SCHMIDT'SCHE®
TRANSFER LINE EXCHANGERS
FOR ETHYLENE PLANTS

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1 | CONSTRUCTION AND OPERATION

1.1 INTRODUCTION

Schmidt'sche® Transfer Line Exchangers have long been linked to the history of ethylene pyrolysis furnaces. The reliability and flexibility of the Schmidt'sche double tube and double pipe designs have played an important role in the development of modern furnace technology, where long run lengths, high yields, selectivity and equipment availability determine the commercial success of the operation.

Ethylene and other olefin products are produced by the thermal cracking of gaseous feedstocks such as ethane, propane, LPG or liquid feedstocks such as naphtha, gas oil or pre-processed hydrocracker output products.

The cracking process occurs in the radiant coils of a pyrolysis furnace where gas flows at low pressure and temperatures between 750 °C and 900 °C (1,382 °F to 1,650 °F) depending on the feedstock used. The olefins formed are chemically unstable at these temperatures.

The highly reactive cracked gas must be quickly quenched below a critical temperature within a very short interval "residence time" of milliseconds to provide the highest yield. The critical temperature range for the production of ethylene lies between 650 °C and 700 °C (1,202 °F to 1,292 °F).

The rapid cooling or quenching takes place in the transfer line exchangers where the high heat content is used to produce high pressure steam. Figure 1 illustrates a typical furnace and transfer line exchanger layout.

Early on, the standard practice for cooling the pyrolysis furnace effluent gas was by direct oil or water injection. Today such methods are unacceptable.

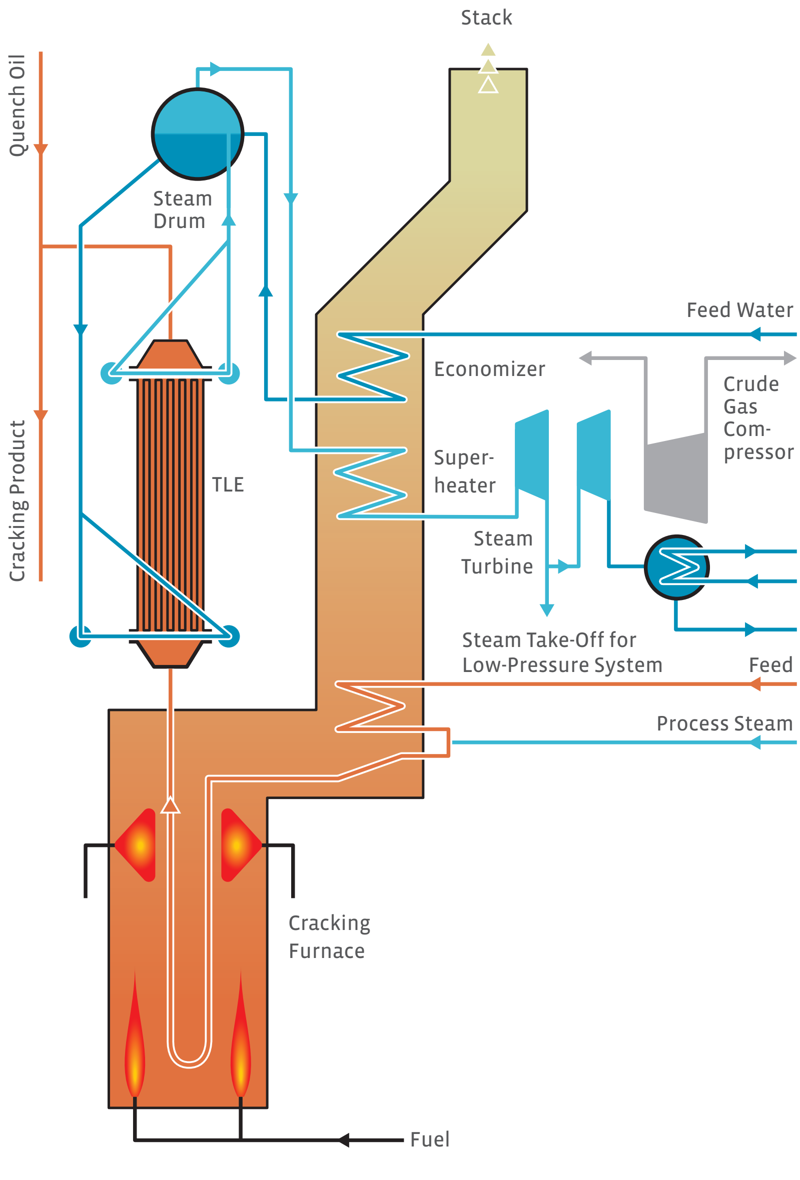

Figure 1: Typical Furnace/TLE Layout

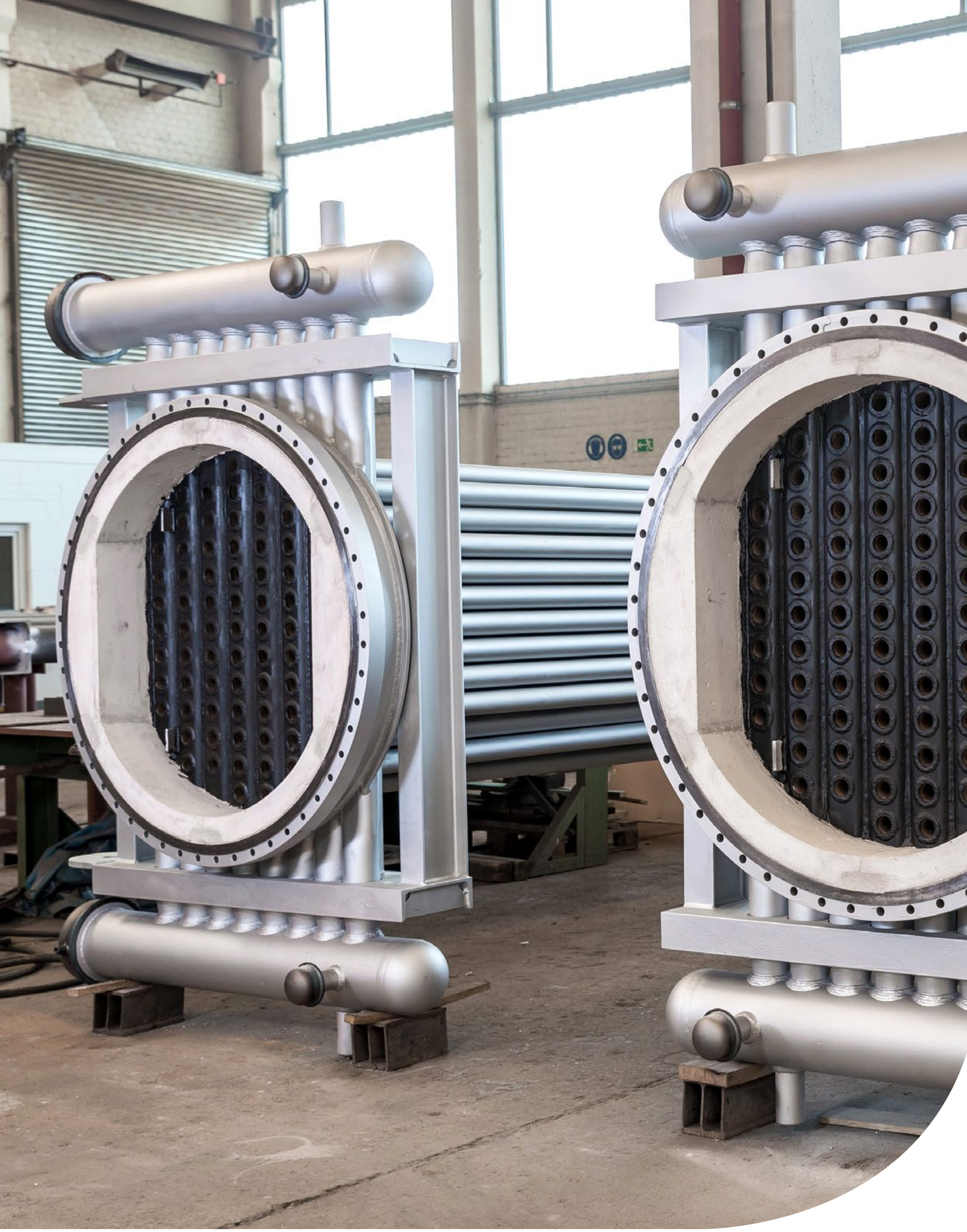

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Figure 2: Schmidt'sche® Round-Type TLE

In 1960 SCHMIDTSCHE SCHACK engineers pioneered the recovery of the enormous heat available from the cracking process by installing the Schmidt'sche® double tube/oval header exchanger design at Rheinische Olefinwerke, in Wesseling, near Cologne. Then, for the first time a high-pressure steam generator was used as a transfer line exchanger.

