

# **PRACTICAL CONSIDERATIONS FOR THE DESIGN OF ADSORBENT BEDS – MOLECULAR SIEVE LIFETIME OPTIMIZATION**

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## **ABSTRACT**

Oil & Gas facilities have to achieve outstanding reliability in their various processes in order to be cost effective and honor their commitments. An unplanned shutdown is a loss of millions of dollars. Adsorbent beds are commonly used in refineries, petrochemical and gas plants, to dry and purify various streams. They face the same logic and in practice, have to perform during a set lifetime without a hitch and, sometimes, even while bearing slightly different operating conditions than design. Taking the example of natural gas drying with molecular sieves, the dehydration unit is typically designed by the molecular sieve manufacturer. This does not only involve choosing the right adsorbent(s), but also designing the adsorption and regeneration procedures so that the beds will be immediately efficient and resistant at once. Upstream of the dehydration unit is raw gas that goes through a series of purifications and treatments. Before entering the molecular sieve towers, it has to be free of liquids. To do this, specialized filtration and separation companies design and implement dedicated equipment that mechanically separate liquid droplets from the gaseous stream. Prepared jointly by CECA SA and Pall Corporation, two leading companies in their respective fields, this paper describes the main contaminants, threats and constraints that are likely to damage a dehydration unit in case of a poor design leading to the presence of liquids. It explains how experienced suppliers anticipate the risks as they design the unit and its surroundings to ensure optimal performance that goes beyond the EPC and owner expectations.

*Keywords:* molecular sieve, adsorbent, liquid carry-over, hydrothermal damaging, coalescer, regeneration procedure

## **INTRODUCTION**

Oil & Gas facilities have to achieve outstanding reliability in their various processes in order to be cost effective and honor their commitments. In that regard, the vast majority of plants around the world operates in a satisfactory manner, although there is always room to improve processes, and eventually to minimize OpEx and to maximize profitability.

Adsorbent beds are commonly used in refineries, petrochemical and gas plants to dry and to purify

various streams. In the more critical processes that include a cryogenic section, such as NGL recovery plants and LNG production plants, the gas is dehydrated down to typically, less than 1 ppmV water: a very low specification that only molecular sieves can achieve.

The dehydration unit is typically designed by the molecular sieve manufacturer. Upstream of the dehydration unit, the raw gas goes through a series of purifications and treatments. Before entering the molecular sieve beds, it has to be

free of liquids. To do this, a dedicated technology is implemented to mechanically separate the fine liquid droplets from the gas stream.

The efficiency and the lifetime of a molecular sieve dehydration unit can be enhanced by paying more attention to the design of the unit itself and of its surroundings. Field experience greatly helps analyze a process specification to anticipate the risks.

This paper focuses on the potential operation issues related to the presence of liquids in the adsorbent beds, whether these liquids are carried over from the upstream liquid/gas separator, or are due to inappropriate regeneration procedures. It does not explicitly deal with chemical contaminants in the gas phase (oxygen, acids, etc.), which were described in a previous paper by CECA<sup>[1]</sup>.

A two-step approach is implemented. First the liquid/gas separation unit upstream of the driers has to be designed and specified correctly to minimize liquid carry-over. Second, the molecular sieve dehydration unit itself has to incorporate the right type of adsorbent(s) as well as the regeneration procedures to make beds efficient and resistant at once and in the long run.

### BASICS OF INDUSTRIAL ADSORPTION

Molecular sieves are alumino-silicate adsorbents made from a porous material in powder called zeolite that can be shaped into beads and pellets of a few millimeters thanks to binding clays. This material shows a crystal structure with channels and pores, and a wide electronically active surface area. Thanks to these characteristics, zeolites have the ability to selectively capture and retain (“adsorb”) polar molecules that are small enough to enter their pores. The lower the temperature, the higher the adsorption capacity. Reciprocally, when the temperature is increased, the molecules are desorbed. It is therefore possible to use zeolites to selectively sift impurities from a fluid until they are saturated, and then to desorb these impurities to recover fresh adsorbent. These two steps are referred to as “Adsorption” and “Regeneration”. Different zeolites can be used depending on the application. This paper will focus on natural gas drying for which, typically,

“4A” type zeolites are used (zeolites that show a pore opening of approximately 4 angstroms). Molecular sieves are loaded in vertical adsorbers. The gas to be dried goes through the adsorbers, and water is captured along the way. Within a few hours (12 to 36 hours depending on the size of the adsorption unit), a given bed is saturated with water and it has to be regenerated. Therefore, at least two beds have to be used: one in the adsorption phase, while the other is being regenerated. In order to accommodate high flow-rates and acceptable diameters, several adsorbers are often used in parallel with a time lag during which they are alternatively regenerated (Figure 1).

