**MODELING OF REFRIGERATION BASED HYDROCARBON DEW POINT CONTROL PLANT**

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***ABSTRACT*** *Present work is an attempt to develop a steady state model of refrigeration based hydrocarbon dew point (HCDP) control process using propane as a refrigerant and ethylene glycol as an absorbent. The primary aim is to get converged model of the process at prescribe operating conditions of a commercial unit operated by PPL company with feed flow rate 2.547* [*million standard cubic feet per hour*](http://en.wikipedia.org/wiki/Million_standard_cubic_feet_per_day) *(MMSCFH) having 66% methane, feed temperature 265.8 oF* $265.8℉ $*and pressure 1325.45 psig*$1325.45psig$*. The model was developed and converged in standard flow sheeting software Aspen HYSYS®7.1 with given parameters. Peng-Robinson equation of state was used to perform thermodynamic calculations. The simulation outcomes were compared with real process conditions and in good agreement. The results were also within the standard specification of sale gas. The model was further analyzed to determine the effect of different operating parameters like temperature, pressure and molar flow rate of feed on HCDP of product gas as well as different intermediate streams. It was observed that feed stream temperature, pressure and molar flow rate has significant impact on the overall performance of the process particular on the HCDP. The minimum values of HCDP 28 °F and water content 2.5 lb/MMSCF were observed at 97.7 °F temperature and 1276.14 Psig pressure of feed stream.*

**Key Words:** Process Simulation, Aspen Hysys, HCDP

**INTRODUCTION**

Natural gas is fossil fuel like petroleum and coal. Natural gas is trapped in underground rocks much like sponge traps water in pockets. Natural gas is a complex mixture of non-hydrocarbons and hydrocarbon constituents and at the atmospheric conditions it exists as a gas. Even two wells producing from same reservoir may produce gas of different composition as the reservoir is depleted. Wet natural gas contain condensable hydrocarbon more than 0.3 gallons per 1000$ft^{3}$ of gas. Wet natural gas has low methane content as compared to dry natural gas [1-2]. Condensation is the major operational consideration of heavy hydrocarbon for gas pipelines in natural gas. Different hindrances are seen in the pipe lines due to liquid hydrocarbon in gas pipelines like reduced line capacity, equipment problem such as compressor damage and increased pressure drop. Several control parameters are monitored to get rid of hydrocarbon condensation or “liquid dropout” in gas pipelines and assigned limits including C6+ GPM (gallons of liquid per thousand standard cubic feet of gas), mole fraction C6+, cricondentherm hydrocarbon dew point (CHDP) and hydrocarbon dew point (HDP or some time HCDP). When natural gas changes its phase from gas to liquid by condensation of hydrocarbon rich mixture that temperature is known as hydrocarbon dew point. Water due point issue is similar to HCDP, except that it has a multi-component system. Natural gas typically contains many heavy hydrocarbon components in smaller amounts than the lighter gaseous ends. Among those heavy hydrocarbons, the heaviest component that first condense basically defines the HCDP of the gas.

Controlling HCDP and water dew point is also necessary to qualify the gas for transportation through pipelines to high efficiency gas turbine end users that have need of a consistent and dry quality fuel [3-6]. Natural gas liquids (NGL) are recovered from natural gas at purifying facility as a byproducts with a HCDP control unit.  The quality and quantity of recovered NGLs depend on the composition of the gas. Therefore gas composition has a major impact on the process selection.  These are few prominent processes for a HCDP control.

* Mechanical refrigeration
* Turbo Expanders
* J-T Valve Expanion

As this work is based on mechanical referigeration process so subsequent section is a brief description abou this process.

**Mechanical Refrigeration Process**

Mechanical refrigeration as shown in Fig-1 is the most direct and simplest process for NGL recovery and dew point control. External or mechanical refrigeration, is supplied by a vapor-compression refrigeration cycle that usually uses propane as the refrigerant and reciprocating or centrifugal types of compressors to move the refrigerants from low to high pressure operating conditions. Additional refrigeration is recovered in the gas-to-gas heat exchanger by leaving the cold separator countercurrent to the warm inlet gas, passing the gas. The temperature of warm inlet gas countercurrent to cold gas stream leaving this exchanger approaches up to 5$℉$. The H.E (chiller) is kettle-type unit typically a shell and tube. The refrigerant flows in annulus while process gas flows inside the tubes and energy is transferred from process gas to refrigerant. The propane (refrigerant) escape the chiller vapor space after boiling leaves as essentially as a saturated vapor.