The evolution of Schmidt'sche® Transfer Line Exchangers parallels the development of modern furnace technologies. Over 7,000 units have been shipped worldwide using Schmidt'sche® double tube/oval header designs, including the workhorse of the industry, the Schmidt'sche® Round-Type Transfer Line Exchanger shown in figure 2 and figure 3. Today Schmidt'sche® Transfer Line Exchangers are found on the latest generation of ethylene furnaces.

Figure 3: Gas inlet chamber of Schmidt'sche® Round-Type TLE

The unparalleled success of the Schmidt'sche® double tube/oval header design can be grouped into two broad categories:

1. The Multi-Tube Exchangers
2. The Linear Closed-Coupled Exchangers

Each exchanger concept meets specific furnace process requirements and provides the optimum match between furnace coil arrangement and transfer line exchanger design.

Modern Schmidt'sche® Transfer Line Exchangers share the double tube/ oval header arrangement that provides maximum operating reliability and ease of maintenance.

Using online decoking techniques the exchangers can virtually operate continually without having to take the furnace out of operation to mechanically clean the exchangers.

In the following pages the Schmidt'sche® Round-Type, Bathtub, Quick Quencher and Linear Transfer Exchangers will be described.

2 | SCHMIDT'SCHE® DOUBLE TUBE/ OVAL HEADER DESIGN PRINCIPLES

2.1 DOUBLE TUBE REGISTER

The basic element of the Schmidt'sche® Transfer Line 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 on either end to form the double tube register as shown in figure 4. The process gas at temperatures between 800 °C and 900 °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 (2,030 psi). The water/steam mixture flows to the top oval header and returns to the steam drum through the risers.

Since each process tube in the Schmidt'sche® Exchangers has its own cooling element provided by the outer tube, the amount of cooling required for each process tube is individually determined by the heat input, thereby automatically adjusting to the heat load in each tube.

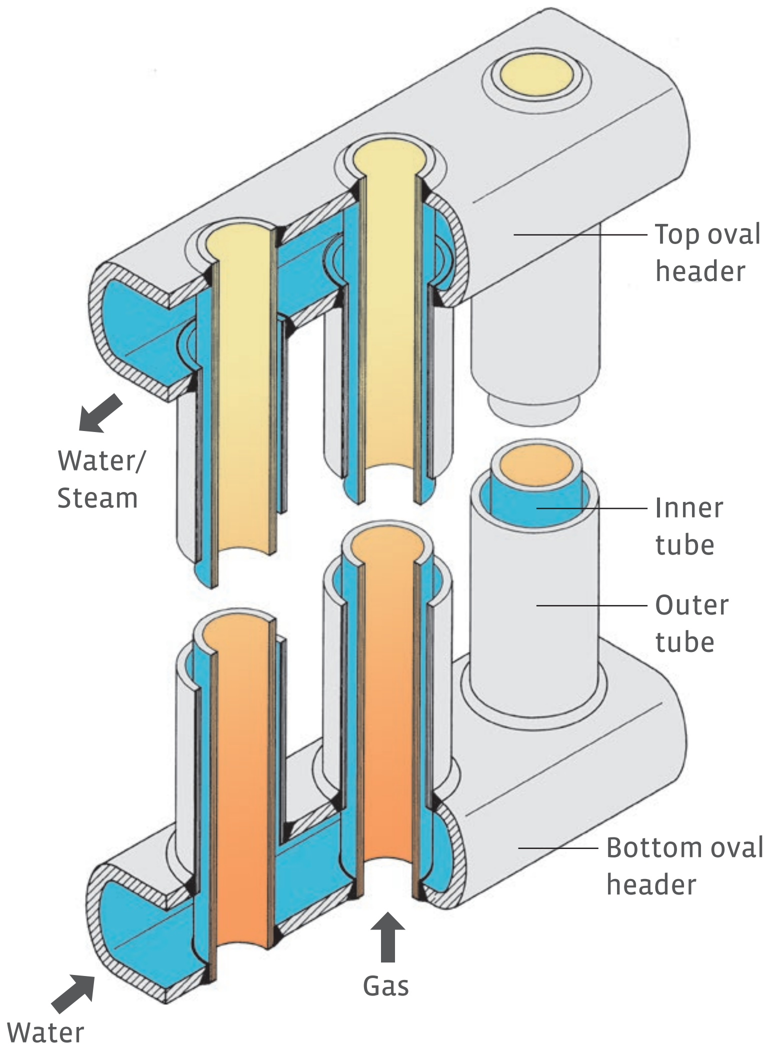


Figure 4: Schmidt'sche® Double Tube/Oval Header Register

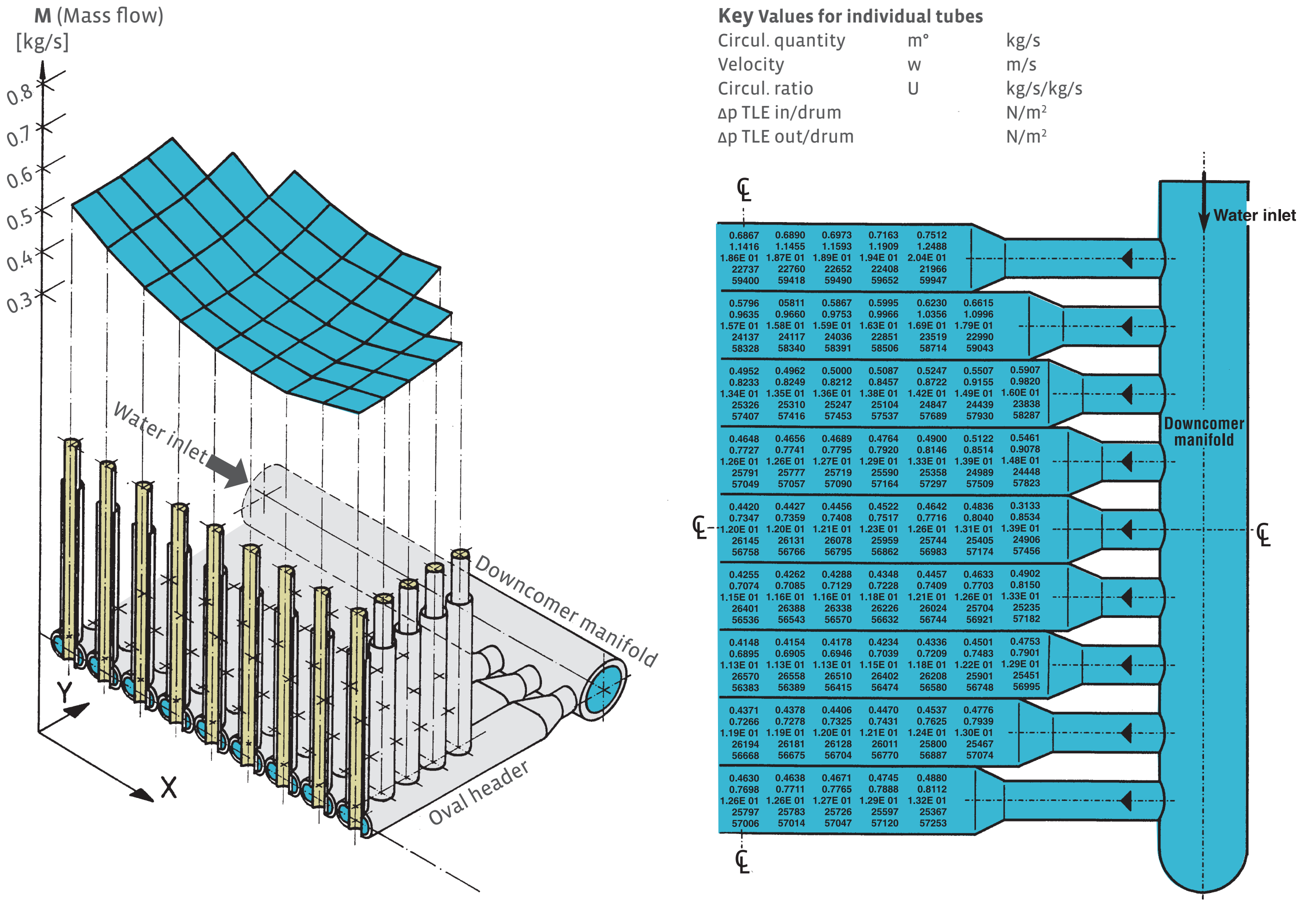


Figure 5: Water circulation in Schmidt'sche® Round-Type Transfer Line Exchangers

This is an important advantage of the system which can compensate for uneven gas flow distribution among the furnace coils or among individual exchanger tubes as may be caused by poor flow calibration among coils or obstructions resulting from coke build-up on the process side.

Proprietary software is used to calculate water flow 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. This data is illustrated in figure 5.

2.2 TECHNICAL ADVANTAGES

Schmidt'sche® Transfer Line Exchangers' unique design features provide for operational advantages, such as high reliability and long life.

- High flow velocities in the bottom oval header and in the annulus between the inner and outer tubes ensure maximum cooling of the oval header 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 header 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 in the first few inches at the inlet of the transfer line exchanger.

