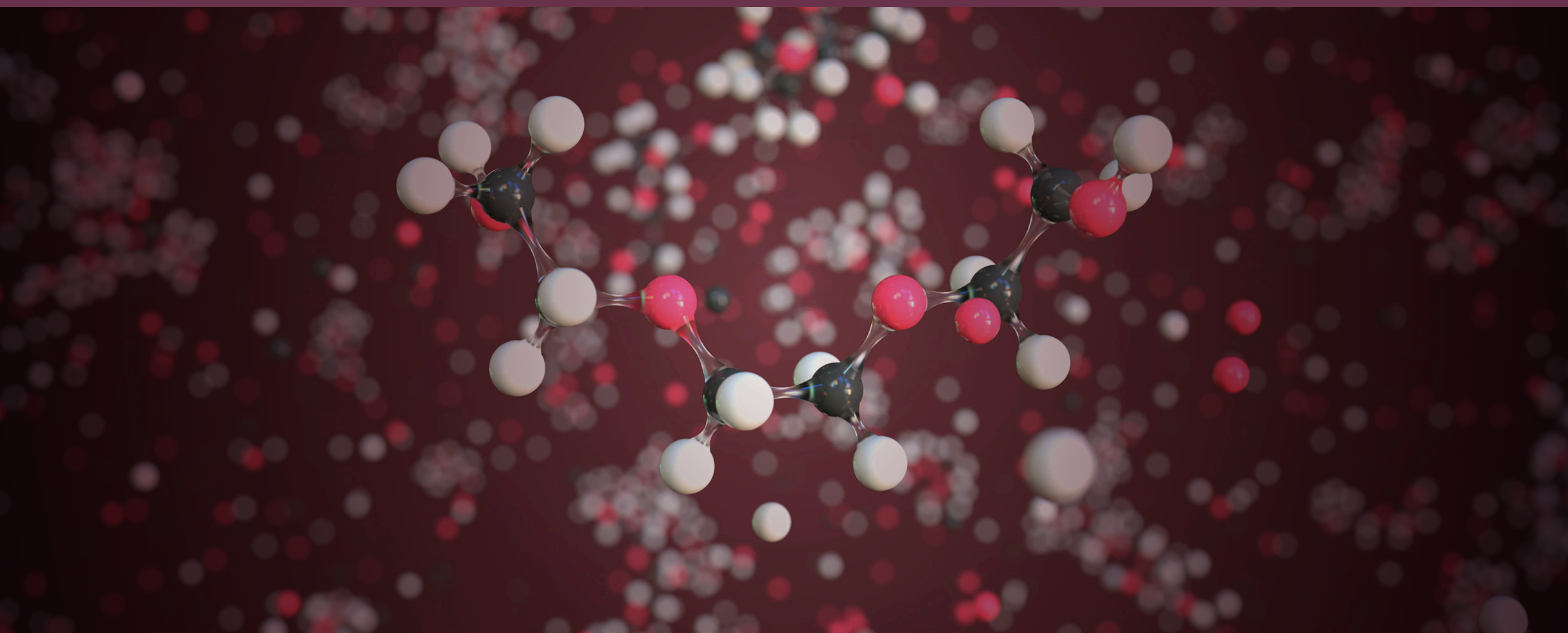
SUPER DEHYDRATION USING TEG

Ralph Weiland, Optimized Gas Treating, Inc., USA, demonstrates how cryogenic gas can be produced using only triethylene glycol alone, with significant cost and operational advantages over mol sieves, using a case study as an example.



In the LNG production process, before gas can be sufficiently compressed and liquefied, it must: have heavy hydrocarbons removed, its carbon dioxide (CO_2) content reduced to at least 50 ppmv CO_2 to prevent solid CO_2 from forming, and its moisture content reduced to below 0.1 ppmv to prevent icing, before entering the cryogenic liquefaction process itself. There, it is liquefied at near-atmospheric pressure by cooling to -162˚C. In most cases, dehydration is achieved in a sequence of two or three columns of molecular sieve desiccant (mol sieves) while a fourth column is being regenerated. The main challenge using glycol is the regeneration of triethylene glycol (TEG) into a super-dry state.

