THE MIRACLE OF PETROCHEMICALS

OLEFINS INDUSTRY:

AN IN-DEPTH LOOK
AT STEAM-CRACKERS

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by
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PREFACE

The purpose of this book is to provide readers with a thorough introduction to the essential design and operation aspects of olefins plants. For this purpose, it is necessary to develop the knowledge of the readers who are interested to know more about olefins plants employing steam-cracking technology. The author has gathered and developed this book based on extensive experience in many olefins projects as well as olefins operating plants.

Included with this book are valuable materials provided by some contributions representing top and reputable olefins licensors and olefins equipment manufacturers for readers to gain insight information and content about steam-cracker plants.

The material in this book deals with various aspects and topics related to steam-cracker plants. The author realizes that some readers may have extensive backgrounds in steam-cracker plants and possibly from courses available to them in their work or through their education. However, the author strongly believes that for all readers interested in the olefins field, olefins technology and equipment manufacturing and supply, additional context and points of view are useful. Thus, the involvement and contributions of top and reputable olefins licensors and vendors helped me make this material interesting and valuable to all readers.

An effort has been made to include essential and useful material for readers in the form of guidelines and suggestions (G&S) as well as design and operation checklists gathered and based on the author's extensive experience in many steam-cracker plants.

Website

The author has developed a website to provide useful information about the olefins industry. It is expected to be one of, if not, the best website dedicated for olefins industry.

Available at **www.olefinsonline.com**, it is a resource for readers and those interested in the olefins industry. It offers breaking news about the petrochemicals and olefins industries worldwide, a weekly quiz, discussion boards (forums) in various subjects including design, operation, project, etc.

Acknowledgments

Praise and gratitude be to ALLAH, almighty, without whose gracious help it would have been impossible to publish this book. To provide proper acknowledgement of the source of much of this material proved to be an impossible task. The author acknowledges his indebtedness to those who have contributed to the literature on the topics presented here, and on those whose work I have drawn. I am grateful for the contribution of one of the top olefins technology providers "Linde", who have provided me with their valuable contribution about their steam-cracker plants. I am also grateful for the contributions of Chevron Phillips Chemical Company LLC (CP-Chem), TSKE, NATCO, Graham, SNM and YJ-TMC, who have provided me with their valuable contributions about their extensive experience in manufacturing the critical equipment and process catalysts of the olefins industry.

I very much appreciate the comments on the manuscript received from experience reviewers: Mr. Hua-An Liu (Technology Manager, Fluor Company), Mr. John Webb (Process Manager, KBR), Mr. Naif Al-Anazi (Olefins Operation Manager, SABIC), Mr. John Burk (Consultant), and Mr. Santosh Kumar (Cracker Sr. Process Engineer, TASNEE Company). I also thank my colleagues for their forbearance and comments, both written and oral, during the development of this book. Special thanks goes to Mr. Wael Hamri (System Specialist, Projects Management Company) who helped me during the website development and provided helpful comments.

This is a great opportunity to express my gratitude to National Industrialization Company (TASNEE) for agreeing to sponsor this book. Special thanks to the senior management of TASNEE and especially for Mr. Mubark Al-Khafrah (Chairman), Dr. Moayyed Al-Qurtas (Vice Chairman), Mr. Saleh Al-Nazha (President, TASNEE Complex) and Mr. Sameer Al-Humaidan (VP, Technical Affairs, TASNEE Complex). Thanks are also due to Mr. Hamdan Al-Shammari, (Process Engineering Manager, TASNEE) and Mr. Adel Al-Makinzy (Public Relations Manager, TASNEE), Mr. El Samman Ali (Ad & Media Relations Coordinator, TASNEE) and Mr. Tareq Alghulaigah (Director, TASNEE Administration Affairs) for their sincere cooperation extended during the process of book sponsorship.

Some of the material for this book was previously published as a CD-ROM from my website. I anticipate future updated versions of this book. Suggestions for improvement of this book are highly appreciated.

Fahad H. Falqi

NATIONAL INDUSTRIALIZATION COMPANY

Clear Vision and Extended Horizons

TASNEE was established 24 years ago as the first Saudi industrialization joint-stock company wholly owned by the private sector, with strong belief that industrialization is the right choice for economic diversification and the development wheel acceleration in Saudi Arabia. TASNEE has built—on its own and with the participation of other Saudi and foreign partners—many significant industrial projects and, after diversifying its activities, TASNEE restructured its production sectors to accommodate new business standards of globalization. TASNEE now focuses on five core businesses that are believed to be the strong building blocks of the company for its mission towards industrialization in Saudi Arabia. They are:

- *Petrochemicals*, such as polypropylene and high- and low-density polyethylene.
- *Chemicals*, such as titanium dioxide and chlorine & derivatives.
- *Diversified*, such as automotive batteries, carton packaging, and polycarbonate and acrylic sheets.
- *Metals & Metallurgical*, such as lead and metal products (steel wires, castings, trucks axles, and fasteners).
- *Services*, such as polyolefins marketing, products, distribution and sales, and waste treatment and quality services and inspection.