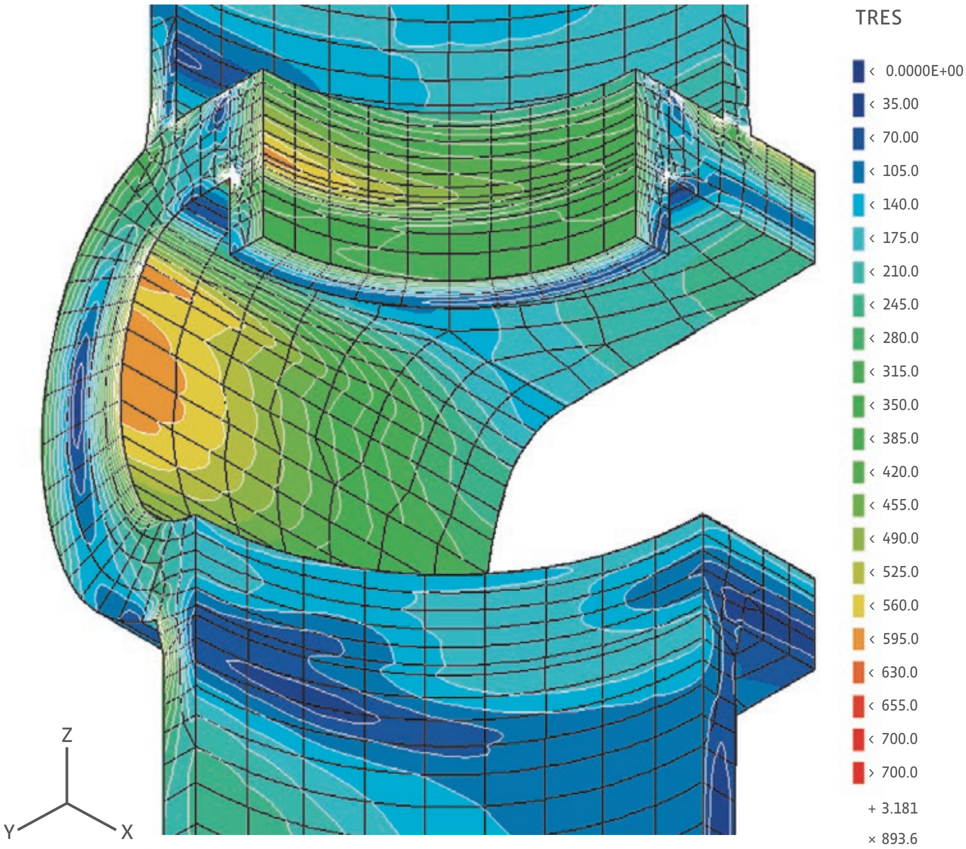


Figure 6: Stress distribution along the inside of the header and outer tube

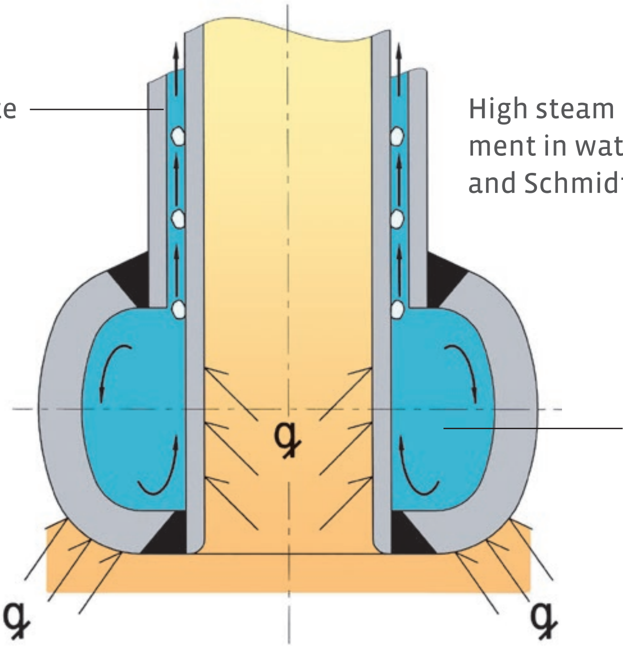
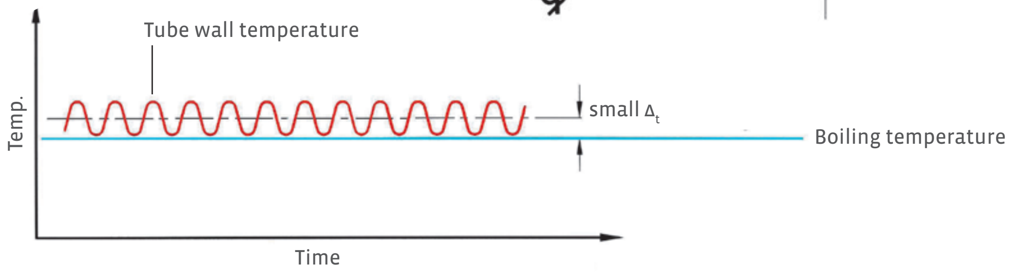


Figure 7: Stable magnetite protection layer, mandatory for long durability, due to low tube wall temperature amplitudes



Low tube wall temperature amplitudes are characteristic of water tube boilers and Schmidt'sche® TLEs, due to high steam bubble dislodgement.

- The oval header acts as a flexible member that compensates for the difference in thermal expansion between the inner and outer tube, in effect reducing the mechanical stresses on the system, especially at the inlet to the transfer line exchanger (Figure 6).
- Mechanical and thermal stresses are reduced by using thin-walled oval headers, pipes and tubes. Mechanically a thin-walled system is more flexible and the temperature gradient across the wall thickness is lower.
- 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 Schmidt'sche® Transfer Line Exchangers. Refer to figure 7.

Many plants using the double tube/oval header register have been running for over 20 years using the original equipment and without a single failure. The longest running exchangers were taken offline after 35 years of operation without failure. These exchangers were replaced during a furnace revamp and redesign. This record has given Schmidt'sche® TLEs a worldwide reputation for durability and reliability, which translates to lower maintenance costs and increased productivity.

3 | SCHMIDT'SCHE® TRANSFER LINE EXCHANGER DESIGN

3.1 MODERN DESIGN

The Schmidt'sche® Transfer Line Exchanger design concepts maximize the benefits of modern furnace design arrangements. They perfectly complement the process requirement for short and ultra-short residence time furnaces.

Schmidt'sche® TLE configurations optimize the gas flow distribution between the radiant coil outlet and the exchanger tubes. Low radiant coil back pressure which results from low pressure drop across the exchanger maximizes ethylene yields.

The Schmidt'sche® TLEs are decoked online during the decoking of the furnace coils. This reduces and even eliminates the need to mechanically clean them.

Modern Schmidt'sche® Transfer Line Exchangers are grouped into the categories:

- **Multi-Tube** Transfer Line Exchanger
- **Linear Closed-Coupled** Transfer Line Exchanger

Multi-Tube Transfer Line Exchangers such as the Round-Type and Bathtub exchangers offer the following advantages:

- Low pressure drop
- Low residence time through the tubes
- Short tubes and compact exchanger
- Minimized furnace structure needs
- Ethylene stabilization temperature reached in one pass

The selection of either design category of transfer line exchanger is largely determined by the feedstock characteristics, the furnace coil layout, the residence time requirement, and the process cracking severity.

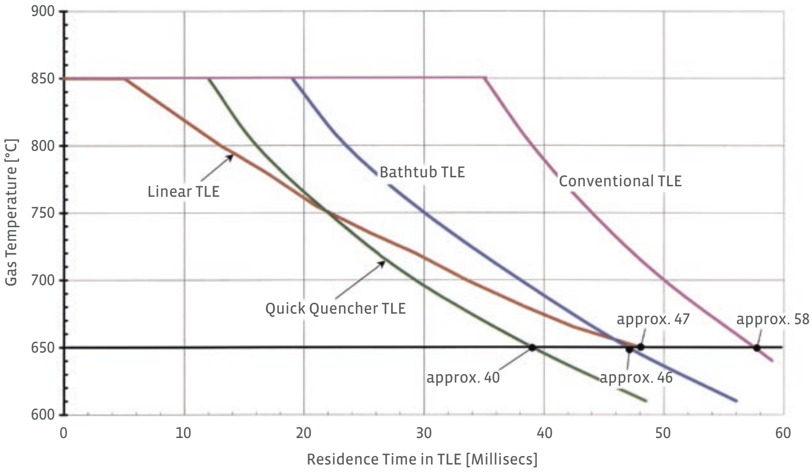


Figure 8: Residence time in Schmidt'sche® Transfer Line Exchanger

Linear Closed-Coupled Transfer Line Exchangers are typically connected directly to a single furnace coil outlet. They offer the following advantages:

- Low adiabatic volume
- Low residence time in the adiabatic zone
- No tube sheets
- Minimized or eliminated coke formation and exchanger plugging

Quick Quencher Transfer Line Exchangers are patented and combine the design advantages of the Multi-Tube exchanger and the Linear exchanger, as noted below:

- Low pressure drop
  Low residence time through the tubes
- Ethylene stabilization temperature reached in one pass
- Short tubes and compact exchanger
- Minimized furnace structure needs
- No tube sheets
- Low adiabatic volume
- Low residence time in the adiabatic zone
- Minimized or eliminated coke formation and exchanger plugging

3.2 DESIGN TOOLS AND CONSIDERATIONS

Schmidt'sche® Transfer Line Exchanger designs meet the most demanding processing requirements imposed by modern furnace designs. The thin-walled and flexible oval header/double tube design assures the safe and long-term operation of these units which are subjected to intense heat flux, high temperatures and the erosive effect of coke particles flowing from the furnaces.

