

**We create
chemistry
that makes natural gas
love solutions.**



BASF Solutions for Natural Gas Treatment

 **BASF**
The Chemical Company



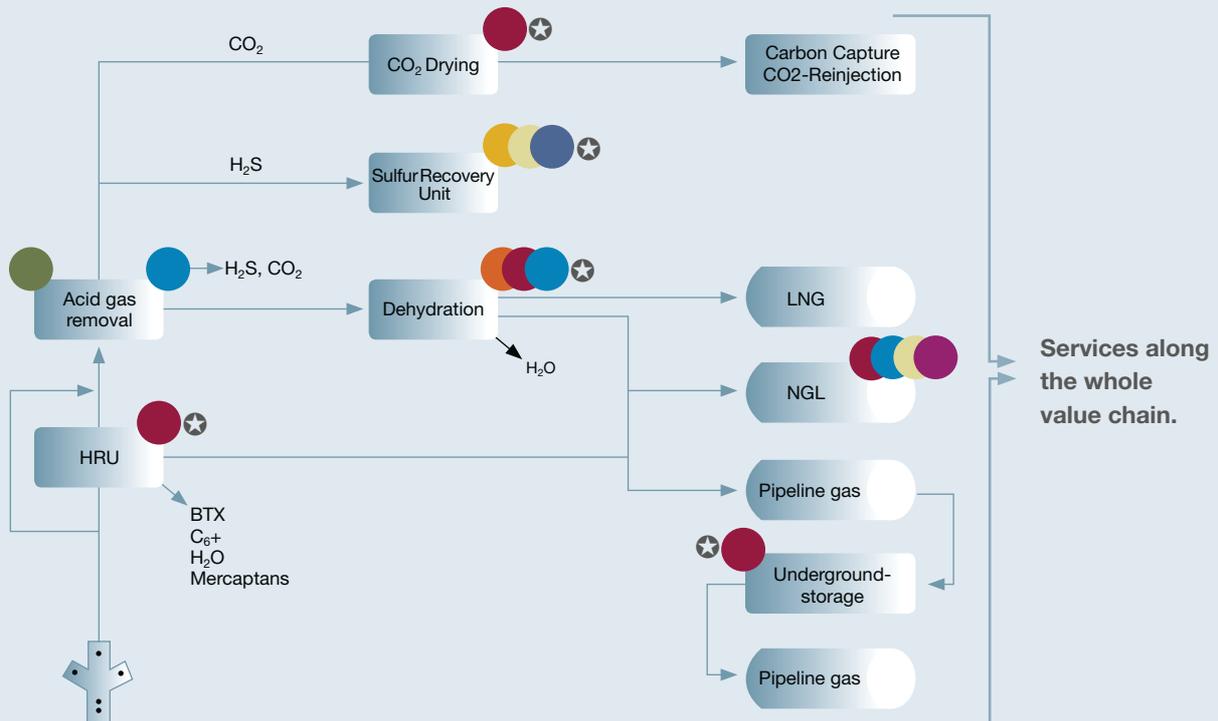
BASF SOLUTIONS FOR NATURAL GAS TREATMENT

Introduction

Natural Gas Treatment is a complex process, as shown in the process flow chart. BASF offers a broad range of technical solutions based on the appropriate absorbent (solvent), adsorbent, and catalyst. Moreover, BASF supports its customers in the design and operation of gas treatment plants by providing process design and

engineering support and a range of technical services such as debottlenecking and process optimization, troubleshooting and revamps, analytics, and training. In addition to traditional applications in natural gas purification, BASF has the expertise to support developing applications such as shale gas, coalbed methane, biogas, and floating LNG.

