GAS COOLING SYSTEMS FOR STEAM REFORMING PLANTS
1.1 INTRODUCTION

SCHMIDTSCHE SCHACK is a leading and highly regarded supplier of components and systems for the petrochemical, chemical, refining & metallurgical industries. Decades of experience in process heat transfer for steam reforming processes generating synthesis gas have established ARVOS technical reputation, leadership in the industry and recognition as a reliable partner.

1.2 STEAM REFORMING PROCESS

This applies predominantly to the production of synthesis gas (CO, H₂) from various feed stocks including natural gas, refinery off-gases, LPG or naphtha. High value products such as hydrogen, ammonia and methanol are generated in further steps downstream of the steam reforming reactor in different catalytic processes.

Growing demand for steam reforming based products for chemical and refinery processes as well as the increasing push for alternative fuels is leading to a greater need for steam reforming plants.

Different steam reforming processes are the result of a knowledge based interaction between the process heat transfer and reaction kinetics.

Plant capacity, product specifications, catalyst technology, feedstock characteristics and desired steam production vary in each individual case.

Plant reliability is ensured and production costs are minimized by optimum integration of steam reforming processes and waste heat recovery.

Figure 1: Typical flow diagram of a steam reforming process
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2.1 WASTE HEAT RECOVERY IN DOWNSTREAM STEAM REFORMER

The combustion process in a steam reformer generates flue gas which leaves the reformer at about 1,000 °C and is then cooled down to temperatures below 180 °C in the convection section.

Preferably the recovered heat is returned to the steam reforming process, making the flue gas cooling system an integral part of a steam reforming plant.

All process and site specific requirements must be taken into account and integrated in the design.

For the material flows in the steam reforming process different types of heat exchangers and a wide variety of arrangements are possible.

Following the direction of the waste gas flow, the typical flow diagram shows the following equipment:

- 2-stage reformer feed superheaters, hairpin type
- Steam superheater, hairpin type
- Combustion air preheater second stage, tube bundle type or plate type
- Steam generator, tube bundle type
- Combustion air preheater first stage, tube bundle type or plate type

Depending on the process requirements an additional pre-reformer feed preheater as well as a natural gas preheater made as hairpin type can be supplied. For some processes a boiler feed water economizer or even a process condensate preheater is required.

For specific operation modes which may result from varying load cases the convection section will be equipped with a combustion system – known as duct burner – enabling the flue gas to be reheated.
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2.3 SCHMIDTSCHE SCHACK’S DESIGN CONCEPTS

SCHMIDTSCHE SCHACK offers two basic design concepts.

- Boiler derived designs usually use small tube diameters. The tubes hang vertically in a horizontal casing allowing for free thermal expansion downwards. These convection sections consist of prefabricated modules with casing, refractory lining and heating surfaces – hence erection time and cost are minimized. For special applications the refractory lined casing can be substituted by a water-cooled membrane wall construction.

- Refinery based designs are in accordance with API 560 and usually incorporate larger diameter tubes. The tubes are horizontally arranged, guided and held in place in a horizontal casing. In this design the tubes expand thermally in horizontal direction. A special SCHMIDTSCHE SCHACK design is a vertical convection section, where the flue gas duct is built as a water-cooled membrane wall construction.

2.2 SCHMIDTSCHE SCHACK’S EXPERIENCE

SCHMIDTSCHE SCHACK designs and fabricates convection sections custom-made to meet specific process requirements ideally. SCHMIDTSCHE SCHACK experts with extensive knowledge in process design, stress analysis, static calculation and project management expertise assure the reliability, integrity and long life of the equipment.

Through the years of experience and close working relationship with its clients, SCHMIDTSCHE SCHACK provides standard or adapted designs and modularized components to meet customers’ specific requirements. State of the art CAE software is used and continuously improved through experience parameters and R&D leading to superior design solutions.
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3.1 SYSTEM DESCRIPTION
The process gas leaving the reformer catalyst tubes and the secondary reformer enters the process gas cooler where saturated steam is produced on the shell side while cooling the gas in the process tubes. The unit operates under natural circulation and is connected to the steam drum via downcomers and risers where the steam and water are separated. Depending on the process requirements, the gas downstream of the process gas cooler is used to superheat steam, preheat boiler feed water/feed or enters the CO-shift converter.

3.2 SCHMIDT’SCHER PROCESS GAS SYSTEMS
SCHMIDTSCHE SCHACK’s main design features are
- Fire tube design
- Single- or twin-compartment design
- Refractory lined gas inlet chamber
- Thin, flexible or super flexible tube sheets
- Inlet tube sheet is protected by ferrules and refractory lining
- Full penetration, crevice-free tube to tube sheet welding to avoid crevice corrosion
- Two bypass designs to control gas outlet temperature: a conventional “hot” bypass design or an improved “cold” bypass design for operation free of metal dusting.

