SYNGAS COOLER SYSTEMS FOR GASIFICATION PLANTS
INTRODUCTION

Hydrocarbons accompany us in all areas of life in a variety of chemical compounds such as plastics, fertilizers, paints, lubricants and fuels. The dominant basis for their production is still formed by natural gas and oil.

However, the industrial gasification of coal, refinery wastes, e.g. petroleum coke, and biomass is also steadily growing in importance in this context.

Gasification, a chemical process, converts hydrocarbon material by substoichiometric incineration under intense temperatures and often high pressure to synthetic gas, or syngas. Syngas is composed primarily of carbon monoxide, hydrogen and carbon dioxide and serves as a starting point for the production of a variety of chemical compounds, fertilizers, pure hydrogen, methane or liquid transportation fuels. It can also be used directly for electric power generation, for example by firing gas turbines.

Gasification technology represents an alternative feedstock-based chemical and fuel production system. Gasification breaks down virtually any carbon-based feedstock into its basic constituents.

This enables the separation of pollutants and greenhouse gases to generate clean gas for the production of chemicals, clean liquid fuels and electricity.

Gasification vastly expands the fuel base beyond natural gas and oil to include more abundant and lower cost resources, e.g. locally available coal and refinery waste.

The flexibility to co-produce multiple chemical commodities and different fuels makes the technology economically attractive for a broad range of industrial applications.

Excellent energy efficiency, lower emissions and the potential of waste recycling are clear advantages of gasification technology.

Figure 1: Flow diagram of a typical IGCC gasification process

Figure 2: Dry-feed entrained slagging gasifier

Figure 3: Slurry-feed downflow gasifier

Figure 4: Circulating bed reactor concept

Figure 5: Slurry-feed upflow entrained slagging gasifier
THE SCHMIDTSCHKE SCHACK COMPANY

ARVOS | SCHMIDTSCHKE SCHACK’s area of excellence is process heat transfer technology in the high temperature and pressure range, often combined with additional challenges like high dust loads or aggressive operation conditions.

The internationally renowned company is a leading developer, designer and fabricator of apparatuses for the chemical, petrochemical and metallurgical industries.

Based on mature design concepts, customized to meet process and customer requirements, SCHMIDTSCHKE SCHACK supplies Schmidt'sche® Transfer Line Exchangers, Reactors, Schack® Fired Heaters and Convection Banks.

Chemical process improvement is always accompanied by the development of new, increasingly powerful apparatuses. The excellent reputation of SCHMIDTSCHKE SCHACK stems to a vast extent from the ability to furnish the most suitable and reliable heat exchange equipment solutions for innovative new processes, e.g. reactors for catalytic processes, syngas cooling systems for gasification processes, reaction gas heating systems, superheaters for high temperatures and special designs for coal, shale oil/gas and heavy oil refinery residue.

SCHMIDTSCHKE SCHACK’s decade-long experience in meeting technological challenges from the basic idea to the finished product manufactured in its own specialized workshops makes the difference. Optimal quality and performance are thus ensured and allow our customers to focus on economic excellence. Individual service support assures trouble-free plant operation.

2.1 R&D AND DESIGN AT SCHMIDTSCHKE SCHACK

SCHMIDTSCHKE SCHACK’s R&D excellence combines practical experience with an outstanding command of the underlying theoretical physics. This is the product of numerous apparatuses built and recalculated with operation data in order to verify the calculation results and to refine the calculation methods.

Flow and thermodynamic process simulation in gases and fluids is often carried out in combination with solid particle contents. This forms the basis of stress analyses in linear and non-linear complexes and vibration investigations.

SCHMIDTSCHKE SCHACK experts closely cooperate with process developers on new concepts in order to find optimal technical solutions.
2.2 QUALITY

The quality focus is a guiding principle through all stages from process and layout calculation and basic engineering through to detail and manufacturing engineering and fabrication. A strict quality assurance procedure is defined and secured. SCHMIDTSCHE SCHACK is certified according to ISO 9001.

Design and fabrication take place in conformity with customer requirements, according to all common national standards and in-house know-how acquired over decades.

SCHMIDTSCHE SCHACK fabricates all sophisticated heat transfer components in its own specialized workshops in Kassel, Germany and with well-proven fabrication methods.