BASF Products for Natural Gas Treatment



Natural Gas Reservoir
 - Conventional Gas
 - Sour Gas
 - Associated Gas
 - Shale Gas
 - Coalbed methane
 - Biogas

- Sorbead®
- BASF Molecular Sieve
- Alumina Claus Catalyst
- Selexsorb®
- PuriStar®
- CoMo Tail Gas Catalyst
- ★ BASF Guard Bed materials
- OASE®
- Glycols

HRU: Hydrocarbon Removal Unit
 OASE®: Gas Treating Excellence

Technology and Products Portfolio for Natural Gas Treatment

Process/Application	Contaminants	Product/Technology
Acid Gas Removal (Sweetening)	H ₂ S, CO ₂ (bulk), COS H ₂ S, CO ₂ (trace)	OASE [®] yellow; OASE [®] purple BASF Molecular Sieves
Sulfur Recovery	H ₂ S, COS, CS ₂	BASF Claus & Tail Gas Catalysts
CO₂ Drying (Enhanced Oil Recovery / CO ₂ Capture & Storage)	H ₂ O	Sorbead [®] Dehy
Hydrocarbon Dewpointing	C6+ (H ₂ O simultaneous)	Sorbead [®] HRU
Mercaptans Removal	RSH	Sorbead [®] HRU BASF Molecular Sieves
BTX Removal	Benzene, Toluene, Xylene	Sorbead [®] HRU
Membrane Protection	C6+, BTX, H ₂ O	Sorbead [®] HRU/Dehy
Water Dewpointing > Sales Gas/Pipeline Gas > LNG Pretreatment	H ₂ O (-10°C...-60°C dewpoint) (-110°C dewpoint)	Sorbead [®] Dehy BASF Molecular Sieves
LNG Pretreatment (Export Terminal, Floating LNG, LNG Micro-Plant)	H ₂ O, CO ₂ , COS, H ₂ S, mercaptans, BTX	OASE [®] purple, Sorbead [®] HRU BASF Molecular Sieves
NGL Drying (liquid)	H ₂ O	Sorbead [®] Dehy
NGL/LPG Purification	Various contaminants	PuriStar [®] , Selexsorb [®]
Underground Storage (UGS)	H ₂ O Hydrocarbons (H ₂ O simultaneous)	Sorbead [®] Dehy Sorbead [®] HRU
Coal Bed Methane (CBM) Drying	H ₂ O, CO ₂	Sorbead [®] Dehy, OASE [®] purple BASF Molecular Sieves
Guard Bed for adsorbents & catalysts		Sorbead [®] , BASF Activated Alumina

OASE[®]: Gas Treating Excellence

Sorbead[®]: alumino-silica gel adsorbent

Sorbead[®] Dehy: Sorbead technology for natural gas dehydration (adsorption)

Sorbead[®] HRU: Sorbead technology for heavy hydrocarbons removal /recovery (adsorption),

BASF Molecular Sieve technologies for removal of H₂O, CO₂, H₂S, mercaptans (adsorption)

PuriStar[®]: metal oxide-based adsorbents

Selexsorb[®]: activated alumina adsorbents

LNG: Liquefied Natural Gas

NGL: Natural Gas Liquids (propane, butane, C5+)

LPG: Liquefied Petroleum Gas (butane, propane)

