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Controlling hydrocarbon dew point and water dew point of natural gas using Aspen HYSYS

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Abstract

A great attention is subjected to the environmentally friendly natural gas. Compared to other fossil fuels, natural gas is a cleaner burning due to the lower emission of carbon dioxides into the air. Removal of associated hydrocarbons from natural gas streams plays an important role to sell and to achieve the pipeline specification of natural gas. To satisfy the specification of pipelines, the hydrocarbon dew point and water dew point of natural gas must be controlled below the pipeline operating conditions to prevent many problems: two-phase flow and hydrate formation in the system. The main purpose of this paper is to simulate the gas plant process to study the effect of natural gas composition and changing in differential pressure of Joule–Thomson expansion valve on the obtained values of hydrocarbon, water dew points, and cricondenthem temperature.

The results of process simulation using Aspen HYSYS have shown that the control of hydrocarbon dew point, water dew point, and cricondenthem of natural gas is achieved through increasing the Joule–Thomson valve differential pressure. There is an inverse relation between increasing Joule–Thomson valve differential pressure (Δp) and hydrocarbon dew point, water dew point, and cricondenthem to meet the specification of gas pipeline transmission. Increasing differential pressure (Δp) from 14 bar to 24 bar causes a decrease in hydrocarbon dew point, water dew point from -1 to -26°C and from 0 to -18°C , respectively. Cricondenthem is also decreased from 4 to -12°C by increasing differential pressure (Δp) from 14 to 24 bars. The operating conditions at differential pressure below 14 bar is not advisable because cricondenthem temperature does not meet the specification of gas pipeline transmission and hence lead to many problems. Careful adjustment of the operating conditions of gas processing plant is very important by making such simulations to choose the optimum operating conditions which meet gas pipeline transmission.

Keyword: Natural gas, Process simulation, Control, Hydrocarbon dew point, Water dew point, Cricondenthem

Introduction

The production of natural gas and derivatives play an extremely important role in Egypt. Natural gas consumption is about 53% of the total energy used. Gas total production peak was in 2020 that reached an average rate of 85 BCM/year produced from three areas in Egypt which are Nooros field, West Delta Deep Marine, and Zohr. Currently in 2022, Egypt has three areas of production of natural gas which are Nooros field, West delta deep marine, and Zohr. In 2027, it is expected that gas production will be produced from two areas which are West Nile Delta and Zohr. Natural gas is used in various sectors such as electricity, industry, petroleum, residential, and CNG (compressed natural gas) sectors. The electricity sector is the largest gas consumer, as natural gas consumption reached 62.3% of the total local gas consumption. The industry sector consumes around 22.5% of the total local gas consumption. The petroleum sector consumes about 10.1% of total local consumption. After that, the residential and CNG sectors come at the least sectors that consume natural gas which reached 5.1% of total local natural gas consumption [1–4].

Natural gas, a highly efficient form of energy, produces a lot of energy and emits fewer pollutants than many other energy sources. It has an increasing demand to provide energy in heating homes, cooking food, and generating electricity. It is considered as a source of hydrocarbon needed in petrochemical feedstocks. It also provides the main ingredients for such varied products as plastics, fertilizers, anti-freezes, and fabrics [5, 6]. Industrial consumers get advantages from operating natural gas combined heat and power (CHP) and combined cooling, heat, and power (CCHP) systems, similar to those used in commercial settings. Natural gas has different compositions depending on the well type and location [5]. Natural gas is formed from methane mainly and smaller amounts of ethane, propane, butane, and heavier hydrocarbons along with varying amounts of water vapors, carbon dioxide, sulfur compounds, and other non-hydrocarbons [7]. Ethane, propane, and butane are known as associated gases or (NGL) [8–12]. They have a variety of different purposes including the improvement of oil recovery in oil wells, providing raw materials for oil refineries or petrochemical plants, and as sources of energy. These NGL components must be recovered to control the dew point of the natural gas stream and also to earn revenue by selling out the separated components. Refrigeration is applied using a direct expansion Joule-Thomson technique or turboexpander to control the dew point of both water and hydrocarbons of natural gas in order to improve gas quality and satisfy the specification of pipelines to obtain saleable and useful energy forms to be used in a wide variety of applications [11–14]. The hydrocarbon liquid dropout causes some difficulties in gas transmission systems including the increase in pressure drop, reducing in line capacity and some equipment problems [15, 16]. Avoiding liquid dropout, the operating current specifications of gas transmission lines require to be operated above the hydrocarbon dew point or cricondentherm temperature. The achievable control of hydrocarbon dew point and water dew point depends on the differential pressure available and the composition of the feed gas. In industry, there are many widely applied different methods used for hydrocarbon dew point control. Joule-Thomson (J-T) expansion technique is the most preferable method rather than mechanical refrigeration if enough pressure is available [17].

