

World Market Leader in Aromatics Extraction

ThyssenKrupp Industrial Solutions has always been the first choice to supply the growing world aromatics demand with its MorphyLane® Extractive Distillation Process by Uhde. More than 75 installed MorphyLane® plants are processing all different kinds of feedstocks with a total capacity of more than 15 million t/year of highly purified aromatics within a refinery.

310,000 t/year Aromatics plant

for Japan Energy Co. in Kashima, Japan

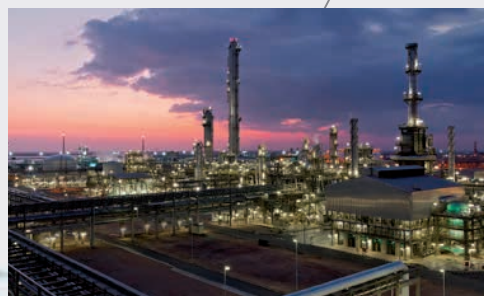
Engineering
Excellence ³



ThyssenKrupp
Industrial Solutions

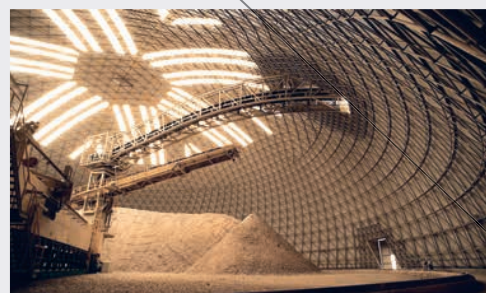
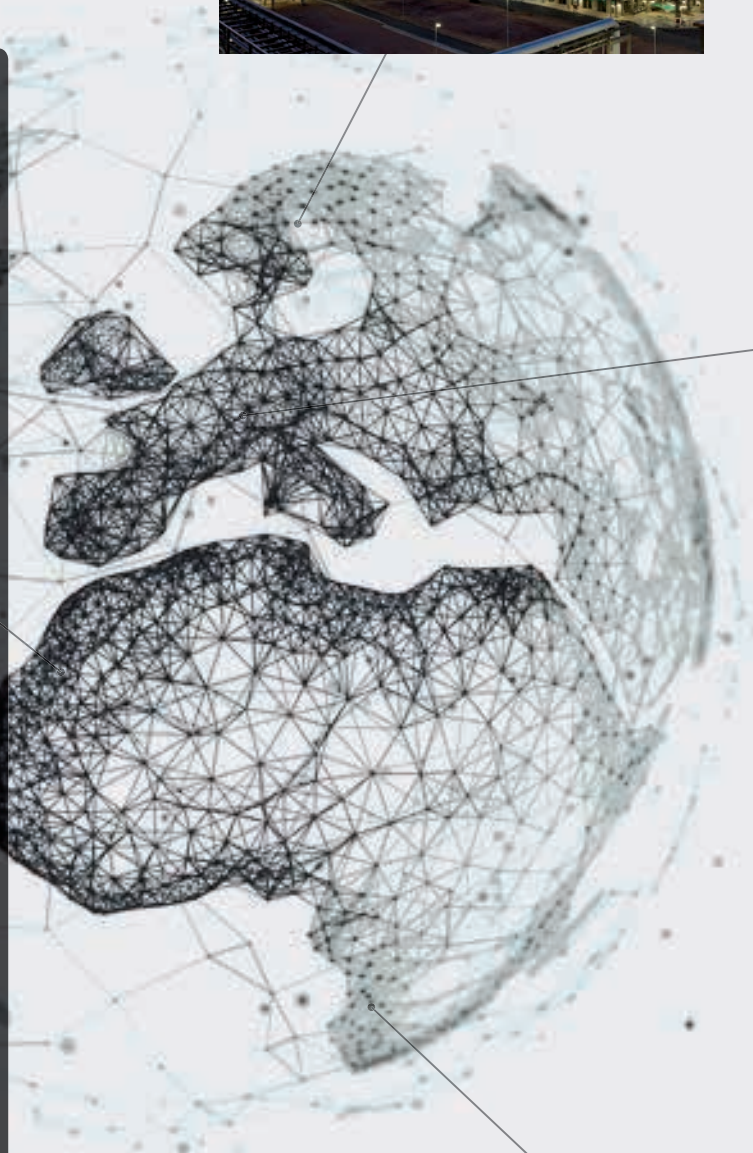


ThyssenKrupp

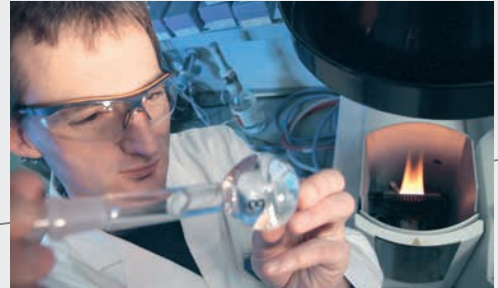
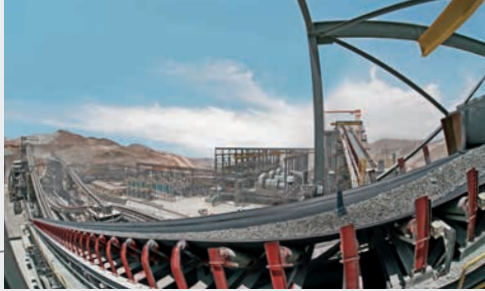


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Engineering Excellence³ – Think globally, act locally



Having erected several thousand plants, ThyssenKrupp Industrial Solutions is one of the world's leading engineering companies. Our Business Unit Process Technologies supplies chemical plants, refineries and coking plants on the basis of tried-and-tested technologies made by Uhde, while the portfolio of the Business Unit Resource Technologies comprises complete cement plants and grinding systems of the Polysius brand, as well as machines, plants and systems for mining, extraction, preparation, processing or transshipment of commodities.

With many years of experience in the EPC business, we offer our customers concepts, market studies, plant layouts, design engineering, supplies, manufacturing services, erection and commissioning – all from a single source. Our employees on all continents use their knowledge and engineering competence to create innovative solutions and to look for ways to conserve natural resources.

Over 40 locations in 25 countries – divided into six regions – form a close-meshed network that allows us to align our services to local conditions consistently. Thanks to this on-site expertise and global networking, we are able to set standards that offer our customers a true competitive edge.

Our comprehensive service concepts take the entire life cycle of a plant into account. We offer OEM spare parts service and complete maintenance management, as well as servicing, modernisation projects and conversions.

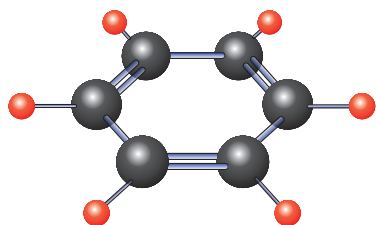


Erection of the 60 meter high benzene extractive distillation column for Titan Petrochemicals, Pasir Gudang, Malaysia. Capacity: 168,000 t/year benzene and toluene from pyrolysis gasoline.

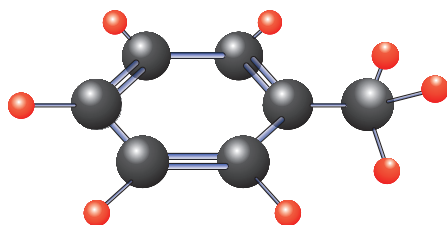


ThyssenKrupp Industrial Solutions and Aromatics

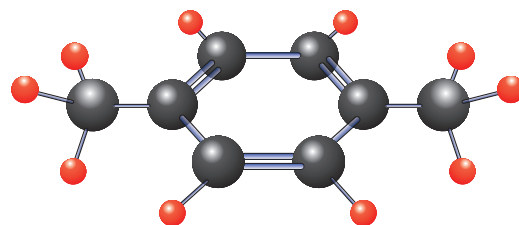
Remarkably long experience



Benzene



Toluene



Para-Xylene

ThyssenKrupp Industrial Solutions' extensive knowledge in extractive distillation technology and its excellent laboratory facilities have led it to develop the most advanced process configurations for recovering aromatics and other products, such as butenes, α -olefins, cumene, isoprene and phenols, from different feedstocks.

Our history in aromatics goes back to the first decades of the 20th century when Heinrich Koppers developed the Koppers coke oven technology for the production of coke for the steel industry. Right up to the fifties, coke oven light oil, which is recovered as a by-product of crude coke oven gas in coke oven plants, was the world's main aromatics source.

Due to the large quantity of impurities (diolefins, olefins, nitrogen, oxygen and sulphur compounds) the coke oven light oil had to be purified before the aromatics could be recovered. In those days, the lower benzene quality requirements could be met by sulphuric acid treatment and conventional distillation processes. However, the large quantity of aromatics lost during sulphonation and the relatively high sulphur content in the benzene product were the driving force in the development of a hydrogenation process which was worked on together with BASF AG, Ludwigshafen, Germany and which solved the problems caused by unsaturated and inorganic impurities in the feedstock. The final purification of aromatics continued to be achieved by distillation only.

At the beginning of the fifties, high-purity aromatics recovered by liquid-liquid extraction in refineries came on to the market.

The superior quality of these aromatics made it impossible for the aromatics distilled from coke oven light oil to compete. In addition, the improved purification process using azeotropic distillation was linked with high investment costs and inefficient energy utilisation.

The liquid-liquid extraction process could not be used for coke oven light oil with an aromatics content of 95% as separable phases are not able to form when the aromatics content is this high. At the request of the German coal and steel industry, ThyssenKrupp Industrial Solutions initiated intensive R&D activities and developed a new process for coke oven light oil to obtain aromatics of a similar or better quality than those from refineries.

The process developed by Uhde and now offered by ThyssenKrupp Industrial Solutions was based on a new solvent called N-formylmorpholine and used a different separation principle involving extractive distillation. The process was able to produce all the product purities required whilst reducing utilities consumption considerably as compared to liquid-liquid extraction processes.

The first commercial plant based on this extractive distillation process (Morphylane® process) went on-stream in 1968 and produced excellent results with regard to product quality and utility consumption figures.

Based on the outstanding performance of this plant, the Morphylane® process was subsequently adapted to other feedstocks, such as pyrolysis gasoline and reformat.

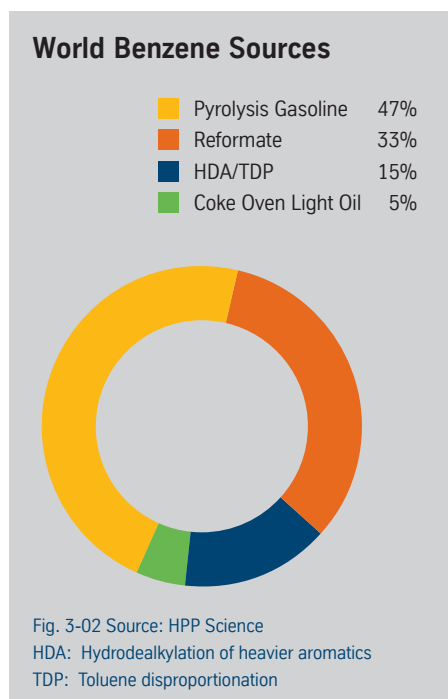
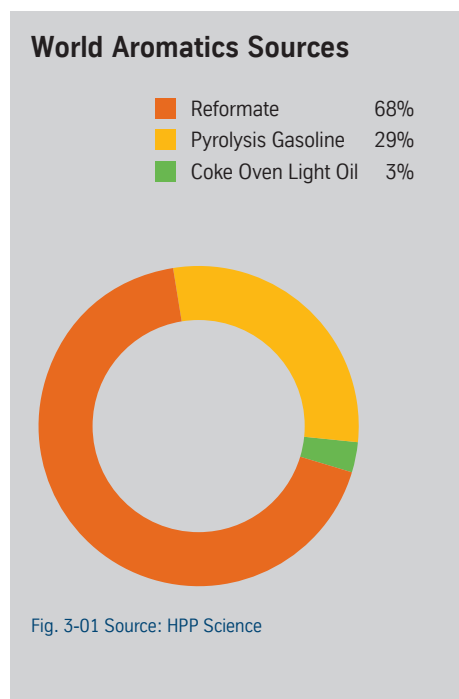
The process has undergone continuous improvements and optimisation and its cost-effectiveness has led it to replace liquid-liquid extraction in all applications. Furthermore, by optimising the combination of all the processes involved, such as hydrogenation, fractionation and aromatics extractive distillation, the complete process line for recovering aromatics from all possible feedstocks was able to be improved to such an extent that competitive processes were left standing.

Up to now, ThyssenKrupp Industrial Solutions has been awarded contracts for more than 60 Morphylane® plants worldwide for recovering aromatics from pyrolysis gasoline, reformat and coke oven light oil. Leading aromatics producers, such as Chevron Phillips, Dow, BASF, Total, Shell and SK Corp., selected the Morphylane® process on the strength of its outstanding performance figures and its optimised process configuration after comparing it with competitive technologies.