RSH: Mercaptans

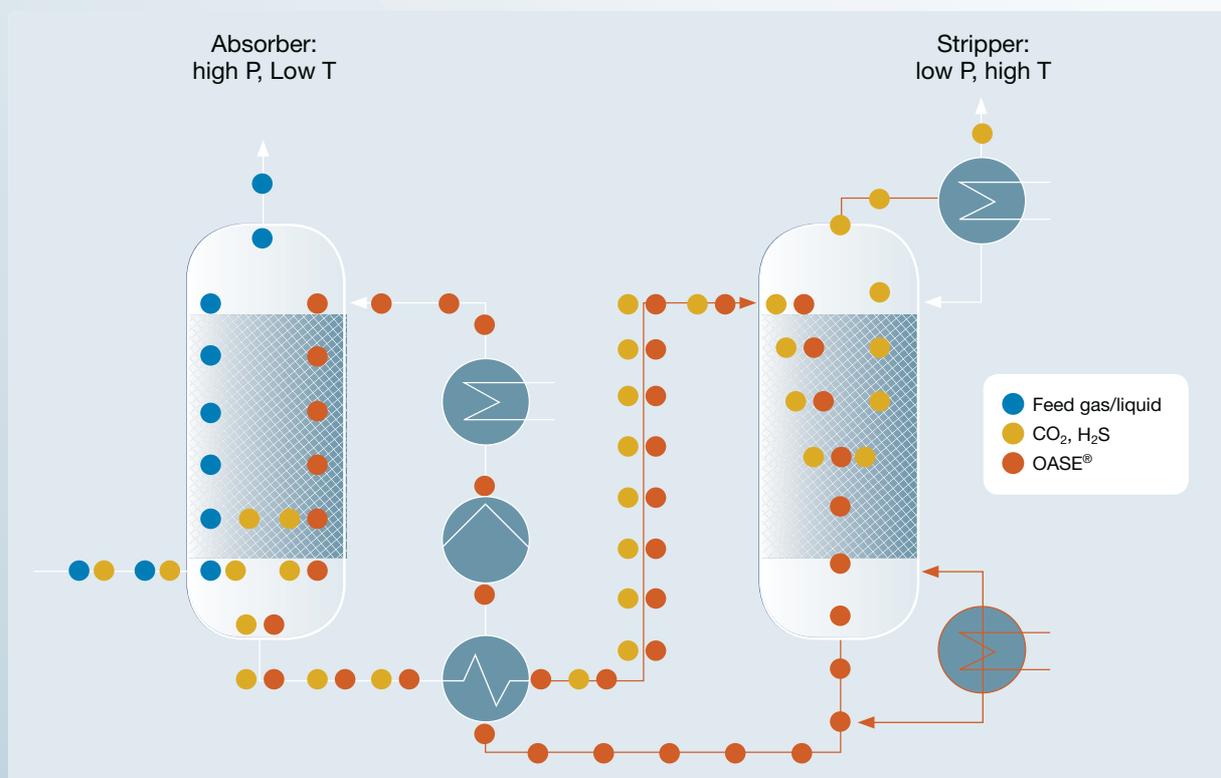
BTX: Benzene, Toluene, Xylene

Acid Gas Removal (Sweetening)

Utilized in the removal of high concentrations of acid gases such as carbon dioxide (CO₂), hydrogen sulfide (H₂S) and carbonyl sulfide (COS) OASE[®] technologies have proven their versatility and reliability in natural gas applications. BASF's solutions portfolio ranges from selective removal of sulfur components for sales gas (OASE[®] yellow) to deep removal of acid gases for LNG applications (OASE[®] purple). Our customers appreciate this highly efficient and environmentally friendly technology for its flexibility and low capital expenditure (CAPEX).

Additionally, the low energy demand of the process combined with the non-corrosive nature of the solvent keeps operating and maintenance costs (OPEX) low. The process also provides a high level of gas purity and product gas recovery while keeping solvent losses to a minimum.

For the removal of trace amounts of H₂S and CO₂ BASF offers a range of Molecular Sieve adsorbents (i.e. 5A and 13X inclusive COS formation minimizing grades) that are employed in fixed bed adsorbents which are thermally regenerated.



The chemical absorption of acid gases: the highly efficient process provides a high level of gas purity and product gas recovery while keeping solvent losses to a minimum. Under the OASE brand, BASF provides customized, high-performance gas treatment technologies.

Sulfur Recovery

Sulfur Recovery Units (SRU) convert unwanted hydrogen sulfide (H₂S) and sulfur dioxide (SO₂) to the desired element, sulfur. This is done most often using the Claus process.

SRUs are essential parts of natural gas plants, refineries and smelters, where large amounts of H₂S are produced. The quality of the Claus Catalyst is critical for maximizing the performance of the SRU.

BASF has the most extensive line of Claus Catalysts in the industry. In addition to non-promoted and promoted activated alumina, we offer two different titania catalysts along with an alumina/titania composite catalyst. Our product portfolio is completed by CoMo catalysts for SRU Tail Gas Treatment Unit (TGTU) applications.





CO₂ Drying (Enhanced Oil Recovery /CO₂ Capture and Storage)

In order to reduce atmospheric emission of CO₂ after being captured by acid gas removal technologies, CO₂ can be re-injected for enhanced oil recovery or permanently stored in suitable underground reservoirs. For these applications it is required to compress CO₂ to very high pressures.

Before CO₂ is transported to the final destinations it needs to be dried in order to protect pipelines and other equipment from liquid water and corrosion. Since CO₂ and water form carbonic acid, Sorbead adsorbents are particularly suited due to their high acid resistance. A most energy efficient and reliable drying process is designed by employing Sorbead Dehy technology (see also page 10).