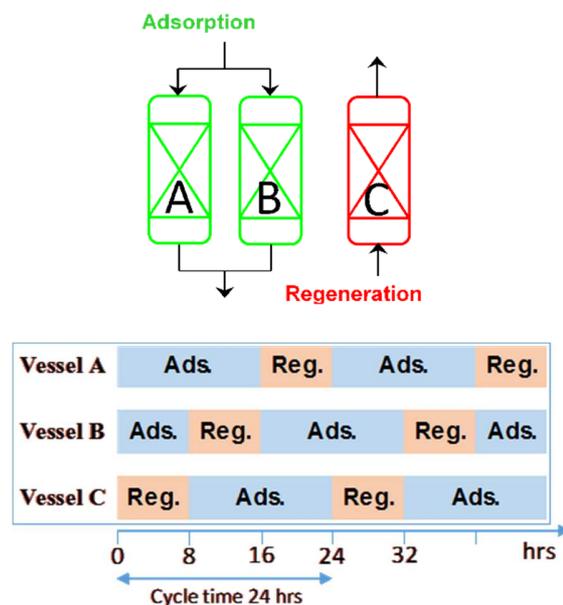


Figure 1: Example of a “2+1” system with 16 hours adsorption time and 8 hours regeneration.

Molecular sieves are efficient and robust materials. Aside from proportional sizing of vessels, and ensuring hydrodynamic constraints are accounted for, there are however two key pitfalls to be avoided in order to perform in an optimized manner. Both relate to the presence of liquids.

- The incoming gas must be free of liquids which can strongly react with the structure of the molecular sieve or foul the porosity

- The formation of liquids in the regeneration process should be avoided. The most suitable and gentle regeneration procedure has to be implemented. Moderation of the process yields the best result

Figure 2 is a schematic view of a typical line up showing the two units discussed in the next chapters:

- The liquid/gas separation unit that prevents liquids to be carried over onto the molecular sieves.
- The adsorption unit itself which has to be efficiently and gently regenerated.

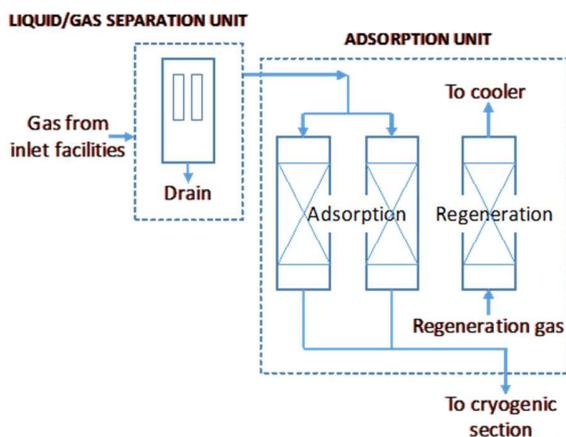


Figure 2: Typical line up showing the liquid/gas separation and the adsorption units.

The inlet gas entering the liquid/gas separation unit may have several origins (raw gas, Acid Gas Removal Unit, physical solvent, heat exchanger, caustic soda washing, etc.), and therefore contains liquid droplets of different nature (water, hydrocarbons, caustic soda, amine, etc.). As regards regeneration, it can be achieved by the dry gas itself, or by another gas, preferentially clean and dry (fuel gas, boil off gas, etc.)

Preventing liquid ingress and managing gentle regeneration are two important issues that are well known to plant Operators and EPC companies in charge of new projects. However, to avoid any trouble in real operation, they must be addressed very carefully during the design phase. Best Practices can be discussed and

implemented with the help of experienced filtration technology suppliers and adsorbent manufacturers.

### TYPICAL OPERATION ISSUES

For a given lifetime, a good design of the dehydration unit guarantees a specified dew point during a given adsorption time, and a maximum pressure drop. However, these are affected by the presence of liquids. The main consequences of poor operation are premature water breakthrough, and fast pressure drop increase. Ultimately these may significantly affect the lifetime of the dryer and would require a change out of the product, earlier than designed.

