Simulation of Gas Dehydration Plants Safe Operation in Chemical Industry

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This article describes a study of the dynamic behavior of a gas dehydration plant that uses triethylene glycol as sorbent agent. The gas dehydration technology in these plants benefits from the high capacity of triethylene – glycol to absorb water from gas. After desorption the hygroscopic qualities of the agent return to the initial state of unsaturation. The authors used the software package HYSYS v3.2® to simulate this process. The main cases refer only to the process safety in operation and the various situations that may occur during this process.

Keywords: triethylene – glycol, gas dehydration plant, Hysys® software, water dew-point

The main water source in natural or associated gas is represented by the interstitial water in rocks leading to a significant presence in all natural gas and crude oil fields. Due to the thermodynamic equilibrium conditions, temperature and pressure in the field, the water may have a certain concentration in the natural and associated gas [1, 2]. If those conditions are changed, the water vapor content changes as well. Therefore, the water vapor represents one of the unwanted components in natural gas or gas from oil wells because, under some favorable temperature and pressure conditions, it can cause important difficulties in gas transportation and processing. Thus, by increasing pressure and decreasing temperature along the pipes some amount of the water vapor condenses and accumulates in certain zones of the transport system. Then, from these zones, the condensate is mechanically driven at high gas speed. That is why the tracking, reducing and controlling the water content in natural gas are very important operations to ensure continuity in gas extraction, transport and processing [3, 4].

Gas dehydration means partial (to a certain dew point) or almost total (to 0.5–10 ppm) removal of water vapor from natural or associated gases as nitrogen, hydrogen, syngas mixture, carbon dioxide and other gases used in chemical and petrochemical industry. Water in gas generates difficulties in pipelines transport such as: the decrease of pipe carrying capacity due to accumulation of water in the lower zones of the pipe, the cryohydrates formation, the promotion of corrosion inside pipes due to the carbon dioxide and hydrogen sulphide presence, and the jeopardy for the safe operation of compressor stations [5].

Gas dehydration is also imposed when solving problems about pipes corrosion is necessary and the advanced dehydration must be made in the industrial process. Thus, since the C_{2+} fraction in the natural gas represents a valuable raw material for the pyrolysis process when ethylene is obtained, this gas is de-metanized by fractionation at low temperatures (–109 ^{0}C) performed with an expansion turbine (turbo-expander). Avoiding cryohydrates formation at these low temperatures implies practically complete gas dehydration (up to 0.5–10 ppm) [6]. Some processes in chemical and petrochemical industry, when catalysts for chemical reactions are needed, require also an advanced dehydration of the involved gas.

Since the dew point of gases characterizes their moisture and defines the saturation temperature (the point when the first water droplets appear), when gas dehydration is to be done, the professionals in petrochemical industry talk about *dew point depression* representing the number of degrees with which the gas saturation temperature drops when the mixture pressure remains constant. This means that the drying degree of a gas can be set up by specifying either the final moisture content or the final dew point [7, 8].

Many methods are known and used to achieve gas drying and one of them is the absorption in glycol. This procedure is based on property of glycols to easily absorb water vapor at low temperatures and to release back at high temperatures. Diethylene-glycol (DEG) was the first glycol used for natural gas dehydration. Later, triethylene-glycol (TEG) started to be used (for air drying too) together with aqueous solutions of lithium chloride and calcium.

A classical gas drying plant with DEG or TEG is shown in figure 1. According to this diagram [3], the wet gas enters the absorption column base **1** and it circulates in counter current with the regenerated glycol (concentrate) introduced at the top. Glycol, enriched with water vapor in gas (diluted), leaves the absorption column at the bottom, passes successively through the heat exchanger **3**, through the phase separating vessel (degassing vessel) **4** and the filter **5**, then it enters the regeneration column **6**. This column is a classical fractionation column which is used to separate at the top the more volatile component (water) and at the bottom the less volatile component (glycol with the desired concentration). If a higher concentration is desired, the fractionation is done in vacuum in order to avoid exceeding, in the re-boiler, the DEG or TEG thermal decomposition temperature. The glycol regenerated in this way is taken with a pump at the base of column **6**, it is passed through the heat exchanger **3** and the cooler **8** and introduced again at the top of the absorption column [3].