SCHMIDTSCHE SCHACK’s scope of supply and services includes
- Process gas cooler
- Steam superheater
- HT shift gas boiler
- Steam drum
- Interconnecting piping
- Accessories
- Steel structure
- Supervision of erection and start-up

Figure 9: 3D model of a process gas cooling system
Figure 10: Thermocolour painted gas inlet chamber
Figure 11: Schmidt’sche® Process Gas Cooler for a 2000 MTPD ammonia plant during erection
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3.3 SCHMIDTSCHE SCHACK’S FLEXIBLE TUBE SHEET DESIGN

The thin flexible tube sheet design in Schmidt’sche® Process Gas Coolers is an optimal solution to avoid excessive stress build-up in the tube to tube sheet connection which results from differential thermal elongation between the tubes and shell.

The combination of high gas side pressure, high gas temperature and process gas composition results in heat fluxes in the tube inlet area which are higher than those found in other boiler applications.

This requires efficient cooling of the process tubes and tube sheets which is accomplished by keeping the wall thicknesses as thin as possible.

In comparison to a non-flexible tube sheet design, the tube sheets are supported by process tubes which act as anchors.

With this reinforcement of the tube sheet there is no need for stiffening braces which reduce the water volume in the area of the highest heat flux where the highest flow of cooling medium is required.

As a result, the tubes stay straight during operation, preventing plastic deformation caused by tube buckling as observed in other designs.

3.4 SCHMIDTSCHE SCHACK’S SUPER FLEXIBLE TUBE SHEET DESIGN SUPLEX®

For extreme process conditions and mechanical design requirements, such as high pressures, long tubes or larger boiler diameters, SCHMIDTSCHE SCHACK has developed and is using a highly sophisticated proprietary design called “super flexible tube sheet” (SUPLEX® tube sheet). This tube sheet concept is characterized by specially shaped connections of tube sheet with cooler shell and gas chamber respectively, allowing for highly flexible behaviour.

As with SCHMIDTSCHE SCHACK’s flexible tube sheet design, the process gas tubes act as anchors, hence the tubes stay straight during operation of the Process Gas Cooler.

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3.7 MANAGING METAL DUSTING

Metal dusting is a special form of high-temperature corrosion, generally occurring in reducing and strongly carburizing atmospheres at metal temperatures in the range of approximately 500 to 750 °C. Metallic ferrules, bypass liners and in particular the bypass control devices are exposed to metal dusting.

Several measures can limit and preferably avoid the effects of metal dusting:

- **Substitution of metallic by ceramic material**
  Limited measure due to brittle nature of ceramic material.

- **Application of high chrome or nickel base alloys**
  Improves resistance and lifetime but does not eliminate the risk in general.

- **Thermal spray or diffusion coating**
  Results are similar to the application of high chrome or nickel base alloys but at a higher cost.

- **Avoidance of metal dusting**
  Designing the boiler such that all critical metal surfaces operate below or above the temperature range to avoid the effects of metal dusting.

3.6 FERRULES

The tube inlet area is protected by refractory lining and ferrules. Two types of ferrules are used:

- **Ceramic ferrules**
  Offer the highest metal dusting resistance at reasonable cost but have low resistance to cracking.

- **Metallic ferrules**
  Provide lower pressure loss due to low wall thickness and higher resistance to cracking but are exposed to metal dusting effects.

Both ferrule designs extend into the tubes and are wrapped with ceramic fibre paper to increase the insulation effect.

3.5 TUBE TO TUBE SHEET CONNECTION

Due to the high heat flux at the tube inlet, the conventional tube to tube sheet connection, in which the tubes are rolled, expanded and welded, are not used, because crevice corrosion may occur in the non-welded portion where water can evaporate and decompose in the crevice between the tube and bore hole.

The only reliable way to avoid crevice corrosion is to use full penetration crevice-free attachment of tubes. SCHMIDTSCHE SCHACK has used this design for more than 30 years. Neither crevice corrosion nor mechanical problems have been reported.

For this cooler design the SCHMIDTSCHE SCHACK tube to tube sheet connection is made on the rear of the tube sheet. The design is in accordance with all relevant national codes and is the only crevice-free weld type expressly implemented in ASME Code Section I.

Figure 16: Tube to tube sheet connection executed as a full penetration weld

Figure 17: Crevice-free tube to tube sheet connection

Figure 18: Tube to tube sheet connection with ceramic fibre paper insulation
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Several types of protective coatings can be used. However, the application of thermal spray is an inexpensive method to increase the resistance of the metal surface.