Hydrocarbon Dewpointing

Natural gas streams contain species of heavy hydrocarbons that may condense on pressure or temperature decrease. These heavy hydrocarbons can cause plugging of downstream valves and pipes or lead to potential mal-performance of other equipment (e.g. membranes).

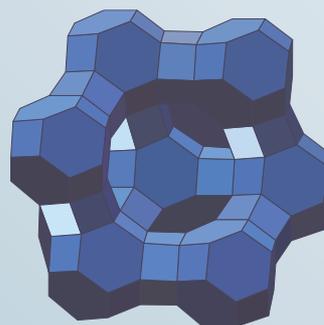
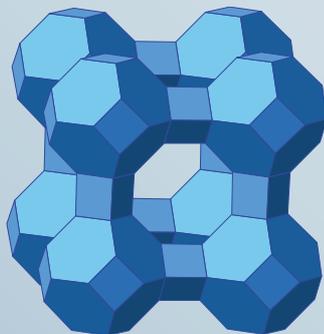
The temperature at which condensation of hydrocarbons occur is called the hydrocarbon dewpoint. Sorbead HRU (see also page 11) technology prevents hydrocarbon

condensation and offers other advantages such as simultaneous water dewpointing, minimal differential pressure and high operational flexibility (wide range of dewpoint temperatures and feed gas flows). Removed hydrocarbons end up in the recycle condensate for further use as fuel or downstream operations (petrochemical, refining).

Mercaptans Removal

Mercaptans are undesired components of natural gas. Mercaptans cause odour and can pose operational challenges for acid gas removal, sulfur removal, and LNG units. Sorbead HRU technology removes mercaptans together with water and heavy hydrocarbons.

BASF Molecular Sieve technology selectively removes mercaptans based on 5A and 13X. Before recycling to the feed, the mercaptans enriched regeneration gas is typically further treated in a solvent based purification process.



Characteristic cavity structure of zeolite A (left) and zeolite X (right)



BTX Removal

Benzene, Toluene and Xylenes (BTX) can be present in natural gas and can lead to operational challenges if not removed early in the process of a gas treatment plant. For example, BTX can cause significantly reduced lifetime of the Claus catalysts in sulfur recovery plants. In LNG production BTX needs to be removed to prevent freezing

in the cryogenic part of the process. Sorbead HRU technology can be tailored to remove BTX upstream in gas treatment processes. Sorbead H adsorbent removes BTX along with other heavy hydrocarbons and water resulting in BTX rich condensate.

Membrane Protection

Some sour natural gas streams contain CO₂ at levels that make the combination of membrane technology and subsequent solvent-based gas treatment economic (hybrid system). Membranes are sensitive to condensed

hydrocarbons and BTX on the cold surfaces of the membrane. Sorbead HRU technology removes BTX and adjusts hydrocarbon & water dewpoint to the required level leading to extended life of the membrane system.

Water Dewpointing (Sales Gas/Pipeline Gas, LNG Pretreatment)

Water in natural gas can form hydrates which can result in blockage of pipes and valves. In LNG production even smallest amounts of water will freeze out in the cold section of the plant. Sorbead Dehy technology reliably and environmentally friendly provides water dewpoints over a broad range down to -60 °C at operating pressure.

For very deep dewpoints down to -110 °C BASF Molecular Sieve technology based on 3A or 4A is employed. Sorbead R and Molecular Sieve could be employed in a combined adsorbent bed in order to take advantage of the higher water uptake capacity and lower required desorption energy of Sorbead leading to reduced OPEX.

LNG Pretreatment (Export Terminal, Floating LNG, LNG Micro-Plant)

Supply of natural gas in form of Liquefied Natural Gas (LNG) has become an important way to transport gas to the point of demand. LNG is produced by cooling natural gas to less than minus 160°C. In order to meet LNG product specification and ensure trouble-free operation of the cold section of the plant a number of common natural gas contaminants need to be removed upstream. BASF offers a broad range of products and technologies to remove the most dominant impurities. OASE® purple technology removes CO₂, H₂S and COS, Sorbead HRU technology purifies the gas from H₂O, heavy hydrocarbons, mercaptans and BTX and BASF Molecular Sieve technology addresses the removal of water and mercaptans and also trace quantities of CO₂ and H₂S.

All technologies can be designed for operation on tilting or rolling surfaces and are therefore suitable for offshore and floating applications.