Locally and regionally, TASNEE has enhanced its role in the field of petrochemicals and occupied its prominent position among the elite as the second largest Saudi Industrial and petrochemical company. It is also a major producer of Titanium Dioxide (through its subsidiary CRISTAL, the second largest TiO_2 producer in the world).

Enhancing its role as a leading industrial company and as one of the rising pillars of the Saudi economy, and with an understanding that it has an active role to play in local as well as in international arena, TASNEE contributes in activating the programs of social responsibility by organizing and supporting social services programs. In addition to its humanitarian role by supporting more than 190 charitable organizations throughout the Kingdom continuously since 2005, TASNEE sponsored small business incubators to help small entrepreneurs and enhance their ability to succeed. TASNEE also concentrated in qualifying residents of correctional facilities to help prisoners to return successfully to the society and work effectively within it. TASNEE was aware to play a prominent role in supporting campaigns for social awareness and health care. TASNEE also sponsors many conferences and seminars for creating job opportunities and environmental protections, in addition to many other social programs that add value to the Saudi economy and social and environmental development.

Enhancing the cultural and scientific activities in Saudi Arabia and encouraging talented Saudi citizens, TASNEE also sponsors many books in different fields of theoretical and applied sciences. TASNEE sponsorship for this distinguished and valuable book is an example of its encouragement to authors especially in petrochemicals industry.

Thanks to TASNEE for its support of this publication — F.F.

This book is dedicated to
my parents, wife, and children.

Chapter One

OLEFINS PROCESSES & TECHNOLOGY PROVIDERS

1.1 – OVERVIEW

A big and fully petrochemical complex produces a host of products and an olefins plant is at the heart of it. Today's petrochemical industry is firmly based on olefins and it is the largest building block of a variety of petrochemical products like solvents, resins or fibres. The traditional method of manufacturing olefins is by thermal cracking of hydrocarbon feedstock (raw material) derived from either crude oil or natural gas. Modern methods of manufacturing ethylene have also evolved after a lot of research but have failed to make a dent the processes currently used due to investment and risk factors.

The process design of an olefins plant is typically a contractor—supplied technology. Five major licensors/contractors (Linde, Lummus, KBR, Technip, and Stone & Webster) are offering olefins plant designs employing steam-cracking process to the petrochemical industry. These licensors continue to introduce improvements to their process, and, on occasion, they offer new and innovative process routes.

The on-stream factor of the olefins plant, the plant energy efficiency, and the olefins selectivity of the cracking heaters are important factors in deciding the reliability and cost effectiveness of olefins plants. These factors are direct results of the applied process technology. Therefore, duty specifications of olefins plants usually require that the licensors demonstrate a combination of proven technology and reliability in their designs. At the same time, plant owners are principally interested in producing olefins at the lowest possible cost. To meet this demand, they require that the technology helps minimize plant investments, while improving the rate of return on their capital investments.

In addition, environmental legislators are applying considerable pressure on olefins plants to reduce plant emissions (NOx, CO2), noise and flaring. Once again, the challenge lies with the olefins technology licensors to introduce a design offering modern but proven technologies in order to meet these environmental requirements.

This book will discuss in-depth the olefins plant employing steam-cracking process which is the most common process technology adopted by companies worldwide producing olefins (mainly ethylene and propylene) products being used as main feedstocks to downstream petrochemical plants.

The reader should be aware that the definition and type of olefins plant discussed in this book employs steam-cracking tchnology.

1.2 – STEAM-CRACKER PROCESSES

1.2.1 – Introduction

The bulk of the worldwide annual commercial production of olefins is based on thermal cracking of petroleum hydrocarbons with steam; the process is commonly called pyrolysis or “steam-cracking.” This process is now considered to be a mature technology. However, steam-cracking is not as simple as it seems and involves complex processes like heat reactions, mass and heat transfer systems, extreme temperature and pressure control and other unit operations.