The dehydrated (dried) natural gas leaves the absorption column at the top, it passes through the separation vessel being mechanically driven and then, it is sent to the destination.

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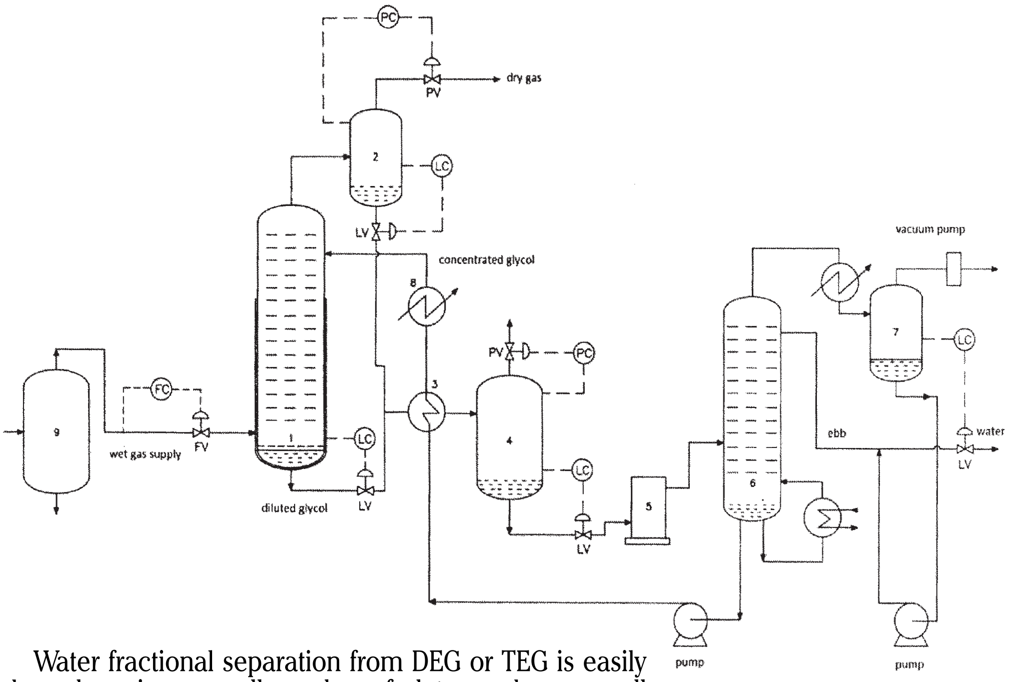

Fig. 1. A classical plant used for gas dehydration with DEG or TEG [3]
1-Absorber; 2-Liquid separator; 3-Heat exchanger;
4-Gas separator vessel; 5-Filter; 6-Glycol regenerator;
7-Glycol column; 8-Cooler; 9-Three-phase separator; FC-Flow controller; LC-Level controller;
PV-Pressure valve; FV-Flow valve; LV-Level valve

Water fractional separation from DEG or TEG is easily done, by using a small number of plates and very small reflux ratios (e.g. values of 0.1–1) although for the top product (water) very high concentrations are imposed (99.99%) in order to reduce the glycol loss.

This easy separation is due to large differences between normal boiling temperatures of the two components (water and glycol) but, especially, it is due to the high relative volatility of the two binary mixtures, water – DEG and water – TEG, according to the shape of the liquid – vapor equilibrium curves [9].

Extracting water from gas is an essential process that solves the problems associated to gas quality diminishes. Also, some international rules regarding the need for gas drying are required as well as imposing a very small percentage of water in gas in the final product, depending on the real case and on the type of drying process. All these make the drying process an essential part of the gas treatment process [3].

The first step in simulating a drying unit operation is investigating the process implementation. Then, the simulation is done by using the thermodynamic equations. Those equations are established for non-polar components such as hydrocarbons. The main part of the drying process simulation refers to the calculation of the interaction between glycol and water. Because of the nature of these complex mixtures, more thermodynamic equations are needed to describe the above mentioned interaction.