NGL Drying

Liquid hydrocarbons or Natural Gas Liquids (NGL) such as propane, butane, benzene and xylene can be effectively dried by employing Sorbead Dehy technology. Typically Sorbead R with a guard layer of Sorbead WS upstream is

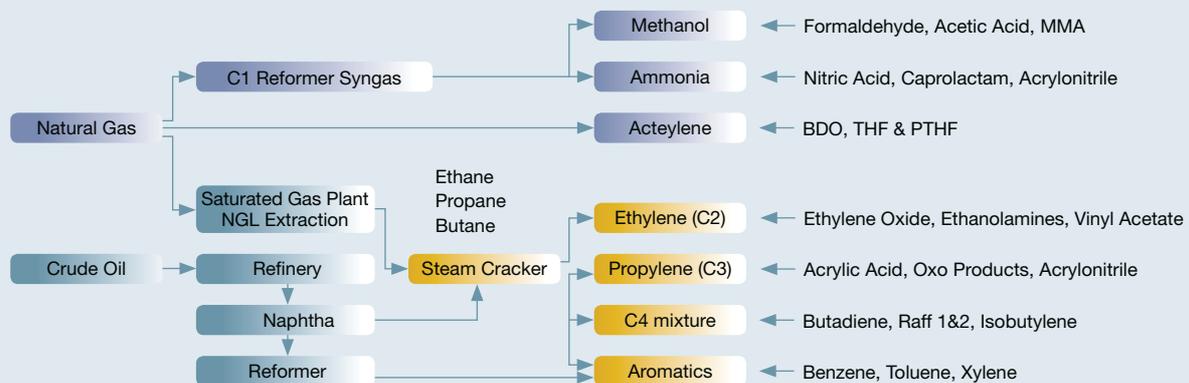
used achieving residual water contents in the range of 10 to 20 ppm. Under very favorable conditions water contents of a few ppm can be attained.

NGL/LPG Purification

BASF offers a wide range of Cu based products (sold under the trade name PuriStar®) and alumina based materials (sold under the trade name Selexsorb®) which are used widely in industry as guard beds for petrochemical units or in industrial gas applications. These materials are either used in sacrificial mode to achieve very low

concentrations of contaminants (like COS or AsH₃) or in regenerative mode to achieve a bit higher concentrations of contaminants. BASF has wide experience on how best to combine these and other products from our portfolio and state-of-the-art tools to design these units to provide our customers the most economical solutions.

Petrochemical Value Chains



Underground Storage (UGS)

Underground storage facilities use salt caverns and partially depleted oil or gas fields. They provide a balance between the supply of natural gas by the producer and the demand pattern by the final customer. While natural gas is stored underground it picks up water and/or heavy hydrocarbons which needs to be removed to meet transmission specification. Sorbead Dehy and Sorbead HRU

technologies provide ideal solutions for water and hydrocarbon dewpointing respectively since both technologies are suited for intermittent operation, very rapid response times and load-following characteristics and require minimal maintenance and can be operated remotely.

Coal Bed Methane (CBM) Drying

Natural gas recovered from coal beds is near pipeline specification but needs to be compressed and dried before injection into the pipeline. Sorbead Dehy technology is suited to achieve required water dewpoints. Water is

removed as liquid from the system. In case gas engines are used for compression, the waste heat can be partly used for the regeneration of Sorbead thus reducing system OPEX.

Guard Bed for Adsorbents and catalysts

Most adsorbents and catalysts that are tailored to the main duty of the purification task are sensitive to carry-over of liquids that are not fully separated by knock-out devices upstream the adsorption or catalyst unit. Sorbead WS is the only liquid water-stable, high moisture capacity alumino-silica gel and therefore particularly suited as guard bed for all Sorbead and BASF Molecular Sieve

technologies. In fact, Sorbead WS contributes to reducing the water load significantly resulting in improved margins for the subsequent adsorbent bed. Furthermore Sorbead WS is highly acid-resistant and therefore the preferred guard bed or adsorbent for sour gas treatment. In special cases of operational problems by liquid carry-overs BASF can provide a number of tailored guard bed solutions.