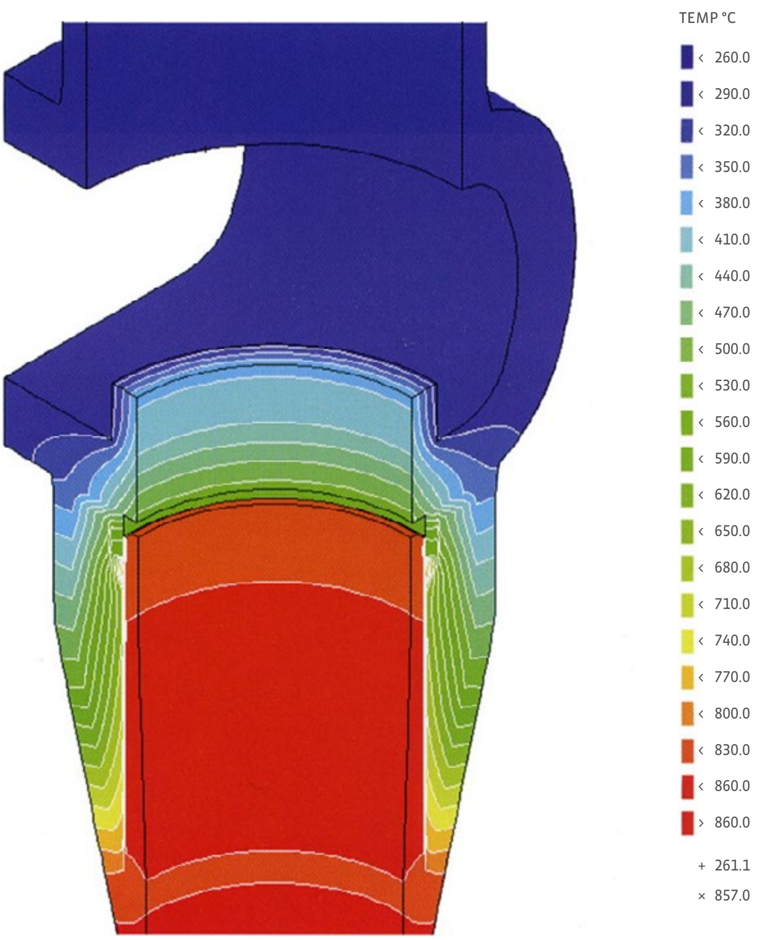


Figure 9: FEA of the temperature profile along the inlet transition piece of a Schmidt'sche® Linear Closed-Coupled TLE

Schmidt'sche® TLEs have been critically evaluated and methodically designed to ensure operational reliability.

Three-dimensional CFD (computational fluid dynamics) tools provide the means of optimizing gas flow distribution through the exchanger.

To design the safest and most reliable exchangers, a combination of Schmidt'sche proprietary software and design formulas are used together with FEA (finite element analysis) tools available to the industry (figure 9). The double tube system permits operation in the vertical upflow or downflow direction.

The double tube design with its low water volume quickly reacts to changes in operation and automatically adjusts to handle differences between adjacent furnace coils as well as, among exchanger tubes as may occur in fouled conditions.

4 CONSTRUCTION AND OPERATION OF SCHMIDT'SCHE® TRANSFER LINE EXCHANGER

4.1 ROUND-TYPE MULTI-TUBE EXCHANGERS

Schmidt'sche® Round-Type Transfer Line Exchangers are multi-tube exchangers having several double tube registers welded together to form a compact exchanger (figures 10, 12, 13). The "tube sheets" are formed by the oval headers. This TLE configuration typically has a single gas inlet connected to multiple furnace coils. Between one and up to eight Round-Type Transfer Line Exchangers are installed on one furnace as shown in figure 11.

The ends of the double tube registers are connected to the riser and downcomer manifolds. The "tube sheets" are then connected to the process gas inlet and outlet channels using specially designed flanges. The inlet channel is internally lined to protect the shell from high gas temperatures.

The exchanger outlet channel is either of conical or cylindrical design with the outlet nozzle flange located either on the top or on the side and connects to the downstream piping. The outlet channel is not internally insulated unless the cracked gas temperature is higher than approx. 530 °C to 550 °C. The outlet flange is made of highly resistant materials without internal insulation.

The gas inlet channel of the Schmidt'sche® Round-Type exchanger is designed to provide uniform gas distribution, minimize residence time, gas flow recirculation and coke formation.