This paper mainly focuses on the drying process. Some associated aspects, such as power consumptions, are not taken into consideration. The simulated cases refer only to the safety of the process in operation and to the various situations that may occur during this process.

In the dynamic simulation, PID controllers are used. They monitor various process parameters and send commands (depending on pressure, level or flow) to actuators which are control valves [10]. The PID controllers tuning is done in order to satisfy the *quarter amplitude damping* performance criterion. This criterion enforces to the automatic system, a particular step response characterized by a 1/4 ratio between two consecutive maximal values (a damping factor of 0.25). Quarter amplitude damping is the quality global index for the transient regime and it is used to obtain a good enough stability reserve for the automatic system, without any guarantee concerning the technological imposed parameters (overshooting and response time). Under these conditions, Ziegler – Nichols tuning criteria should be understood as realizing a controller preliminary tuning and some tuning parameters correction will be done in order to get the desired (specified) performances [11, 12].

Experimental part

The purpose of this simulation is the process monitoring for different scenarios that can occur in normal and abnormal system operation. These possible situations are: start, planned stop, emergency stop, fire situation. HYSYS v3.2® (build 5029) by Aspen Technology Inc. has been used to obtain all the simulations.

The process model for the dynamic state is shown in figure 2. It contains the following elements:

– a flow control loop (FIC-100) with the control valve (depending on flow) FV-100 at the separator input. This loop represents a hypothetical unit and it should be included into the model to avoid manipulating the system input flow;

– a safety valve (SDV-002) at the separator input. This valve allows the system isolation when abnormal situations appear (e.g. liquid level maximum – maximorum or minimum – minimorum in the separator);

– another safety valve (SDV-003) used on the leaking line of the separator;

– the separator unit itself;

– the separator level control loop (LIC-002) and the control valve (depending on the separator level) LV-002;

– the serial pressure control loop at the separator output (PIC-003 and the control valves, PV-003A and PV-003B depending on the separator pressure). The PIC controller is a split range pressure controller which means it has a double action (for this case);

– a pressure valve PSV-001 at the separator output, after mounting a T shape (TEE-001);

– an isolation valve (VLV-003) at the separator liquid output. This one is included to model the discharge blocking at the separator liquid output;

– a second isolation valve (VLV-002) at the separator gas output. This valve is included to model the discharge blocking at the separator gas output;

– a third isolation valve (VLV-001) at the separator gas output, towards the flare system. This valve is included to model the discharge blocking at the separator gas output;

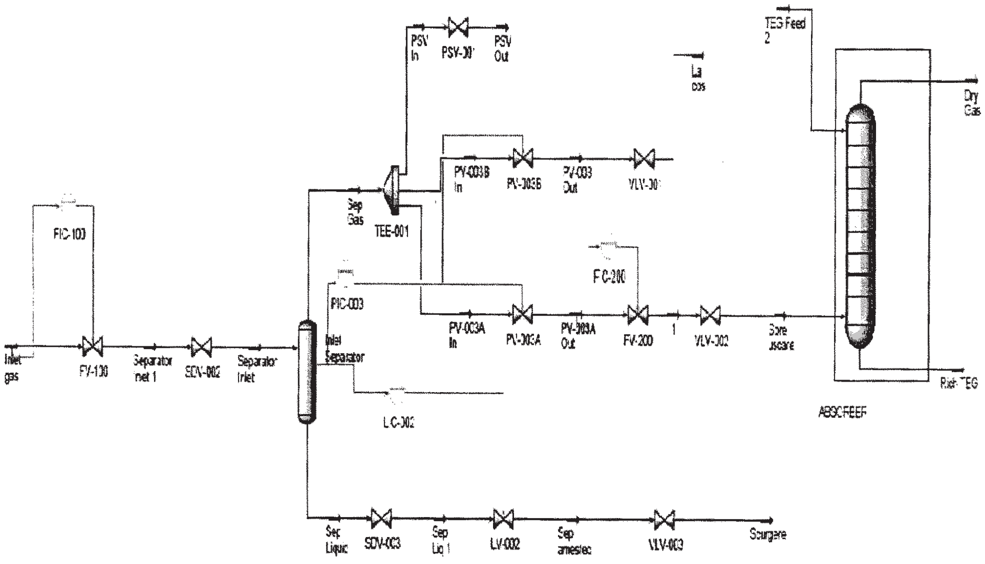

Fig. 2. The process model for the dynamic state

– a flow control loop (FIC-200) and the control valve FV-200 depending on flow, at the separator gas output. This loop is a hypothetical unit and it should be included into the model to avoid simulation of gas export at the output of this system.