The design concept of the steam-cracker plant scheme comprises:

1. Thermal cracking of the hydrocarbon feed stock in presence of steam at high temperature in a short residence time.
2. Abrupt termination of the cracking reactions by quenching the cracking furnace effluents.
3. Compression of the cracked gas to a high pressure, removal of acid gases and drying it to make it moisture free.
4. Separation of various components by liquefaction and fractionation.
5. Purification of various components after catalytically/selectively hydrogenating dienes into olefins.

Processes used to manufacture olefins today are based on the above steps, although seemingly simple, design and implementation do have a very wide gap. Optimum process flow with respect to feedstock is a part of contention between various designers and technology consultants.

As evident from the above a fully functional steam-cracker plant is no child’s play and involves complex integration. Successful implementation of a good plant design depends on the detailed study and care aimed to bring out the technical details in life and integrate them to operate economically and efficiently. Technology is ever changing and steam-cracker plant processes have also evolved over the past few decades.

1.2.2 – The Impact of Feedstock Diversity

All feedstocks involved in olefins production are derived primarily frm petroleum or natural gas. Choosing a feedstock is solely an economic issue and is mainly governed by the availability of feedstocks locally and any other considerations like market for the by-products generated, etc. The prices are however governed by market conditions and seasonal changes in demand. In case of an absence of market for by-products products, ethane becomes the preferred choice. Conversely, if the market for C3 and allied by-products is good, propane or other liquid feedstocks can be considered.

Selection of the right feedstock is a very important aspect of the economics of olefins manufacture. The net cash margins and return on investment from an olefins manufacturing proposal which is arrived at by taking in to account, the feedstock cost, capital cost, variables cost, ethylene and by-product pricing plays an important role is deciding the economic viability of the proposal.

Steam-cracker plant designs need to provide some flexibility to handle and process multiple and different feedstocks. A gas-based steam-cracker plant is generally designed to crack gas feeds only (either a single feedstock like ethane/propane or a combined feedstock of butane, ethane, and propane), where as a liquid cracker plant is normally designed to crack a combination of feeds ranging from vacuum gas oils to LPGs. Due to opportunistic and seasonal pricing, this flexibility lends a wider range of feedstocks to produce olefins and help in optimizing profitability.

Due to the above reasons, many of today's steam-cracker plants are designed and equipped to crack varied feedstocks ranging from ethane to gas oils. While the plants in the Middle East mostly use ethane due to cost considerations and availability, plants across the world are similarly equipped with a design that facilitates the use of a wider variety of feedstocks.

Although feedstock cost is a major factor in an olefins plant, the choice of feedstock also has a considerable impact on the investment. The investments required for an olefins plant is lowest for an ethane-cracking plant, and then increases as the feedstock selected is propane, butane, naptha, or gas oil.

Feedstock Composition

Feedstock composition is a very important factor in the commercial viability calculation of olefins production. The feedstocks used in steam-cracker plants normally consist of straight and branched chain alkanes (also known as paraffins), naphthenes (also known as cyclo alkanes), and aromatics. For example, ethylene is produced from naphthanes and other alkanes present in the feedstock. However, high ethylene yields are possible from using n-Alkanes as feedstock. Thermal cracking of n-Alkanes also results in production of propene (also known as propylene), whose yield is directly proportional to the chain length.

Ethylene production and its yields can be improved by using highly saturated feedstocks. Parraffins hydrocarbons have a higher hydrogen-to-carbon ratio and break down to produce high quantities of gaseous products and lower quantities of heavy aromatic oils. The ring rupture causes cycloparaffins to break down and form alkyl radicals. In these cases, the hydrogen-to-carbon ratio is much lower than paraffins but slightly higher than aromatics causing the yield of gaseous products and heavy liquids in the intermediate range (range between paraffins and aromatics). On the other hand, aromatics—being refractory—have the lowest hydrogen-to-carbon ratio and yield only negligible quantity of olefins.

Summarizing, the above information is a little preliminary but will help decide on the feedstock requirements in a steam-cracker plant. A detailed evaluation has to be made before deciding the feedstock taking in to account aspects like product slate desired, product demand, feedstock availability, profit margins, etc.

Classification of Steam-Crackers

Typically, a steam-cracker plant can be classified as a liquid or gas cracker plant, depending on the type of feedstock used. The olefins processes differ in the case of cracked gas derived from light and heavy feedstocks. This is due to the fact that the portion of heavy components increases when processing naphtha or even heavier feedstocks such as gas oil.

When the only feedstock used is ethane, the quantity of C3 and heavier by-products is too small to be recovered. As the concentration of heavier components increases, more C3 and heavier components are available for further processing or for direct sale. By adding significant amounts of propane in place of ethane feedstock, the recovery of C3 becomes more economically feasible.