ThyssenKrupp Industrial Solutions provides its customers with the following services in the field of aromatics production:

- Consulting services
- Analytical services
- Licensing
- Engineering
- Procurement
- Construction
- Plant operation
- Maintenance services
- Plant optimisation services

Aromatics – Sources, Demand and Applications



Aromatics (benzene, toluene and xylenes) rank amongst the most important intermediate products in the chemical industry and have a wide range of applications.

Sources

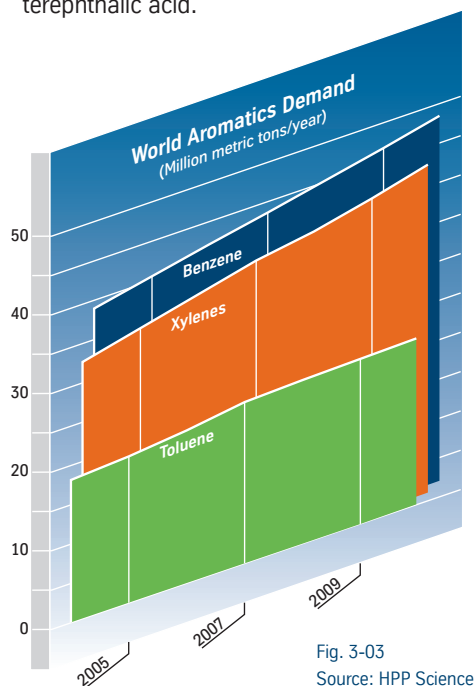
The main sources of aromatics (benzene, toluene, xylenes) are reformate from catalytic reforming, pyrolysis gasoline from steam-crackers and coke oven light oil from coke oven plants (Fig. 3-01). The reformate from catalytic reforming provides the basic supply of benzene, toluene, xylenes and heavier aromatics. The majority of toluene and heavier aromatics from reformate is converted to benzene and xylenes and is mainly used for p-xylene production. The remaining supply of aromatics is produced from pyrolysis gasoline and from coke oven light oil.

Benzene, which has the highest production rate beside xylenes and toluene, is mainly produced from pyrolysis gasoline, followed by reformate. A significant percentage of Benzene, i.e. 15%, is also obtained from the hydrodealkylation (HDA) of heavier aromatics and from toluene disproportionation (TDP). The smallest percentage of about 5% of benzene is obtained from coke oven light oil (Fig. 3-02).

Demand

Worldwide, approx. 110 million tonnes of BTX aromatics are currently produced per year. An increase in demand of almost 4% p.a. is predicted for benzene due to the growth of end-use markets such as polystyrene, polycarbonate, phenolic resins and nylon (Fig. 3-03).

In the case of xylenes the increase in demand is determined by p-xylene, the biggest isomer in terms of quantity. Growth in consumption of this isomer is expected to well exceed 5% p.a. in the near future. Para-xylene is used almost exclusively for the production of polyester via purified terephthalic acid.



The estimated growth in overall toluene consumption is less than 3% p.a. Its major direct chemical use is toluene diisocyanate (TDI), a raw material for the production of polyurethane. Toluene extraction will increase as toluene is converted into benzene and xylenes via disproportionation.

Applications

The wide range of applications involving the main aromatics, benzene, toluene and xylenes (Fig. 3-04), illustrates the importance of these intermediate products to the chemical industry.

Fig. 3-04
Main Applications of BTX Aromatics



Process Configuration

Aromatics from Pyrolysis Gasoline, Reformate & Coke Oven Light Oil

Aromatics (benzene, toluene, xylenes) are mainly recovered from the following three feedstocks:

- Pyrolysis gasoline from steamcrackers
- Reformate from catalytic reformers
- Light reformat from aromatics production
- Coke oven light oil from coke oven plants

The type of aromatics recovered and the process configuration are dictated by the feedstock used, as the composition of these feedstocks differs with regard to the content of paraffins, olefins, naphthenes and aromatics (Fig. 4-01) and the amount of impurities, such as chlorine, oxygen, nitrogen and sulphur components.

Typical Composition [wt.%]

Component	Pyrolysis Gasoline	Reformate	Light Reformate	Coke Oven Light Oil
Benzene	30	3	24	65
Toluene	20	13	46	18
Xylenes	4	18	< 0.5	6
Ethylbenzene	3	5	< 0.5	2
C ₉₊ Aromatics	3	16	0	7
Total Aromatics	60	55	70	98
Naphthenes	High	Low	Low	High
Olefins	High	High	Low	High
Paraffins	Low	High	High	Low
Sulphur	Up to 1000 ppm wt.	< 1ppm wt.	Low	Up to 1 wt. %

Fig. 4-01

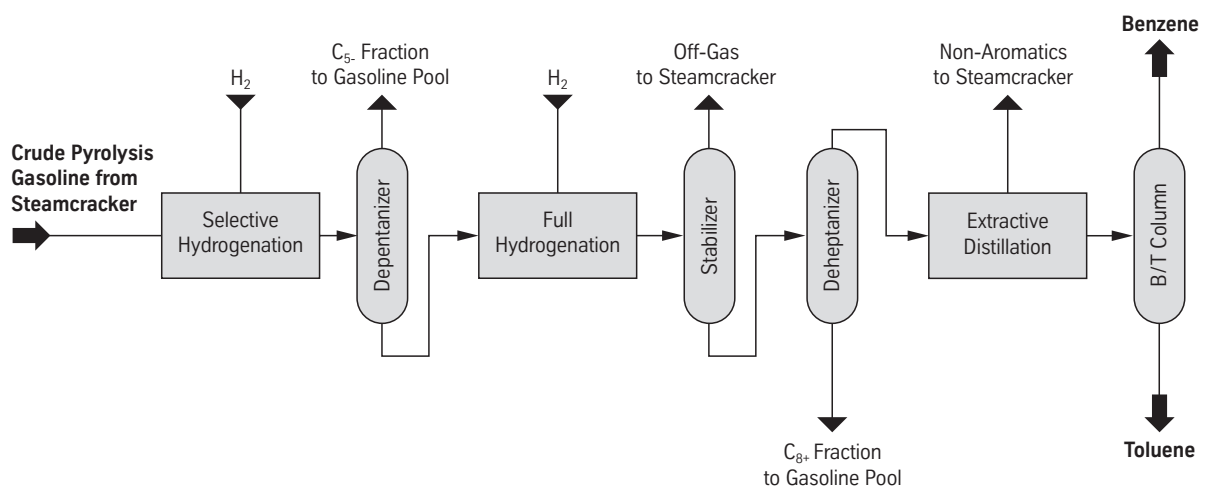


Fig. 4-02
Aromatics from Pyrolysis Gasoline

Aromatics from Pyrolysis Gasoline

Pyrolysis gasoline is mainly used to recover benzene as well as benzene and toluene together. Producing mixed xylenes from pyrolysis gasoline is uneconomical due to the low xylene content and the high ethylbenzene content in the pyrolysis gasoline.

A typical process route for recovering benzene and toluene, starting from crude pyrolysis gasoline, is illustrated in Fig. 4-02. In the first step, the selective hydrogenation, diolefins are saturated at a relatively low temperature to avoid polymerisation. The C_{5-} fraction is usually separated from the selectively hydrogenated pyrolysis gasoline in a depentaniser upstream of the full hydrogenation stage and sent to the gasoline pool as an octane-blending component. Thereby, hydrogen consumption is minimised and the size of the full hydrogenation unit can be reduced.

If, however, the C_{5-} fraction is sent back to the steamcracker as feedstock, it should be fully hydrogenated and separated with the non-aromatics downstream of the full hydrogenation unit in a combined depentaniser/stabiliser or an extractive distillation stage. This dispenses with the need for a complete depentaniser system.

Olefins as well as impurities, such as nitrogen, sulphur and other components, are completely hydrogenated in the full hydrogenation unit. The off-gas containing H_2S is separated in the stabiliser and then returned to the steamcracker.

In order to extract the required aromatics, a specific aromatics cut has to be separated from the pretreated pyrolysis gasoline. In the case of benzene recovery, a C_{6-} cut is separated, in case of benzene and toluene recovery, a C_{7-} cut is separated in a predis-

tillation column and sent to the extractive distillation. The C_{7+} or C_{8+} fraction is sent to the gasoline pool as feedstock.

Benzene or benzene and toluene are separated from the non-aromatics in the extractive distillation unit which comprises a simple two column system. The non-aromatics are sent back to the steamcracker as feedstock. In the case of combined benzene and toluene recovery, both products have to be separated downstream in a benzene/toluene column system.

In some cases it can be more economical to convert the C_{7+} aromatics into benzene to maximise the benzene output. In this case, a thermal hydrodealkylation unit is integrated in such a way that the extracted toluene and xylenes from the predistillation stage are dealkylated to form benzene (Fig. 4-03).

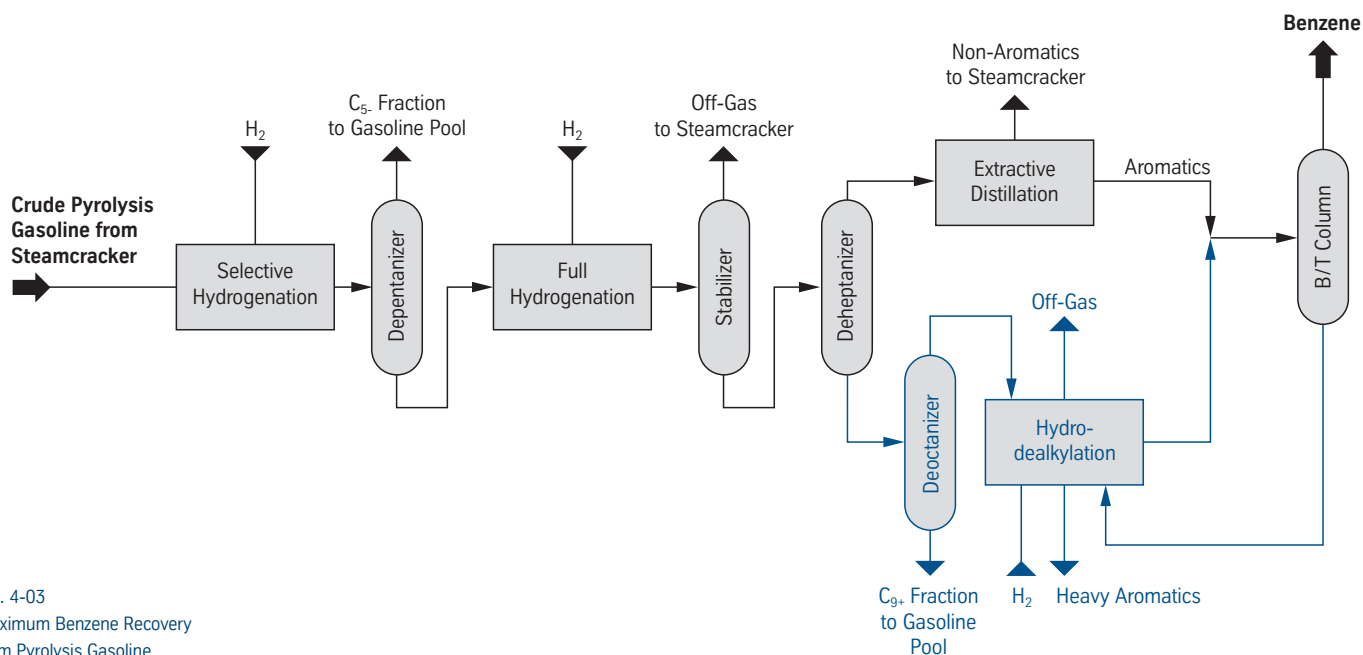


Fig. 4-03
Maximum Benzene Recovery
from Pyrolysis Gasoline

**Aromatics complex for
BASF in Mannheim/Germany.**

Capacities: 405,000 t/year aromatics extraction,
340,000 t/year hydrodealkylation

The full range:

Consisting of pyrolysis gasoline full hydrogenation,
pyrolysis gasoline separation, reformat separation,
benzene extractive distillation, toluene/xylene
extractive distillation and hydrodealkylation.





The off-gas produced can then be used as fuel gas. The toluene does not necessarily have to be extracted before being fed to the hydrodealkylation stage. However, if the toluene fraction is fed directly from the pre-distillation stage, more hydrogen has to be consumed to crack the C_7 non-aromatics and consequently more off-gas is produced.

Depending on the feedstock available and the products required, individual process configurations and heat integration of the individual units can be optimised whilst taking into account local conditions such as specific utility availability and costs. We find the most cost-effective solutions with regard to investment and operating costs for its customers.