Results and discussions

The simulation experiments have included the following operation cases:

– Starting the separator and filling it up; level and pressure monitoring and controlling in a normal mode of operation;

– Decreasing the liquid level because of a malfunction of the level control loop;

– Blocking the suppression path and operating the pressure valve;

– Depressurizing the vessel due to an ESD (Emergency Shut Down) event in case of system fire;

– Stopping the separator as a planned action.

Filling up the vessel and PIC/LIC operations (fig. 3). In the beginning of simulation, the equipment operating conditions are as follows: the set point for FIC-100 is 0 kg/h, the control valve FV-100 is closed and the gas does not enter the system; the separator is under pressure but the liquid level is 0%; the set point for PIC-003 is 44 barg; there is no gas flow in the system, therefore the two valves PV-003A and PV-003B are closed; there is no liquid in the separator, therefore the valve LV-002 is closed; in this case, FIC-200 will not be used and this controller was set so that the valve FV-200 to be opened all the time.

In order to simulate the vessel gradual filling, together with the pressure control loop (PIC-003) and the level control loop (LIC-002), the events programming with this software (using software event scheduler) was set in such a way to increase the setting point of the flow controller (FIC-100) from 0 kg/h to 148200 kg/h (which represents the separator normal operation point) in an hour. This will simulate a gradual opening of the valves, allowing the gas to enter the separator.

During the simulation, the software was set to register the relevant variables for this situation: the flow rate of the produced fluid, the pressure in the separator, the flow rate of the produced gas, the liquid level in the separator. Evolutions of these variables are shown in Fig. 3. One can observe that when a positive flow rate in the separator appears, PIC-003 opens the valve PV-003A, and the gas flow in the separator starts to increase; thus, pressure in the vessel remains constant, at 44 barg. The liquid level in the vessel starts increasing gradually. After about 20 min, LIC-002 will open the valve LV-002 in order to allow the separated liquid to flow to the equipment that will take it (e.g. to the drain collection system).