The C3 handling systems generally run as follows:

1. depropanizer
2. hydrogenation of MAPD
3. fractionation of the C3 cut thru C3 splitter

The cracking of butane and heavier feedstocks leads to increasing yields of fuel oil and pyrolysis gasoline components. Their removal before the cracked-gas compressor is necessary. This step is typically achieved in the primary fractionator column.

The reader should be aware that it is impractical to feed heavier feedstocks such as naphtha or gas oils to a gas cracker that has been designed principally to handle lighter feedstocks such as ethane and/or propane feedstocks. In order to handle heavier feedstocks, major modifications and/or additions to the cracking and cracked gas cooling sections of the plant will be required as well as the addition of much more capacity for handling C3 and heavier product. On the other hand, a naphtha cracker can handle the cracking of light feedstocks such as propane.

1.2.3 – Recovery Section Flow Sheets

The majority of differences among the various processes suggested by the licensors can be found in the sequence of unit operations for product separation and recovery. The sequences primarily depend on the type of feedstock as well as the number and the specification of the plant products. The main steps for downstream processing are:

- removal of the heat contained in the cracked gas generated by the cracking heaters,
- condensation of water and heavy hydrocarbons,
- compression,
- caustic washing,
- drying,
- separation, and
- hydrogenation of certain unsaturated components.

The downstream processing steps are principally intended to recover the desired products within predetermined specifications and at the desired battery limit conditions (temperature, pressure, quantity, and phase). During the operation of a typical olefins plant, the unconverted feedstocks—such as ethane, propane, and butane—that leave the cracking heaters are commonly recycled back to the cracking section. This process is designed to increase the overall yield of olefins per ton of feedstock processed.

In the following sections, the three common recovery section schemes of a typical olefins plant, will be stated and explained.

Most of the earlier olefins plants used front-end demethanizers, with the acetylene reactor being placed after the light gas components (methane and hydrogen) separation step, i.e., the demethanizer.

Until now, olefins technology has been based around three recovery section flow sheets. These three schemes are:

1. Front-end demethanizer
2. Front-end deethanizer
3. Front-end depropanizer

All three recovery section flow sheets have proven themselves in commercial operation. Their principal distinctions are the nature of the first separation step and the position of the acetylene hydrogenation reactor in the process scheme. The fractionation sequence can vary according to the design philosophies of the different licensors, with some favoring front-end demethanizer as the first step and the others favoring front-end deethanizer or front-end depropanizer.

Generally speaking, the front-end demethanizer scheme has been the most commonly adopted in the long term by companies that specialize in olefins plant technology. The front-end demethanizer scheme can be applied to all types of feedstocks from ethane to gas oil feeds. The alternative schemes (front-end deethanizer and front-end depropanizer) have been used more often for propane, naphtha, and gas oil feedstocks as well as for ethane feedstock, especially where flexibility towards heavier feeds is needed.

These last two schemes when compared to the front-end demethanizer have been known to provide improved economies of scale and a reduction in cost for large-capacity projects. Both later scheme designs display high efficiency and feedstock flexibility.

An examination of these schemes in detail follows.

1.2.3.1 – Front-End Demethanizer

In the front-end demethanizer scheme, the cracked gas dried in the gas dryer enters into the recovery section beginning with the chilling train and demethanizer tower. Unlike other recovery schemes, the front-end demethanizer scheme separates the light gases (methane, hydrogen, and CO) from the cracked gas as the first step in fractionation. The dried cracked gas is first chilled using refrigerants from the refrigeration systems. The refrigerants most commonly used are ethylene and propylene since they are available from other processes in the olefins plant. The next stage is typified by further chilling utilizing the coldest streams that are generated through the expander or the JT effect.

A significant feature for the front-end demethanizer scheme is that a back-end acetylene reactor is commonly used and located downstream of deethanizer tower. The hydrogen and CO are separated along with other light gases in the demethanizer upstream of the hydrogenation reactor unit. So this scheme usually requires purified hydrogen to be supplied externally from a PSA unit or a hydrogen methanator. The CO needed for moderating reaction selectivity in acetylene hydrogenation also must be supplied externally. Excess hydrogen and CO remaining from the reaction must be removed from the product ethylene via a pasteurization section at the top of the ethylene purification column. This operation places a practical limit on the purity of the product ethylene. In addition, due to green oil formation (the most common problem in back-end acetylene reactor), the acetylene reactor requires periodical regeneration, therefore requiring a spare reactor and regeneration facilities.

