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Comparison of methods for dehydration of natural gas stored in underground gas storages

Introduction

The idea of storing natural gas (NG) is to straighten demand and become less dependent on supply. NG is being stored in summer periods when the needs are lower and withdrawal in the winter periods. For large volumes of gas to store the underground gas storages (UGS) are the most advantageous. Nowadays there are nearly 200 UGS within the Europe and another 50 are projected. For instance in Poland there are operating 6 UGS of which 3 are being expanded and another 3 are projected. Total store capacity of Poland is 1575 million Nm^3 and it will be increased by 1250 million Nm^3 [1].

Types of UGS are: 1) Aquifer, 2) Depleted oil/gas field and 3) Salt cavern reservoir. Each of these types possesses distinct physical characteristics. Allowable gas pressure within the UGS is usually around 20 MPa. The pressure within increases as the gas is being injected and decreases during withdrawing. Output pressure depends on further pipeline distribution, usually should exceed 7 MPa. Temperature of gas ranges from 20–35°C. Disadvantage of UGS is that during the storage the gas is saturated by water vapors. In case of depleted oil field UGS additionally vapors of higher hydrocarbons are contaminating stored gas. The distribution specification set the allowable water concentration in NG by specifying the dew point temperature (T_{dew}) of NG. T_{dew} is -7°C for NG at 4 MPa, [2] this value is equivalent to roughly 5 g_{H2O}/m^3 NG at 4 MPa. Water content which NG at saturation can contain is dependent on the temperature and pressure within the UGS. Good presentment is in the GPSA Data Book 12th Edition, Chapter 20 as Figure No. 20 [3]. The average value of H_2O in NG is five times higher than requested. Therefore dehydration step of NG from UGS is essential before its distribution.

Dehydration methods

There are three main methods of dehydration NG. First of them is absorption of H_2O by TriEthyleneGlycol (TEG). Absorption is done in glycol contactor (tray column or packet bed) by countercurrent flow of wet gas (20-35°C) and TEG. TEG is enriched (by H_2O) and flows out in the bottom of contactor, then runs through flash and heat exchanger into reboiler. In the reboiler the H_2O is boiled out. Temperature inside should not exceed 208°C due to decomposition temperature of TEG. Regenerated (lean) TEG is then recycled back through heat exchanger and additional cooling unit back into the top of contactor. Whole method is depicted on fig. 1 below [4].

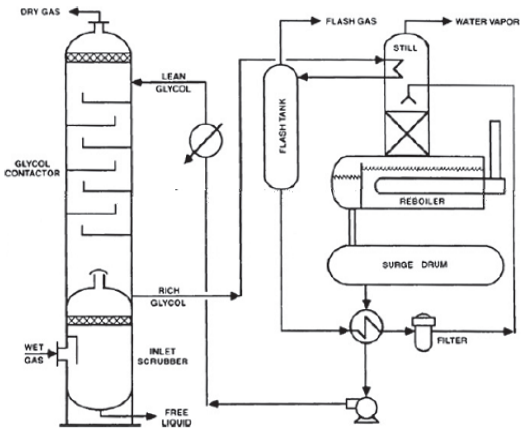

Fig. 1. Absorption dehydration scheme

The second dehydration method is adsorption of H_2O. In this method the H_2O is adsorbed by solid desiccants, most often by mole sieve, silica gel or alumina. As a minimum, two beds systems are used. Typically one bed is drying gas and the other is being regenerated. Regeneration is done by preheated gas, as it is depicted on the fig. 2 below or by depressurizing (PSA), but that is less often.

Finally the last dehydration method is expansion of NG which causes *Joule – Thomson* effect. The wet NG is throttled in flash tanks and as the consequence of the pressure decrease the temperature decreases. Lower temperature of the gas stream leads to partial condensation of H_2O vapors. Created droplets are removed from the gas stream by a demister inside the flash. Essential part of the system is injection of hydrate inhibitors (methanol or MonoEthylenGlycol – MEG). This prevents hydrate formation and thus plugging. In cases where is insufficient pressure difference between the UGS and distribution network available, additional external cooler is required. The fig. 3 below shows the method.