Table 1 Pipeline specifications of natural gas [11]

Parameter	Pipeline specifications
Water dew point, °C	< 0 @ 70 bars
Hydrocarbon dew point, °C	< 5 @ 70 bars
Cricondentherm, °C	< 5
Gross calorific value, BTU/SCF	> 1000

Table 2 Feed compositions of different wells (C1 and C2) of natural gas

	C1, mass %	C2, mass %
N ₂	0.20	0.05
CO ₂	0.70	0.46
Methane	60.00	61.27
Ethane	5.00	5.49
Propane	3.92	6.48
i-Butane	2.00	3.16
n-Butane	1.51	2.77
C ₅	6.50	1.25
C ₆ ⁺	13.77	15.00
H ₂ O	6.00	3.66
Methanol	0.40	0.40

This work aims to simulate the gas processing plant in order to illustrate the optimum operating conditions using Joule–Thomson expansion technique. The effect of feed composition of natural gas and changing in Joule–Thomson valve differential pressure (Δp) on hydrocarbon dew point, water dew point, and cricondenthem temperature is studied to meet the specification of pipeline gas transmission Table 1.

Methods

Gases, coming from the wells located in North Nile Delta, contain mainly methane and other hydrocarbons. The feed composition of two wells (C1 and C2) are listed in Table 2. Aspen HYSYS steady-state simulation software version 11 is used to study the effect of different process variables on hydrocarbon dew, water dew point, and cricondenthem in the gas processing plant and choose the optimum process condition. The selected physical property package for the HYSYS model developed is the Peng-Robinson Equation-of-State [18, 19]. The gas processing plant is shown in Fig. 1 and described as follows:

Plant general description

- Gas streams from the wells are gathered and delivered to the inlet manifold, and methanol solution is injected to prevent hydrate buildup at low temperatures [20].
- Gases, condensate, and produced water are separated in three-phase separator.
- Gases are treated in a low temperature separation train which contains gas/gas heat exchanger for cooling, Joule–Thomson (J-T) valve for reducing pressure and a low

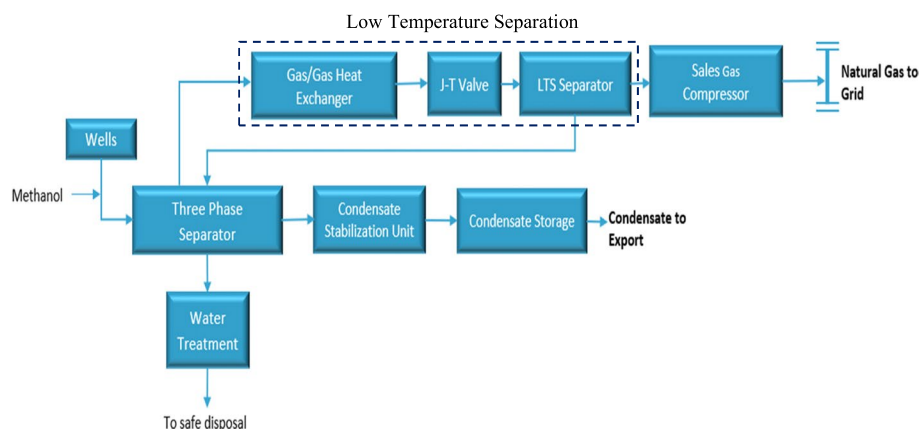


Fig. 1 Gas plant block flow diagram [15]

temperature three-phase separator to separate the condensate liquid, water, and sale gas.