In any glycol-based process for removing moisture from a gas, the main factors controlling performance are:

- Glycol flow rate.
- Dryness of the entering lean solvent.
- Temperature of the wet gas.
- Number of trays, or depth and size of packing.

But, if the water-lean solvent is insufficiently dry, no amount of adjusting its flow rate and temperature and adding extra trays or packed depth will change the situation. The regenerated solvent must not contain too much water, a parameter that is controlled by the glycol stripper.

A conventional, reboiled TEG stripper is hopelessly inadequate for producing truly dry, lean TEG. Removing water from wet glycol by contacting it with steam presents some serious challenges, even conceptually. First amongst them is the fact that one is trying to transfer water into a vapour phase that is already water saturated. What is the driving force that is responsible for drawing water from liquid to vapour? The answer: really, there is none. Beyond the heat being passed into the liquid boiling in the reboiler, which is causing some of the water and a little of the glycol to evaporate, there is no driving force for mass transfer (water vaporisation) in the column itself – the vapour is already water-saturated. Therefore, even without running any simulations or much further thought, it should be apparent that attaching a column to the reboiler is unlikely to be of much benefit. In fact, it is barely dry enough to produce gas sufficient to meet pipeline specifications (water content of approximately 7 lb/million ft^3 or 148 ppmv). The crucial realisation is that there is no way to continually evaporate water into an already water-saturated gas just by mass transfer alone, without continually supplying energy for further boiling. For the stripper shown in Figure 1, this fact is unequivocally demonstrated by the simulation results shown in Figure 2.

Although invisible in Figure 2, there are actually nine TEG profiles plotted there, for three different reboiler duties (1200, 1500, and 2000 Btu/h) and three different tray counts (6, 8, and 16). All profiles are nearly coincident. Trays 1 – 3 are reflux trays whose purpose is to recover TEG from the vapour before it reaches the condenser and is lost with the stripped water. Apart from Tray 4 (which serves as a feed tray), there is no obvious reason for including Trays 5 – 16 in the column at all; in fact, Tray 4 could be eliminated, too, by feeding the hot rich TEG directly to the reboiler and allowing the column to function as a three-tray TEG recovery column. Only the reboiler itself is directly able to transfer water to the vapour phase. The question then is, apart from boiling harder, what can be done to strip more water from the solvent? The answer to this enigma is a Stahl Column.

The Stahl Column

The Stahl Column was described in US Patent 3,105,748 issued to Willi Stahl in 1963, and assigned to The Parkersburg Rig & Reel Company, Houston, Texas, the US. As shown in Figure 3 (taken directly from the patent), a Stahl Column

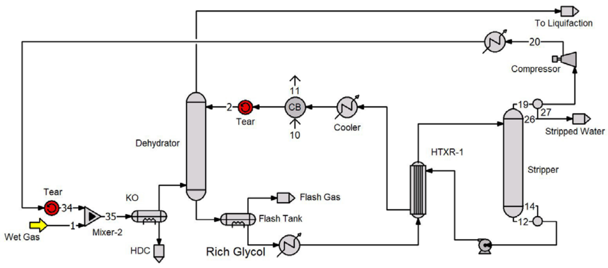


Figure 1. Gas dehydration using TEG with solvent regeneration in a single reboiled stripper.