The hydrate formation or freeze up are the common problems in gas-to-gas exchangers. Freeze up partially blocks exchanger tubes, thus increasing pressure drop and decreasing heat exchange. The weak glycol solution, containing absorbed water, is separated in the cold separator, re-concentrated, and recycled. A mechanical refrigeration process is adopted when sizeable amounts of condensate are expected [7-10].



**Fig. 1** **Schematic of refrigeration package for dew point control plant**

The present study was conducted through the simulations on the model of mechanical refrigeration process. The model was developed in standard flow sheeting software Aspen HYSYS®7.1. The designing of refrigeration model was based on data obtained from Pakistan Petroleum Limited (PPL) Company. Ethylene glycol was injected at the inlet of the gas-to-gas exchanger to avoid hydrate formation or freezing issues. The refrigeration process basically controls hydrocarbon dew point (HCDP), Water DP, Water Content, gas calorific valve, pressure and temperature of natural gas to meet standard sale point specifications. As per those standard conditions [11a], the HCDP must be less than 32℉, water content should be less than 6 lb/MMSCF, gross calorific value must be greater than 950 BTU/SCF and Wobbe Index should be greater than 1220 BTU/SCF.

Methodology

Development of Model

Modeling and simulation are the modern tools to conduct the several scientific and engineering. Aspen HYSYS is a powerful engineering simulation tool, has been uniquely created with respect to the program architecture, interface design, engineering capabilities and interactive operations. Aspen HYSYS serves as the engineering platform for modeling processes from upstream, through Gas Processing and Cryogenic facilities, to Refining and Chemicals processes [12, 13].

In present study, the model of mechanical refrigeration based HCDP control process was developed in standard flow sheeting software Aspen HYSYS®7.1. Peng-Robinson (PR) equation of state as described by Eq. (1) was solved to calculate the specific volume of a gaseous mixture of chemicals at a specified temperature and pressure.



(1)

Where

P = Pressure

T = Temperature

R = General gas constant

 = Specific volume

Z = Compressibility factor of real gas

The converged process flow diagram (PFD) is shown in Fig.2 for the developed model.

**Fig. 2. Process Flow Diagram of Refrigeration Based**

Hydrocarbon Dew Point Control Process

The process begins by mixing two streams i.e., natural gas feed stream and ethylene glycol streams to make a stream identical with industrial conditions. The temperature of mixed feed was then reduced in multi-stream heat exchanger and then this low temperature feed was sent to 1st three phase separator where water, condensate and gas phases were initially separated. The process was repeated with 2nd 3-phase separator after mixing ethylene glycol in the outlet gas from 1st 3-phase separator and getting chilled in cooler for further recovery. Propane was used as refrigerant and ethylene glycol used as an absorbent. The gas stream from chiller was at 4$℉$ $(20℃)$. 2-phase separator (KO vessel or Knock-out vessel) was also added for further recovery of natural gas from condensate. Before entering in the knock out vessel the pressure of condensate was dropped to about 135 Psig through valve. The pressure of gas obtained from knock-out vessel was increased at required outlet pressure of 1300 Psig with the help of compressor.

**Inlet Streams Parameters**

The data for inlet streams is necessary to develop the model. There are basically two inlet streams in the developed case (See Fig-2). One is natural gas stream (FEED) where as other is ethylene glycol stream (EG\_INJ01). Both streams are mixed with mixer MIX-100 to produce one feed stream which meets the actual industrial conditions. The parameters for FEED streams are given in Table 1 and its molar composition in Table 2. Table 3 describes the parameters and molar composition of EG-INJ01 stream.

**Table 1: Inlet Feed Condition**

|  |  |
| --- | --- |
| **Operating Parameter** | **Value** |
| Feed flow rate | 2.547328 MMSCFH |
| Operating pressure | 1325.452 Psig |
| Feed inlet temperature | 265.8 ℉ |