- Sale gas stream is then recycled to the heat exchanger to cool the feed gas and collected the sale gas as the main product with certain conditions.
- Condensate is stabilized via a two-stage condensate stabilization unit, stored in tanks, and exported via pumps and pipeline to the national condensate grid.
- Produced water is degassed and stored in tanks where it is transported by trucks to a safe disposal.
- The actual plant inlet pressure varies from 51 bars to 66 bars related to the required Joule–Thomson valve differential pressure to ensure high quality of sales gas.

Results and Discussion

The results are divided into four main parts: the first part studies the effect of changing differential pressure of Joule–Thomson expansion valve on the specifications of the natural gas such as hydrocarbon dew point, water dew point, and cricondenthem temperature using composition (C1). The second part illustrates the effect of compositions (C1 and C2) of wells on hydrocarbon dew point, water dew point, and cricondenthem. The third part includes the mass balance of LTS train for different feed gas compositions. The fourth part explains the effect of Joule–Thomson valve differential pressure on sale gas gross calorific value using different compositions of natural gas. The conditions of each stream of LTS train are obtained using Aspen HYSYS and the block flow diagram of the gas processing plant is previously shown in Fig. 1.

Effect of Joule–Thomson valve differential pressure (Δp) on the specifications of natural gas using composition (C1)

Effect of (J-T) valve differential pressure (Δp) on hydrocarbon dew point of natural gas

Hydrocarbon dew point plays an important role in the specifications of gas pipeline transmission. Hydrocarbon dew point is the temperature at which the condensation of natural gas occurs when it is cooled at constant pressure [15]. It is necessary to control

the hydrocarbon dew point for economical, operational, and safety reasons [20]. The feed of natural gas composition used is from well (1), C1. The effect of differential pressure (Δp) of Joule–Thomson expansion valve on hydrocarbon and water dew points obtained from the process simulation using HYSYS is shown in Fig. 2. There is an inverse relation between increasing in Δp and the values of hydrocarbon dew point and water dew point. Increasing Δp from 12 bars to 25 bars causes a decrease in hydrocarbon dew point from -1 to -26.5°C which normally indicates a lower proportion of heavy hydrocarbon components included in this composition of natural gas. This is an important parameter for pipeline transmission specifications. If the natural gas contains a high proportion of heavy hydrocarbons, there is a greater risk of liquid condensate forming in the pipelines. These condensates cause an increase in pressure drop and introduce operational problems resulting from a two-phase formation. These condensates can cause harmful damage such as blockage of pipelines.

Effect of (J-T) valve differential pressure (Δp) on water dew point of natural gas

Water dew point is the temperature at which water vapor begins to condensate. Controlling water dew point of gas prevents the condensation and accumulation of water at low points in the pipelines. The water dew point specification is usually achieved by removing water vapor from the process gas plant stream using different dehydrations or other technologies. Methanol is used as hydrate inhibitor and applied in sufficient quantities. The injected inhibitor absorbs water in the gas to prevent freezing or hydrate formation. The effect of the Joule–Thomson valve differential pressure (Δp) is estimated in Fig. 2.