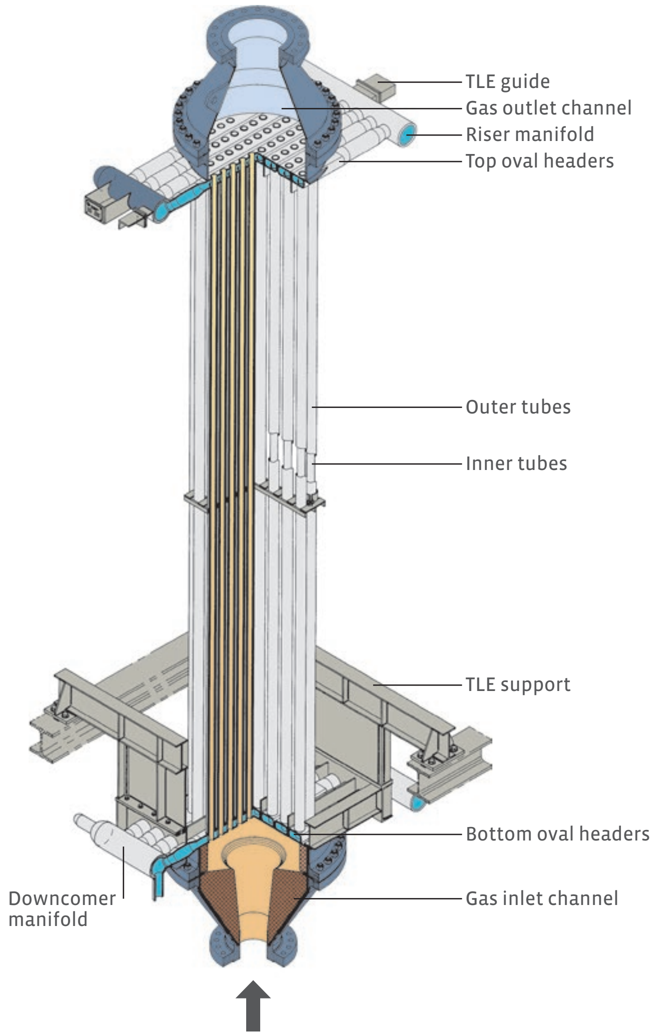


Figure 10: Schmidt'sche® Round-Type Multi-Tube TLE

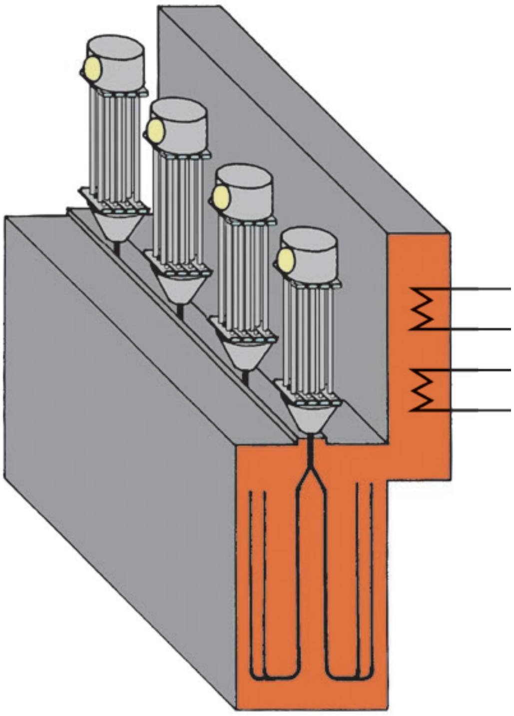


Figure 11: Schmidt'sche® Round-Type Multi-Tube TLE schematic arrangement

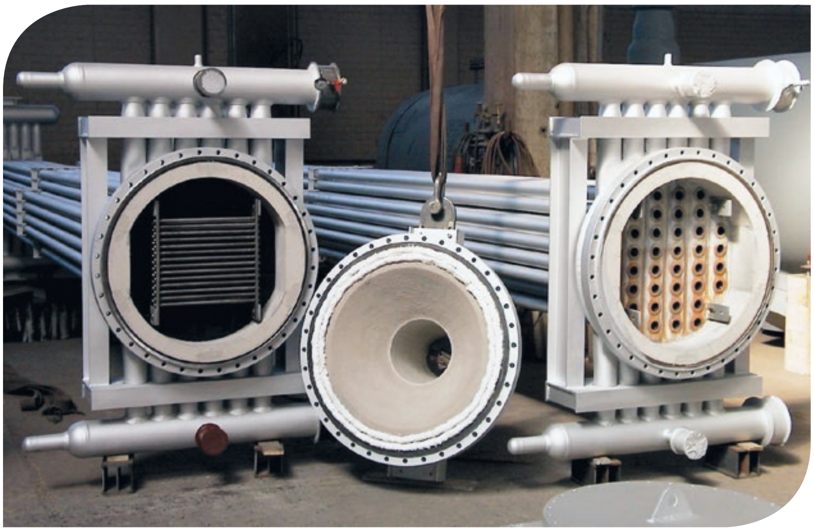


Figure 12: Schmidt'sche® Round-Type Multi-Tube TLE

Figure 13: Schmidt'sche® Round-Type Multi-Tube TLE

4.2 BATHTUB MULTI-TUBE EXCHANGERS

Schmidt'sche® Bathtub Transfer Line Exchangers are multi-tube exchangers having several double tube registers welded together to form an oblong-shaped exchanger inlet thus allowing two or four gas inlet connections as shown in figure 14. Each inlet nozzle is connected to a set of furnace coils.

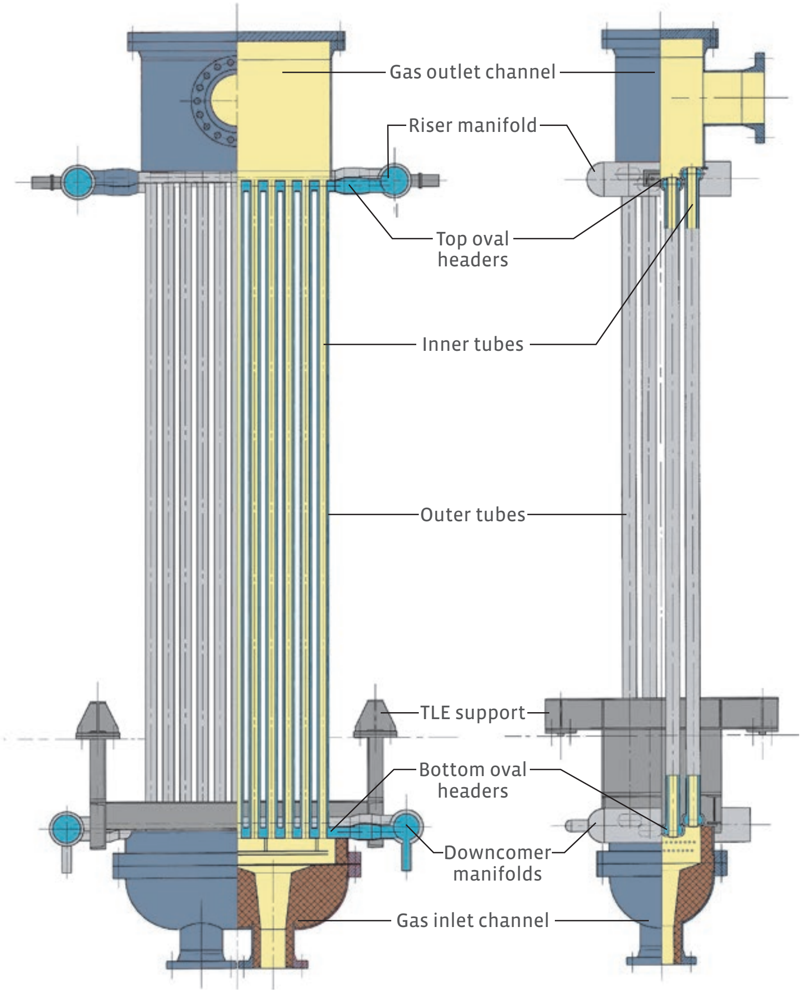


Figure 14: Schmidt'sche® Bathtub Multi-Tube TLE

The "tube sheet" is formed by the oval headers, and is installed in a steplike arrangement to reduce the inlet channel volume and enhance gas flow patterns. A typical furnace will have 3 to 8 exchangers. Refer to figure 15.

The Bathtub TLE inlet channel volume is about 1/2 of that in a conventional transfer line exchanger inlet; minimizing the adiabatic residence time and enhancing olefins selectivity. The residence time in a Bathtub TLE is about 20 milliseconds compared to 40 milliseconds in a Round-Type Transfer Line Exchanger. Refer to figure 8. The unique geometric shape of the bathtub offers better gas flow patterns which reduce recirculation and improve gas distribution to the tubes; hence reducing residence time, which provides quicker cooling of the gas and improved steam generation.

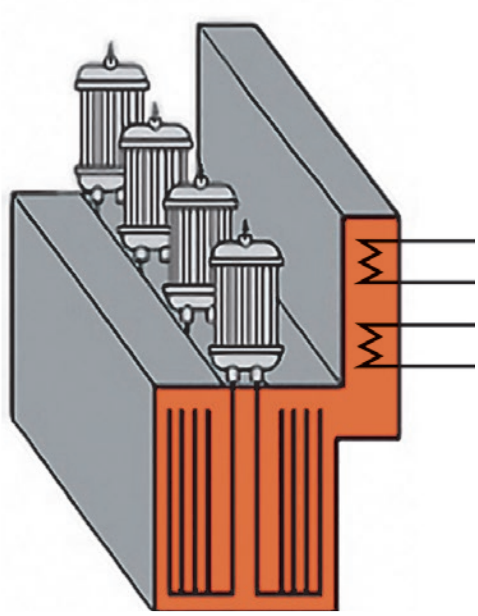


Figure 15: Schmidt'sche® Bathtub Multi-Tube TLE
on multi inlet/single outlet coil furnace

The inlet channel is internally lined to protect the shell from high gas temperatures. The outlet channel is not normally insulated unless the temperature is in excess of 530 °C to 550 °C. The outlet flange made of high temperature resistant materials exits on top or laterally to connect directly to the downstream piping. As with the Schmidt'sche® Round-Type TLE the ends of the double tube register are connected to the riser and downcomer manifolds. The "tube sheets" are connected to the inlet and outlet channel using specially designed flanges.

The Schmidt'sche® Bathtub TLE as shown in figures 14 to 16 has gained wide acceptance in new grassroots plants. Thanks to its unique design it has found its way into the replacement market of conventional TLE where furnace coil configurations lend themselves to the advantages of this short residence time TLE. Using a multiple inlet TLE will eliminate unnecessary Y-pieces and manifolds.