#### Premature breakthrough:

Premature breakthrough happens when the adsorbent becomes unable to meet the water specification before the end of the designed adsorption time. Provided the gas flow-rate and inlet water content are as per design, reasons for premature breakthrough are often due to a premature loss of adsorption capacity of the molecular sieve. This can result from:

- Severe coking: this is due to the presence of liquid hydrocarbons that build-up in the adsorbent's pores and are too heavy to be vaporized and removed during regeneration. They ultimately form heavy carbonaceous deposits that build up in the porosity<sup>[2]</sup>. In normal operation coke shouldn't be a problem in natural gas treatment. However, under certain circumstances like hydrocarbon carry-over from upstream, coking can be severe, and molecules like aromatics or heavy aliphatic compounds (> C<sub>10</sub>) have been identified in past cases.
- Destruction of the adsorbent: this can come as a result of chemical attacks by aggressive species carried over. In severe cases, not only the clay binder is destroyed, but the crystal structure itself can suffer and be slowly altered and turned to powder, thus reducing the quantity of active material. In other cases liquid reflux at high temperature (detailed below) can destroy and

agglomerate large parts of the beds, especially around the vessels walls.

- Channeling (preferential path): this occurs when the flow is not well distributed on the cross section of the bed. If this happens during adsorption, the adsorbent is not evenly used and the global capacity is reduced due to “dead volumes”. If it happens during the regeneration phase, the product is not well regenerated, and some areas in the bed still show high residual water when switching back to adsorption. In both cases premature breakthrough is likely expected. Channeling can have several mechanical causes (poor loading, support grid failure, low flow-rate, etc.) and operational causes. In the present case, the focus is made on the consequences of liquid carry-over and how an inappropriate regeneration can damage the product and result in a non-homogeneous adsorbent bed.

#### **Fast pressure drop increase:**

In natural gas dehydrators, typical pressure drop ranges from 0.2 to 0.5 bar, or 2.9 to 7.2 psi, SOR (Start Of Run: beginning of lifetime). As the number of cycles increase, it is normal that pressure drop slowly increases (“normal” fouling due to hydrocarbons deposit, light dusting due to thermal stress and attrition). The normal evolution of the pressure drop is accounted for the theoretical acceptable pressure drop EOR (End Of Run). But in serious cases, coking, liquid reflux and heavy dusting can lead to a dramatic increase of the bed resistance. Channeling and high pressure drop often occur together as different symptoms for the same causes.

Sometimes pressure drop rises so high that it is no longer possible to process the normal flow-rate, and the adsorbent has to be replaced (if premature breakthrough does not happen first).

Liquids are one possible root cause of the above mentioned operation issues; all of which do affect the adsorbent lifetime. The origins and the effects of these liquids are described in more details below.

## **POSSIBLE ROOT CAUSES AND PRACTICAL SOLUTIONS**

The main causes related to the presence of liquids, that are discussed in this paper are:

- 1/ Liquid carry-over from the upstream unit
- 2/ Retrograde condensation of hydrocarbons
- 3/ Hydrothermal damaging during regeneration

They are described in more details below, as well as practical solutions to prevent these problems.

### **1/ Liquid carry-over**

#### **Nature of liquids**

Water: In natural gas treatment, liquid water is generally carried over onto the molecular sieve bed because the upstream liquid/gas separator experiences upset operating conditions, or it is undersized, or it is not efficient enough. More water has to be handled by the molecular sieves, which has an impact on the adsorption time, possibly leading to premature breakthrough. Besides, water droplets strongly react with molecular sieves, both physically (heat release) and mechanically (hammering the structure). This results in clay binder damage and powdering. Sometimes dusting becomes significant, leading to pressure drop increase, channeling, and premature breakthrough.

Amine and Caustic: Amine- and caustic-based treating processes are widely used to remove “acid gases” (hydrogen sulfide and carbon dioxide) and some mercaptans, upstream of molecular sieves units. It may happen that, under upset circumstances, amine or caustic are carried over onto the molecular sieves. Due to their chemical structure and polarity, these molecules can adsorb in the material porosity, with the following consequences:

- When heated, amines easily decompose and participate in coking, to an extent that can be very significant if the carry-over is substantial and frequent. Ammonia can form and further react with water, leading to ammonium ions  $\text{NH}_4^+$  that react with the zeolite structure and destroy it.

- Caustic chemically attacks the binder and the zeolite structure itself, which can be turned to powder.