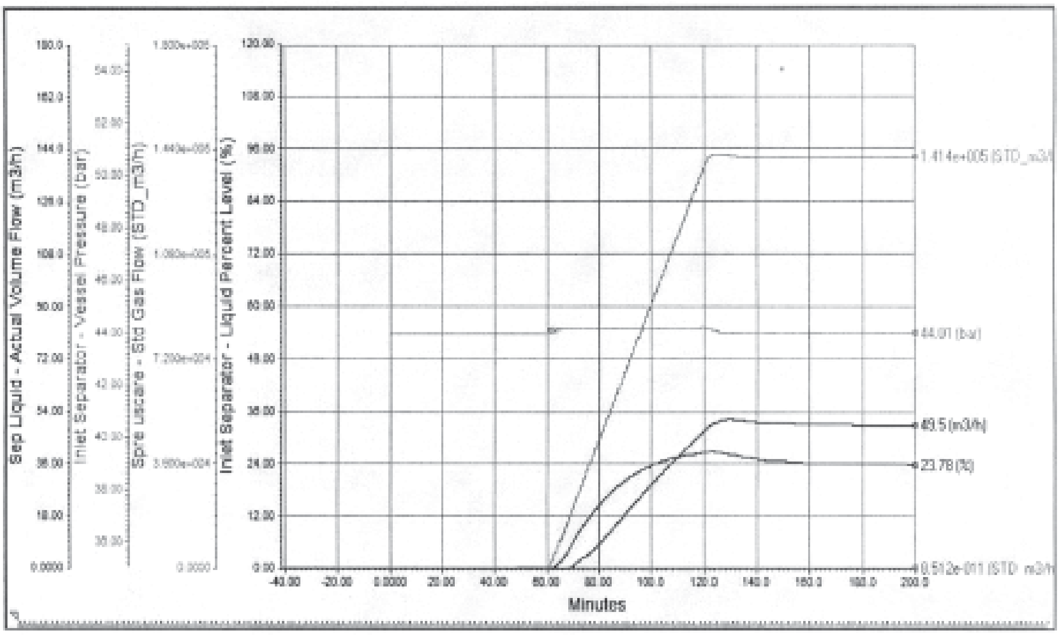

Fig. 3. Filling up the vessel and PIC/LIC operations

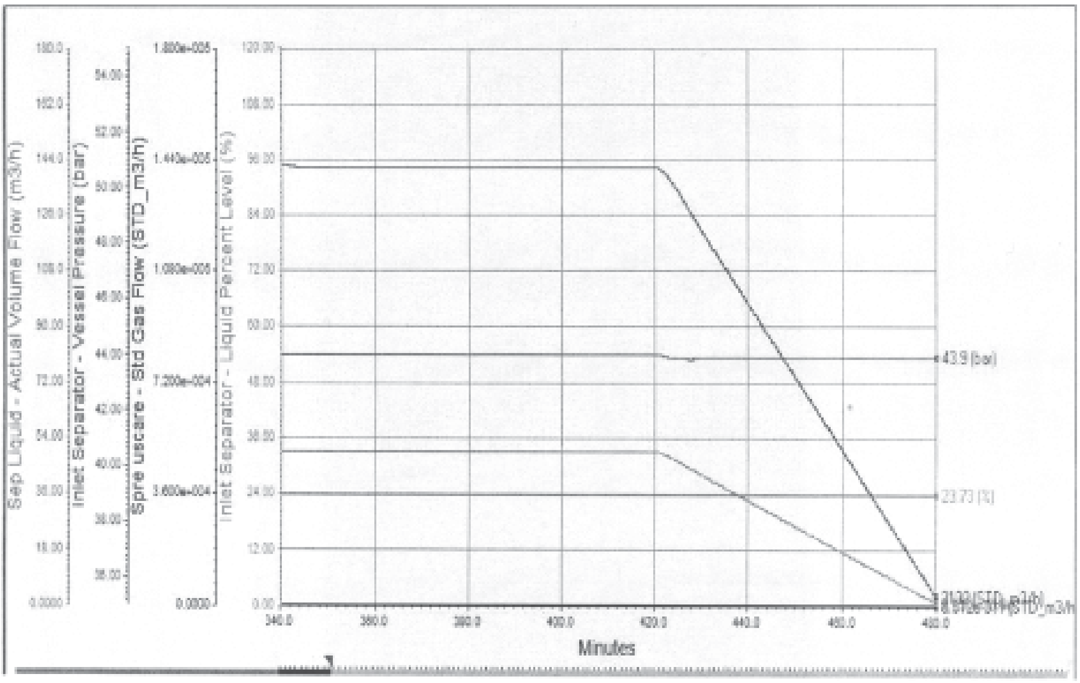

Fig. 4. Stopping the process in normal conditions

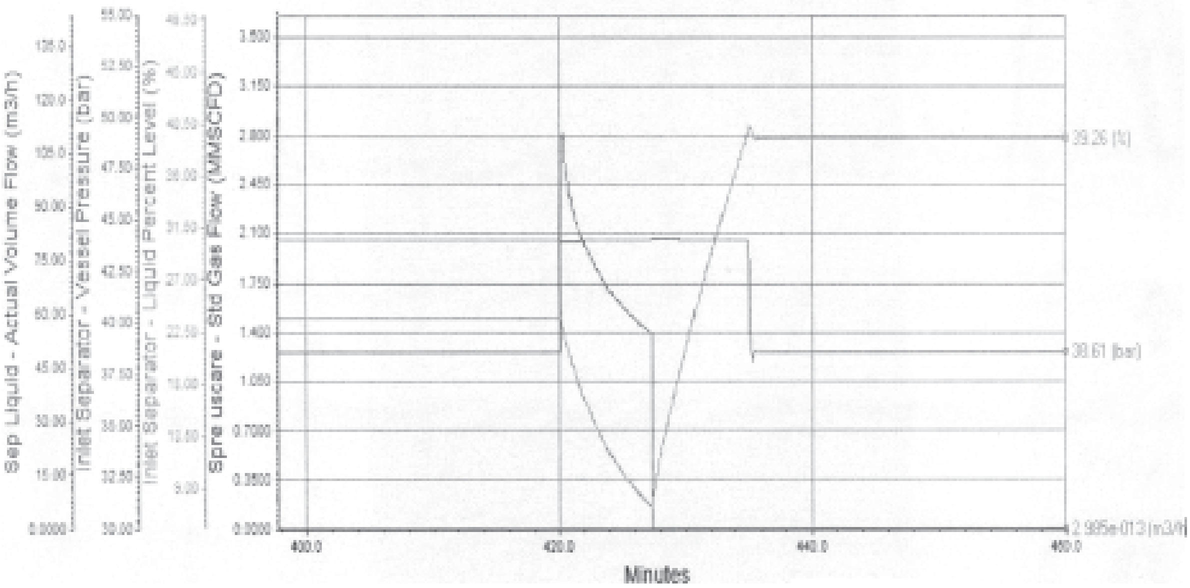

Fig. 5. Decreasing the liquid level in the separator

Stopping the process in normal conditions (fig. 4). In order to simulate the case when the process is stopped in normal conditions, together with the pressure control loop (PIC-003) operation and the level control loop (LIC-002), the event programming in this software (software event scheduler) was set, so that after 7 hours of normal function it will modify the set point for the flow controller (FIC-100) from 148200 kg/h (the normal operation point for the separator) to 0 kg/h in one hour. This will simulate the gradual closing of the valves on the main line.

Again, during the simulation, the software was set to register the relevant variables for this situation. They are the followings: the flow rate of the produced liquid, the pressure in the separator, the flow rate of the produced gas, the liquid level in the separator. These variables are shown in figure 6. One can observe that if the separator input rate flow starts to decrease, the separator output gas flow starts to decrease too. At the end of simulation, the gas flow rate is zero; therefore the vessel pressure remains constant. The pressure control system (PIC-003) will close the valve PV-003A in order to maintain a constant pressure (43.9 barg) inside the separator; the liquid level in the separator remains constant.

Decreasing the liquid level in the separator (fig. 5). In order to simulate the level decreasing in the separator, the events programming were set so that, after 7 h of normal functioning, the below described actions will be realized. Simulating an abnormal function of the LIC-002 controller, the valve LV-002 is open for 10 s. From this moment on, the level in separator starts to decrease. When the level reaches 7.5% (this level corresponds to a minimum – minimorum setting up for the level switch), the safety valve SDV-003 is closed. It is worth to mention that this valve is mounted on the way out of the liquid. From this moment on, the level in separator starts to increase. When the level reaches 40% (which corresponds to the maximum – maximorum setting up for the level switch), the safety valve SDV-002 is closed (this valve is mounted on the input way of the separator). Figure 5 shows this kind of operation mode.

The following mentioned actions can be observed. If the valve LV-002 opens, the level in the separator begins to decrease. From this moment on, a quantity of liquid is discharged to the leakage collector. After about 7 min, the level in separator reaches 7.5% and the safety valve SDV-003 is closed, therefore the liquid evacuation is stopped.