Aromatics from Reformate

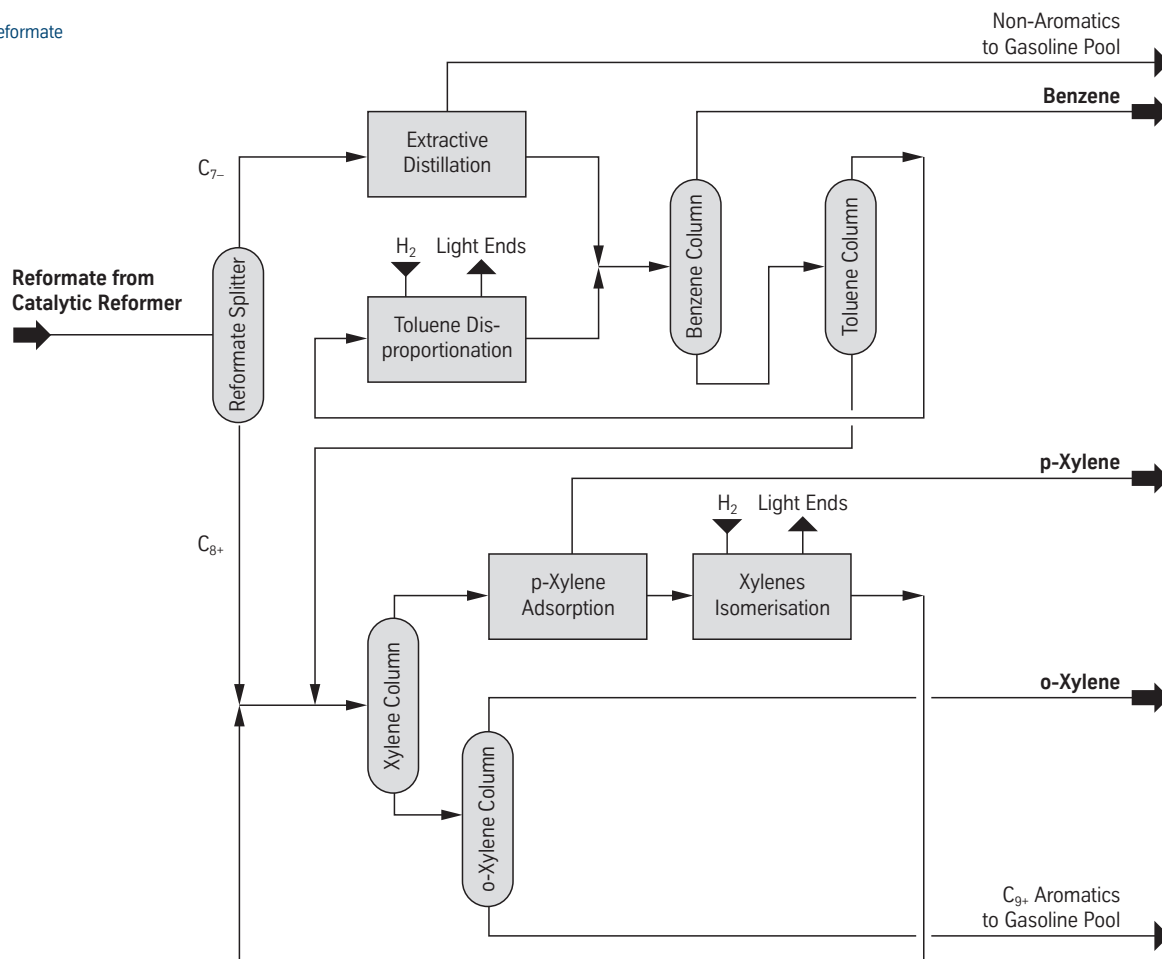
As a result of its relatively low benzene content and relatively high toluene and xylenes content, reformate is mainly used to produce p-xylene. Another application for aromatics recovery is the reduction of benzene in motor gasoline by extracting benzene from the catalytic reformate.

P-Xylene Production

The typical process route for the production of p-xylene from reformate is illustrated in Fig. 4-04.

In this case catalytic reformate is split into a C_{7-} fraction and a C_{8+} fraction. The C_{7-} fraction is then sent to the extractive distillation stage, where benzene and toluene are separated from the C_{7-} non-aromatics.

Fig. 4-04
Aromatics from Reformate



The C_{8+} fraction is sent directly to the p-xylene loop without the xylenes being extracted. The non-aromatics content in this fraction is very low and can therefore be easily handled in the p-xylene loop. Consequently only benzene and toluene have to be extracted and not full-range BTX.

The toluene is fed to the toluene disproportionation stage where it is converted into benzene and xylenes.

The benzene produced is separated as a high-purity product together with the extracted benzene, whilst the unconverted toluene is recycled back to the disproportionation.

After separation, the mixed xylenes fraction from the disproportionation, the xylenes fraction from the reformate splitter and the recycled xylenes from the isomerisation are sent to the p-xylene adsorption, where p-xylene is separated from the xylenes. The remaining xylenes (m-xylene, o-xylene and ethylbenzene) are sent to the isomerisation to be converted into p-xylene.

If o-xylene is also to be obtained as a product, it must be removed as a pure product by distillation in a separate column system before the xylenes enter the p-xylene isomerisation loop.

If maximum p-xylene production is required, a toluene and C_{9+} aromatics transalkylation is integrated into the process configuration (not illustrated). With respect to an optimised heat integration, vapours from the xylenes separation can be used to heat the benzene and toluene columns and other consumers.



Half a million tonnes of benzene from reformate
for Chevron Phillips Chemical Company,
Pascagoula, MS, USA

Benzene Reduction in Motor Gasoline

In order to comply with the latest regulations limiting the benzene content in motor gasoline, the refining industry has to adjust its operations to either convert or recover benzene and other aromatics.

ThyssenKrupp Industrial Solutions has developed an optimised Morphylane[®] extractive distillation process for recovering benzene from reformate with lower investment and operating costs (Fig. 4-05) compared to aromatics saturation, liquid-liquid extraction and other processes.

The reformate from the catalytic reformer is fed to the selective hydrogenation stage to saturate the diolefins which influence the acid wash colour (AWC) of the benzene product.

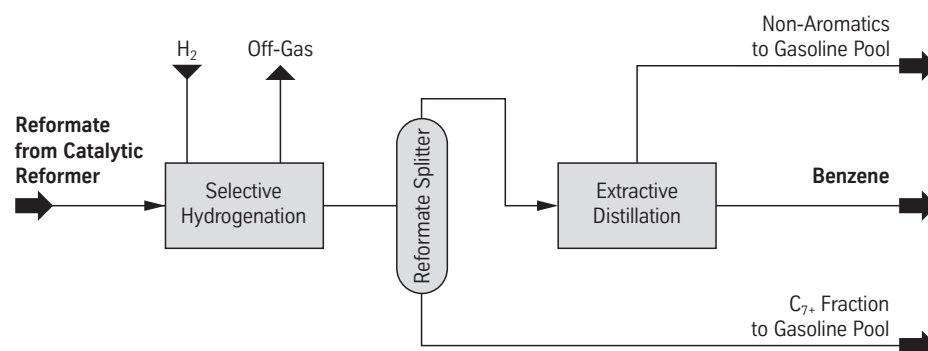
The selective hydrogenation unit consists of a small reactor which is operated at low temperatures and pressure in a trickle phase. The small amount of off-gas is separated in the reactor using only phase separation. This upstream hydrogenation of diolefins eliminates the necessity for a downstream clay treating and subsequent product distillation thus saving considerably on investment and operating costs.

The pretreated reformate is fractionated and the C₆ fraction is sent to the extractive distillation where high purity benzene is removed from the non-aromatics in a simple two column system. One of the advantages of the Morphylane[®] extractive distillation process is that both dissolved hydrogen and light hydrocarbons can be easily removed with the overhead product thereby saving on investment for an upstream depentaniser system.

Another advantage of the process is the excellent benzene purity. A very low benzene content in the non-aromatics (< 0.1 wt%) can be achieved in the optimised extractive distillation configuration.

Determined by the specific requirements of the refiners, ThyssenKrupp Industrial Solutions also provides other process configurations, e.g. a combination of reformate fractionation (producing several blending cuts) and benzene extractive distillation or a combined benzene and toluene extraction.

Fig. 4-05
Benzene from Reformate
(Benzene Removal from Motor Gasoline)



ThyssenKrupp Industrial Solutions engineered the entire aromatics recovery complex for ARSOL Aromatics in Gelsenkirchen/Germany, consisting of hydrotreating, benzene extractive distillation and distillation of the benzene homologues (Toluene, Xylenes and C_{9+} aromatics) from coke oven light oil.

Aromatics from Coke Oven Light Oil

Coke oven light oil is generally used as a feedstock for recovering benzene, toluene, xylenes and higher aromatics as it has a very high aromatics content. The general process line for recovering aromatics from coke oven light oil is illustrated in Fig. 4-06.

In a first step, the feedstock, which has a high content of impurities and a high content of olefins and diolefins, is hydrogenated. A special hydrotreating process with a specific heating/evaporation system and a two stage reaction system is used for this purpose.

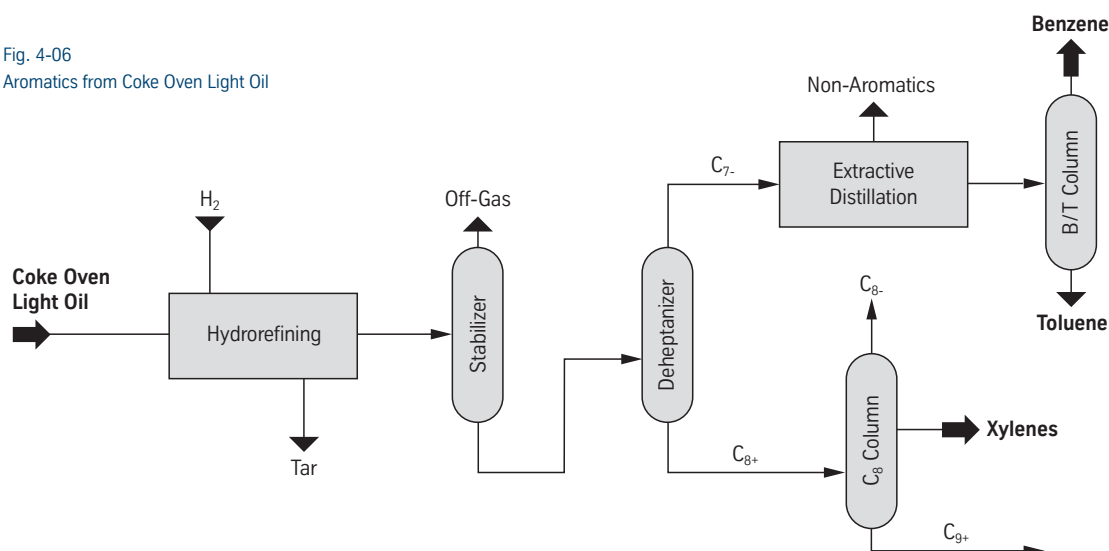
The hydrogenated coke oven light oil is sent to the stabiliser where the off-gas, which contains for instance H_2S , is separated.

The stabilised coke oven light oil is then sent to a deheptaniser. The overhead C_{7-} fraction is sent to the extractive distillation in which benzene and toluene are separated from the relatively small amount of non-aromatics in a single extractive distillation before being split into high-purity benzene and toluene.

The C_{8+} fraction leaving from the bottom of the deheptaniser is usually sent to another fractionation system where xylenes and higher aromatics are recovered by distillation.



Fig. 4-06
Aromatics from Coke Oven Light Oil



Technology

Hydrogenation Technology

Hydrogenation Technology

If pure aromatics are to be obtained, the feed must undergo a pretreatment before the non-aromatics and aromatics can be separated by extractive distillation. Catalytic hydrogenation processes have become the most appropriate technologies for eliminating impurities such as diolefins, olefins, sulphur, nitrogen and oxygen components.

Hydrogenation of Pyrolysis Gasoline

Due to its high diolefin content, crude pyrolysis gasoline from steamcrackers has a tendency to polymerise and to form gum even when stored in tanks under nitrogen blanketing. In view of the fact that polymerisation is encouraged at higher temperatures, the diolefins have to be hydrogenated at relatively low temperatures by highly active catalysts in the so-called selective hydrogenation process. Once the diolefins have been subjected to selective hydrogenation, other impurities can be hydrogenated in the full hydrogenation stage at high temperatures.

Selective Hydrogenation

(see Fig. 5-01)

In this process step, crude pyrolysis gasoline is sent to the hydrogenation reactor after having been mixed with hydrogen. The reaction takes place in the trickle phase or in the liquid phase on noble metal catalysts (palladium on aluminium oxide carrier) or on nickel catalysts.

The selectively hydrogenated pyrolysis gasoline leaves the reactor and is sent to a separator where the remaining hydrogen is separated from the liquid phase. Depending on the catalyst selected, the gas phase is sent either to the fuel gas unit or to the full hydrogenation stage in which the remaining hydrogen is utilised as a make-up agent.

After cooling, part of the liquid phase is recycled to the reactor to control the reactor temperature. The selectively hydrotreated product is fed to a fractionation column or is sent directly to the full hydrogenation.