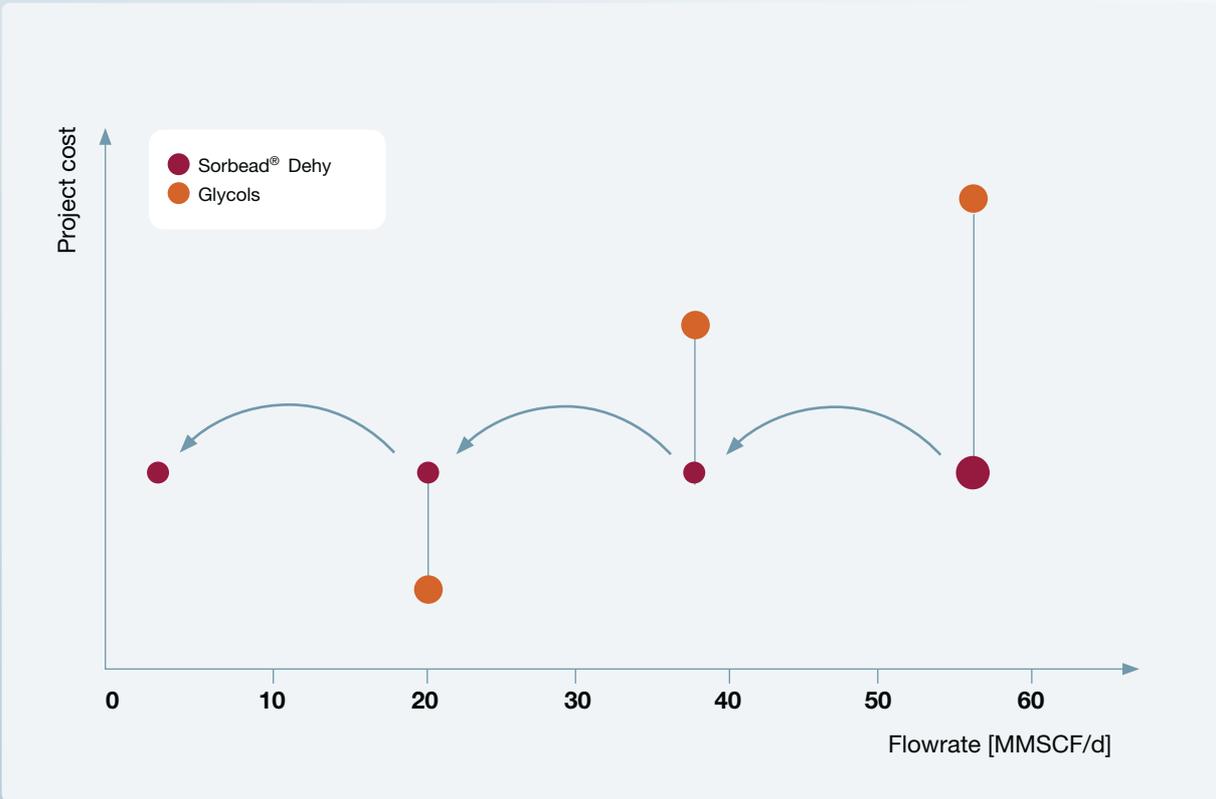


PROCESS DESCRIPTION FOR SORBEAD DEHY AND SORBEAD HRU

Sorbead[®] Dehy

Sorbead Dehy technology for dehydration of natural gas and other gases and liquids is based on Sorbead R's unique properties as an aluminosilica gel adsorbent. Advantages include high water adsorption capacity, low water desorption energy and high mechanical strength resulting in low energy demand and extended service life (low OPEX).

Typically Sorbead Dehy is composed of a twin-tower adsorber design for continuous operation that, compared to other natural gas dehydration processes, offers advantages such as high operational flexibility (e.g. wide dew-point and flow range at minimal pressure drop, intermittent operation), low maintenance (no rotating equipment), ease of operation including the possibility of remote operation, and zero-emissions of volatile drying agent.



Sorbead Dehy can be operated in a broad operational window at competitive cost compared to solvent-based technologies that need to be designed to a specific flow rate.