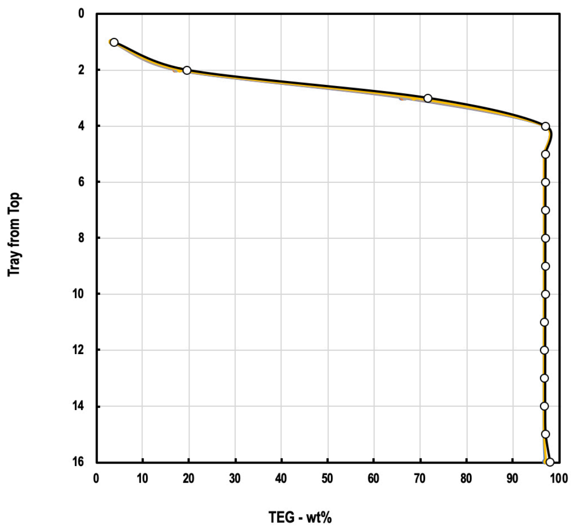


Figure 2. How TEG concentration varies with tray number in a reboiled stripper.

(labelled 'super drier' in the image) is a very short, small-diameter packed or trayed column positioned between the reboiler and the accumulator holding the lean solvent. A small slipstream of dried gas is diverted from the top of the absorber and enters the regeneration section either into the base of the super drier (Stahl Column), or directly into the reboiler via Stream 21, should an actual column not be installed.

No matter where it is injected into the stripping section, the dry gas is a diluent for the stripped water vapour. As the gas and water vapour travel together up the Stahl Column and stripper, the diluent alleviates the otherwise hopeless struggle the water vapour has being drawn into the vapour. The diluent creates a concentration driving force, where before there was none. The focus of the patent is producing a dried gas suitable for transportation by pipeline, i.e., with water content no greater than approximately 7 lb/million ft^3 (~148 ppmv) – the goal for liquefaction is moisture not exceeding 0.1 ppmv.

Figure 4 shows the TEG dehydration unit using a Stahl Column. The vapour feed (Stream 31) to the bottom of the Stahl Column is a small slipstream (0.033%) of the well-dehydrated gas (47 ppb water by ProTreat® simulation) originally destined for liquefaction. Based on what has been gleaned about the ineffectiveness of a reboiled stripper when used to dry TEG, this stripper contains only four trays, with wet glycol fed to Tray 4.

Visually, the Stahl Column shown in Figure 3 has the appearance of a very short column (or even no column at all, in which case stripping gas would be fed directly to the reboiler via Stream 21). The present implementation of a Stahl Column is perhaps unusual in that it is fairly tall, using 15 m of Mellapak M250.X structured packing. As will become apparent, the packing size and bed depth are important parameters in setting system performance. Similar parameters in the contactor are the packing type, size (Mellapak-Plus M452.Y), and bed depth (10 m). The water entering with the wet gas amounts to 827 ppmv. This could vary quite a bit in actual operation so it would be important to know something about what control measures could be taken to accommodate variation in the water content of the wet gas, for example, or its flow rate. It would also be valuable to identify those parameters to which expected performance is most sensitive. Clues to answering such questions are to be found in part in absorber and Stahl Column composition and temperature profiles, and in part in a sensitivity study.

Parameters controlling performance

There are four main equipment items in a dehydration scheme using a Stahl Column. Each one has a very different function, to the extent that each deserves a separate discussion. However, all the equipment items are interconnected, so a change in the behaviour of one necessarily affects the performance of the others.

Contactor

The contactor is the only vessel where the dry gas is actually produced by contacting wet inlet gas with the dehydration agent. The performance of the contactor itself is directly affected by the moisture content of the wet gas, its flowrate, and the dryness of the TEG solvent. Performance is measured by the dryness of the dehydrated gas; however, this metric also affects the performance of the Stahl Column simply because dried product gas is responsible for producing the dry solvent in the first place, and this plays back into the contactor's performance. The Stahl Column and the contactor are intimately connected through both the dry solvent and the product gas. The contactor cannot really be analysed properly in isolation from the rest of the system. Figure 5 shows that the dry gas moisture content falls exponentially with distance up the column until the gas nears the top of the packing where it asymptotically reaches a value of approximately 0.04 ppmv.