Liquid hydrocarbons: Just as for water, amine or caustic, liquid hydrocarbons can be entrained with the feed gas, with the consequences already described above. Liquid hydrocarbon deposits block access to micro-pores of the molecular sieve, and therefore decrease the overall adsorption capacity. Additionally, the heavier molecules can crack and polymerize during regeneration and this exacerbates the problem. Pressure drop increases and channelling may appear.

Mitigation of liquid carry-over can be addressed at the culprit treatment unit but best solved by implementing an efficient liquid/gas separator technology upstream of the driers.

#### **Liquid/Gas separation technologies and performance requirements**

Separator internals of various types are used for the separation of liquids, in the form of mist up to large droplets, from gas streams. The most common separation technologies used in the oil & gas and petrochemical industries include: Knock-Out drums with mesh pads or vane packs, cyclonic separators consisting of axial flow tubes or tangential flow tubes, horizontal filter-separators combining cartridges and a downstream mesh or a vane, and cartridge coalescers. The separation of the liquid droplets and aerosols relies on different mechanisms, namely: direct interception, inertial interception, diffusional interception. Not all mechanisms apply to a given type of separator, due to its construction and geometry. A mesh pad for example, relies on direct interception and inertial interception, where the small liquid droplets impinge on the surface of the wire mesh due to their velocity. The smaller droplets and aerosols however, escape and follow the gas flow. A cartridge coalescer not only relies on direct and inertial interception, but also on diffusion where the smallest micron- and sub-micron sized aerosols are captured by the fine fiber matrix of the coalescer medium.

The efficiency of liquid/gas separation technologies is typically described on the basis

of the droplet size that the internal is able to separate. Within the same product category, the droplet size removal capability reported by the technology suppliers may vary according to the intrinsic product features and according to the rated removal efficiency, but based on the available product literature, typical droplet sizes are shown as follows: down to 2-8 micron for mesh pads, down to 10-25 micron for vane packs, down to 4-10 micron for axial flow cyclones and down to 6-25 micron for tangential flow cyclones, down to 0.5-8 micron for filter-separators, and down to 0.1-0.6 micron for coalescer cartridges.

Liquids such as, but not limited to, water, hydrocarbons, amine, or caustic soda can be detrimental to the operation and lifetime of adsorbents, and the typical operation issues have been described in the above section. As a consequence it is paramount for EPC companies and end users to implement a reliable feed gas separator upstream of the driers, so that the incoming gas contains minimum quantities of liquids. This requirement usually translates into a quite open technical specification such as 'the feed gas should be free of liquids', which is further translated into a more quantifiable specification in the process datasheet. This specification usually varies considerably from one process datasheet to another. This is due to the specifics of the application or the specifics of the project, as well as the experience of the packager or EPC contractor. Based on the habit to describe the removal efficiency of a liquid/gas separator according to the droplet size, the liquid removal efficiency is usually specified as a percentage for a given of droplet size in micron, for example: '99.9% of 10 micron and larger droplets'. More often nowadays, the specification includes in addition a corresponding liquid content in parts per million (ppm) in the outlet gas, for example: 'droplet and particle removal efficiency 99.99% at 10 micron and 99.9% at 1 micron; max outlet liquid content 0.1 ppmwt'.

The latter specification only, relating to a maximum liquid content in the outlet gas, is relevant. This is directly scalable to a mass of liquid entering the driers on a time basis, so that

the adsorbent supplier can make sure of the efficient protection of the driers. Moreover, a liquid content is measurable in the field with dedicated test equipment, so that performance tests can be made at the start-up of the plant to ensure that the separation efficiency is compliant with the design requirements. In addition field measurements can be carried out to evaluate a possible drift of performance, in a troubleshooting situation.

On the other hand the specification of a removal efficiency for a given droplet size is less relevant. Since the process datasheet never specifies the size distribution of the liquid droplets in the feed gas, but a liquid content based on computer calculations derived from the gas composition, this specification becomes void when the EPC contractor or the plant operator intends to verify the actual liquid removal efficiency of the separator. In fact, although the droplet size is the key parameter to select a separation technology and to quantify the liquid removal efficiency, no suitable methods exist to model the droplet size distribution of high pressure gas in the design phase.

A good, quantifiable, specification should be based on a total liquid content in the outlet gas (that is, taking into consideration all possible droplet sizes). A removal efficiency for a given droplet size has a limited relevance.