The CGC is the source of the pressure required for the chilling and separation of the cracked gas components in the recovery section.

1.2.3.2 – Front-End Deethanizer

In the front-end deethanizer scheme, the cracked gas exiting the gas dryer enters the recovery section beginning with the deethanizer tower. The front-end deethanizer separates C3+ components from the C2 components. A front-end acetylene reactor is usually integrated in the overhead loop of the deethanizer tower. This means that an external hydrogen supply is not required for the reactor. Also the presence of CO in the reactor feed can help to moderate the reaction kinetics and enhances the selectivity of the hydrogenation reaction to ethylene rather than ethane.

This process configuration or scheme helps to minimize green oil formation in the acetylene reactor. As a result, the catalyst bed is not easily fouled and there is no need for a spare reactor or regeneration facilities. On the other hand, the CO content often fluctuates in the process gas, requiring more operation skills and attention to help avoid temperature runaways.

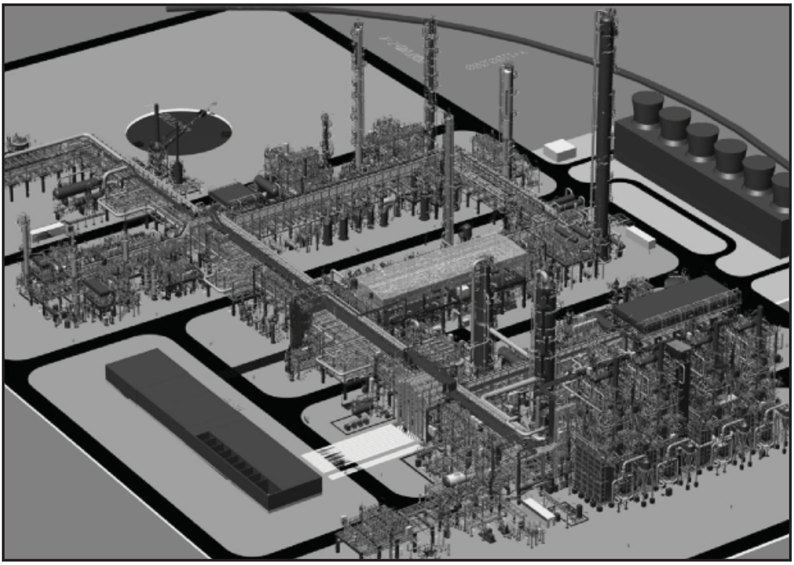
Since the front-end deethanizer tower bottom contains a fairly high concentration of diolefins, such as butadiene, fouling due to polymer formation is possible even with a low reboiler operating temperature. So it is common that desuperheated steam at low pressure is usually used to limit reboiler tube wall temperatures. A spare reboiler and/or polymerization inhibitor injection facility are commonly provided to help assure continuous operation by reducing polymerization on the lower tower trays and in the reboiler. Additional details are provided in Chapter 6.

1.2.3.3 – Front-End Depropanizer

The front-end depropanizer process scheme uses a depropanizer tower immediately after the cracked gas compression and drying steps. The depropanizer separates the C4+ components from the C3 and lighter components. The front-end depropanizer process is similar to the front-end deethanizer scheme in that a front-end acetylene reactor is implemented in its overhead system. This means that there is also no need for external supply of hydrogen and CO. The residual MAPD in the reactor effluent ends up in the feed to the C3 splitter column. When polymer-grade propylene is produced, the MAPD is fractionated with propane and leaves the bottom of the C3 splitter. As such the process can save the MAPD hydrogenation step.

The design engineer must, however, ensure that the residual MAPD does not build to explosive levels within the lower section of the C3 splitter column. Nevertheless, this has been proven to be routinely achievable in past projects. The most frequent measure used to cope with this issue is to deliberately allow more propylene to leak to the bottom product, thereby reducing the concentration of MAPD in the tower. Alternatively, some owners have opted to add a MAPD reactor in front of the C3 splitter, to convert the residual MAPD to propylene. A C3 pretreater column right after the MAPD reactor can be used to remove the undesirable light and heavy components from the C3 stream prior entering the C3 splitter. This has been considered cost-effective, especially when the value of propylene is high. This approach has the added advantages of avoiding the recycling of MAPD to the pyrolysis furnaces, which has been regarded with a tendency of slightly increasing coking. This approach can also help avoid the safety issue of potential MAPD build-up within the lower section of the C3 splitter tower. Additional details are provided in Chapter 6.