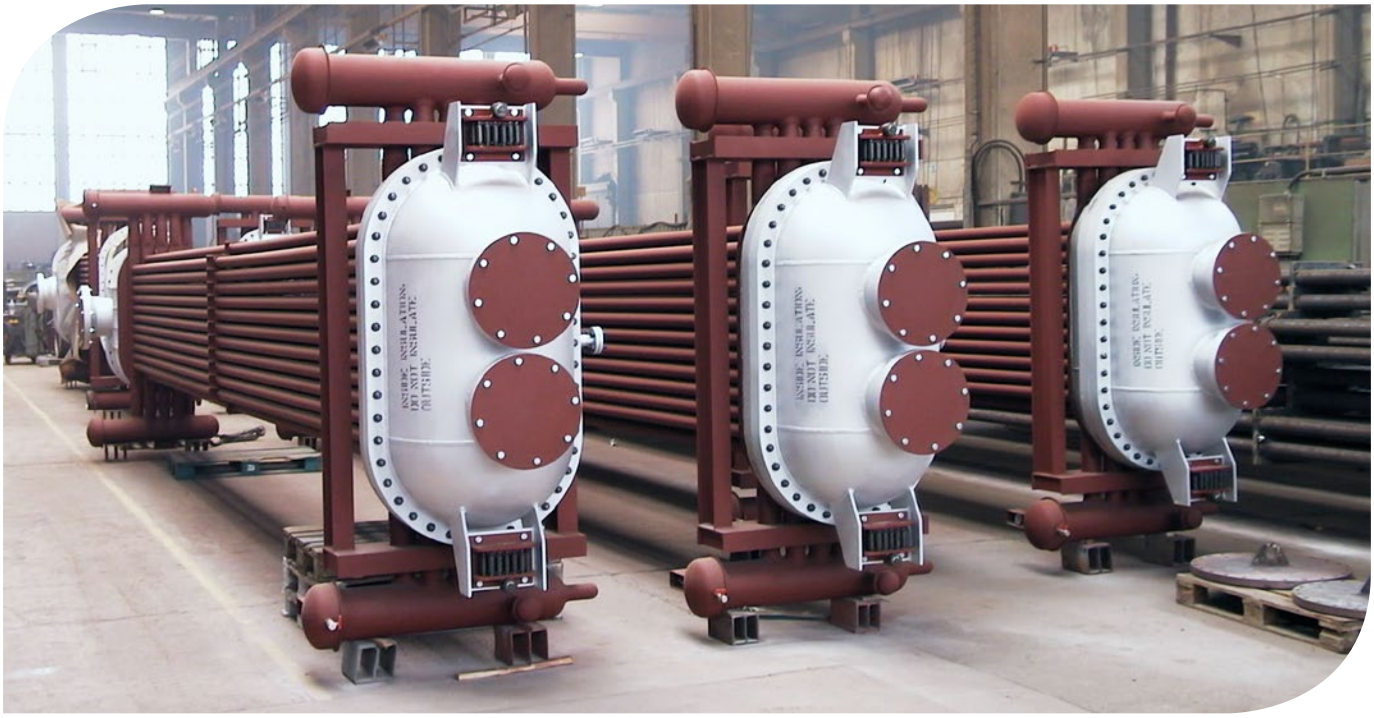


Figure 16: Schmidt'sche® Bathtub Multi-Tube TLE

4.3 QUICK QUENCHER MULTI-TUBE EXCHANGERS

Schmidt'sche® Quick Quencher Transfer Line Exchangers are multi-tube exchangers having a number of double tube registers welded together to form an exchanger tube bundle which accommodates two or four gas inlets that connect to a set of furnace coils. An oblong-type quick quencher and a circular type are illustrated in figures 17 and 18.

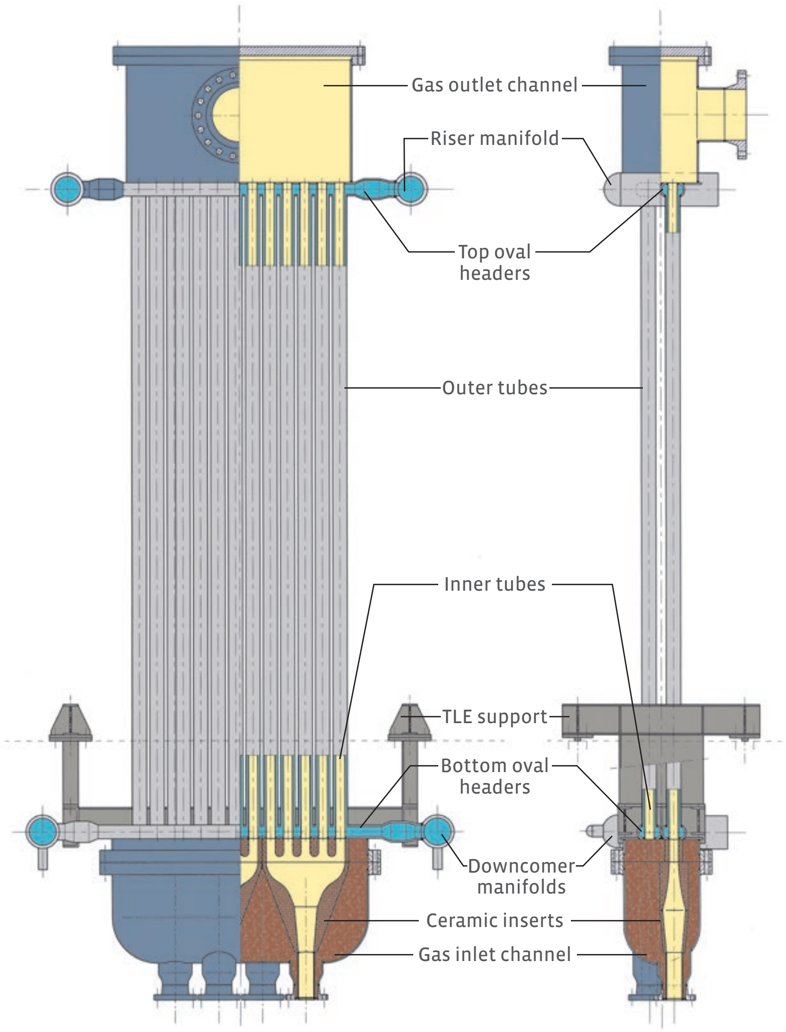


Figure 17: Schmidt'sche® Oblong-Type Quick Quencher

The water/steam mixture flows through the oval header ends through which it flows to the annulus between the inner and outer tube to quench the process gas.

The novel design of the quick quencher was co-developed and patented by ABB Lummus and Schmidt'sche designers. The process gas flows directly from the furnace coils to a defined number of TLE tubes via an aerodynamic ceramic insert. The insert first decelerates the gas through a diffuser and is then uniformly distributed to the tubes as it reaccelerates through a nozzle section.

Using three-dimensional CFD modelling the contour of the insert is properly designed to eliminate flow separation and dead zones that would otherwise promote coke formation and increase residence time.

The Quick Quencher connects up to 12 TLE tubes to one furnace coil outlet. This arrangement provides for a high heat exchanger surface area to volume ratio that translates to rapid quenching of the gas in a single exchanger without the need of a second process cooling stage, hence an additional second process cooling stage, hence an additional secondary TLE.

The Quick Quencher inlet design significantly reduces the residence time between furnace coil outlet and the exchanger tube inlet to the range between 10-12 milliseconds compared to 40 milliseconds in Round-Type TLEs. Refer to figure 8. It does not have a "tube sheet" facing the gas flow, thereby, avoiding the inherent drawbacks of erosion, pressure drop and coke formation.

Typical pressure drop through the Schmidt'sche® Quick Quencher is in the same range as Schmidt'sche® Round-Type and Bathtub TLEs at less than 0.1 bar.

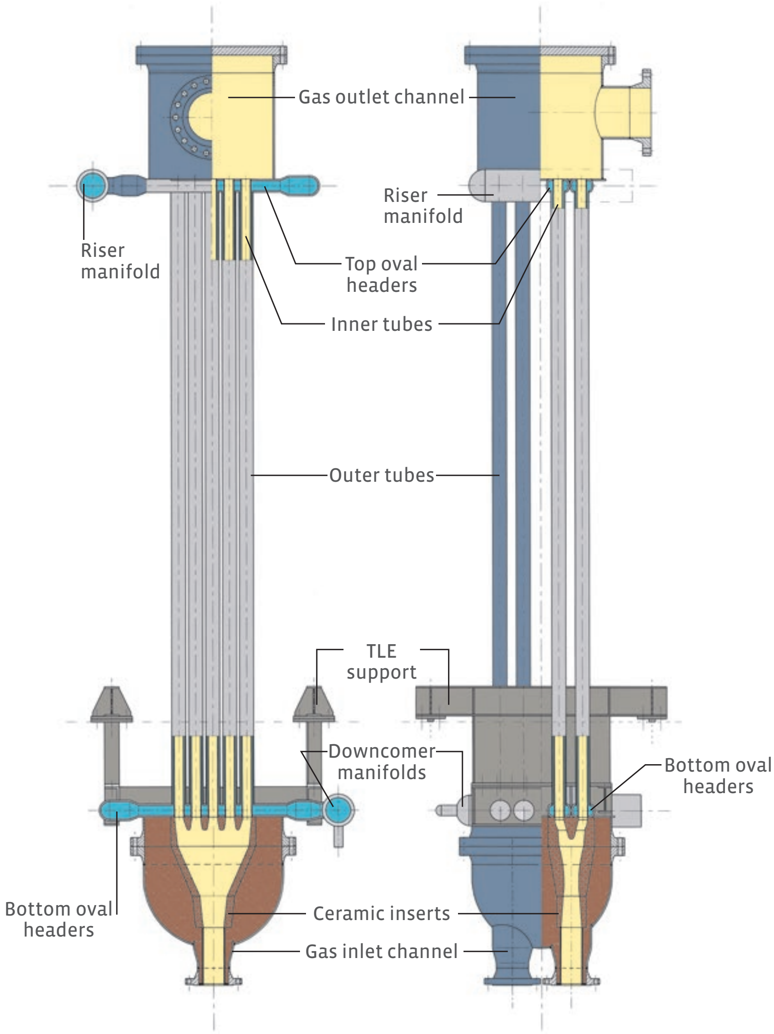


Figure 18: Schmidt'sche® Circular-Type Quick Quencher

Figure 19: Schmidt'sche® Circular-Type Quick Quencher

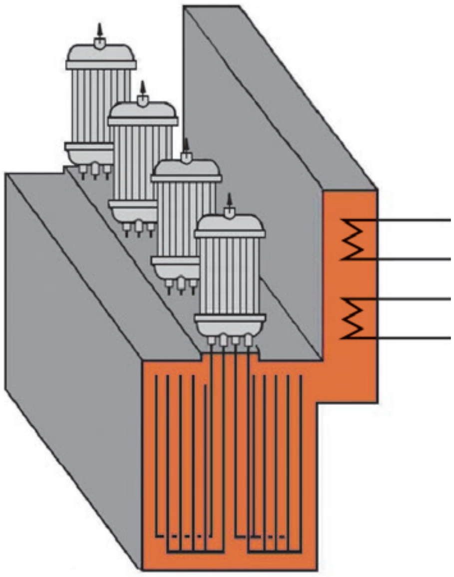


Figure 20: Schmidt'sche® Oblong-Type Quick Quencher on Two-Pass Multi Inlet/Single Outlet Coil Furnace

Figure 21: Schmidt'sche® Oblong-Type Quick Quencher

4.4 LINEAR CLOSED-COUPLED EXCHANGERS

Schmidt'sche® Linear Exchangers, SLEs, are closed-coupled to individual furnace radiant coil outlets, typically arranged in double tube register modules as shown in figure 22. The number of double tubes per module is determined by the furnace coil outlet configuration and limited by overall transportation dimensions. Modules can consist of one double tube arrangement or as many as may be limited by furnace or transport dimensions. Modules of up to 13 double tubes and more are not uncommon.