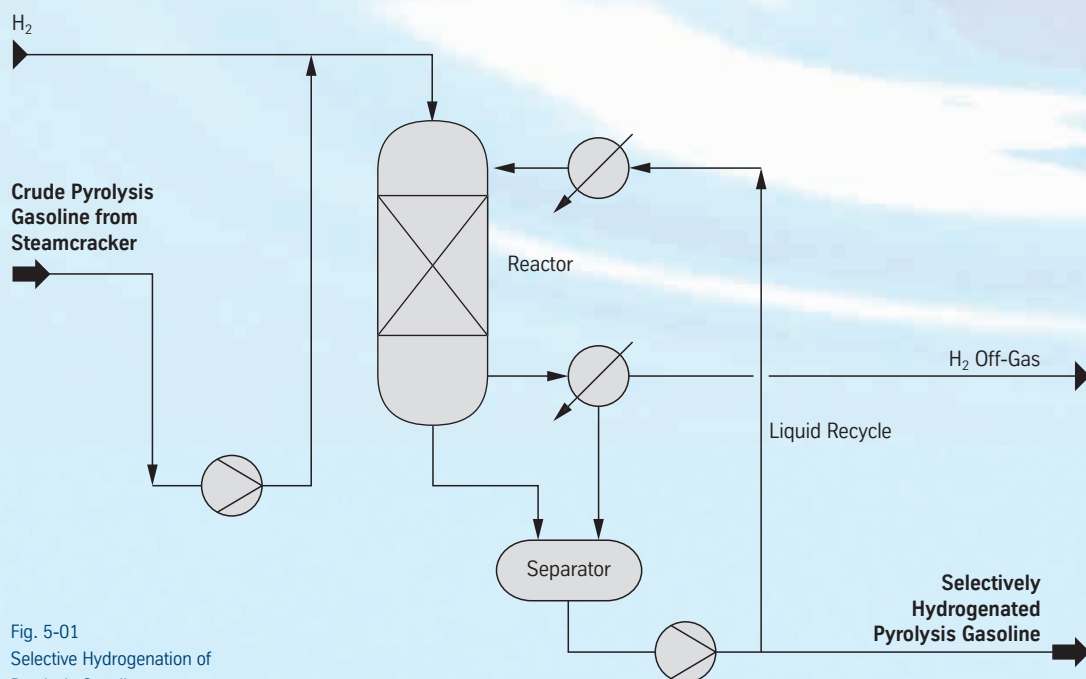


Fig. 5-01
Selective Hydrogenation of
Pyrolysis Gasoline

Full Hydrogenation

(see Fig. 5-02)

Impurities such as sulphur, nitrogen and oxygen components and olefins are hydrogenated in the full hydrogenation stage. The reactions take place in the gaseous phase on nickel/molybdenum and/or cobalt/molybdenum catalysts at reactor inlet temperatures of between 240°C and 320°C.

To this end, the selectively hydrogenated pyrolysis is fed to the reactor via feed/effluent heat exchangers and a process heater after having been mixed with recycled hydrogen. After cooling, the reactor product is sent to a high pressure separator where the hydrogen, which has not been consumed, is separated from the liquid phase.

The remaining hydrogen is mixed with fresh make-up hydrogen and fed back to the reactor.

The liquid reactor product, fully hydrogenated pyrolysis gasoline, is sent to a stabiliser system in which the off-gas containing H_2S is separated from the product. The off-gas is normally recycled back to the steam cracker, whilst the stabilised reactor product is sent either to a fractionation column or directly to the aromatics recovery unit.

Various optimised process designs are provided depending on the specific criteria, such as feedstock specification, hydrogen quality, etc. In this respect some of the most cost-effective solutions with regard to investment and operating costs include reactor-side intermediate quenching by cooled liquid product recycle, steam generation and additional reactive catalyst layers for difficult feedstocks.

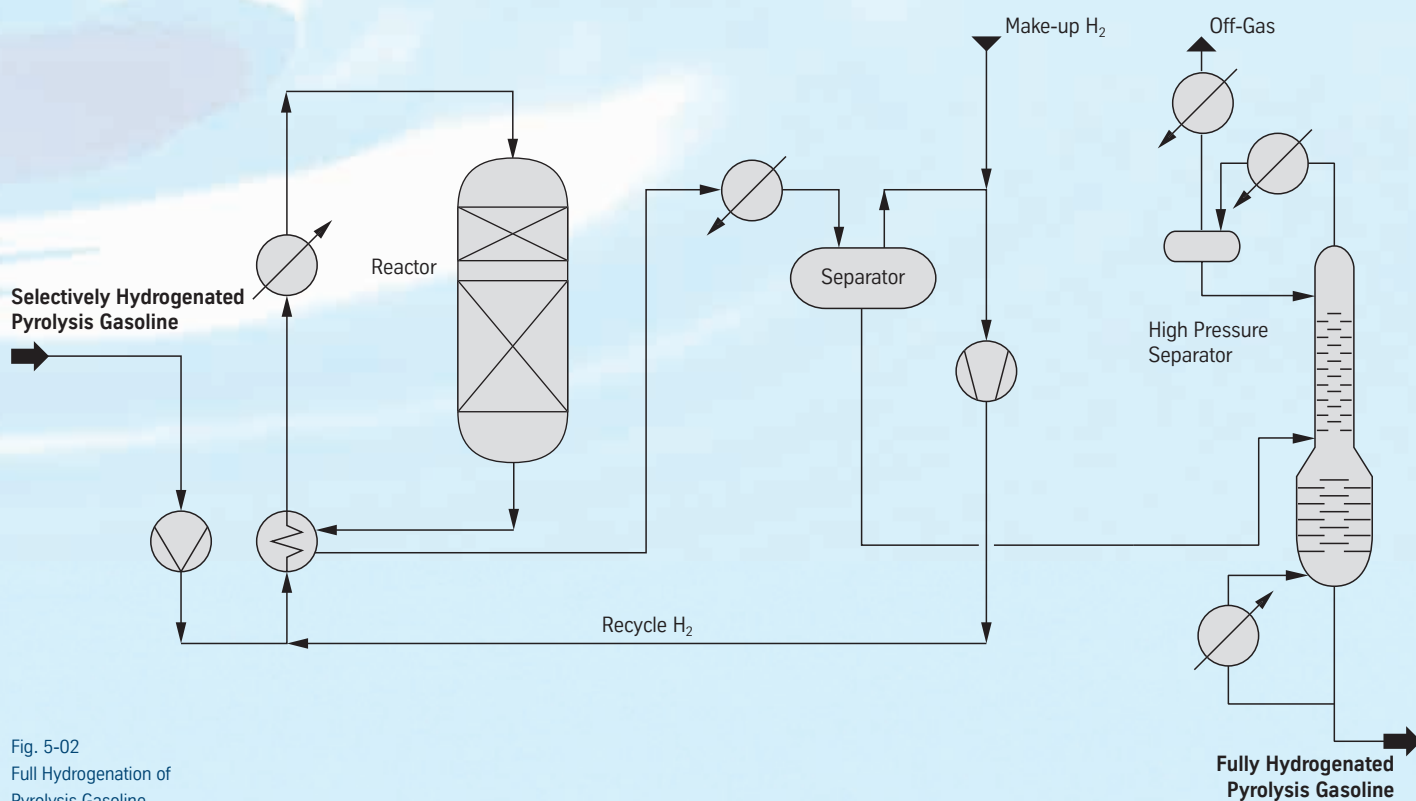


Fig. 5-02
Full Hydrogenation of
Pyrolysis Gasoline

Hydrogenation of Reformate

Although high quality benzene containing less than 30 ppm non-aromatics is produced by extractive distillation, even a small quantity of diolefins (around 5 ppm) can result in an acid wash colour (AWC) specification higher than that which is actually required. If diolefins are present, especially those of a naphthenic nature the reformate must be subjected to an additional treatment stage.

As the most common unsaturated components, such as olefins and diolefins, are mostly removed by clay treating combined with a conventional liquid-liquid extraction plant. One alternative is to install a selective hydrogenation stage for the olefins and diolefins upstream of the extractive distillation process. The catalyst used for the selective hydrogenation of reformate has a

long service life and can usually be regenerated several times. The maintenance savings are thus quite remarkable. In addition, disposing of clay has become more and more difficult due to the enforcement of environmental protection laws in an increasing number of countries.

The essential features of the catalyst can be summarised as follows:

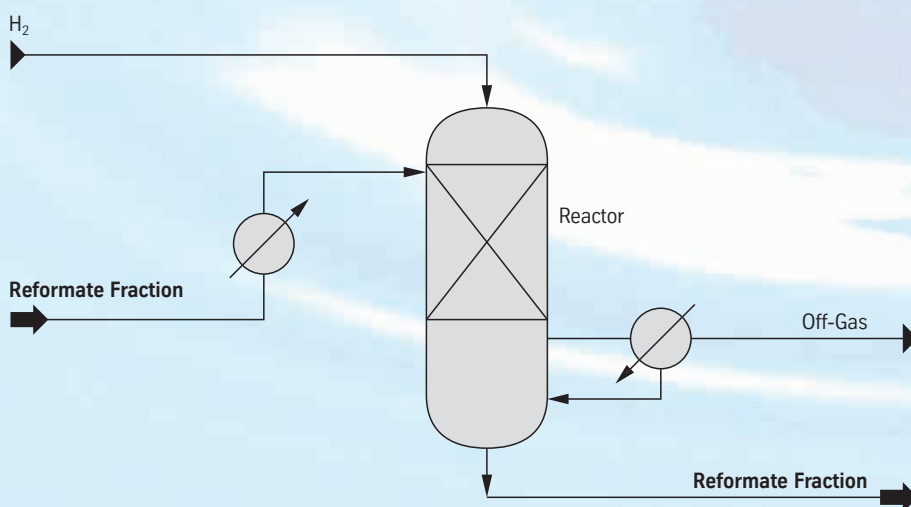
- high conversion rate with regard to diolefins
- reduction of olefins
- low benzene losses (as compared to clay treating)
- long cycle length between regeneration
- long service life
- mild operating conditions

The typical process scheme is illustrated in Fig. 5-03.

The benzene-rich cut upstream of the extractive distillation stage is passed to the selective hydrogenation reactor once the required inlet temperature has been reached. Hydrogen is added to the benzene-rich cut.

Selective hydrogenation takes place in the trickle bed of the reactor at low temperatures and pressures. The product, which is free of diolefins, is then passed directly to the extractive distillation stage. Separation of the gas phase takes place in the reactor bottom. Additional stripping of the product is not necessary.

Fig. 5-03
Reformate Selective
Hydrogenation



Hydrogenation of Coke Oven Light Oil

In a similar way to crude pyrolysis gasoline, coke oven light oil also has to be hydrogenated. Impurities, such as organic sulphur, nitrogen and oxygen components, have to be removed and diolefins and olefins have to be saturated to stabilise the coke oven light oil and to assure high-quality final products.

The “BASF-Scholven” process meets all the above requirements. The reactions take place in the gas phase on a nickel/molybdenum catalyst in the prereactor and on a cobalt/molybdenum catalyst in the main reactor.

Special emphasis is placed on the evaporation of the coke oven light oil feed. ThyssenKrupp Industrial Solutions has developed a proprietary system which permits smooth evaporation in a special multi-stage evaporator thereby minimising

fouling whilst achieving high on-stream factors without the addition of fouling inhibitors.

The coke oven light oil is mixed with make-up hydrogen and recycle hydrogen and passed through a system of feed/effluent exchangers which are combined with the stage evaporator (Fig. 5-04). With the exception of a small quantity of heavy hydrocarbons which are withdrawn at the bottom of the multi-stage evaporator, almost all the feedstock is evaporated.

After being subjected to additional heating, this material is fed to the prereactor where most of the diolefins are converted. The effluent from the prereactor is then heated further by a process heater. In the main reactor the olefins are saturated and the remaining sulphur, nitrogen and oxygen compounds are hydrogenated. After cooling, the effluent from the main reactor is

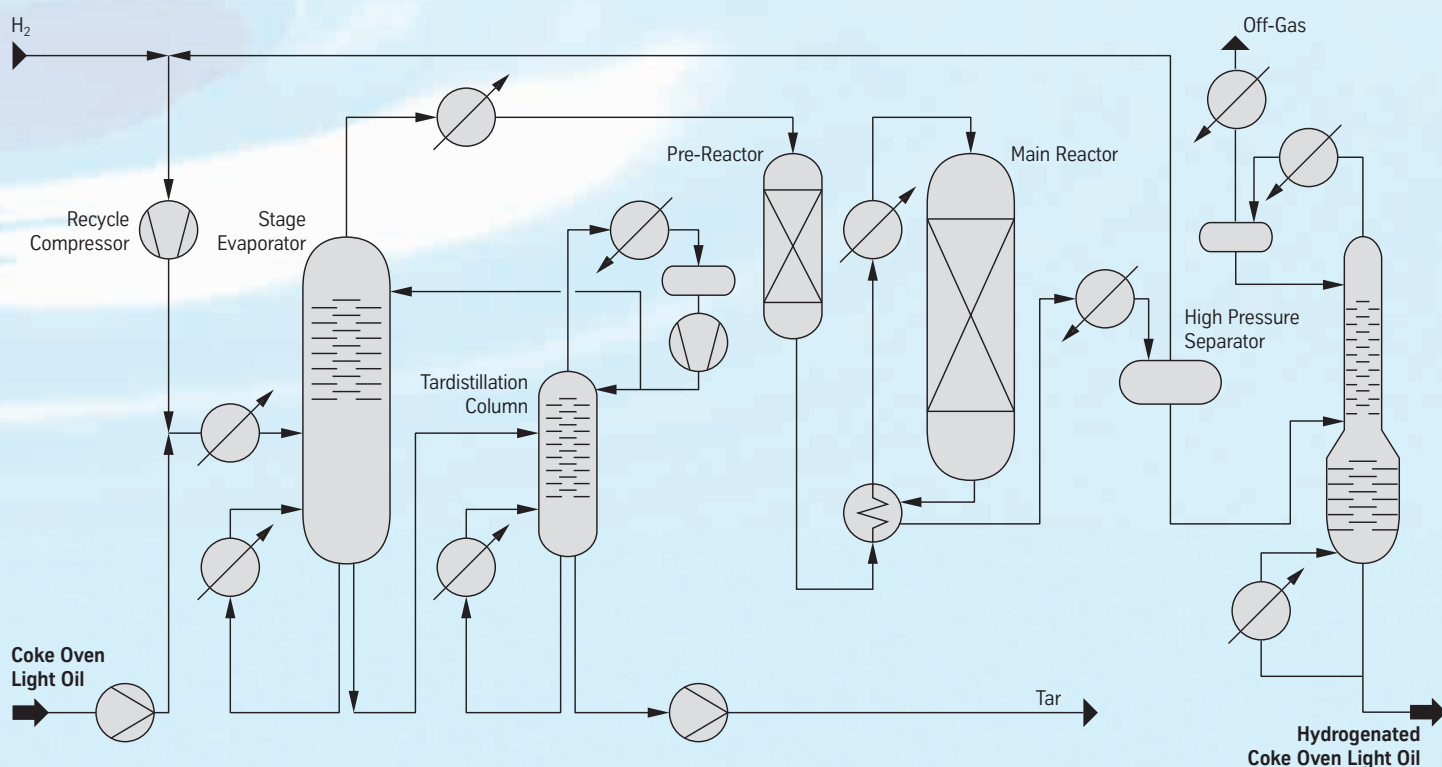
sent to the high pressure separator to disengage the hydrogen from the liquid phase.