1.3 – LINDE OLEFINS TECHNOLOGY[1]



Linde Steam-Cracking Technology Highlights

For some 70 years, since building the world's first steam-cracker plant, Linde has been incorporating the latest improvements and innovations into the design of each new plant. The high degree of creativity and the continuing success of Linde's engineering and design staff in applying new features for the optimum plant design has resulted in Linde building a substantial number of large-scale steam-cracker plants in many different countries. Extensive feedback of operating data and information on process and equipment performance in operating plants has provided Linde with substantial information for the improved design of future plants.

Linde has incorporated features from the results of extensive studies of steam-cracker plant design that provide a high degree of operating flexibility and excellent reliability resulting in long on-stream times and optimum energy utilization. This translates into an economic plant design with low-operating and investment costs that meet the owner's specific requirements for flexibility and profitable operation.

Due to the advantageous design, Linde has the highest current market share of approximately 30% (calculated as capacity awarded from 1998 to 2008) of all new plant projects.

Concerning plant size, Linde steam-cracking technology has been successfully applied in small plants with 200 kta ethylene production to large plants with more than 1,800 kta olefins production. Extensive design studies have been performed for huge olefin plants with capacities as high as 2,000 kta ethylene and have shown that the well-proven technology principles of the Linde steam-cracking technology must not be compromised due to safety, mechanical or constructability reasons.

This section describes and highlights key areas of the design philosophy developed and applied by Linde. It is intended to facilitate the understanding of the key advantages of the Linde steam-cracking process.

The Linde Steam-Cracking Process with Front Deethanizer

The diagram below (Figure 1.1) details the most economical route for steamcrackers utilizing a front end deethanizer and C2 minus hydro-genation. For gas cracking, the hydrogenation can even be a raw gas hydrogenation.

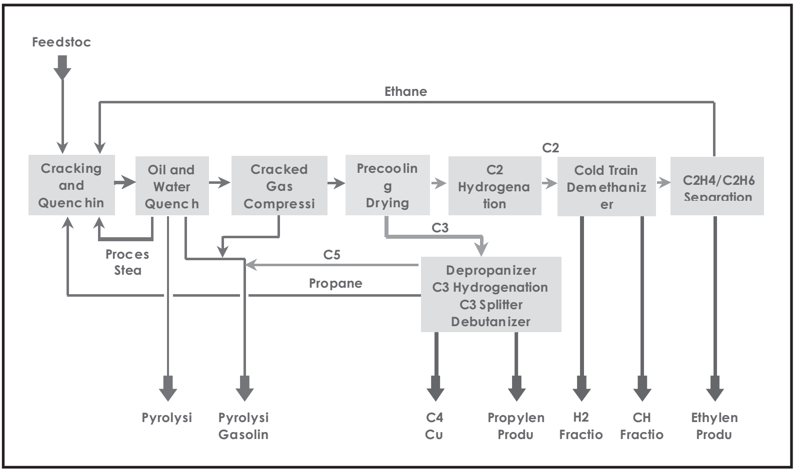
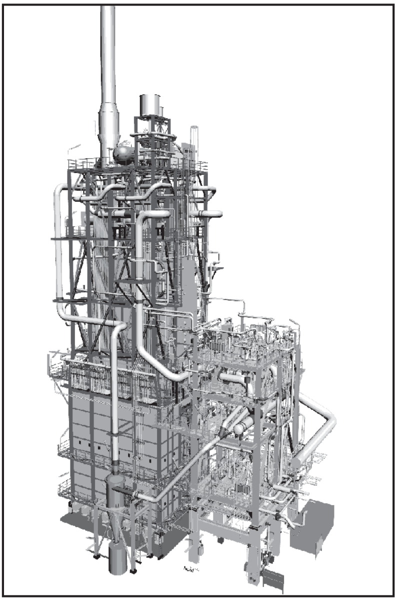


Figure 1.1: The Linde Steam-Cracking Process with Front Deethanizer

The key advantages of the Linde steam-cracking process results from specific process units and their special arrangement in the process sequence:

- A set of highly efficient and reliable cracking furnaces tailored to the specific needs of the actual plant.

- A two-cycle quench tower and two-cycle wash water section, which is divided into a saturation cycle for handling of high-boiling liquid components and a quench section for regeneration of dilution water.
- The raw gas hydrogenation for a combined hydrogenation of C2, C3, and parts of C4; showing excellent performance with respect to investment, energy consumption, safety, yields, and operability.
- Alternatively a front-end hydrogenation downstream from the deethanizer is applied.
- The front-end deethanizer system, which removes all heavy hydrocarbons upstream of an integrated cold train and demethanizer system.
- The integrated cold train and demethanizer system representing a uniquely compact process configuration as well as simplicity and effectiveness.
- The open-loop ethylene refrigeration cycle, leading to savings in investment costs and energy consumption.
- The C3 separation section can be designed optionally as a heat pump system with integration into the existing C3 refrigeration cycle optimizing cooling water consumption figures as well as investment costs.