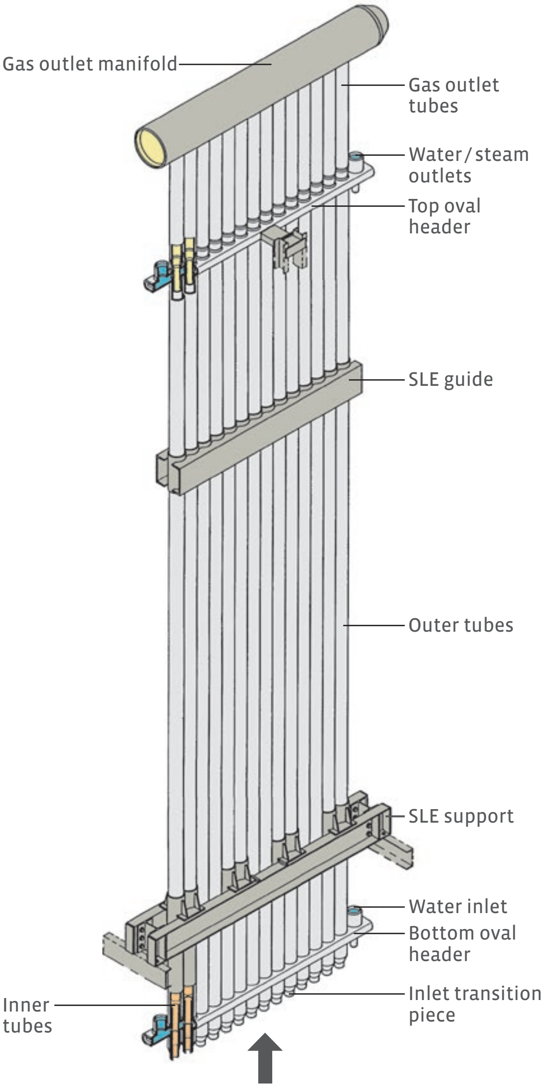


Figure 22: Schmidt'sche® Linear Exchanger (SLE) in upflow position

Short inlet transition pieces connect individual radiant coils to one double tube. The inlet transition piece is designed to gradually reduce the skin metal temperature between the hot coil outlets and the cooled exchanger oval headers from approx. 900 °C to around 320 °C. Thermal stresses that could cause premature failure are avoided by having a moderate temperature gradient in the transition piece.

The selection of the right metallurgy for the inlet transition piece and verification of the design using finite element analysis has resulted in long trouble-free operation. Figure 23 shows a typical inlet transition piece and notes the skin temperature profile.

The top and bottom oval headers of the SLE are connected to the riser and downcomer piping respectively. There is no tube sheet and only a minimum adiabatic zone in the transition between the furnace and the exchanger tubes.

Over 7,000 TLEs use the Schmidt'sche® Oval Header design. Since 1980 over 800 SLEs have been put into operation without a single failure of this component. The high feed water flow velocity through the oval header and the annulus between inner and outer tubes not only assures effective cooling of the process gas but maintains the tube metal temperature uniform at relatively low temperature which guarantees longevity. The high flow velocity also prevents settlement of solids in the bottom oval header thus preventing overheating and under deposit corrosion.

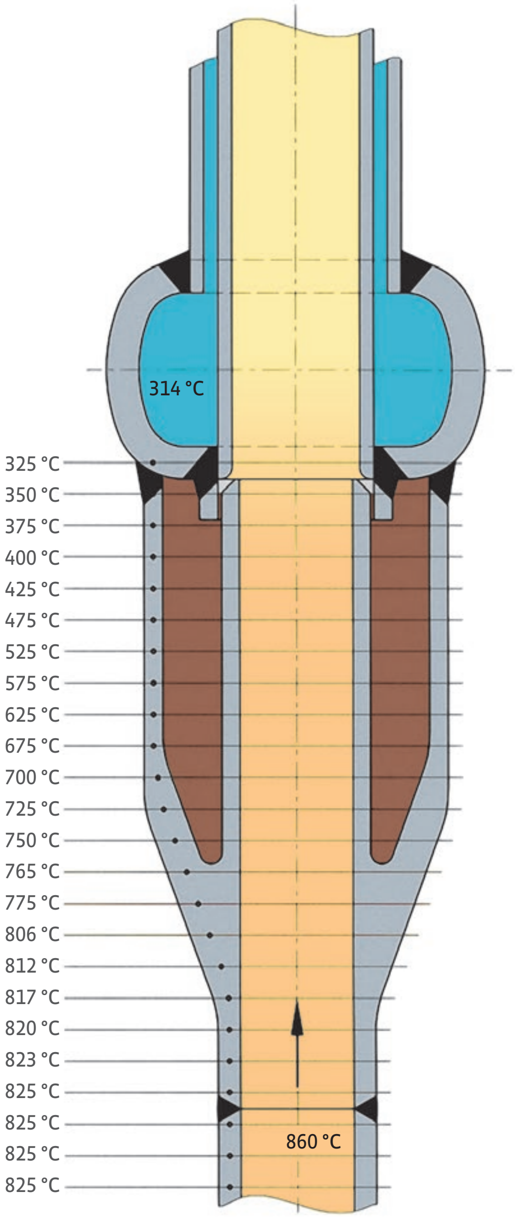


Figure 23: Inlet transition piece

Figure 24: Installation of Schmidt'sche® Linear Exchangers at site

Figure 25: Final inspection and dispatch

The inner bore of the process tubes on a linear exchanger is matched to the inner diameter of the radiant coil outlets. As a result, linear exchangers typically have large bore tubes with inner diameters of up to 160 mm (6.3″).

This requires installation of long exchangers and possibly a second stage to achieve the desired outlet temperature within the allowable furnace structure height. The second stage also operates as a steam generator.

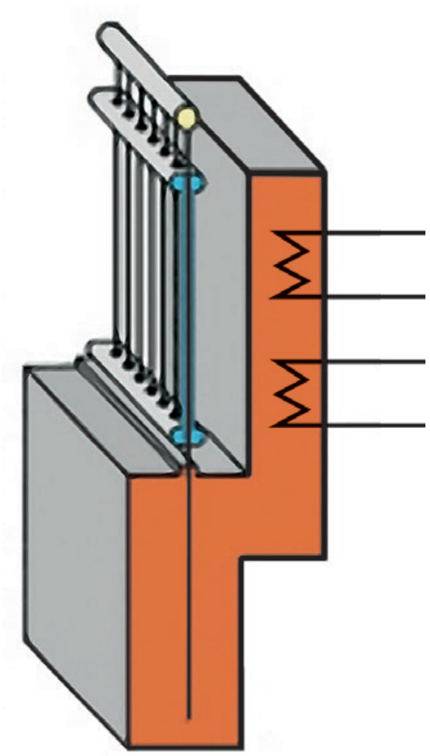


Figure 26: Schmidt'sche® Linear Exchanger (SLE) on ultra short residence time furnace