The separated hydrogen is mixed with make-up hydrogen, recompressed and returned to the coke oven light oil feed.

The fully hydrogenated raffinate from the high pressure separator is sent to a conventional stabiliser system. Off-gas containing H_2S and NH_3 is separated from the raffinate product. The stabilised raffinate is sent to a fractionation and aromatics recovery unit.

ThyssenKrupp Industrial Solutions offers a variety of process configurations adapted to the feedstock conditions and customer requirements. The heavy hydrocarbon residue can, for example, be subjected to further treatment in a tar distillation unit to enhance BTX aromatics recovery or to produce valuable tar-derived products.

Fig. 5-04
Hydrotreating of
Coke Oven Light Oil



Fractionation Technology

Fractionation Technology

For many decades, distillation has been one of our key areas. From hydrocarbon C_2 and C_3 distillation to C_9 and C_{10} distillation, from crude distillation to pure component distillation, we can provide fractionation technology for virtually any hydrocarbon system.

Our extensive experience is very efficiently backed up by our laboratory and pilot plant facilities. Hydrocarbon equilibrium data can be measured in our laboratories and then implemented in conventional standard process simulators.

Pilot testing may also be used to confirm or demonstrate these adapted models. Special feedstocks can be tested in our pilot plants allowing distillation processes to be optimised to meet customer requirements.

Conventional Distillation

ThyssenKrupp Industrial Solutions' expertise includes distillation systems which use conventional tray technology as well as random and structured packing technologies. We have designed columns up to 10 metres in diameter and as high as 100 metres.

Divided Wall Column Distillation

Whenever more than two fractions have to be separated by distillation, the question arises as to which is the most efficient configuration (Fig. 5-05).

Configurations involving columns which are fully thermodynamically coupled have certain energetic advantages over conventional fractionation technologies. Latest technological developments have, however, laid the foundation for adequate calculation techniques and established the generic guidelines for thermodynamic simulations.

This has resulted in the development of engineering tools which permit the application of the divided wall technology and which make use of the thermodynamic advantages.

These advantages are reflected in:

- up to 20% less investment costs
- up to 35% less energy costs
- up to 40% less plant space requirements

ThyssenKrupp Industrial Solutions successfully introduced this technology to aromatics applications. Two commercial-scale divided wall columns have recently been commissioned for aromatics recovery. In addition, ThyssenKrupp Industrial Solutions has installed divided wall column test facilities in its own laboratories to work on further improvements.

The divided wall column technology is an excellent tool for revamping plants, enhancing their capacity and improving product qualities and yields. Existing hardware can be modified within one week resulting in a short shut-down time and low production losses.

Plant converted to the divided wall technology in just five days.

Our team at the Ruhr Oel GmbH refinery in Münchsmünster in Bavaria had just five days to convert a distillation column to a divided wall column using one of our new developments. The ThyssenKrupp Industrial Solutions team managed to complete the task in the allotted time despite inclement weather. The divided wall column saved Ruhr Oel having to build a second column for removal of benzene so that the more stringent benzene specifications in gasoline could be met.



Old section of the existing column



New divided wall section before
installation of packings

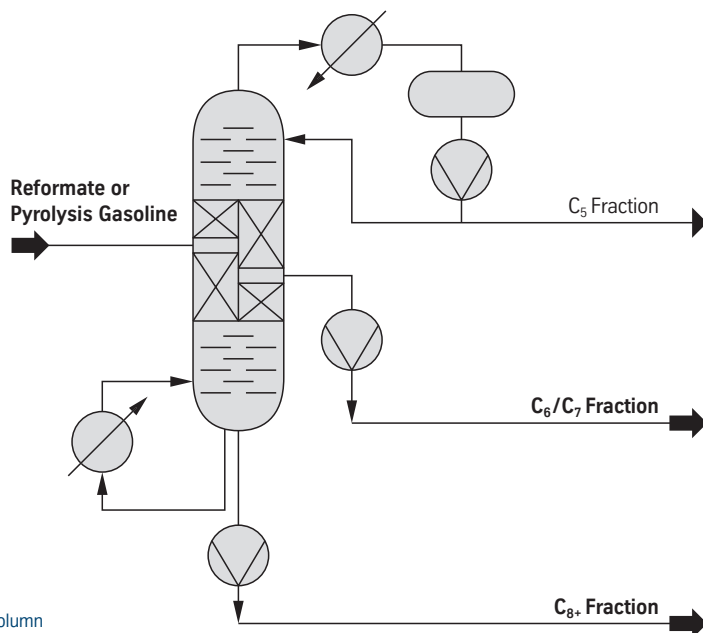
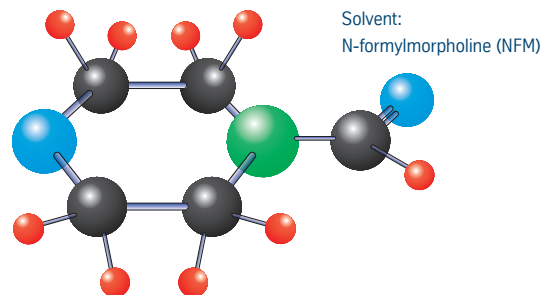


Fig. 5-05
Divided Wall Column

Morphylane[®] Extractive Distillation



Morphylane[®] Extractive Distillation

Due to lower capital cost and utilities consumption, the Morphylane[®] extractive distillation process, developed by Uhde, has replaced the former liquid-liquid extraction technology.

Conventional Morphylane[®] Process

In the extractive distillation (ED) process (see Fig. 5-06), the solvent alters the vapour pressure of the components to be separated. The vapour pressure of the aromatics is lowered more than that of the less soluble non-aromatics. The ED process is relatively simple. The solvent is supplied to the head of a distillation column via a central feed inlet. The non-aromatic vapours leave the ED column with some of the solvent vapours. The internal reflux is controlled by the solvent feed temperature.

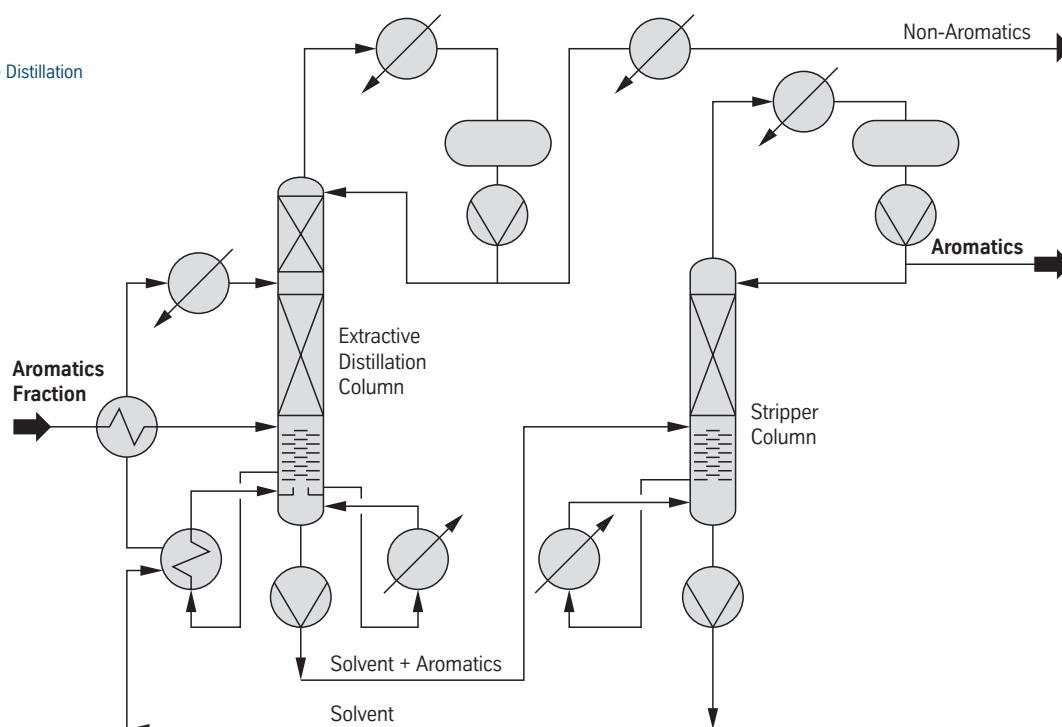
The solvent is recovered from the overhead product in a small column with sectional reflux, which can be either mounted on the main column or installed separately. The bottom product from the ED column is fed to a distillation stage, i.e. the stripper, to separate the pure aromatics and the solvent. After intensive heat exchange, the lean solvent is recycled to the ED column.

The product purity is affected by a number of different parameters including solvent selectivity, the number of separation stages, the solvent/feedstock ratio and the internal reflux ratio in the ED column. The solvent properties needed for this process include high selectivity, thermal stability and a suitable boiling point. The solvent used in the Morphylane[®] process is a single compound, namely N-formylmorpholine (NFM). No agents or promoters are added to the solvent. The salient features of NFM are summarised in Fig. 5-07.

Nitrogen Guard Bed

The Morphylane[®] process withholds the solvent in the unit almost completely. The concentration of NFM in the extract is typically less than 1 wt.-ppm, which corresponds to <0.15 wt.-ppm basic nitrogen. Therefore losses are of no importance to the economics of the process. However, market demands have increased: Due to the invention and spread of zeolithe catalysts for alkylation processes the requirements for the extract of the Morphylane[®] process have become stricter. The nitrogen concentration is required to be as low as possible. Our answer to this market demand is the Nitrogen Guard Bed. This adsorption bed is able to capture even traces of basic nitrogen, such that the product concentration is in the ppb-range, below the detection limit. Therefore aromatics from the Morphylane[®] units can safely be fed to zeolithe-catalysts reactors, producing alkyl-aromatics in world-scale.

Fig. 5-06
Morphylane[®] Extractive Distillation



Single-Column Morphylane® Extractive Distillation

Uhde's new Single-Column Morphylane® extractive distillation process uses a single-column configuration which integrates the extractive distillation (ED) column and the stripper column of the conventional Morphylane® design. It represents a superior process option in terms of investment and operation (Fig. 5-08).

In the Single-Column ED process, the aromatics are removed from the vaporised feed by the solvent (NFM) in packing 2. Residual non-aromatics are stripped off by aromatics vapours in packing 3. Solvent traces in the column head are washed back with the non-aromatics reflux in packing 1, while solvent traces in the aromatics vapours are removed by aromatics reflux in packing 4.

Packings 3 and 4 are separated by a dividing wall forming two chambers. The chamber containing packing 4 is closed at the top side.

The aromatics-solvent mixture draining from the two chambers is fed to the stripping section (packing 5) where the aromatics are stripped off from the solvent. The lean solvent is returned to the top of the column. Intensive stripping is crucial to the aromatics yield.

The first industrial realisation of the new concept has been a toluene recovery plant for ARSOL Aromatics GmbH in Gelsenkirchen, Germany, commissioned in October 2004.

Based on the Single-Column Morphylane® process by Uhde described above, the plant produces pure toluene from fully hydrogenated coke oven light oil.

The plant has a toluene capacity of 30,000 t/year and it achieves purities of

over 99.99%. The column has proved easy to operate, even under varying feed conditions and product specifications.

ThyssenKrupp Industrial Solutions supplied the licence for the plant, provided engineering services and was on hand in a consulting capacity during commissioning.