The Linde Pyro-Crack® Cracking Technology

Linde is the owner and developer of its own proprietary pyrolysis cracking technology-the PyroCrack® technology. Cracking furnace projects are carried out together with Linde's 100% subsidiaries and competent partners for the mechanical design Selas-Linde GmbH, Germany, or Selas Fluid Processing Corporation (SFPC), USA.

Linde-designed cracking furnaces have consistently demonstrated high process performance and excellent operating and maintenance features, including:

- high selectivity for ethylene and other valuable olefins,
- long run lengths of both furnaces and quench exchangers,
- high overall efficiency,
- flexibility for operation with different feed stocks and/or cracking severities,
- high availability and reliability,
- robust radiant coil design,
- easy and safe operation and maintenance, and
- flexibility in handling alternate feed stocks.

Linde PyroCrack® Cracking Coils

Linde's state-of-the-art cracking coils (Figure 1.2) have been used successfully in commercial cracking furnaces for gas and liquid cracking and have the following common design criteria:

- single split as well as non-split coils for advantageous temperature and pressure profiles,
- full range of design residence times from 0.15 to 0.6 seconds for optimal matching of feedstock and profitable operation,
- economical long run lengths due to an adequate heat flux, and
- commercial experience with liquid and gaseous feedstocks for the whole range of residence time.

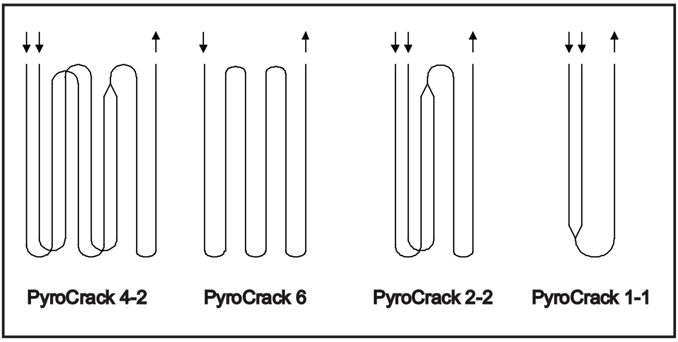


Figure 1.2: Linde PyroCrack® Cracking Coils

The large-capacity PyroCrack® 4-2 coil (four passes of two parallel tubes followed by two passes of a larger single tube) has been installed in many of Linde's plants with great commercial success.

The conventional and robust PyroCrack® 6 coil is a non-split design ("one-in/one-out" coil) of similar residence times. Due to its merits with regard to robustness and reliability, this coil is specifically applied for gaseous feed stocks (in particular for ethane).

PyroCrack® 2-2 coils (two passes of two parallel tubes followed by two passes of a larger single tube), with a shorter residence time, exhibit an excellent performance for cracking of gaseous feedstock by giving high selectivity together with good run-length.

The ultra-selective PyroCrack® 1-1 coil (one pass of two parallel tubes followed by one pass of a larger single tube) is the normally preferred option for cracking liquid feedstocks with maximum selectivity and/or high severity requirements. The latest generation of this coil type, with major design improvements, is advantageous for maintenance as it does not need any guide pins and requires minimum static cast fittings.

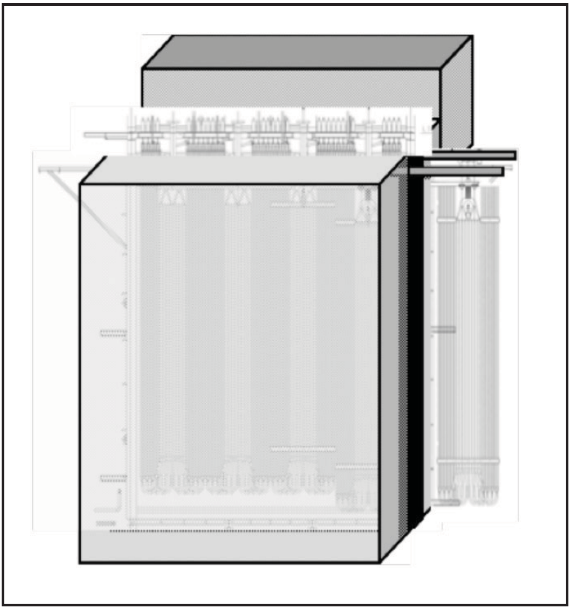


Figure 1.3: Replacement Process for Coils

Installation or replacement of the coils is done by prefabricated bundles (Figure 1.3) . By means of a crane, these coil bundles are hung in a trolley system, moved in position as a unit through special doors in the radiant section end walls, and welded to the inlet and outlet piping. This procedure saves replacement time and significantly reduces erection time as well. Coil erection and exchanger erection are not necessarily successive operations, but can take place independently from one another.