#### **Actual liquid removal performance of liquid/gas separators**

As mentioned above, the liquid content in a gas can be easily measured with dedicated test equipment, as a performance test or as a troubleshooting analysis. One method utilizes a pilot scale cartridge coalescer unit, which is connected on a slipstream to the main process line utilizing existing sampling valves. Thanks to the ability of the coalescer cartridge technology to separate liquids down to the finest aerosols in the sub-micron size range, the coalescer test unit captures and separates any liquid that is present in the gas stream at that location. Liquids are collected into a pressure cylinder located underneath the coalescer housing, so that the weight of liquids collected over time are monitored. As the test is performed at a controlled flow and under actual operating

conditions, the true liquid content in the gas is calculated from the ratio between the mass of liquids collected over a certain period of time to the mass of gas processed over the same period of time. The photograph below shows a typical coalescer test unit utilized by Pall Corporation.

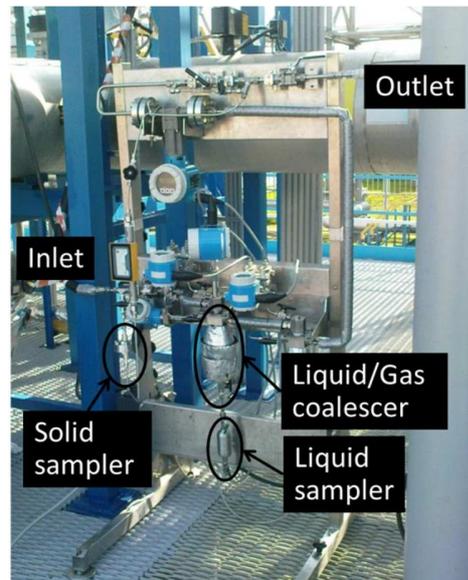


Figure 3: Pilot scale cartridge coalescer unit used for field measurements.

While feed gas separators are always used as normal practice to protect driers, field experience shows that many types can be subject to carry-over. As described in above sections, liquid carry-over is one of the typical issues responsible for poor adsorbent operation. The table below reports results obtained by Pall Corporation, from some field measurements carried-out in troubleshooting surveys around gas driers, using the above described test method. These measurements were requested by plant operators as a means to analyze the root cause of the problems experienced on the driers, and they included measurements downstream of the existing feed gas separator under the plant's normal operating conditions.

Liquid carry-over was confirmed in every case. Results highlight that liquid carry-over can be very significant, as a few tens of ppm wt convert into tens or hundreds of liters entrained into the driers daily. Such high volumes are not expected downstream of a liquid/gas separator.

Type of plant	Equipment designation	Liquid content (outlet gas, ppm wt *)	Nature of liquids
Ethylene production plant	KO drum with mesh pad	74	Hydrocarbons & water
Ethylene production plant	KO drum with mesh pad	0-19 (range)	Hydrocarbons & water
LNG production plant	Horizontal filter-separator	170	Hydrocarbons & water + traces of amine
LNG production plant	Horizontal filter-separator	412	Water & hydrocarbons + MEG + DGA

(\*) Average liquid content in parts per million by weight, unless otherwise stated

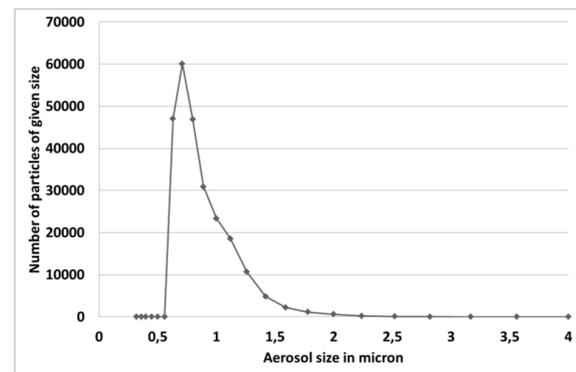
Table 1: Examples of liquid contents measured downstream of feed gas separators (installed upstream of driers), from field measurements performed by Pall Corporation.

### Reasons for performance gaps

Reasons for liquid carry-over are multiple. Performance issues can be due to differences in the physical properties of the liquids or gas, between the design phase and the actual operating conditions. For example, the gas composition or the nature of the liquids may have evolved over time, or the operating pressure or temperature may have changed. Performance issues can also be explained by an increase of the liquid content. In these situations the sizing of the separator may become no longer valid and the separator becomes under-sized, hence the drop in liquid removal efficiency. Another reason may be related to flow rate fluctuations due to plant upsets or declining fields. Liquid/gas separation technologies, whose efficiency is sensitive to flow rate due to a narrow turndown ratio, are subject to a drop in performance.