Reboiler and stripper

The reboiler, i.e., boiling, is the primary means for transferring water from the solvent into the vapour. In fact, that is its sole function – to evaporate water. As the TEG profile in Figure 2 shows, the stripping column does not perform any meaningful removal of water from the solvent. In fact, for the conditions of the case study, a four-tray stripper with TEG fed to Tray 4 produces a dry gas with 0.0483 ppmv water, while a six-tray stripper with TEG fed to Tray 6 produces dry gas with 0.0481 ppmv water. The difference is immeasurable.

However, the three wash trays allow only 1.1 lb/h of TEG to be lost with the removed water (Stream 20), while five wash trays permit only a 0.041 lb/h TEG leak, only approximately 4% of the three-tray case. Calling this a 'stripper' is a misnomer. The stripper is actually just a TEG capture column, and when correctly designed, it is capable of almost completely preventing TEG losses from the system, while stripping little or no water. The reboiler does bulk water removal. For the base conditions of this case study, for example, of the 1455 lb/h of water entering the solvent regeneration section of the process, approximately 80% is directly removed by the reboiler, and the rest is removed by the Stahl Column. There is a small amount of water plus gas recovered during stripping that is recycled back to the contactor, where the contactor removes the recycled water.

Stahl Column

The Stahl Column removes the remainder of the water from the solvent by using a small volumetric flow of dry stripping gas borrowed from the final product. In fact, in the base case here, the stripping gas amounts to less than 0.06% of the total product gas, and 100% of it is recycled from the stripper overhead after being used in the Stahl Column – no hydrocarbons and almost no glycol are lost.

Figure 6 details how water is stripped in the Stahl Column, and how TEG is concentrated there. In the stripper, and particularly across the reboiler, water falls from 3.2 to 0.65 wt% (a net decrease of 2.55 wt%). In the Stahl Column, it falls from 0.65 to 0.0001 wt% (net decrease of 0.65 wt%). The reboiler removes 80% of the water entering the regeneration section while the Stahl Column removes just 20%, but to an extremely low level.

Technical summary

A standard contactor and reboiled regenerator scheme is not even remotely capable of reaching a dry gas moisture content necessary for gas liquefaction in an LNG plant. Perhaps for this reason, mol sieves have become the technology of choice. Once the reasons are understood as to why conventional glycol-based technology fails to work in this application, replacing steam with inert stripping gas becomes an option. In some LNG plants, however, a conventional TEG dehydration unit is installed immediately upstream of mol sieve beds to unload the mol sieve unit.

The Stahl Column proposed here is not a short column – it may need to be quite tall for adequate water removal from the solvent. A relatively tall Stahl Column can easily reach a TEG content of 99.98 wt% or more and produce dried gas with a moisture level of well below 0.1 ppmv, quite suitable for liquefaction in an LNG plant. If an even drier gas is needed, there are a number of operating parameters that can be manipulated to achieve this, including solvent flow rate, reboiler duty, and inert gas flow rate. Operationally, TEG loss can be controlled by stripper reflux flow and higher gas processing rates can be accommodated by adjusting these same parameters. In the design phase, the packed bed depths and reboiler energy capacity set the base or

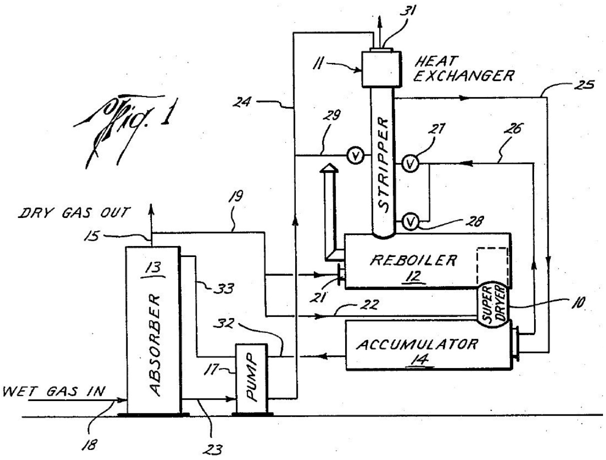


Figure 3. Stahl Column (super drier) as shown in original patent US 3,105,748.