In 2005, ThyssenKrupp Industrial Solutions was presented with the 'Kirkpatrick Honor Award for Chemical Engineering Achievement', a biennial award for innovative products or processes by the journal Chemical Engineering. A vital prerequisite for submission of an innovation is that its first-time industrial-scale implementation was within the past two years. Our technology met this condition with the successful commissioning of the aromatics plant based on the innovative single-column concept for ARSOL Aromatics GmbH in 2004. An international team of experts ranked the process among the five best process innovations of the last two years.

Fig. 5-07

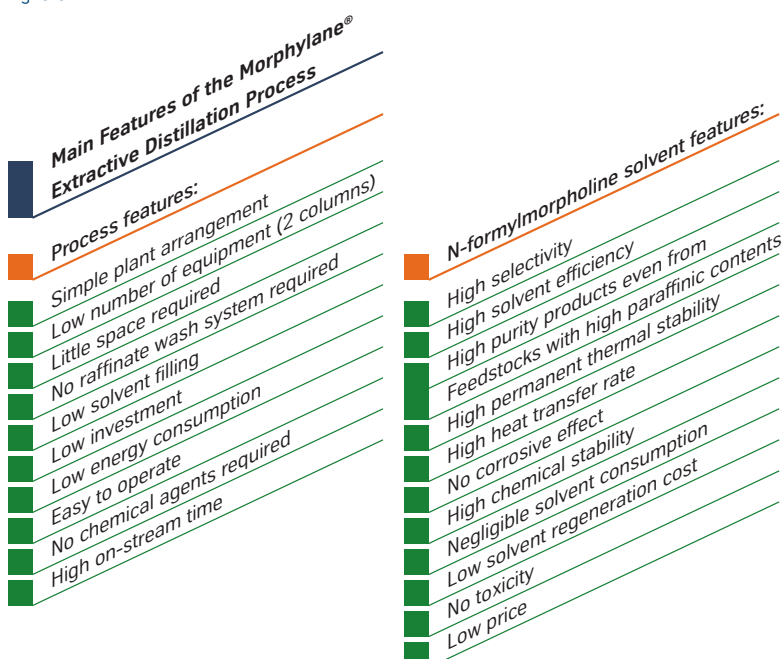
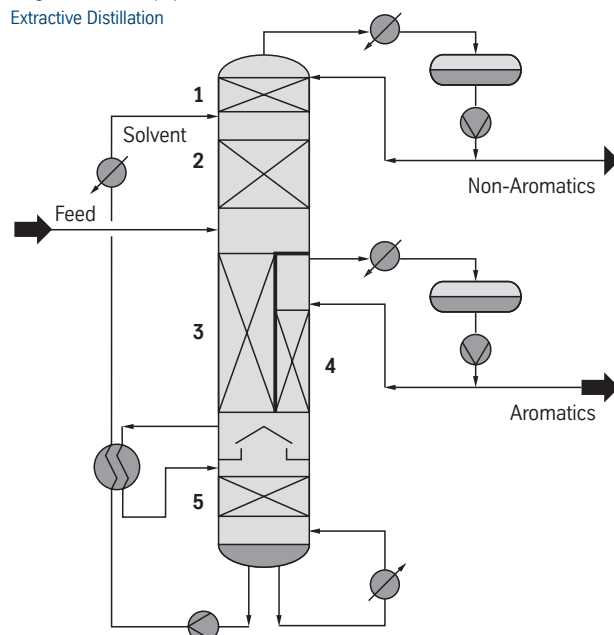


Fig. 5-08

Single-Column Morphylane®
Extractive Distillation



525,000 t/year of pyrolysis
gasoline extractive distillation for
Rayong Olefins Corp., Thailand



Hydrodealkylation and Toluene Disproportionation Technology

Hydrodealkylation Technology

Hydrodealkylation, commonly known as HDA, is a well-established process for converting C_7 and C_8 (even up to C_{9+}) alkylbenzenes to high purity benzene. Very few new plants are being built, however, as the huge hydrogen consumption makes the benzene quite expensive.

The preferred technology uses non-catalytic thermal reactor systems which have a high benzene yield, extremely high on-stream factors and lower operating costs as compared with catalytic systems. A typical process configuration is shown in Fig. 5-09.

Several options, e.g. to enhance benzene yield or to minimise hydrogen consumption are available, depending on the quality of the feedstock treated in the HDA. Co-processing C_8 and even C_{9+} aromatics will enhance benzene output but will also increase hydrogen consumption considerably. An upstream extraction stage reduces the content of non-aromatics to such an extent that the amount of hydrogen consumed in the cracking reaction is minimised.

A major technological break-through was achieved when the zeolite catalyst geometry was developed to maximise para-xylene selectivity. The TDP with improved selectivity produces a xylene fraction which contains up to 90% para-xylene. Consequently,

the downstream para-xylene recovery and xylene isomerisation stages are smaller and more efficient.

Fig. 5-10 shows a typical process configuration for a TDP.

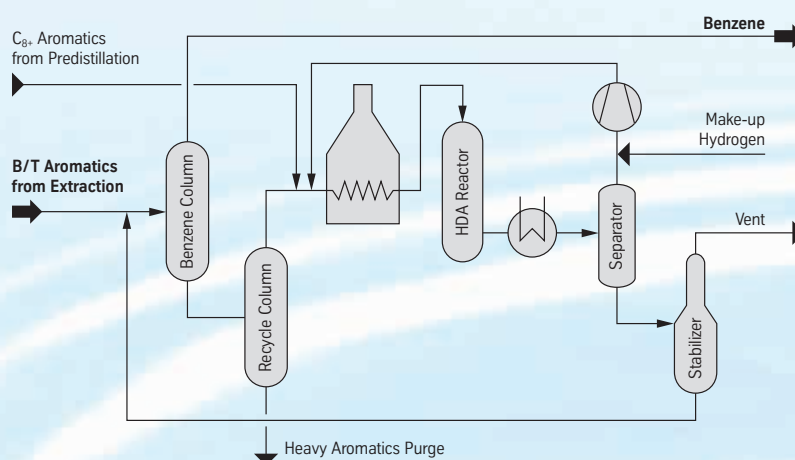


Fig. 5-09
Hydrodealkylation (HDA) Unit

Toluene Disproportionation Technology

Toluene Disproportionation Technology (TDP) converts toluene to benzene and mixed xylenes in approximately equimolar quantities. The reaction is carried out in the vapour phase on a variety of acidic zeolite catalysts. Conventional TDP produces a xylenes fraction in which the xylene-isomer equilibrium is reached. The para-xylene concentration is therefore limited to 24%. Further processing is required to increase the para-xylene yield.

This involves separating the para-xylene isomer by selectively adsorbing or by crystallising and isomerising the remaining meta-xylenes and ortho-xylenes (optionally) to form para-xylene. Since the para-xylene concentration in isomerisation is only 24% as well, a large recycle loop is required to completely convert the undesired isomers to para-xylene.

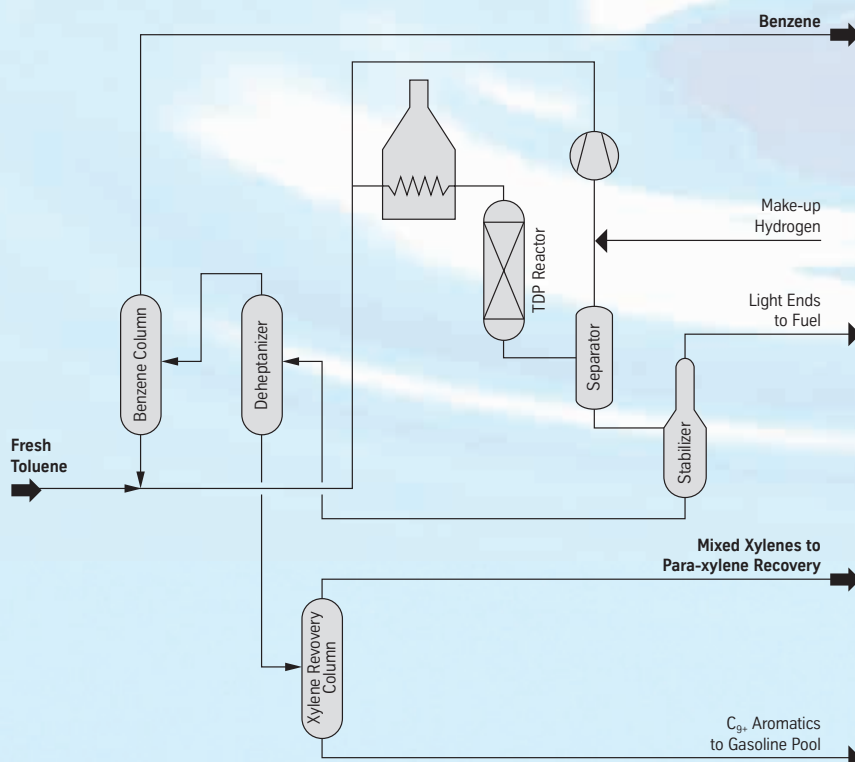


Fig. 5-10
Toluene Disproportionation Unit

Toluene/C₉₊ Transalkylation and Para-Xylene Adsorption Technology

Toluene/C₉₊ Transalkylation Technology

In contrast to the TDP, toluene and C₉₊ aromatics are converted to mixed xylenes in the transalkylation technology. The xylenes-to-benzene ratio increases if more C₉₊ aromatics are mixed with the toluene feed and if the transalkylation reaction rate increases. Similar catalysts to those used in TDP units are used.

Para-Xylene Adsorption Technology

Para-xylene can practically not be separated from meta-xylene by conventional distillation due to the closeness of their boiling points. In contrast, ortho-xylene can be recovered by conventional distillation because its boiling point is considerably higher than that of the other isomers.

The most common para-xylene separation technology used today involves adsorption using molecular sieves.

Crystallisation technology is also widely used, especially in North America and in Western Europe. However, one of the main advantages of adsorption over crystallisation is its high recovery rate per pass (up to 97%). In contrast, crystallisation units have a eutectic limitation of 65%. All commercialised para-xylene adsorption processes use isothermal, liquid phase adsorption. The adsorbent's selectivity, capacity and reversibility are the key properties relevant to desorption.

At the heart of the adsorption process are the adsorption columns in which the following steps occur in a sophisticated semi-continuous operation:

- feeding in mixed xylenes
- diluting out extract (para-xylene) with a desorbent
- diluting out raffinate (ethylbenzene, meta-xylene and ortho-xylene) with a desorbent
- feeding in recycled desorbent

The diluted extract and raffinate streams are fractionated in an extraction column and a raffinate column to recover the desorbent which is recycled back to the adsorbers.

Any residual toluene contained in the mixed xylenes feed and carried over with the para-xylene extracted is separated in a finishing column. The concentrated raffinate, meta-, ortho-xylene and ethylbenzene, is sent to the isomerisation stage. A simplified process configuration is shown in Fig. 5-11.