Each of presented method has its advantages and disadvantages. Absorption by TEG is nowadays the most widely used method and usually reaches the outlet T_{dew} around -10°C. Furthermore with improved reboiler design (Vacuum striping, Drizo, Coldfinger) the outlet T_{dew} is even 2–3 times lower. However TEG has a problem with sulfur or higher hydrocarbons contaminated gas. TEG in reboiler is foaming and with time is changing into ”black mud”. Another disadvantage are BTEX emissions in reboiler vent [5].

Adsorption dehydration can achieve very low outlet water concentration T_{dew} < -50°C and contaminated gases are not a problem. On the other hand adsorption requires the highest capital costs and space requirements. Expansion dehydration is the most suitable in cases where a high pressure difference between UGS and distribution connection is available. However the difference during withdrawal period decreases and when it is insufficient, an external cooling cycle is needed. Also a cycle for hydrate inhibitor regeneration (out of liquids separated inside the flashes) is required.

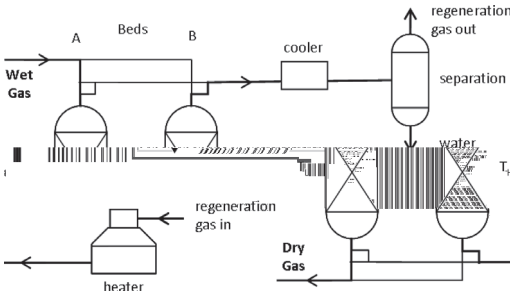

Fig. 2. Adsorption dehydration scheme

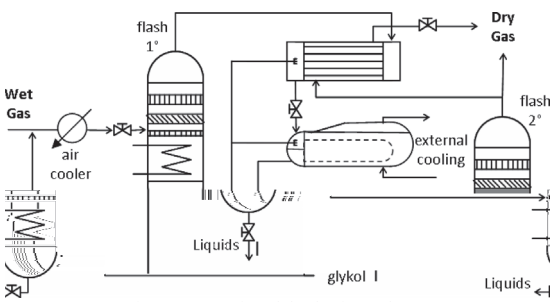

Fig. 3. Expansion dehydration scheme

Comparison of overall energy demand

Hereinafter comparison of overall energy demand for each presented method will follow. As a referential situation is taken dehydration of 10^5 Nm^3/h water saturated NG at 30°C and 10 MPa (also 15 MPa for expansion). Required T_{dew} is set to -10°C for NG at 4 MPa. That means a water removal performance of 37 kg_{H2O}/h.

Firstly the absorption method was calculated based on publication by GPSA (2004) [3]. The most economical designs employ circulation rates of about 25 to 40 l_{TEG}/kg_{H2O}. Therefore circulation rate of 30 l_{TEG}/kg_{H2O} is assumed. Appropriate concentration of lean TEG is 99%. The temperature within the reboiler is 204°C. The losses of TEG are estimated to 2 l/h. The particular heat requirements of reboiler and performances of equipment used are listed in tab. 1 below.

Tab. 1. Absorption dehydration energy demand

Heat requirements of reboiler [MJ/h]			
Increase TEG temperature	Boil out the H_2O from TEG	Boil out condensed reflux	Heat losses
193	87	22	15
Particular performances [kW]			
Reboiler	TEG pump	TEG cooling	Total
88	4	1	93

The calculated performance of reboiler is in perfect conformity with practical data of industrial application provided by ATEKO a.s.

Secondly the energy demand for adsorption method is presented. Due to lack of practical data it was used several calculation sources. Unfortunately they did not show the same results. Calculations were based on publication by GPSA (2004) [3], *Gandhidasan* (2001) [6] and *Kumar* (1987) [7]. For economical reasons it is recommend to design long cycle operating. Therefore a 12 h cycle with 2 adsorbers was assumed. As a suitable adsorbent the 4 Å molecular sieve in the form of spherical pellet with diameter 3–5 mm is assumed. 100 g of the sieve can adsorb up to 12 g of H_2O. Weight of the adsorbent in the bed is around 3800 kg. Lifetime of an adsorbent depends on operating conditions and usually varies around 3–5 years. Temperature of regeneration gas is 300°C. Usually 10% of inlet gas is used as regeneration gas. The main difference between calculations is the ”losing factor”. GPSA assumes that 40% of the heat in the regeneration gas transfers to the bed, vessel steel, and heat loss to atmosphere, and the balance leaves with the hot gas. E contra Gandhidasan calculates heat transfer of 55% for the same situation. The particular heat requirements and performance of regeneration gas heater (the sole energy consumer in adsorption method) are listed in tab. 2 below.