**Table 2: Composition of Well Stream Gas**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S. No.** | **Component** | **Mole fraction** | **S. No.** | **Component** | **Mole fraction** |
| 01. | NO2 | 3.33×10-3 | 14. | n-Nonane | 1.17×10-3 |
| 02. | CO2 | 2.22×10-6 | 15. | n-Decane | 7.03×10-4 |
| 03. | H2S | 3.29×10-3 | 16. | n-C11 | 4.31×10-4 |
| 04. | Methane | 0.66068 | 17. | n-C12 | 3.22×10-4 |
| 05. | Ethane | 3.57×10-2 | 18. | n-C13 | 2.86×10-4 |
| 06. | Propane | 3.37×10-2 | 19. | n-C14 | 2.15×10-4 |
| 07. | i-Butane | 7.48×10-2 | 20. | n-C15 | 2.06×10-4 |
| 08. | n-Butane | 2.79×10-3 | 21. | n-C16 | 1.50×10-4 |
| 09. | i-Pentane | 1.03×10-3 | 22. | n-C17 | 1.13×10-4 |
| 10. | n-Pentane | 9.93×10-4 | 23. | n-C18 | 9.74×10-5 |
| 11. | n-Hexane | 1.29×10-3 | 24. | n-C19 | 7.85×10-5 |
| 12. | n-Heptane | 2.02×10-3 | 25. | n-C20 | 6.41×10-5 |
| 13. | n-Octane | 2.29×10-3 | 26. | H2O | 0.17419 |

**Table 3: Inlet condition & composition of EGLYCOL stream**

|  |  |
| --- | --- |
| **Operating Parameters** | **Composition Ratio** |
| Flow rate | 0.3 MMSFCH (0.209 MMSCFH for stream 2) | H2O | 0.75 |
| Operating pressure | 1325 psig (1299 Psig for stream 2) | Ethylene Glycol | 0.25 |
| Temperature | 140 °F |  |  |

**Unit Operations used in the Model**

There are various unit operations connected with streams to achieve the task of reducing HCDP. Table 4 shows a list of those unit operations along with their names in PFD and types.

**RESULTS AND DISCUSSION**

In present work standard chemical engineering process modeling software Aspen HYSYS®7.1 was used to simulate the mechanical refrigeration based hydrocarbon dew point control process. The feed data has taken from a running process operated by Pakistan Petroleum Limited (PPL).

**Verification of Modeling Results**

The model results were verified having a comparison with actual industrial data for some important sale gas parameters. Further the results were also checked against the standard specifications set by gas marketing companies. Both the comparisons are shown in Table 5. The comparison between the results obtained from model and actual industrial values depicts that there is less than ±1% for all important parameters of sale gas. Further it is also confirmed that the values for all those important parameters fall well within the standard specification ranges set by gas marketing companies. Reports (DPR) of the running process operated by PPL.

As model results are in good agreement with actual industrial data and found well in standard sale gas specification ranges so the model is verified and considered as validated for further analysis.

**Simulated Effects for Various Important Input Parameters on the Performance of Process**

Operating parameters like feed temperature, pressure and flow rate of feed gas are important parameters for hydrocarbon dew point control process [14]. After the confirmation of validity of model results, further simulations were carried out in order to study the impacts of various important parameters like temperature, pressure and molar flow of feed stream. These effects are discussed in individual sub-sections as follows:

**Effect of FEED stream Temperature on HCDP**

The effects of FEED stream temperature on HCDP for outlet stream and different intermediate streams are shown in Fig. 3. The relationship between feed temperature and HCDP of various streams (Fig. 3) is developed keeping constant pressure and molar flow of feed streams.

**Table 4. Various Unit Operations Used in the Process.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No.** | **Unit Operation** | **Name in PFD** | **Type** |
| 1 | Heat Exchanger | COLD BOX | Cross flow, Coil wounded heat exchanger |
| 2 | 1st 3-Phase Separator | INLET SEPARATOR | 3-Phase Horizontal Separator |
| 3 | Cooler | PROPANE CHILLER | Mechanical Propane Chiller |
| 4 | 2nd 3-Phase Separator | LOW TEMPERATURE SEPARATOR | 3-Phase Horizontal Separator |
| 5 | 2-Phase Separator | KO Vessel (Knock Out Vessel) | Liquid-Vapor Separator |
| 6 | Compressor | COMPRESSOR | Centrifugal Compressor |
| 7 | Different Valves | VLV-100, 101, 102, 103, 104 | Gate Valves |
| 8 | Mixers | MIX-100, 101, 102, 103 | Simple Mixing the stream compositions |

**Table 5: Comparison of Model Results with Actual Conditions and Standard Sale Gas Specifications.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Important Parameters** | **Running Process Values at PPL Company\*** | **Model Results** | **% Error** | **Standard Sale Gas Specifications** |
| HCDP | 28.51 ℉ | 28.32℉ (-2°C) | 0.66 % | ≤32℉(0℃) |
| Water Content | 2.5 lb/ MMSCF | 2.52 lb/MMSCF | -0.8 % | ≤6lb/MMSCF |
| GCV | 1165.4 BTU/SCF | 1174.7 BTU/SCF | -0.79 % | >950 BTU/SCF |
| Wobbe Index | 1452.2 BTU/SCF | 1443.41 BTU/SCF | 0.6 % | >1220 BTU/SCF |
| Temperature | 98.6 ℉ | 97.7℉ (36.5°C) | 0.91 % | ≤110℉(43℃) |
| Pressure | 1279.2 Psig | 1276.14 Psig | 0.24 % | >1275 Psig |
| Carbon | 0.392 % | 0.39 %mol | 0.5 % | <2.8 % mol |