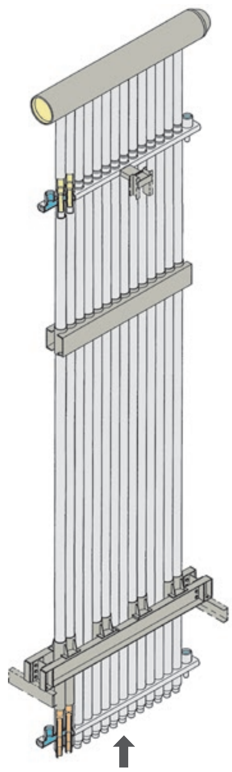


Figure 27: Schmidt'sche® Linear Exchanger (SLE) in upflow position

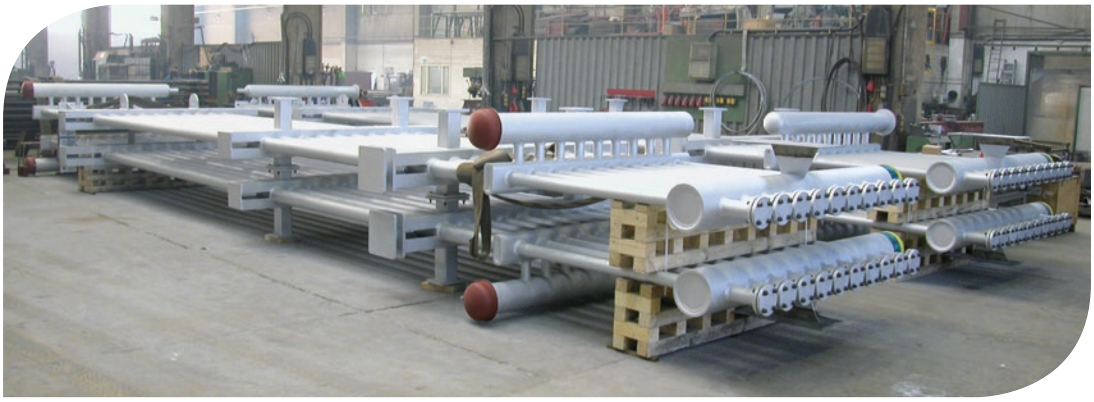


Figure 28: Schmidt'sche® Linear Exchanger (SLE)

The linear exchanger is typically called primary quench exchanger, PQE, whereas a second unit is referred to as the secondary quench exchanger or SQE.

The SQE can be either a Schmidt'sche® Round-Type Multi-Tube TLE operating in vertical position with gas flow from top to bottom (Figure 29) or bottom-up or

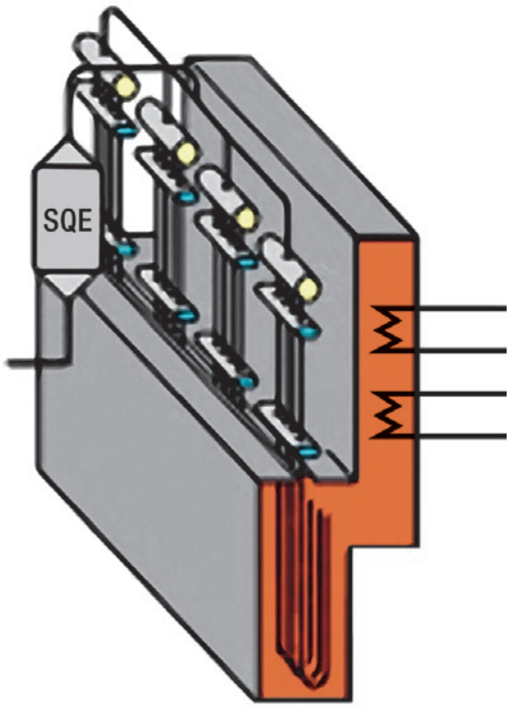


Figure 29: PQE (Linear Closed-Coupled Unit) with SQE (Schmidt'sche® Conventional Multi-Tube Unit) on u-coil furnace

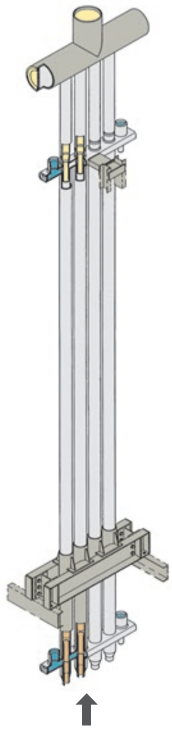


Figure 30: PQE (Schmidt'sche® Linear Exchanger)

Figure 31: Gas inlet of a Schmidt'sche® Linear Exchanger (SLE)

alternatively a horizontal shell and tube unit. In some installations, a second Linear Exchanger leg is used in place of the SQE as is illustrated in figure 32.

The primary quench exchanger is then connected to the secondary leg using return elbows.

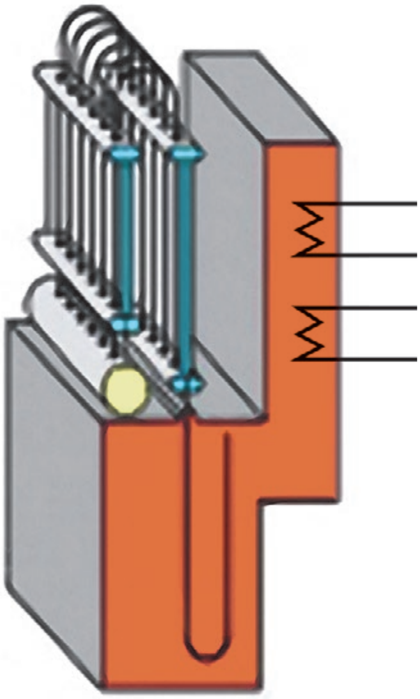


Figure 32: Double Pass Schmidt'sche® Linear Exchanger (SLE) on u-coil furnace

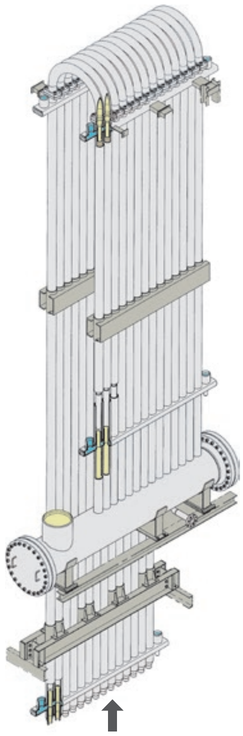


Figure 33: Double Pass Schmidt'sche® Linear Exchanger (SLE) in up- and downflow position

Figure 34: Double Pass Schmidt'sche® Linear Exchanger (SLE)

5 | KEY TERMINOLOGY

Adiabatic Zone
Volume from furnace coil outlet to TLE/SLE double tube/pipe system.

Bathtub TLE
A multi-tube exchanger with an oblong-shaped inlet channel having 2 or 4 gas inlets.

Demineralized Water
Mandatory requirement for the successful operation of high heat loaded exchangers such as ethylene transfer line exchangers.

Diffusor
Aerodynamically efficient cone to decelerate the cracked gas in the TLE inlet channel without flow separation, resulting in pressure recovery and contributing to equal flow distribution in front of inlet tube sheet (bottom oval headers).

Double Tube
A tube within a tube arrangement used in high and medium pressure steam generators since 1940 and first applied in the ethylene industry in 1959.

Double Pipe
This is the same concept as double tube, however referring to larger sizes. Double pipe transfer exchangers have become synonymous with linear closed-coupled transfer line exchangers.

Heat Flux
The amount of heat transferred across a surface of unit area in a unit time. Typically given in units of W/m^2. Also known as thermal flux.

High Flow Velocity
Water side characteristic of all Schmidt'sche® TLEs/SLEs to maximize heat dissipation. Ensure removal and transport of particles carried over by the feedwater or that may settle during shutdowns.

Linear TLE
A transfer line exchanger characterized by a one to one connection between exchanger tube and radiant coil outlet in a furnace.

Magnetite
Protective iron oxide layer formed on the water side of the TLEs/SLEs that is susceptible to damage poorly designed water side systems.

Mechanical Stress
Overall stresses in a TLE/SLE but easily dissipated by oval header design in the double tube/double pipe design.

Online Decoking
Thermal decoking of furnace coils together with TLEs/SLEs (online). Bypassing of exchangers not necessary.

Oval Header
A mechanically shaped tube or pipe component part of Schmidt'sche® TLEs and SLEs.

Quick Quencher®
TLE designed jointly with ABB Lummus for use on high selectivity, short residence time furnaces, with advantage of having no tube sheet and small diameter tube (2 to 2½ in).

Register
A component consisting of a row of double tubes or double pipes connected to oval header on top and bottom.

Residence Time
Intervals of milliseconds are required for quenching the furnace cracked gas below the critical temperature between 650 °C and 700 °C.

Round-Type TLE
A multi-tube round-type exchanger typically with one gas inlet.

Schmidt'sche®
Registered trademark name given to transfer line exchangers created by the original development of high pressure steam generators by Mr. Wilhelm Schmidt.

SLE
Schmidt'sche® Linear Exchanger

Thermal Stress
Minimized in the Schmidt'sche® design by the combined use of thin-walled oval headers, tubes and pipes, and maintaining high velocity in the water side of the exchanger.

TLE
Transfer Line Exchanger

Tube Sheet
In the Schmidt'sche® Round-Type and Bathtub TLE it is formed by welding a number of registers together along the oval header at either end of the exchanger.

Turbulent Flow
At water flow velocities above 1 m/s turbulent flow enhances the thermal transfer coefficient of the water side of the Schmidt'sche® exchangers.

Schmidt'sche® Transfer Line Exchangers for Ethylene Plants 07/2015

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