Sorbead[®] HRU

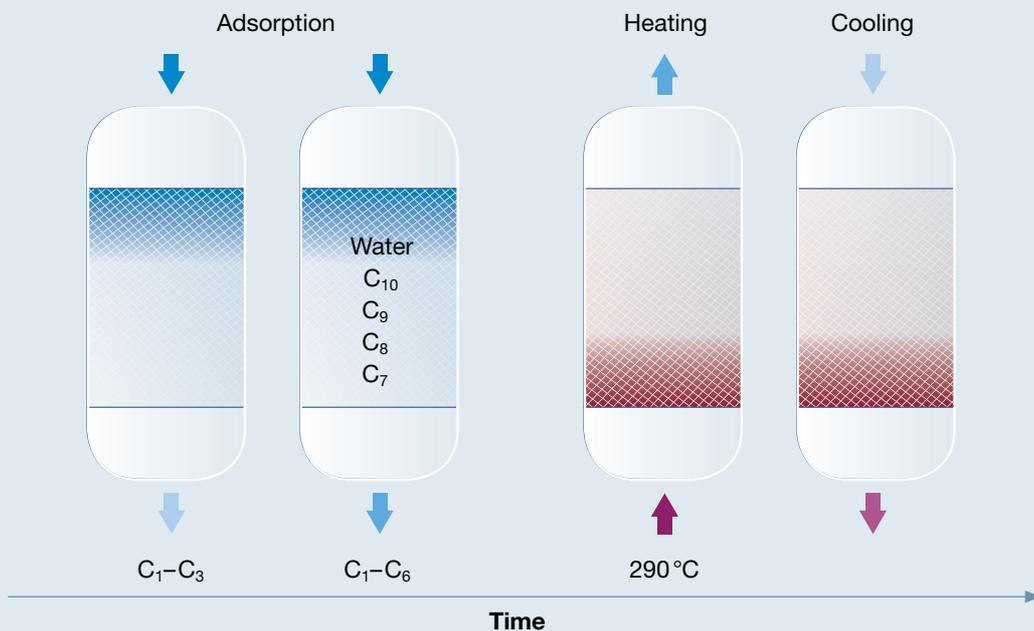
Sorbead Hydrocarbon Recovery Unit (HRU) technology for the simultaneous removal of hydrocarbons and water from natural gas is based on the unique properties of Sorbead H. Sorbead H is a specialty alumino-silica gel adsorbent with a pore structure tailored to the adsorption of hydrocarbons such as C5+, BTX and mercaptans.

The technology is adjusted such (cycle time) that the desired contaminant is preferably removed. The principle of operation is shown in the image for a 3-adsorption tower design (other arrangements are also possible).

While one tower is in adsorption mode, two towers are being regenerated which involves a first step of heating

followed by a cooling step. Feed gas is commonly used as regeneration gas which is then recycled to the tower in adsorption. During cooling of the previously heated tower the gas takes up heat therefore reducing the energy required for heating a portion of the feed gas for regeneration. Contaminants are removed as liquid phase from the system during cooling via a condenser while the gas phase is recycled to the feed side of the adsorption unit. The technology offers the same advantages over competing technologies as described for Sorbead Dehy. In addition, Sorbead HRU technology provides significant CAPEX savings compared to low temperature technologies that require hydrate inhibition or dehydration.

Stages of Adsorption and Regeneration



Americas

BASF Corporation
25 Middlesex/Essex Turnpike
Iselin, NJ 08830, USA
Tel: +1-732-205-5000
Fax: +1-732-205-5687
Email: catalysts-america@basf.com

Asia Pacific

BASF East Asia Regional HQ Ltd.
45th Floor, Jardine House
No. 1 Connaught Place
Central, Hong Kong
Tel: +852-2731-0191
Fax: +852-2731-5634
Email: catalysts-asia@basf.com

Europe, Middle East, Africa

Customer Service
BASF Nederland B.V.
Tel: +31-30-6669555
Fax: +31-30-6669340
Email: catalysts-europe@basf.com

About Us

BASF's Catalysts division is the world's leading supplier of environmental and process catalysts. The group offers exceptional expertise in the development of technologies that protect the air we breathe, produce the fuels that power our world and ensure efficient production of a wide variety of chemicals, plastics and other products, including advanced battery materials. By leveraging our industry-leading R&D platforms, passion for innovation and deep knowledge of precious and base metals, BASF's Catalysts division develops unique, proprietary solutions that drive customer success.

BASF – The Chemical Company

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