SCHMIDTSCHE SCHACK’s outstanding heat transfer equipment quality ensures customer value through highest availability, best performance and longest service life.

2.3 FABRICATION

Figure 7: SCHMIDTSCHE SCHACK fabrication shop in Kassel – birthplace of Schmidt’sche® Syngas Coolers
Through exothermic chemical reactions of feedstock with an oxygen/steam mixture, hot syngas is generated in a gasifier.

The syngas needs to be cooled before entering the gas cleaning stages, comprising a syngas scrubber and the downstream sulphur removal system. This task is performed by the syngas cooler, which acts as a heat exchanger, receiving the hot raw gas from the gasifier and cooling it by transferring the reaction heat to the cooling medium, water/steam.

The syngas cooler is one of the most crucial and highly loaded components in the gasification plants. Convective syngas coolers operate in a gas inlet temperature range between 1,400 °C and 400 °C and gas-side pressures up to 70 bar. The high operation parameters and harsh operating conditions, such as corrosive raw gas components (H₂S, HCl, H₂) and high dust loads, impose challenging requirements on the design and material selection. SCHMIDTSCHE SCHACK thus applies its unique Schmidt’sche® design principle with Double Tube/Oval Header System which is in operation in more than 7,000 Schmidt’sche® Transfer Line Exchangers in the ethylene industry.

The syngas cooler operates as a steam generator in natural circulation mode.

SCHMIDTSCHE SCHACK has developed special Schmidt’sche Convection Syngas Coolers for fixed bed, fluidized bed or entrained flow gasification processes.

Figure 8: 3D CAD model of a Schmidt’sche® Syngas Cooler with Double Tube/Oval Header System for a gasification plant in India. On top with steam drum and interconnecting piping.
3.1 DOUBLE TUBE SYSTEM

The SCHMIDTSCHE SCHACK design has various key features ensuring long, durable and reliable operation of the syngas cooler.

3.1.1 FUNNEL SHAPED TUBE INLET, NO FERRULES!

The Schmidt’sche® Double Tube/Oval Header System has no tube sheets in the classical sense, which would need to be refractory lined, nor do they need ferrules for the tube inlets. Aerodynamically optimized tube inlets together with intensively cooled oval headers have been shown by experience to offer the best protection against tube inlet erosion and the formation of gas-side deposits, see figure 10.

The high velocities on the water/steam side maintain the tube wall temperature at safe levels. The Schmidt’sche® design thus avoids the use of ferrules, resulting in the most reliable technology for this application.

The funnel shaped tube inlet reduces the propensity for deposits forming due to eddy currents, thus minimizing erosion of the tubes by managing the velocity profile at the tube inlet.

Furthermore, high alloy composite tubes can be used for the inner tubes and all gas bearing surfaces can be clad with alloy material in order to avoid high temperature H₂S corrosion.
3.1.2 REGISTER

The basic element of the Schmidt’sche® Double Tube/Oval Header Heat Exchanger is the double tube register. This element consists of a row of double tubes (tube within a tube), which are welded to oval headers at either end to form the double tube register as shown in figure 11. Double tube registers with different numbers of tubes are assembled to form one body by gas-tight welding of the adjacent oval headers. The ends of the oval headers are connected to downcomer distributors and headers for connection to the water circulation system. The cylindrical connections for the gas inlet and outlet chambers are welded to both tube sheets formed by a row of oval headers.

The process gas at temperatures up to 1,400 °C flows through the inner tube and is cooled by the water/steam mixture that flows through the oval headers and the annulus between the inner and outer tubes.

The water side of the exchanger operates in natural circulation. Water from the steam drum is fed through the downcomer to individual bottom oval headers for distribution to the annulus between the inner and outer tubes.

Steam is generated in the annulus at pressures up to 140 bar. The water/steam mixture flows to the top oval header and returns to the steam drum through the risers.

Since each process gas tube (inner tube) in the Schmidt’sche® Double Tube/Oval Header Heat Exchanger has its own cooling element provided by the annular gap between the inner and outer tubes, the amount of cooling required for each process tube is individually determined by the heat input, thereby self-adjusting to the heat load in each tube.