\*Note: The values were taken from Daily Progress

**Fig. 3: Effect of FEED stream Temperature on hydrocarbon dew point (HCDP).**

No effects for feed stream temperature were observed on HCDP of exit streams for both 3-phase separators (i.e. Stream G-03 A and G-05). The fundamental reason is that both the 3-phase separators are operating on fixed conditions and getting controlled temperature inlet feed all the time as per explanation by Hammer schmidt et al [15]. The HCDP for intermediate stream G-07A of natural gas coming out from 2-phase separator (knock-out vessel) increases from 0 to 400°F on increasing feed stream temperature from 0 to 45°F and then decreases again after 150°F and become negative for some time. The HCDP of sale, gas stream shows no effect up to 250°F feed temperature and then little increased was observed after that temperature as per previous studies [16].

**Effect of FEED stream Pressure on HCDP**

The effects of FEED stream pressure on HCDP for outlet stream and different intermediate streams are shown in Fig. 4 at constant temperature and molar flow. Like temperature, similar trends of no effects on increasing feed stream pressure was observed for exit streams from both 3-phase separators (stream G-03A and G-05). The HCDP for exit stream from 2-phase separator (knock-out vessel) was initially increased up to above 250°F on increasing feed stream pressure from 200 to near about 300 Psig and then decreased up to 100 °F on further increase in feed stream pressure. The sale gas HCDP is first increased up to 200°F at about 300 Psig of feed stream pressure and then decreased and become constant at 50°F after the feed stream pressure of 1200 Psig. It shows the gas at higher pressure remain in gas state up to 50°F and after this temperature the condensate formation could start in gas pipelines as per earlier study [16,17].

**Effect of FEED stream Molar Flow on HCDP**

The effects of FEED stream molar flow on HCDP for outlet stream and different intermediate streams are shown in Fig. 5 keeping temperature and pressure constant.

**Fig.4: Effect of FEED stream Pressure on hydrocarbon dew point (HCDP).**

**Fig.5: Effect of FEED stream Molar Flow on hydrocarbon dew point (HCDP).**

Once again no effect on the HCDP was observed for exit stream (G-06) for first 3-phase separator on increasing the molar flow of feed stream. Rest of the intermediate streams G-05, G-06, G-07A and G-07B along with Sale Gas stream show slight increase and the drop in HCDP when feed stream flow increased from 0 to 0.6 MMSCFH. There is HCDP of these streams become constants after 0.6 MMSCFH and have not affected on further increment in molar flow rate of feed streams confirming the outcome of previous studies [14, 18].

**CONCLUSION**

The mechanical refrigeration based hydrocarbon dew point control process was successfully modeled in commercial flow-sheeting software Aspen Hysys®7.1. The model results were compared against the real running process outputs and found good agreement with less than 1% error. Further the model results were also found within acceptable limits as per standard sale gas specifications for important parameters. Further simulations were carried out on a validated model to study the impacts of various important operating conditions like temperature, pressure and molar flow of feed stream.

The brief conclusions are as under:

* It is concluded that Peng-Robbinson equation of state gives good results for the thermodyanic calcuations of different species in natural gas systems.
* In hydrocarbon control processs based on mechanical referigaration system, there is no effect on HCDP of outlet natural gas stream from 0 to 200°F of feed stream temperature. After this temperature there is little increase in HCDP of sale gas from the process.
* To meet the standard sale gas specifications regarding HCDP the pressure of feed stream must be above 1275 Psig.
* It is also concluded that at low molar flow of feed stream, the HCDP of product gas stream is higher which is unwanted. In order to maintain the required HCDP of product gas the molar flow of feed stream should be above 0.6 MMSCFH.
* The minimum values of HCDP 28°F and water content 2.5 lb/MMSCF were observed at 97.7°F temperature and 1276.14 Psig pressure of feed stream.

Overall it is concluded that hydrocarbon dew point control process for natural gas with the mechanical relegation system is capable to meet the standard sale gas specifications. There is a significant impact of temperature, pressure and molar flow rate of feed stream on the overall performance of the process.

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