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3.8 SCHMIDTSCHE SCHACK’S COLD BYPASS DESIGN

In conventional hot bypass cooler designs, the gas leaves the bypass essentially uncooled. The internal bypass in SCHMIDTSCHE SCHACK’s cold bypass design uses a number of individual larger process tubes installed in the centre of the boiler that cool the gas as it flows to the outlet channel. The temperature of the gas on leaving these bypass tubes is high enough to control the process gas temperature at the cooler outlet as it mixes with the gas flow from the main tube bundle of the boiler. Throughout the cooler, the temperature is kept below the critical metal dusting temperature, hence the “cold bypass” design which eliminates metal dusting corrosion.

The process gas leaving the cold bypass tubes is collected in a gas-tight conical channel and guided through a central flap for controlling the gas flow. The process gas stream leaving the main heating surface is also collected in a gas-tight channel before passing through two additional flaps for controlling the gas flow. The control of both process gas streams achieves the desired mixed cooler gas outlet temperature.

Since all three flaps are installed on a common shaft, only one actuator is required, which means that the cooler gas outlet temperature is defined by a single control variable.

The patented cold bypass design with more than 20 years of successful operating results is still the state of the art and is a dependable means of avoiding metal dusting corrosion. Experienced clients have made the cold bypass design a mandatory requirement in their specifications.
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3.10 HT SHIFT GAS BOILER

The process gas leaving the shift reactor is cooled in an HT shift gas boiler. The boiler is a fire tube design with flexible tube sheets. Operating temperature and heat flux in this boiler are relatively low. For this application SCHMIDTSCHE SCHACK uses its standard tube to tube sheet connection in which the tubes are hydraulically expanded and welded.

The HT shift gas boiler operates under natural circulation and is connected to a steam drum via downcomer and riser piping.

3.9 STEAM SUPERHEATER

Saturated steam leaving the steam drum may need to be superheated. For this a superheater is installed, e.g. downstream of the process gas cooler. SCHMIDTSCHE SCHACK’s steam superheaters are vertical heat exchangers with U-tubes and baffle plates.

Further design features:
- The hot process gas at no point contacts the pressure vessel wall.
- The upper head is designed as a combined steam inlet and outlet chamber.
- The internal gas bypass valve is used to control the gas outlet temperature.
- The complete U-tube bundle together with the upper head can be removed through the top.

Figure 26: Principle sketch of HT shift gas boiler
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![Figure 23: Tube sheet detail](image)

![Figure 24: SCHMIDTSCHE SCHACK steam superheater for a 650 MTPD ammonia plant (during manufacture)](image)

![Figure 25: Principle sketch of a SCHMIDTSCHE SCHACK U-tube type steam superheater](image)

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The waste heat boilers in the ammonia synthesis loop are exposed to very high operating pressures, resulting in huge mass flow densities and thermal heat fluxes. The synthesis gas consisting essentially of hydrogen, nitrogen and ammonia is under pressure of 200 to 250 bar. In the waste heat boiler the synthesis gas is cooled down from approx. 450 °C to approx. 340 °C whereby high pressure saturated steam of about 120 to 140 bar is produced.

SCHMIDTSCHE SCHACK’s competence in engineering work and highly qualified manufacturing guarantee the required high quality of the Synloop Boiler.

Main features of the SCHMIDTSCHE SCHACK Synloop WHB design are
- U-tube design
- Tube sheet face on the gas side is covered by an Inconel cladding
- Inlet tubes are protected by Inconel ferrules
- The hot gas stream is led from the gas inlet nozzle via internal metal duct directly to the tube sheet
- No contact of the hot synthesis gas with the ferritic wall of the pressure shell
- The metal skin temperature of ferritic parts can be kept safely under the critical nitriding temperature

The steam drum in a steam generating system operating under natural circulation provides:
- spare water volume which allows further operation of the steam generator for a limited time period to take adequate countermeasures in case of boiler feed water cut-off
- separation of the water/steam mixture generated in the boiler which enters the steam drum via the riser piping. The required steam quality is achieved by the installation of a wire mesh demister in front of the steam outlet nozzle. To avoid water droplets being directly carried over from the turbulent water surface (especially at high water levels) to the surface of the demister, a special plate construction is provided below the demister surface.

The steam drum is furnished with adequate internals and with all required nozzles and manholes. If required by the plant operation, a surface-type attemperator may be installed into the steam drum to control the steam/feed temperature.

The arrangement of the steam drum can be either saddle supported or directly on top of the process gas boiler by heavy walled risers as a “piggyback” version.
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