This is an important advantage of the system which is able to compensate for uneven gas flow distribution.

Proprietary software developed in-house is used to calculate water flow conditions in each set of double tubes based on individual process-side input data. The result of the calculation provides specific operational data for each process tube as well as the aggregate performance data for the exchanger as a whole.
Figure 11: Register: Key element of Schmidt'sche® Double Tube System

- Water/Steam Outlet
- Top Oval Header
- Inner Tube with Funnel Shaped Inlet
- Outer Tube
- Bottom Oval Header
- Water Inlet
3.1.3 ADVANTAGES OF DESIGN PRINCIPLES

- High flow velocities in the top and bottom oval headers and in the annulus between the inner and outer tubes ensure maximum cooling of the oval headers and each process tube. It also ensures removal and transport of particles carried over by the feedwater or that may settle during shutdowns.

- High velocities and turbulent flow in the oval headers and in the annulus between the inner and outer tubes provide for high heat transfer coefficients. This maximizes the cooling of the tubes and protects the high heat flux areas by keeping the gas-side metal skin temperature as low as possible. In addition the high turbulence and the defined flows within the oval headers ensure disturbance-free removal of the steam bubbles and prevent the undesired formation of steam cushions.

- The oval header acts as a flexible membrane that compensates for the difference in thermal expansion between the inner and outer tubes, in effect reducing the mechanical stresses on the system.

- Mechanical and thermal stresses are reduced by using thin-walled oval headers, inner and outer tubes. A thin-walled system is mechanically more flexible and assures a lower temperature gradient across the wall thickness.

- By effectively mitigating and/or eliminating high thermal and mechanical stresses, the magnetite layer on the process tubes is protected and ensures the operational longevity of the Schmidt’sche® Double Tube/Oval Header System.

Figure 12: Stable magnetite protection layer, mandatory for long durability, due to low tube wall temperature amplitudes.
The Schmidt'sche® Double Tube Design with Oval Headers is a unique heat management system for cooling gases on one side and generating high pressure steam on the other. This design principle has been applied successfully for more than 60 years worldwide to cracked gas coolers, so-called Schmidt'sche® Transfer Line Exchangers in ethylene plants (more than 7,000 units have been delivered). And for more than 20 years this type of heat exchanger has been successfully operating in various coal and biomass gasification processes. Many plants using the Double Tube/Oval Header design have been running for over 20 years using the original equipment and without a single failure. The longest running exchangers were taken off line after 35 years of operation without failure. These exchangers were replaced during a revamp and redesign. This record has given Schmidt'sche® heat exchangers a worldwide reputation for durability and reliability, which translates to lowest maintenance costs, highest productivity and thus optimal plant operation economy.
3.2 SYNGAS COOLER DOWNSTREAM PARTIAL OXIDATION OF LIQUID AND GASEOUS FEEDSTOCKS

The development of syngas coolers, which are installed downstream of partial oxidation reactors, requires a high level of technological know-how and practical experience that address the complex technical and physical issues of processing heavy residual oil and for hydrocarbons which are loaded with heavy metals.

Continuous efforts by SCHMIDTSCHE SCHACK in R&D, engineering and fabrication techniques have permitted higher operating temperatures and enabled pressures at the syngas coolers/steam generators to be increased to as high as 100 bar on the synthesis gas side and 150 bar on the steam side.

The generated syngas is used as feedstock for IGCC power generation or for various chemical processes. In addition to reactors and syngas coolers all other components such as economizers and steam superheaters are available from SCHMIDTSCHE SCHACK.
3.3 RADIANT SYNGAS COOLER (RSC)

One of the key elements of the Integrated Gasification Combined Cycle (IGCC) process is the Radiant Syngas Cooler (RSC), which generates high pressure steam by means of heat transferred from the hot raw gas. Compared to a gasifier without heat transfer but with direct water quenching, the syngas cooler increases the process efficiency by approximately 5 percentage points. The steam produced can be utilized for process purposes or to generate electric power.

Advanced radiant and convective syngas cooler concepts, developed and supplied by SCHMIDTSCHE SCHACK and predecessor companies, were put into operation 2007 in “Ningxia” the first coal gasification plants in PRC using radiant cooler technology in a Coal to Methanol Plant.