Referring back to the droplet size that describes the efficiency of liquid/gas separation technologies, another reason for liquid carry-over is that an undefined portion of the incoming liquid droplets are simply too small for the separator to capture and to separate them. In fact, it is generally admitted that liquid droplets in

high pressure gas streams are fine, where aerosols in the micron- or sub-micron size range can be generated. The graph below illustrates the size distribution of liquid aerosols measured in a natural gas stream at 66 barg, upstream of adsorbent driers in an LNG production plant. Measurements were made by Pall Corporation using a high pressure (100 bar rated) laser particle counter, downstream of the feed gas Knock Out drum equipped with a mesh pad. In this case the size of liquid aerosols ranged between 0.6 – 1.2 micron mainly, with a peak at 0.7 micron. Droplets above 11 micron were not detected.



Graph 1: Size distribution of liquid aerosols measured downstream a feed gas separator and upstream of driers, from field measurements performed by Pall Corporation. Plotted data are the average values of over 350 measurements.

Although measurements were made downstream of the Knock Out drum, the liquid loading to the particle counter remained too high to avoid a rapid saturation due to liquids. This represents a significant limitation of the use of counters to clean gas streams.

### Practical solution to maximizing adsorbent protection and lifetime

No suitable method exists to model the droplet size distribution of high pressure gas in the design phase, nevertheless, according to field experience, it is likely that droplets are present as fine aerosols, particularly where condensation can occur. If not captured efficiently by the liquid/gas separator, liquid carry-over will be observed. Referring back to the droplet size that describes the efficiency of liquid/gas separation

technologies, it is obvious that coalescer cartridges only should have the capability to separate all possible sizes of incoming liquids, hence maximizing the protection of the adsorbent downstream. Horizontal filter-separators, although claiming capabilities to separate sub-micron droplets, have shown liquid carry-over issues in many applications, as illustrated in Table 1, and consequently their use is not recommended. A typical layout of a liquid/gas coalescer, utilizing coalescer cartridges, is depicted in Figure 4. The gas flows upwards into the tubesheet and adaptors, then through the coalescer cartridges with an inside-out flow pattern. While passing through the coalescer media, the liquid droplets and aerosols are captured, following the direct interception, inertial interception or diffusion mechanism according to their size, and coalesce into larger droplets that are heavy enough to drain down the cartridge by gravity. The clean gas flows upwards while the liquids are collected underneath the cartridges then drained according to liquid level control.

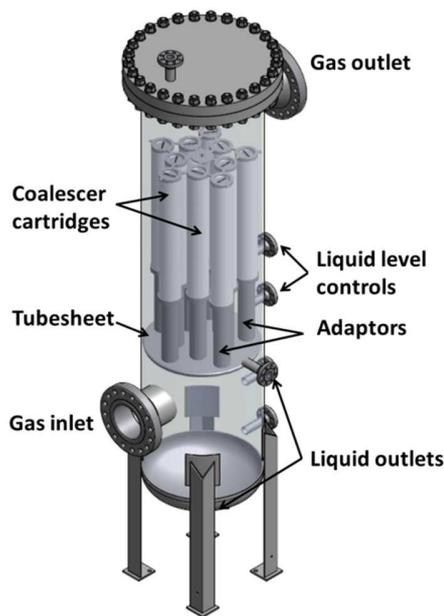


Figure 4: Typical layout of a liquid/gas coalescer

Cartridge coalescers should not be viewed as only good for polishing purposes, where the bulk liquids have been removed upstream. With the development of high efficiency coalescer cartridges, this is not required anymore. High

efficiency coalescer cartridges, that exhibit full element surface treatment features that enable a rapid drainage of the liquids to maximize the liquid handling capability of the cartridge, allow for liquid loadings of up to several hundred ppm wt. As a consequence, with a feed gas containing several thousand ppm wt of liquids, a single housing containing a combination of coalescer cartridges with a pre-separation stage in the form of a vane pack or cyclone tubes, is appropriate to produce a gas with a liquid content down to 0.1 ppm wt for example, depending on the application.