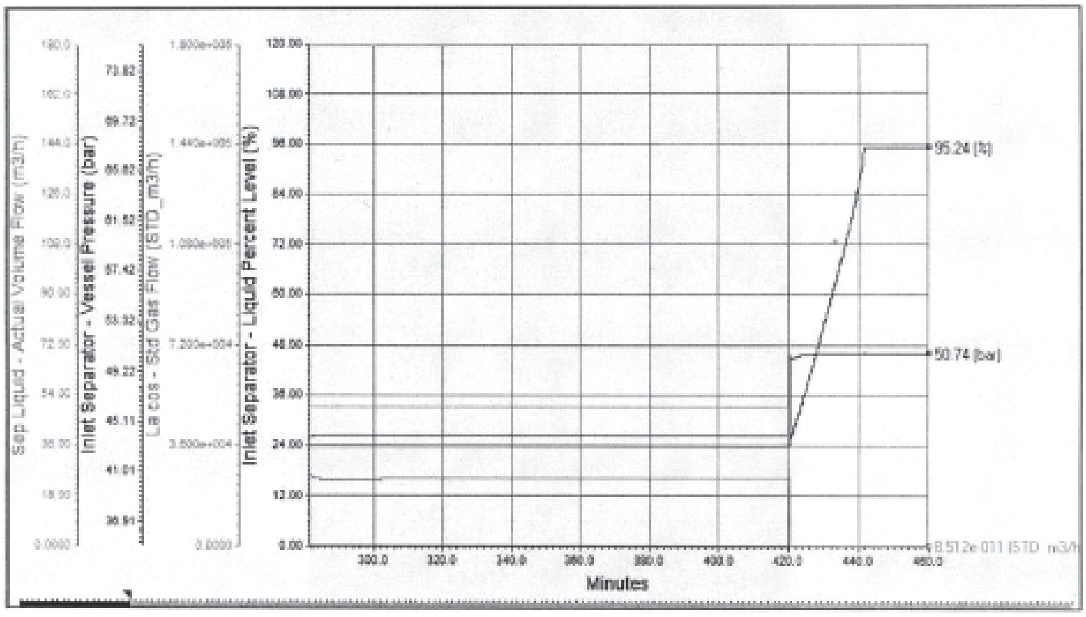

Fig. 6. Operation of the safety valve PVS

Then, the level in separator starts to increase again. After another 8 min, the level in the separator reaches 39.26% and the valve SDV-002 is closed. Thus, the vessel is isolated from the input fluid. In the end, the produced gas and liquid quantities are zero and the vessel remains under pressure.

Operation of the safety valve PVS (fig. 6). In order to simulate the safety valve operation, the gas discharge was totally blocked together with the liquid. The events programming were set so that, after 7 hof normal operation, the valves VLV-001, VLV-002 and VLV-003 are closed. When the pressure in the separator reaches at about 50 barg, the safety valve opens to protect the separator at overpressure (fig. 6).

The registered variables are shown in figure 6. One can see that if the valves VLV-001, VLV-002 and VLV-003 at the separator output are closed, the pressure in the separator increases sharply from 44 barg to 50 barg. Gas and liquid enter the separator without having the possibility to evacuate in safety conditions. The level in the separator increases from 23.75 to 95.24% in only 20 min. Then, the safety valves open since it was reached a 50 barg pressure (set up pressure).

Conclusions

There are four possible methods for gas dehydration, but glycol is chosen because it offers the best cost benefit choice. The efficiency of a dehydration plant is determined by the water dew-point for the gas. There are several design options for a glycol dehydration plant. The integration of heat exchangers is very important to minimize the energy consumption in the dehydration plant. This is due to the temperature differences between the contactor and regenerator columns.

There are several thermodynamic models that can be used for simulation where ideal liquid mixtures can be assumed. For non-ideal liquid mixtures it is however necessary to introduce equations like the Wong-Sandler mixing rule, that incorporated the excess Gibbs energy and the activity coefficients in the calculations.

In Hysys® the easiest way to simulate a dehydration plant is to insert a component splitter. Also, it is possible to simulate the dehydration plant in Hysys® using the thermodynamic packages absorption and regeneration. The result differs a little between the two thermodynamic packages; although it cannot be determined which package yields the most accurate result.

There are several processes involved in processing the reservoir fluid into oil, gas and water. One of the most important processes is gas dehydration, because wet gas increases corrosion and can cause problems from ice or gas hydrate.

Without having any clear knowledge about the real dehydration process it is almost impossible to find out which thermodynamic package produces the best results.

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