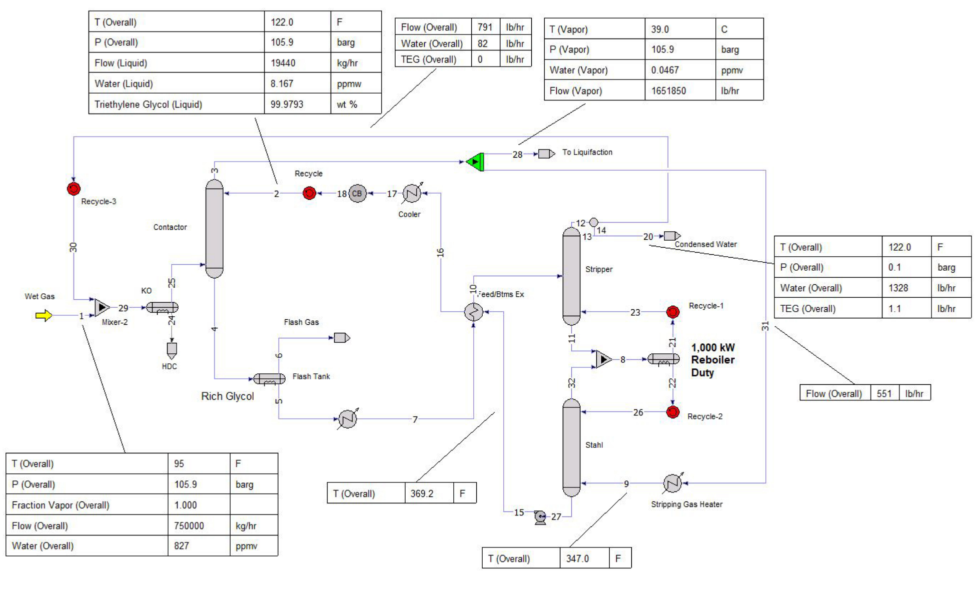


Figure 4. Gas dehydration using TEG and a Stahl stripping column.

design capacity of the plant and how these items perform and respond to changing process conditions is well mirrored and predicted by ProTreat mass transfer rate-based simulation.

A conventional system with a tall Stahl Column is well within the scope of normal plant operating procedures and should present absolutely no unique challenges to plant operators. In fact, being fully continuous, this process is simpler to operate than a mol sieve system where, for example, operator intervention is required to switch and regenerate beds of solid adsorbent. Operationally, a conventional TEG unit with a Stahl Column is quite a manageable proposal. The immediate question is one of economics.

Economics

The economics of the Stahl Column process were compared with a typical molecular sieve dehydration unit via an independent cost estimate quote from Reset Energy LP, Midland, Texas, the US.[2] Reset Energy provided three different quotes: a typical TEG plant (US$2.32 million), a TEG plant with Stahl Column (US$2.75 million), and a traditional mol sieve unit (US$10.89 million). Costing used the same feed as in the ProTreat simulations, and prices are quoted FOB West Texas Intermediate.

A Stahl Column adds 18.5% to the cost of a conventional TEG unit but leaves one with a more easily operable plant, and at only 25% of the cost of the molecular sieve-based unit. The main equipment difference is that the reboiler and overhead condenser are actually smaller in the Stahl unit. The Stahl Column has a slightly larger diameter (725 mm) than the stripper (640 mm) but, of course, it is an additional column so it makes the final price higher than the basic TEG unit. The mol sieve unit is much more expensive.