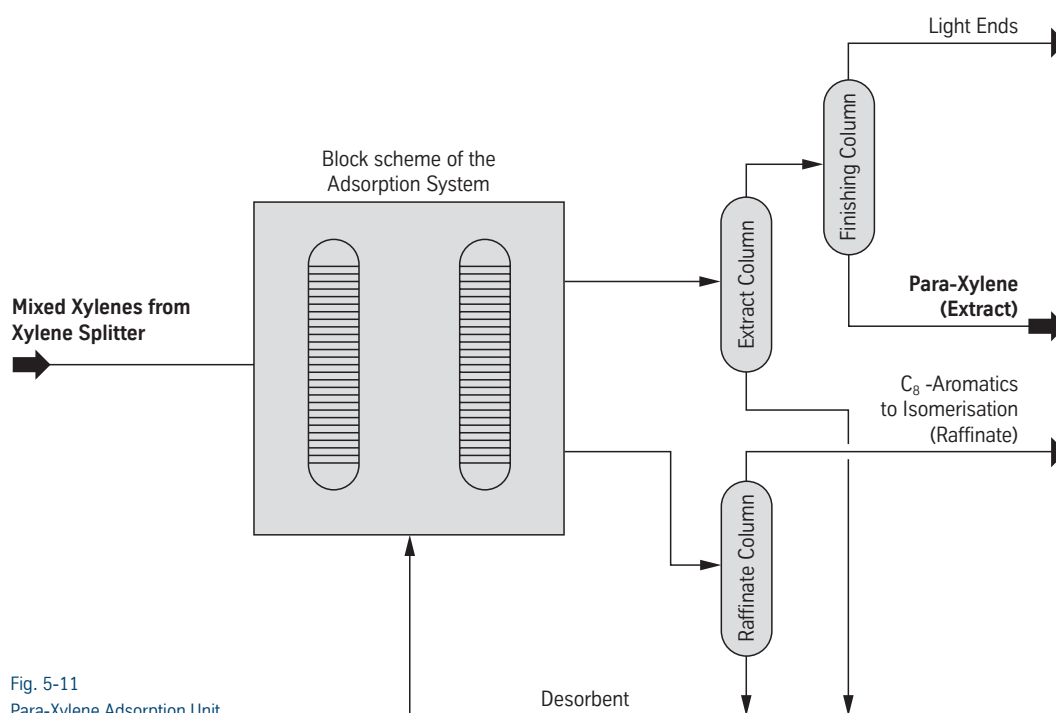
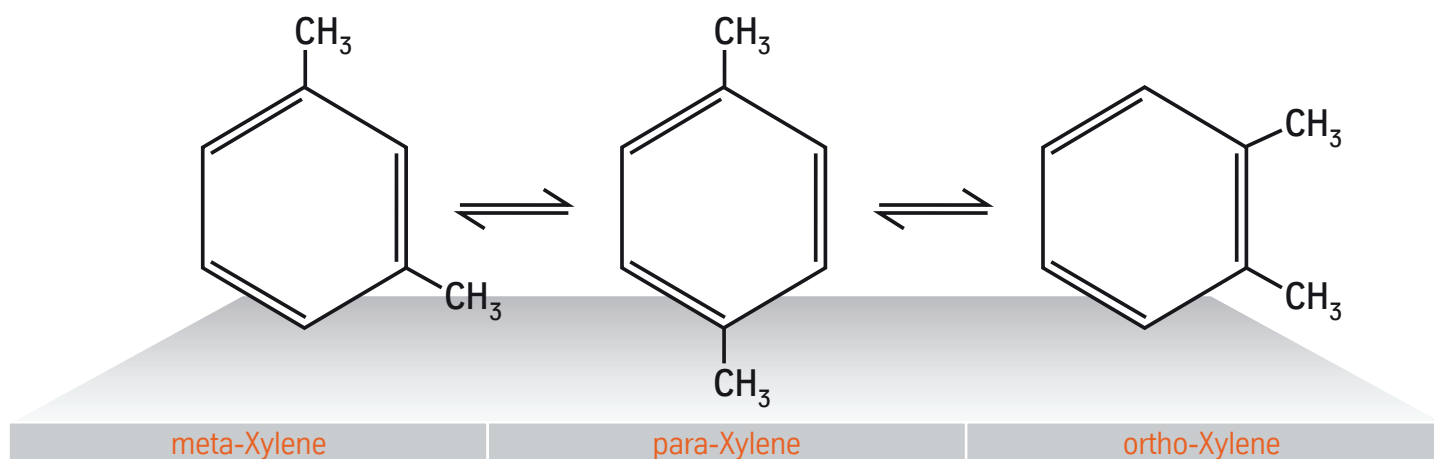


Fig. 5-11
Para-Xylene Adsorption Unit

Xylenes Isomerisation Technology



Xylene Isomers

Xylenes Isomerisation Technology

Once the C_8 aromatics stream has been depleted of para-xylene (and optionally of ortho-xylene as well), the stream is sent to an isomerisation unit to re-establish the equilibrium of the xylene mixture. This occurs by converting the meta-xylene (and ortho-xylene, if present) and the ethylbenzene (EB) to para-xylene by isomerisation until the equilibrium is reached. The isomerisate is then returned to the xylene fractionation section in which valuable para-xylene, and optionally ortho-xylene, are recovered. Meta-xylene and EB are returned to the recycle loop.

Alternatively, EB can be dealkylated to form benzene and ethane.

The method of EB conversion is influenced by the catalyst type. Xylene isomerisation catalysts can be categorised according to their ability to isomerise EB into additional xylenes or their ability to dealkylate EB. Both types of catalyst isomerise the xylenes to form a close equilibrium xylene isomerisate mixture.

EB isomerisation catalysts result in the highest para-xylene yield from a given feedstock due to the conversion of EB to additional xylenes. EB isomerisation is more difficult than xylene isomerisation and requires a bifunctional acid-metal catalyst. EB isomerisation occurs using C_8 -naphthene intermediates. This type of catalyst must be operated with a substantial concentration of C_8 -naphthenes in the reactor recycle loop to allow efficient conversion of EB to xylenes.

Xylene feedstocks containing high EB concentrations, such as pyrolysis gasoline feedstocks, are particularly suitable as the EB is converted to naphthenes thereby producing the naphthene concentration required. The EB isomerisation conversion rate typically amounts to 30-35%.

EB dealkylation is not limited to equilibrium conditions and permits EB conversion rates of up to 65%. EB dealkylation catalysts generally contain a shape-specific molecular sieve with a given pore size, which minimises xylene loss caused by xylene disproportionation, transalkylation or hydrocracking.

Operating Results of Extractive Distillation Plants



ED column and stripper, aromatics complex
at the Kashima refinery, Japan

Reformate feed with high aromatics content

Typically, reformates which contain large quantities of aromatics are processed in aromatics complexes in which a high aromatics yield reformer is installed. The C_6 core cut contains aromatics levels which well in excess of 50%. The operating results of four plants are summarised in Tables 7-01 and 7-02.

Reformate feed with high aromatics content

Plant for	Japan Energy, Kashima	Repsol, Spain
Year of commissioning	2007	2007
Benzene in ED-feed	30%	75%
Toluene in ED-feed	49%	0%
Benzene production	136,000 mtpy	221,000 mtpy
Toluene production	223,000 mtpy	-
Benzene quality	max. 400 wt.-ppm non-aromatics	400 wt.-ppm non-aromatics
Toluene quality	99.0 wt.-%	-
Solvent loss	max. 0.007 kg/t aromatics	max. 0.010 kg/t aromatics
Steam consumption	480 kg/t ED-feed	470 kg/t ED-feed
Yield	Benzene: 99.92%	Benzene: 99.7%

Table 7-01

Reformate feed with high aromatics content

Plant for	BASF Antwerp, Belgium	SPC, PR China
Year of commissioning	2000	1999
Benzene in ED-feed	~ 65 wt. %	~ 75 wt. %
Toluene in ED-feed	-	~ 85 wt. %
Benzene production	258,000 mtpy	135,000 mtpy
Toluene production	-	65,000 mtpy
Benzene quality	max. 100 ppm wt. non-aromatics	max. 80 ppm wt. non-aromatics
Toluene quality	-	max. 600 ppm wt. non-aromatics
Solvent loss	max. 0.005 kg/t benzene	max. 0.08 kg/t aromatics
Steam consumption	450 kg/t ED-feed	680 kg/t ED-feed *)

Table 7-02

*) including the benzene/toluene splitter

Reformate feed with low aromatics content

Plant for	Holborn Refinery, Germany	Tonen, Kawasaki, Japan
Year of commissioning	2003	1999
Benzene in ED-feed	~ 27 wt. %	~ 30 wt. %
Benzene production	66,000 mtpy	100,000 mtpy
Benzene quality	max. 10 ppm wt. non-aromatics	max. 50 ppm wt. non-aromatics
Solvent loss	max. 0.002 kg/t benzene	max. 0.001 kg/t benzene
Steam consumption	450 kg/t ED-feed	380 kg/t ED-feed

Table 7-03

Reformate and pyrolysis gasoline feed with high aromatics content

Plant for	PKN Orlen, Poland	Shell Moerdijk, The Netherlands
Year of commissioning	2006	2002
Benzene in ED-feed	33%	65 wt.-%
Toluene in ED-feed	41%	-
Benzene production	178,000 mtpy	550,000 mtpy
Toluene production	222,000 mtpy	-
Benzene quality	70 wt.-ppm non-aromatics	max. 200 wt.-ppm non-aromatics
Toluene quality	470 wt.-ppm non-aromatics	-
Solvent loss	0.006 kg/t aromatics	max. 0.003 kg/t benzene
Steam consumption	540 kg/t ED-feed	400 kg / t ED-feed
Yield	Benzene: 99.9; Toluol: 98.2 %	-

Table 7-04

Reformate feed with low aromatics content

Reformates processed in gasoline-based refineries generally contain smaller quantities of benzene. Reformers are often operated at lower severity levels. If the benzene content of gasoline is to be reduced, the benzene content of the C_6 core cut fed to the extractive distillation stage needs to be well below 50 wt%. In this type of application, the energy consumption of extractive distillation processes is lower than that of reformate streams with a higher aromatics (benzene) content. Table 7-03 shows the operating results of two plants recently commissioned for benzene reduction.

Pyrolysis gasoline feed

Pyrolysis gasoline from steam-crackers has a relatively high aromatics content which is dictated by the cracker feedstock and the severity of the cracker. The results obtained from an aromatics distillation process in a typical naphtha-based steam-cracker are shown in Table 7-04. The two examples are based on a benzene ED, which was started up in the Netherlands at the end of 2002, and a benzene/toluene ED, which went into operation in Poland in 2005.

Laboratory, Analytical and R&D Services



Gas-phase chromatographs used in the separation and quantitative analysis of liquid and gaseous samples

ThyssenKrupp Industrial Solutions operates laboratory and pilot plant facilities in Ennigerloh, Germany. The facilities are used for ongoing developments to new processes and for optimising established processes. In conjunction with their colleagues in the central R&D division, a highly qualified team of 30 employees is committed to providing R&D services for our customers. This team includes:

- 12 chemists and chemical engineers
- 10 chemical technicians and mechanics
- 4 administrative staff is committed to providing R&D services for our customers.

Using the latest state-of-the-art equipment, our R&D staff is dedicated to:

- improving Uhde processes
- searching for new processes and process opportunities
- improving analytical methods and preparing analytical instructions and manuals
- providing a wide range of analyses for feedstocks and products
- providing analytical support during the commissioning of our plants

Our process engineers in Dortmund and Bad Soden work closely with the laboratory staff and are able to support operations whenever needed. The laboratory and pilot facilities are certified in accordance with ISO 9001 to ensure consistently high standards.

Analytical facilities

The laboratory consists of 5 working sections:

- laboratory for inorganic chemistry/physical analyses
- gas chromatography
- laboratory for fuel and coal analysis
- laboratory for oil and wax analysis
- test laboratory

The analytical facilities permit standard DIN/ISO or ASTM analyses of virtually any type of fuel and refinery/petrochemical feedstock, as well as a variety of inorganic analytical methods and water analysis methods. Some of the main methods are summarised below.

Gas chromatography

Our laboratory uses gas chromatographs to categorise all types of hydrocarbon feedstocks, products and intermediate products. The samples are separated analytically in capillary, widebore or packed columns of suitable polarity. Standard analytical methods using flame ionisation detectors (FID) and thermal conductivity detectors (TCD), are enhanced by special detection methods which use selective sulphur detectors (S-CLD) or nitrogen detectors (NPD and N-CLD). Additionally, a powerful GC-MSD system enables us not only to identify unknown components in a complex matrix, but also to quantify components of special interest even when present as trace amounts.

Physical and chemical methods

Hydrocarbon components are completely broken down and other properties and impurities are also of interest. We use various analytical methods to analyse these properties and impurities, including elemental analyses (CHNS), chloride content, bromine index/number, acid wash colour, specific gravity, molecular weight, acidity, refraction index and many more. The methods used include:

- UV-Vis spectroscopy
- ion chromatography
- atom absorption spectroscopy
- potentiometry
- coulometry
- viscosimetry (Hoeppler, Ubbelohde, Engler)
- ignition point determination (Abel-Pensky, Pensky-Martens)
- surface tension (DeNouy)

- hydrogen/oxygen combustion
- water determination (Karl Fischer)
- solidification point acc. to ASTM D 852
- boiling range acc. to ASTM D 850 and D 1160
- total sulphur acc. to ASTM D 5453 and D 7183
- total nitrogen acc. to ASTM D 6069 and D 7184

Other analytical methods

In addition to the standard analytical methods mentioned above, our laboratory is able to develop other analytical methods to cater to special customer requirements, or to support troubleshooting in our customers' plants. This means that we can measure:

- thermal stability of chemicals
- corrosion of materials in chemicals
- 2-liquid phase separation abilities
- polymer content in solvents
- foaming tendencies
- chemical stability

Determination of thermo-physical properties

Simulation models must be constantly enhanced using data gained during plant operation or in laboratory tests to ensure the continuous improvement of process simulation and equipment design.

ThyssenKrupp Industrial Solutions has continuously developed and increased its thermo-physical property data banks which are used for process simulation of its separation technologies. Vapour-liquid equilibrium (VLE) or liquid-liquid equilibrium (LLE) data for specific solvent/hydrocarbon systems (used in ED and LLE) is measured in our laboratories, evaluated and linked to our process simulators. Simulation results can later be verified or checked in our pilot



The ThyssenKrupp Industrial Solutions research centre



Research facility with PC-based process control system for process development in the fields of distillation, extraction and extractive distillation

plant facilities under real operating conditions. This procedure allows us to develop tailor-made separation processes for our customers.

Our laboratory includes equipment to:

- determine the VLE data of binary and tertiary systems at temperatures of 20°C-160°C and pressures of 0-40 bar
- determine the LLE data of binary, tertiary, and quaternary systems at temperatures of -40°C to 95°C for 1 bar, and temperatures of 20°C-160°C for pressures ranging from 0-5 bar
- measure crystallisation equilibria
- measure the solubility of gases in liquids
- determine mass transfer coefficients

Pilot Plant Tests

The ThyssenKrupp Industrial Solutions pilot plant tower is a three-storey building situated next to the laboratory. The 3 platforms cover an overall height of 12 m. Larger pilot plant facilities can be erected on various other ThyssenKrupp sites if required.