Moreover cartridge coalescers are cost effective technologies, when they include the appropriate features. In fact high efficiency, full element surface treated coalescer cartridges can process more gas, providing up to 30% more compact pressure vessels when compared to standard Knock-Out drums with mesh pads for example. The cost of a pressure vessel being mainly dictated by its diameter, savings on Capex are substantial. The replacement of the cartridges is defined by the pressure drop across the coalescer, where the progressive fouling is caused by the solid particles flowing with the gas. The service life is completely dependent on the solid content in the feed gas, but lifetimes in excess of four years are expected typically. In the case of adsorbent protection, very low solids are expected because the gas often goes through other treating steps which act as a scrubber towards solids (for example in an amine sweetening unit).

## 2/ Retrograde condensation of hydrocarbons

The presence of liquid hydrocarbons can also be explained by a phenomena known as “retrograde condensation”. It is difficult to diagnose, but scientifically founded and admitted by a majority of authors<sup>[3],[4],[5],[6]</sup>. A heavy gas at hydrocarbon dew point, when operated at high pressure can, depending on the shape of the PT Phase envelope (Phase diagram), be subject to condensation of the heavy molecules when the pressure is decreased. Therefore such a gas is expected to have liquids being formed due to pressure drop across the bed. Even though it can be computer-simulated, it is difficult to

accurately estimate how much liquids form and stay in the molecular sieves porosity.

For such gas at hydrocarbon dew point, the most practical and efficient solution is to preheat the inlet stream by 3-5°C in order to avoid the dew point.

### **3/ Hydrothermal damaging during regeneration** <sup>[7]</sup>

Another destructive effect of liquid caused by liquid water, is likely to form when the regeneration heating step is done too fast. This is often referred to as “hydrothermal damaging”.

By heating too fast at a high temperature, water rapidly desorbs from the lower layers of the adsorbent, while the bed is subject to an important temperature gradient: its bottom section is already hot, but its upper section is still at adsorption temperature. When reaching these colder parts of the bed, the regeneration gas gets oversaturated, and water “retro-condenses” on the top layers, especially near the vessel wall. This phenomenon can be observed on the outlet temperature curve of the regeneration gas that shows a plateau which is typical of a change of physical state. As the temperature increases, it soon results in boiling the water in the molecular sieve bed, as depicted in Figure 5. This phenomenon is enhanced by high pressures and low regeneration flow-rates.

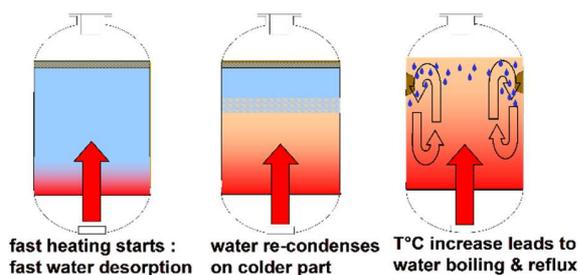


Figure 5: Hydrothermal damaging

The consequence of water condensation (also known as “water reflux”) is the weakening of the binder and of the zeolite structure. The binding clay disaggregates to powder. Eventually it also rearranges to form agglomerates all around the vessel wall under the action of water soluble

salts that can ion exchange with the zeolite and cement the structure<sup>[8]</sup>. In some cases, the agglomerates can account for very significant volumes of the bed, causing preferential paths and high pressure drop. A hammer is sometimes required for the maintenance crew to remove those clusters during unloading.

All these gas / liquid interactions at high temperature are mechanically damaging. They create attrition and can result in bed movements, also leading to uneven distribution of the flow and pressure drop increase. Zeolite A crystal structure itself is affected by an overall loss of capacity, especially in terms of adsorption kinetics.

### **Practical solution to maximizing adsorbent protection and lifetime**

Hydrothermal damaging can be significantly reduced, and sometimes stopped, by the use of a suitable heating and regeneration procedure. Good practice based on field experience generally admits that a heating ramp of a few degrees per minutes, together with a preliminary heating step of 30 minutes to 1 hour at around 80 to 130°C are effective. The benefit of a gentle heating step is to control water desorption whilst delivering a more even movement of initial heat through the bed. This is preferred to a situation where the hot, saturated gas arrives at the colder parts of the vessel to condense. Another good practice may also increase the regeneration gas flow-rate in order to strip more water out of the bed and heat the upper sections faster, or to lower the regeneration pressure.

