carried out effectively through the close interaction between engineers from GE, the associated manufacturer, and Shell. In fact, the active contribution from both the refinery and Shell Global Solutions played a vital role in the success of the project during the design, implementation, and commissioning of the machines.

**Heat Recovery Steam Generator (HRSG)**

Two heat recovery VHP-steam generators (HRSG) with supplementary firing were installed, which lead to an enhanced reliability of the system as compared to the single HRSG configuration. A bypass stack is not included, since stand-alone gas turbine operation is not foreseen. Gas turbine exhaust gases with a temperature of 535°C are routed to the HRSG. Saturated VHP-steam, generated in the waste-heat exchangers of the SGHP, is co-superheated in the HRSG units as well. In order to maintain appropriate VHP and MP steam header conditions, continuous supplementary firing of the HRSGs is necessary up to a flue gas temperature of 590°C. However, the firing facilities have been designed such that the flue gas temperature can be raised to 800°C, thus attaining maximum operational flexibility in steam production. In this way the total steam production of the HRSGs can be varied from 145 to 185 t/h each, within a matter of minutes. The supplementary firing control is automatically triggered by a trip signal of another major steam producer. This is a very strong tool to keep steam grid pressure swings within the safe margin. In winter, with relatively high steam consumption in the refinery complex, the supplementary firing capability of the HRSGs is fully utilised, whilst in summer, minimum firing is required in normal operation. The supplementary fired HRSGs are using low pressure refinery fuel gas. In this way it is a valuable tool in controlling the refinery fuel gas system.

**Steam Turbine Generation Unit (ST)**

Most of the superheated VHP steam is expanded over a back-pressure steam turbine, driving a 28 MWe generator. MP-steam is supplied from this generation unit to the refinery-wide distribution grid. A second steam turbine driving a 15 MWe generator is installed in which MP steam is expanded to LP and further down to condensing conditions. This turbine has the facility to extract or to take LP steam. In this way it is designed for maximum flexibility and can operate in various modes. The steam turbine enables control of the LP-steam balance in the refinery. Both steam turbines were supplied by Nuovo Pignone.
5.2 Plant Integration

Integration of SGHP with GT

The clean syngas from the SGHP plant forms the major fuel gas for the gas turbines. Flash gases from the CO2 removal unit are also available as fuel gas. The amounts and the heating values of these streams can vary considerably, depending upon the hydrogen produced and the gasifier intake. As a result, the gas turbines get a varied fuel gas diet that consists of four fuel gas streams in which the syngas content can vary between 0 to 100%. During start-up of the gas turbine, natural gas is used. After start-up, the fuel can be rapidly switched to syngas within a time frame of five to ten minutes.

Modification of the standard design of turbines, such as nozzles, was necessary. The gas turbines have been designed to have dual fuel gas nozzle combustors, double gas manifolds and parallel gas control systems, which enable to deal with the wide variation in fuel gas properties. At the end, both manifolds are in principle being supplied from one fuel gas header. The second manifold comes in operation if the total flow exceeds a certain quantity at that moment the modulating transfer valve allows gas to flow to the second manifold and the second set of nozzle openings of the dual fuel nozzles. The gas turbines are equipped with ten radially located combustors, which contain the dual fuel gas nozzles, connected to dual gas ring manifolds.

The design of the fuel gas systems to apply the fuel gas diet and to satisfy the complex requirements of flexibility and reliability has been a major issue. Corner stone in the design is the gas turbine fuel gas control system. The control mechanism is based on the pressure ratio, fuel pressure over combustor pressure, of primary fuel gas nozzles. For high calorific fuel gas only the primary nozzles will be in operation. For lower calorific, higher specific volume gas, the secondary nozzles will come in operation, triggered by the control mechanism. This design allows to combust either 100% syngas or 100% natural gas or any combinations thereof, supplemented with up to 24 wt% LPG, if desired. The concept of system control on basis of gas-composition analysis was considered to have too long a lag time, and was therefore not applied.