The pilot plant is completely surrounded by scaffolding made from Mero cuboid structural components (edge length 1 m) and can be accessed every 2 m to permit simple and fast installation of equipment and bulk.

Most modern DCS and instrumentation elements are used for measuring and controlling the pilot plant.

A 2-channel gas chromatograph with FID is used for online liquid analysis. The chromatograph is equipped with 2 completely separated systems of recycle pumps and automatic liquid injectors. Time-controlled processing and analytical operations are performed using a computer.

Separation techniques

A variety of fractionation utilities is available:

- conventional distillation with up to 160 theoretical stages. Modules with an ID of 100 mm, 72 mm, and 50 mm made of stainless steel or glass for laboratory type structured packings (Sulzer DX/EX) and bubble cap trays
- extractive distillation with up to 70 theoretical stages. Modules with an ID of 72 mm in stainless steel equipped with structured packings

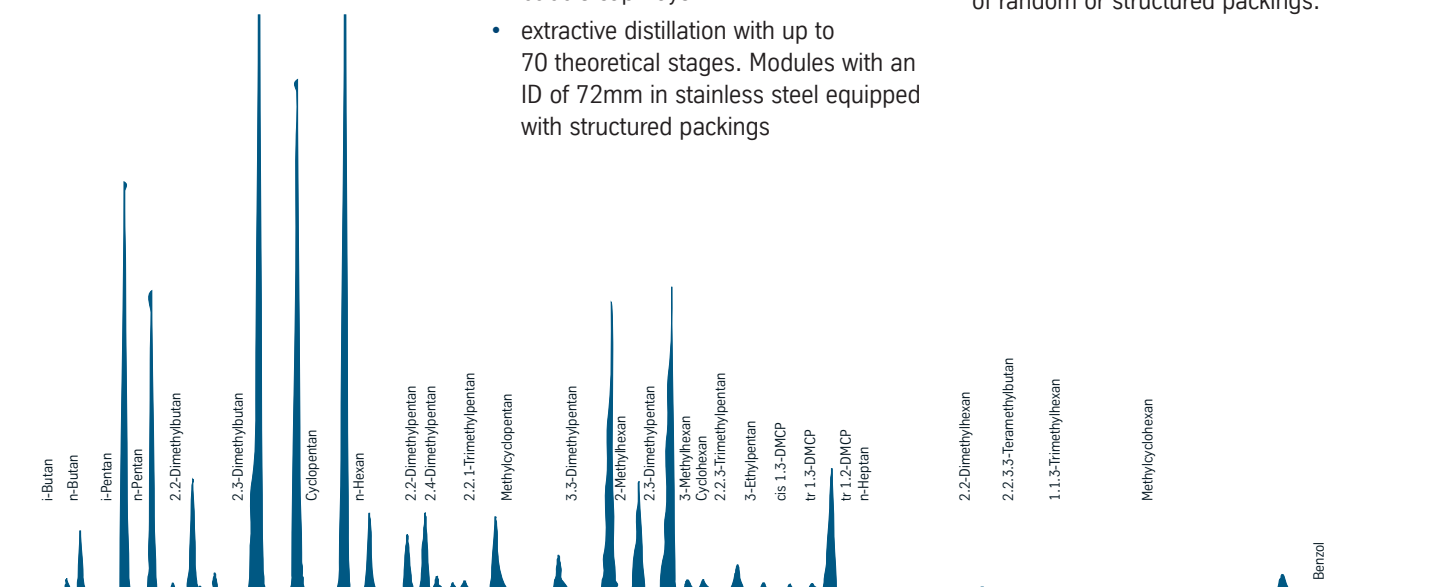
- liquid-liquid extractors with up to 50 theoretical stages. Modules with an ID of 40 mm in glass equipped with structured packings (Sulzer BX)
- divided wall columns with up to 40 theoretical stages in the partition section.

The operating range can be varied from a high vacuum to 6 bar.

Several types of tubular reactors, some of which are jacketed, and agitated autoclaves (CSTR) can be used for catalyst and absorbents testing, and for measuring reaction kinetics. Pressures of up to 200 bar and temperatures of up to 600°C can be applied to test catalytic reactions and catalyst formulations.

Absorption/adsorption techniques

The specially designed equipment in our pilot plant facilities allows us to test or measure static and dynamic absorption equilibria and mass transfer for gas scrubbers. This equipment includes autoclaves, falling-film adsorbers and scrubbers fitted with a variety of random or structured packings.



Services for our customers

ThyssenKrupp Industrial Solutions is dedicated to providing its customers with a wide range of services and to supporting them in their efforts to succeed in their line of business.

With our worldwide network of local organisations and experienced local representatives, as well as first-class backing from our head office, ThyssenKrupp Industrial Solutions has the ideal qualifications to achieve this goal.

We at ThyssenKrupp Industrial Solutions place particular importance on interacting with our customers at an early stage to combine their ambition and expertise with our experience.

Whenever we can, we give potential customers the opportunity to visit operating plants and to personally evaluate such matters as process operability, maintenance and on-stream time. We aim to build our future business on the confidence our customers place in us.

ThyssenKrupp Industrial Solutions provides the entire spectrum of services associated with an EPC contractor, from the initial feasibility study, through financing concepts and project management right up to the commissioning of units and grass-roots plants.

Our impressive portfolio of services includes:

- Feasibility studies/technology selection
- Project management
- Arrangement of financing schemes
- Financial guidance based on an intimate knowledge of local laws, regulations and tax procedures
- Environmental studies
- Licensing incl. basic/detail engineering
- Utilities/offsites/infrastructure

- Procurement/inspection/transportation services
- Civil works and erection
- Commissioning
- Training of operating personnel using operator training simulator
- Plant operation support/plant maintenance
- Remote Performance Management (Teleservice)

ThyssenKrupp Industrial Solutions' policy is to ensure utmost quality in the implementation of its projects. We work worldwide to the same quality standard, certified according to: DIN/ISO 9001/EN29001.

We remain in contact with our customers even after project completion. Partnering is our byword.

By organising and supporting technical symposia, we promote active communication between customers, licensors, partners, operators and our specialists. This enables our customers to benefit from the development of new technologies and the exchange of experience as well as troubleshooting information.

We like to cultivate our business relationships and learn more about the future goals of our customers. Our after-sales services include regular consultancy visits which keep the owner informed about the latest developments or revamping options.

ThyssenKrupp Industrial Solutions stands for tailor-made concepts and international competence. For more information contact one of the ThyssenKrupp Industrial Solutions offices near you or visit our website:

www.thyssenkrupp-industrial-solutions.com

Further information on this subject can be found in the following brochures:

- Oil & Gas
- Polymers



Main references

Just a few of more than 100 reference plants in the last ten years

Completion	Customer Plant Site	Process Plant	Prod. Capacity t/year	Licensors or Know-how
Morphylane® Extractive Distillation				
2014	Refineria Del Pacifico Manabi, Ecuador	Benzene from Reformate	143,000	Uhde
2014	Petrobras S.A. Rio de Janeiro, Brazil	Benzene/Toluene from Reformate	940,000	Uhde
2013	Atyrau Refinery Kazakhstan	Benzene/Toluene from Reformate	289,000	Uhde
2012	Sasol Technology Secunda, South Africa	Benzene from Coal tar naphththa SCC Gasoline	106,000	Uhde
2012	Rabigh Refining and Petrochemical Co. Rabigh, Saudi Arabia	Benzene/Toluene from Reformate	881,000	Uhde
2012	Total Jerp Al-Jubail, Saudi Arabia	Benzene from Reformate	140,000	Uhde
2011	Tianjin Binhai Tiansheng Coal Chemical Co. Tianjin, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	87,300	Uhde
2011	S-Oil Corporation Ulsan, South Korea	Benzene/Toluene from Reformate	680,000	Uhde
2011	Tabriz Oil Refining Co. Tabriz, Iran	Benzene from Reformate	33,600	Uhde
2010	Xingtai Risun Coal&Chemical Company Xingtai, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	88,000	Uhde
2010	Baosteel Chemical Co. Baoshan, China	Benzene/Toluene from Coke Oven Light Oil	80,800	Uhde
2010	Tangshan Risun Chemical Company Tangshan, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	173,000	Uhde
2010	Qatar Petroleum Qatar	Benzene/Toluene from Reformate	762,000	Uhde
2010	Yunnan Dawei Group Co. Ltd. Yunwei, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	89,000	Uhde
2010	Shell Eastern Petroleum Ltd. Singapore	Benzene from Pyrolysis Gasoline	210,000	Uhde
2009	China Steel Chemical Corporation Kaohsiung, Taiwan	Benzene/Toluene from Coke Oven Light Oil	27,000	Uhde
2009	Wuhan Iron and Steel Co. Ltd. Wuhan, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	94,000	Uhde
2009	Xingtai Risun Coal & Chemical Company Xingtai, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	88,000	Uhde
2009	GCW Anshan I&S Group Co. Anshan, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	128,000	Uhde
2009	Oman Oil Company Sohar, Oman	Benzene/Toluene from Reformate	350,000	Uhde
2008	Jiantao Chemical Co. Ltd. Hebei, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	45,000	Uhde
2008	Yunnan Kungang IT Co. Ltd. Kunming, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	44,000	Uhde
2007	Shanxi Sanwei Group Co. Ltd. Zhahocheng, China	Benzene/Toluene/Xylenes from Coke Oven Light Oil	178,000	Uhde
2007	Sasol Secunda, South Africa	Benzene from Pyrolysis Gasoline	100,000	Uhde
2007	Hood Oil Sanaa, Yemen	Benzene from Reformate	110,000	Uhde
2007	Japan Energy Co. Kashima, Japan	Benzene/Toluene from Reformate	310,000	Uhde

Completion	Customer Plant Site	Process Plant	Feed Capacity t/year	Licensors or Know-how
Reformate Hydrogenation				
2002	Shell Nederland Chemie B.V. Moerdijk, Netherlands	Selective Hydrogenation	850,000	Axens
2000	Tonen Corporation Kawasaki, Japan	Selective Hydrogenation	320,000	BASF
2000	Saudi Chevron Petrochemical Al Jubail, Saudi Arabia	Selective Hydrogenation	860,000	BASF
Pyrolysis Gasoline Hydrogenation				
2010	Shell Eastern Petroleum Ltd. Singapore	First and Second Stage Hydrogenation	733,000	Axens
2005	CNOOC / Shell Petrochemicals Co. Ltd. Huizhou, China	Hydrogenation	800,000	Axens
2005	BASF / Yangzi Petrochemical Co. Nanjing, China	Hydrogenation of Pyrolysis Gasoline	600,000	BASF
2004	Bouali Sina Petrochemical Co. Bandar Imam, Iran	First Stage Hydrogenation Second Stage Hydrogenation	139,000 106,000	Axens
2001	BASF/FINA Port Arthur, Texas, USA	First Stage Hydrogenation Second Stage Hydrogenation	795,000 563,000	BASF
Coke Oven Light Oil Hydrotreating				
2010	Xingtai Risun Coal&Chemical Company Xingtai, China	Hydrotreating	100,000	Uhde/BASF
2010	Baosteel Chemical Co. Baoshan, China	Hydrotreating	100,000	Uhde/BASF
2010	Tangshan Risun Chemical Co. Tangshan, China	Hydrotreating	200,000	Uhde/BASF
2009	Yunnan Dawei Group Co. Ltd. Yunwei, China	Hydrotreating	100,000	Uhde/BASF
2009	Wuhan Iron and Steel Co. Ltd. Wuhan, China	Hydrotreating	100,000	Uhde/BASF
2009	Xingtai Risun Coal & Chemical Co. Xingtai, China	Hydrotreating	100,000	Uhde/BASF
2009	GCW Anshan I&S Group Co. Anshan, China	Hydrotreating	150,000	Uhde/BASF
2008	Jiantao Chemical Co. Ltd. Hebei, China	Hydrotreating	50,000	Uhde/BASF
2008	Yunnan Kungang IT Co. Ltd. Kunming, China	Hydrotreating	50,000	Uhde/BASF
2007	Shanxi Sanwei Group co. Ltd. Zhahocheng, China	Hydrotreating	200,000	Uhde/BASF
Divided Wall Column Distillation and Single-Column Morphylane®				
2000	Saudi Chevron Petrochemical Al Jubail, Saudi Arabia	Divided Wall Column Distillation	140,000	BASF/Uhde
1999	VEBA OEL AG Münchsmünster, Germany	Divided Wall Column Distillation	170,000	BASF/Uhde
2004	Aral Aromatics GmbH Gelsenkirchen, Germany	Single-Column Morphylane® Toluene from Coke Oven Light Oil	28,000	Uhde
Isomerisation, Transalkylation, Adsorption				
2004	Bouali Sina Petrochemical Co. Bandar Imam, Iran	p-Xylene Adsorption	428,000	Axens
2004	Bouali Sina Petrochemical Co. Bandar Imam, Iran	Xylenes Isomerisation	1 970,000	Axens
2004	Bouali Sina Petrochemical Co. Bandar Imam, Iran	Transalkylation	883,000	Sinopec

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