Radiant Cell and Firing Arrangement

Linde has wide experience with both types of furnace layouts:

- Single Cell concept, and
- Twin Radiant Cell (TRC) concept for maximised capacities.

From the process performance point of view, both concepts can be optimized without significant difference.

For large capacity furnaces, the twin radiant cell concept (see Figure 1.4) offers the advantage of very high capacities per furnace with a cost savings, since the length of each radiant cell is still reasonable. Compared to a conventional single cell set-up, the twin cell design leads to a smaller cross-sectional area in the convection section, which results in improved heat transfer due to higher flue gas velocities. The improved heat transfer contributes to lighter weights in the convection banks, allowing the use of less steel structure for the twin radiant box arrangement compared to the conventional arrangement.

In addition, the twin radiant cell set-up enables cracking operation in both radiant cells with different feedstocks and/or cracking conditions in each firebox at adequate cracking conditions without interference. Ultimately, this set-up even allows designing the furnace for a "cell decoking" operation, in which one radiant cell is on decoke mode while the other cell is still in cracking mode.

Linde has experience with a variety of firing concepts, from 100% sidewall firing to today's preferred combinations of floor/sidewall firing to 100% floor firing.

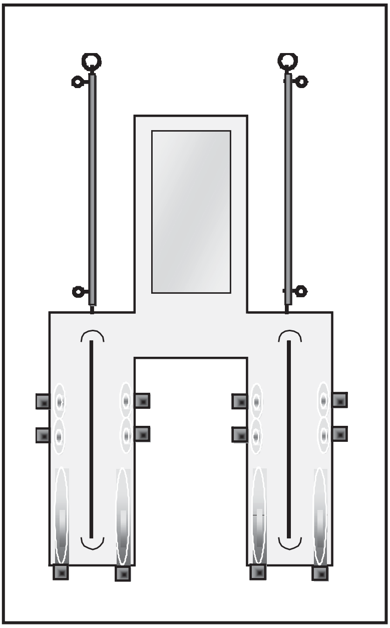


Figure 1.4: Twin Radiant Cell Set-up

A mixed firing arrangement combines the advantages of a low number of burners to be maintained and equal distribution of the heat release over the radiant cell.

A 100% floor firing concept leads to a minimum number of high-capacity burner units with a minimized maintenance requirement. The remote control potential of this approach is very high due to the high possible turndown ratios of typical floor burners. But the reduced number of high capacity burners is directly connected to high concentration of heat release in the center region of the flames.

Flexible firing systems provide a staged shutoff of the burners in case of a furnace trip. Linde has installed staged shutoff systems to minimize the thermal shocks on the radiant coils and to allow a quicker furnace restart in case of a trip.

Quench System

Linde has furnished pyrolysis furnaces with all available designs of quench exchangers. These designs vary from conventional double pipe, or shell and tube, exchangers over linear-type transfer line exchangers (LQE) to two-stage (and even three-stage) exchanger systems.

Modern quench exchangers are designed for minimal pressure drop and maximum heat exchange capacity over the total run length. The linear-type quench exchanger additionally benefits from a lack of the refractory inlet cone and inlet tube sheet, which can be subject to blockage and erosion.

Feedstock Flexibility

More and more, cracking furnaces have to provide high flexibility for processing the complete range of cracking feedstocks, from ethane over LPG, light- and full-range naphtha, and atmospheric gas oil (AGO) to heavy hydrocracker residue (HCR or HVGO). Considering all the different feed services, the size of each single convection bundle and the sequence of the bundles have to be calculated accurately to optimize the utilization of the heat content within the flue gas for process stream preparation and utility production.

LPG/Naphtha/AGO Feeds

Linde has built numerous furnaces for all types of LPG, naphtha, and AGO, including pure C4; C4/C5; light, full-range and heavy naphtha; and various grades of atmospheric gas oil. All available coil types and firing concepts have been applied for those feedstocks. P/E ratios from 0.4 to 0.7 have been realized. These furnaces have operated successfully for decades.