Whilst hydrothermal damaging often originates from an un-controlled heating procedure, another possible source of hydrothermal damaging is when the desorbed water gets in contact with the top head of the vessel. In the situation where the top head is not hot enough, some water is likely to condense and the formed droplets fall down onto the adsorbent. Good practice developed by CECA based on field experience, includes a 300 to 500 mm layer of water stable silica gel on top of the molecular sieve and it offers a good protection against condensed water. This good practice is part of most CECA designs for natural gas treatment.

## PRACTICAL CONSIDERATIONS FOR THE DESIGN OF ADSORBENT BEDS

As discussed in the above sections, the operation of the driers can be affected by the presence of liquids. The source of liquids may be external, due to carry-over from the upstream liquid/gas separation unit, and/or may be internal, due to condensation of water during the regeneration step. Two practical considerations for the design of adsorbent beds that can be easily implemented during the design phase of new projects are summarized below. A combination of both will contribute to greatly enhance the protection of the driers, and extend the lifetime ultimately.

**Prevent liquid ingress by avoiding liquid carry-over:** considering that the liquid droplet size distribution is not an actual available data, the performance of the liquid/gas separation unit is specified as a total liquid content in the outlet gas (for example: max outlet liquid content 0.1 ppm wt). This recommendation is met through the implementation of vertically configured cartridge coalescers, featuring full element surface treatment.

**Prevent liquid condensation in the molecular sieve bed:** to avoid desorbed water to retro-condense in the bed, it is recommended to adjust the regeneration procedure to each specific case. Most of the time gentle regeneration would include a slow heating ramp and a preliminary heating step in order to control the water desorption rate. In order to avoid water droplets to fall down onto the molecular sieve bed if some of the water condenses on the top of the vessel, it is also recommended to implement a silica gel guard bed. In case the gas is at hydrocarbon dew-point with a risk of condensation, it is highly recommended to pre-heat the incoming gas by 3-4°C.

## CONCLUSION

The design of the molecular sieve dehydration unit and the design of the liquid/gas separation unit are a key to optimizing the lifetime of the driers, while consistently meeting the performance requirements in terms of dew point, adsorption time and pressure drop. The design phase of a new project is obviously the best time to discuss and to implement a best practice approach, in a cost-effective manner, following

the project's or the Client's requirements. The impact of a poor design on the plant operation and revenue, is much higher than the cost impact at project stage. Nevertheless in the event that the driers no longer meet their performance requirements after few years of operation, solutions still exist with the support of experienced technology suppliers. Depending on the nature of the problem, the plant operator can contract CECA Molecular Sieves to evaluate the operation and the design of the existing adsorbent beds, or Pall Corporation to evaluate the performance of the existing liquid/gas separation unit. Process recommendations are made based on a combination of the findings of the site survey and of the supplier's experience, as inputs to an upgrade project.

## REFERENCES

- [1] A. Terrigeol, "Molecular Sieves Contaminants: Effects, Consequences and Mitigation", Annual Gas Processors Association Europe Conference, Berlin, May 2012.
- [2] B. Wang (University College London), "Zeolite deactivation during hydrocarbon reactions: characterisation of coke precursors and acidity, product distribution", *Thesis*, December 2007.
- [3] R.R. Eguren (BP America production Company), "Molecular Sieves operational challenges", *62<sup>nd</sup> Laurance Reid Gas Conditioning Conference*, Norman, Oklahoma, February 2012.
- [4] R. Trent (Zeochem), "Dehydration with Molecular Sieves", *51<sup>st</sup> Laurance Reid Gas Conditioning Conference*, Norman, Oklahoma, February 2001.
- [5] H. Rastelli and J. Stiltner Shadden (UOP LLC), "Extending Molecular Sieve life in Natural Gas dehydration units", *86<sup>th</sup> Gas Processors Association US annual convention*, San Antonio, Texas, March 2007.
- [6] R.N. Maddox, J.H. Erbar (Sch. of Chem. Eng. Oklahoma State University Stillwater), "Low-pressure retrograde condensation", *Oil & Gas Journal*, July 11, 1977, p.64-68.
- [7] P.B.C. Meyer (CECA), "Hydrothermal Damaging of Molecular Sieves and how to prevent it", *Gas Processors Association Europe*, Paris, France, February 2003.
- [8] R.J. Bombardieri and T. Elizondo (BP), "Extending mole-sieve life depends on understanding how liquid form", *Oil & Gas Journal*, May 19, 2008, p.55-63.