Figure 19: Gasifier with downstream Radiant Syngas Cooler

Figure 20: Interior view of the Radiant Syngas Cooler with high alloy heat recovery walls (for a 300 MW plant)

Figure 21: Computerized flow modelling of a radiant cooler with slag entering the water sump (courtesy of GE Energy)
3.4 SCHMIDT’SCHÉ® RAW GAS – CLEAN GAS HEAT EXCHANGER

The efficiency of an IGCC can be further enhanced by installing a Raw Gas – Clean Gas Heat Exchanger in front of the gas cleaning system. The latent heat of the raw gas preheats the clean gas fuelling the gas turbine.

SCHMIDTSCHÉ SCHACK has developed a heat exchanger concept based on the well-proven Schmidt’sché® Double Tube System. This special design achieves highly uniform flow distribution on the shell side and therefore identical thermal input (load) on all tube surfaces.

Typical operating conditions are:
- Raw gas pressure and clean gas pressure 10 to 30 bar
- Raw gas temperature 600 to 350 °C
- Clean gas temperature 250 to 530 °C
Depending on the type of gasification process the syngas downstream of the steam generator may be further cooled by a steam superheater (special SCS design) and economizers.

### 4.1 SPIRAL COIL STEAM SUPERHEATER

The SCHMIDTSCHE SCHACK Steam Superheater with the special spiral wound heating surfaces is able to operate under high steam-side as well as high gas-side pressure and high dust load. A large number of wound tube spirals are interlaced to form a compact tube bundle with circumferential gaps. Steam flows through the spiral tubes, whereas the syngas to be cooled flows through the circumferential gaps to the outside of the tube bundle.

Due to the high flexibility of the spirally wound tube bundle, thermal stresses remain at safe levels even at all operating temperatures. Use of high alloyed steel permits operating temperatures of up to 850 °C on the gas side and 560 °C on the steam side. Down flow arrangement and specially shaped gas inlet channels, optimized by CFD modelling, allow operation with gases featuring high dust loads. For such applications or difficult fouling conditions, SCHMIDTSCHE SCHACK has developed efficient mechanical cleaning devices.
Growing demand for SNG (Substitute Natural Gas) is driving investors’ interest in the methanation stage behind syngas generation, mainly from petcoke, coal or biomass gasification.

The Schmidt’sche® Bayonet-Tube Steam Superheater based on its well-proven, reliable and robust tube-in-tube design principle provides a controlled gas and coolant flow and thus ensures supremely efficient heat exchange at low pressure drop. In addition a smooth material temperature distribution at a moderate level is achieved in the mechanical structure and the tube sheet.

In consequence, uniform thermal expansion and low thermal stresses lead to a robust design, which is of particular importance for cyclic operation. The minimal use of inner refractory and the application of internal cooling ensure low maintenance and high availability.

Operational experience with the Schmidt’sche® Bayonet Tube-in-Tube design principle proves the reliability of this robust concept.

The Schmidt’sche® Bayonet-Tube Steam Superheater is able to operate at gas-side temperatures of up to 640 °C at 40 bar and steam-side temperatures of 540 °C at 120 bar.
Syngas from gasified biomass like wood and straw contains solid particles, tar and chemical components like chloride which need to be taken into consideration for dimensioning and material selection. Heat recovery equipment can be designed as water tube or fire tube heat exchangers, with natural or forced water circulation systems.

SCHMIDTSCHE SCHACK designs and manufactures Schmidt’sche Syngas Coolers with Double Tube/Oval Header System for biomass gasification processes.

Figure 27: Syngas Cooler for biomass test gasification plant
Black liquor, a secondary product of the pulp and paper industries with a high calorific value, is usually incinerated in special furnaces in order to make use of the thermal heat.

Black liquor can be converted into “green liquor” by means of dedicated gasification processes and rerouted into the paper production process. Downstream of the gasifier, heat transfer equipment like cooler condensers is installed to collect the green liquor produced and to recover the heat energy from the gasification process.

SCHMIDTSCHE SCHACK implements highly sophisticated heat transfer technology and has a wealth of excellent know-how with the radiant shield cooler. SCHMIDTSCHE SCHACK also offers suitable products to meet the continuously growing demand for plastic waste gasification systems.