All these specific features were built in the software that accompanied the hardware supply. The extensive modifications in the standard GE gas turbine control software required for this dual fuel system were developed through a close cooperation between Shell engineers from the refinery as well as from Shell Global Solutions and engineers from GE and its associated manufacturer. The sophisticated fuel control and safeguarding system was the key elements in the gas turbine control package, the triple module Speedtronic Mark 5.

Integration with HRSG

Additional saturated VHP-steam, generated in the waste-heat exchangers of the SGP is superheated together with other steam streams in the HRSG units.

To secure the superheat the total stream of this steam, even if one HRSG is out of operation, or to operate without any imported steam, the superheaters consist of three sections in series and a two-stage temperature control by means of water injection attemperators. Increasing the efficiency of high pressure HRSG by decreasing the stack temperature is usually accomplished by adding a low
pressure steam generating section. In this case, an alternative solution has been chosen to obtain more flexibility to adjust to the HRSG steam load. The economiser section in this design has been extended and the boiler feed water flow is partly recirculated via a flash vessel. In this vessel LP steam is flashed off and added to the LP steam for deaeration. Part of the superheated steam is mixed with saturated steam to produce process steam (71 bar and 380°C, 100 t/h) for the gasifiers and CO-shift. By applying two reducing stations upstream of the mixing point, the required steam condition will be obtained without injection of water, but by means of a ratio controller.

5.3 Performance and Operation Experiences

The IGCC plant was designed to generate more than 130 MW of electricity. Together with existing generators, the total installed generation capacity at the Penis refinery reaches more than 300 MWe. More than one quarter of the electricity generated in the IGCC complex is exported to users outside the refinery, partly for operating the air separation unit which provides the oxygen required and the rest to other users and the public grid. The hydrogen supply for the new hydrocracker of the refinery is secured by the SGP plant. The IGCC plant was designed to produce 200 ton per hour steam for export. Hence it has a significant contribution to the medium-pressure steam and low-pressure steam systems of the whole refinery. In fact, it controls the pressure levels of the two steam distribution grids in the refinery. The flexibility and reliability of the systems have been improved by the new sources. The flexibility of the refinery as a whole to process higher-sulfur crude oil has been enhanced by the implementation of the IGCC plant. This allows to process lower-cost crude oils which results in the improvement of the margin in the refinery. The emission of sulfur was reduced greatly from the refinery. The IGCC unit has a significant contribution to the sulfur reduction, as the sulfur concentrated in the residue is removed in the gas-treating part of the IGCC unit. Currently, the total Pernis IGCC plant is running at its full capacity. A high reliability of supply of hydrogen and electricity has been attained which meet the requirements of downstream users. The operators of the refinery are highly satisfied with the multi-functional, high-performing, environment-friendly IGCC plant.

CONCLUSIONS

Shell Global Solutions offers two gasification technologies, the SGP for liquid and gaseous feedstocks and the SCGP for solid feedstocks. Both technologies have outstanding track records of commercial application. More and more gasification projects select Shell technologies due to their high efficiency, versatile applicability, and excellent performance, in addition to Shell Global Solution’s technological know-how and operational experiences. The short review of the Shell licensed gasification projects underlines this. The Shell Pernis refinery IGCC plant on basis of the SGP technology has been running successfully for nearly three years. The plant has met the general requirements of high reliability and flexibility of the supply of the products, as well as optimal energy efficiency. The flexibility of the refinery as a whole to process higher-sulfur, higher-metal crude oils has been enhanced by the implementation
of the IGCC plant. This allows to process lower-cost crude oils, resulting in the improvement of the margin in the refinery. The emission of sulfur was reduced greatly from the refinery with the implementation of the plant. The operators of the refinery are highly satisfied with the multi-functional, high-performing, environment-friendly IGCC plant.