Tab. 2. Adsorption dehydration energy demand

Heat requirements of adsorber [MJ/h]			
Increase bed temperature	Desorption of H_2O	Heat to the vessel	Heat losses
83	153	53	14
Regeneration gas heater performance [kW]			
GPSA	*Gandhidasan*	*Kumar*	Total (average)
210	152	170	177

The heat to the vessel could be saved by installment of proper internal isolation. Applying this leads to reduction of total performance to 158 kW hence it is highly profitable.

Finally the energy demand for expansion method is presented. The basic step in this method is to adequately calculate and employ *Joule–Thompson* effect (the temperature decrease of NG as a consequence of its pressure drop). Hence the main role plays the available pressure difference of NG between its inlet and outlet. For illustration 2 situations are compared: (1) inlet pressure 15 MPa (2) 10 MPa. Operation design was taken from industrial application of TEBODIN s.r.o. The 15 MPa wet NG is throttled in two stages and no external cooling of NG is required. A heating inside each flash is recommended to easily carry away condensed liquid. The 10 MPa wet NG needs to be firstly precooled by an air cooler and then is throttled just in one flash. The rest of H_2O in the gas has to be removed by an external cooling cycle. In both cases MEG is sprayed into NG before each cooling to avoid hydrate formation. In 15 MPa case 350 l_{MEG}/h is added to wet NG stream and in 10 MPa case 500 l_{MEG}/h. The hydrate inhibitor has to be regenerated (the MEG regeneration is quite similar to TEG regeneration mentioned in absorption method) and recycled back to the process. The particular performances of equipment used are listed in tab. 3 below.

Tab. 3. Expansion dehydration energy demand

15 MPa Equipment performance [kW]			
MEG and condensate pump	MEG regeneration	Flash heating	Total
6	36	10	52
10 MPa Equipment performance [kW]			
MEG and condensate pump	MEG regeneration	Air precooling and external cooling	Total
6	52	265	323

Conclusions

From the comparison of dehydration methods it can be concluded that if there is sufficient pressure difference available in the UGS the most efficient method is expansion. However as the pressure difference decreases energy demand rises markedly as it is seen on fig. 4.

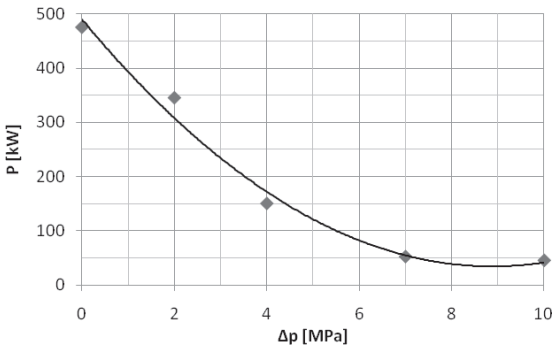

Fig. 4. Expansion dehydration scheme

The steep rise on the left of graph is thanks to high energy demand of external cooling. This is needed due to weak *Joule–Thompson* effect. External-cooling helps to reach specified T_{dew}.

Comparison of absorption and adsorption method speaks in favor to absorption. The calculated energy demand for reference situation is 1:1.7 (1.9 adsorbers without internal insulation). This is in good conformity with comparison made by *Kumar* (1987). He states that operating cost for these two methods are 1:1.53 for $1.2 \cdot 10^5$ Nm^3/h and 1:1.33 for $5.9 \cdot 10^5$ Nm^3/h in favor to absorption. Therefore it is recommended to employ absorption method in cases where it is possible. Although the heat requirements are nearly similar for both methods, it is the ”losing factor” (low heat transfer from regeneration gas) which hinders the adsorption method.

Adsorption dehydration method finds its use in cases of treatment of sour gases because do not suffer on sulfur contamination. Advantages of adsorption method are extreme low T_{dew} of NG obtained. The gas could be nearly totally dehydrated. This is used as pretreatment of NG before liquefying it.

LITERATURE

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