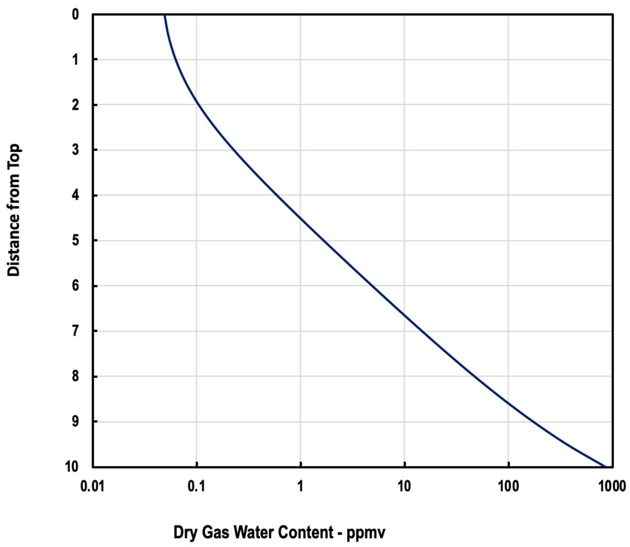


Figure 5. Dry gas water content falls with distance up the contactor. Dry gas to regeneration is 250 kg/h.

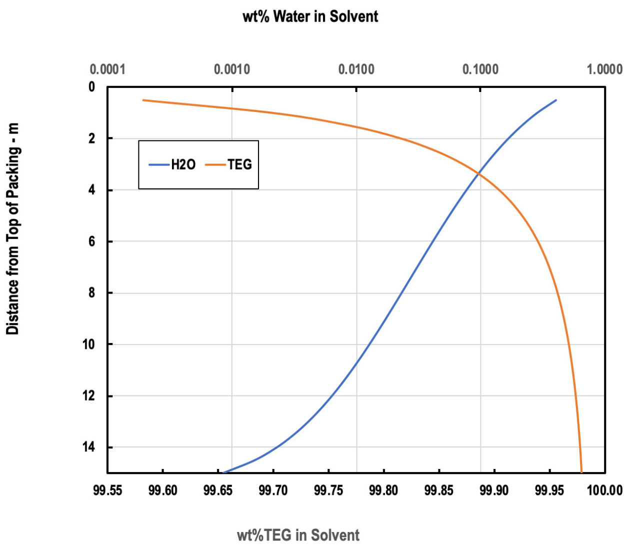


Figure 6. Water removal in the Stahl Column.

Possible pitfalls

There are several potential pitfalls with this process. They include the potential for:

- Co-absorption of oils, and other contaminants (likely to be rejected into the stripped water).
- Entrainment of glycol into the product gas (can be mitigated using mist elimination).
- Glycol decomposition in reboilers. Temperature never exceeded 182˚C or 360˚F anywhere in the process, and lower than usual temperatures seem characteristic of using a Stahl Column. If 99.98 wt% TEG were to be produced by boiling the solvent, the temperature would far exceed 400˚F and decomposition would be a truly serious issue. In this process, however, boiling only occurs in the reboiler where the TEG concentration is fairly low. Water removal in the Stahl Column takes place via direct contact with an inert stripping gas at modest temperatures – there is no boiling there so high temperatures do not exist, and thermal decomposition is not an issue.

If these pitfalls are recognised and engineered around, there is quite significant upside CAPEX benefit to using TEG dehydration with a Stahl Column. Although not investigated here, OPEX is likely to be lower because this is an essentially lossless system so there are virtually no makeup requirements and, being a completely continuous process, manpower requirements will be minimal. The most effective way to get a handle on the technical aspects of the process is by mass transfer rate-based simulation, specifically ProTreat, which performs detailed design by calculating actual absorption and stripping rates, and which allows reliable sensitivity analyses to be conducted. **LNG**

References

1. For more information, see 'Moisture measurement in the production of Liquefied Natural Gas (LNG)', *Michell Instruments*, (2016), www.michell.com/downloads/appnotes/Moisture_measurement_in_the_production_of_Liquefied_Natural_Gas-LNG.pdf
2. Cost figures were independently provided by personal communication from Chris Villegas, CEO, Reset Energy, USA.
3. WEILAND, R.H., et al., 'Stahl Columns – an Alternative to Molecular Sieves?', *PTQ Gas*, pp. 22 – 25, (June 2022).