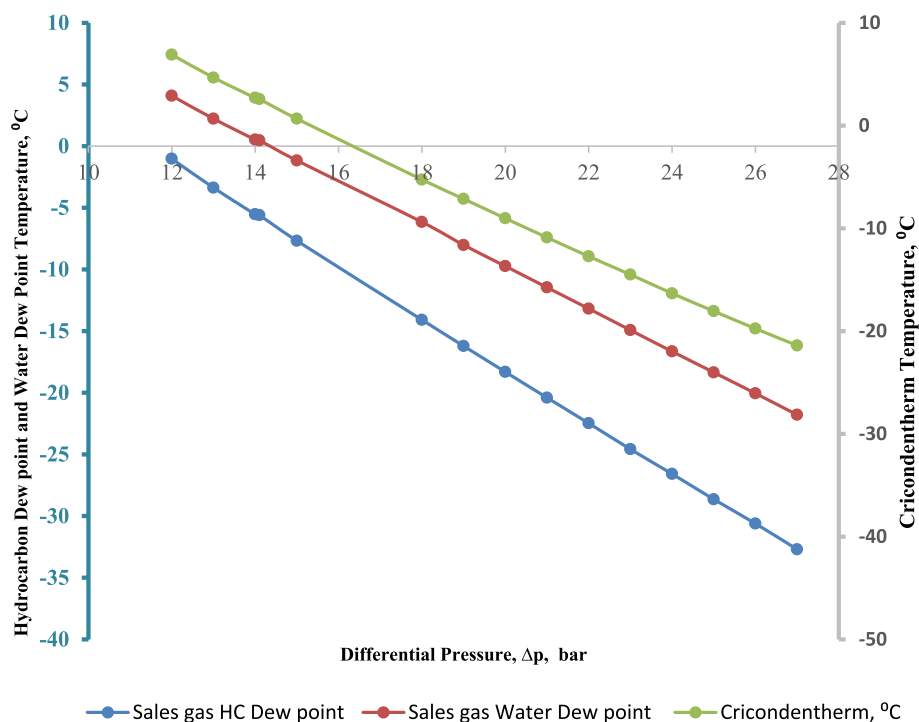


Fig. 2 Effect of (J–T) valve differential pressure (Δp) on hydrocarbon dew point, water dew point, and cricondetherm using composition of natural gas, (C1)

It is clear that increasing the differential pressure obtained from J–T expansion from 14 bars to 24 bars causes a reduction in water dew point from 0 to -18°C which meet the specification of pipeline transmission.

Effect of (J-T) valve differential pressure (Δp) on cricondenthem temperature of natural gas

Cricondenthem can be defined as the maximum temperature at which liquids and vapors can coexist. One phase is present at any pressure at higher temperatures than cricondenthem. The liquid–vapor boundary terminates at a critical point with a critical temperature and critical pressure. By simulating the effect of Joule–Thomson valve differential pressure (Δp) on the cricondenthem temperature as shown in Fig. 2, it is found that increasing differential pressure (Δp) from 14 bars to 24 bars causes a reduction in cricondenthem temperature from 4 to -12°C . This means that operating at values of differential pressure (Δp) lower than 13 bars is not safe because cricondenthem records values greater than 5°C which does not meet gas pipeline transmission.

Effect of different compositions of natural gas on hydrocarbon dew point, water dew point, and cricondenthem

The results of this part illustrate the effect of different compositions of natural gas obtained from wells. Gas compositions mentioned in Table 2 contains well 1 (C1) and well 2 (C2) with various concentrations of different components. The results are given in Figs. 3, 4, and 5. It is obvious that hydrocarbon dew point, water dew point, and cricondenthem are affected by changing the composition of natural gas. A natural gas with a certain composition (C1) listed in Table 2 gives lower values of hydrocarbon dew point and cricondenthem compared to these values obtained using natural gas with composition (C2) which contains more heavier hydrocarbons C_6^{+} . This result explained as follows: increasing the concentration of heavier hydrocarbons, especially C_6^{+} causes an increase of hydrocarbon dew point which is very sensitive to the specific components of the gas stream and is strongly influenced by the concentration of the heavier hydrocarbons. The results listed in Table 3 shows that at differential pressure (Δp) equals to

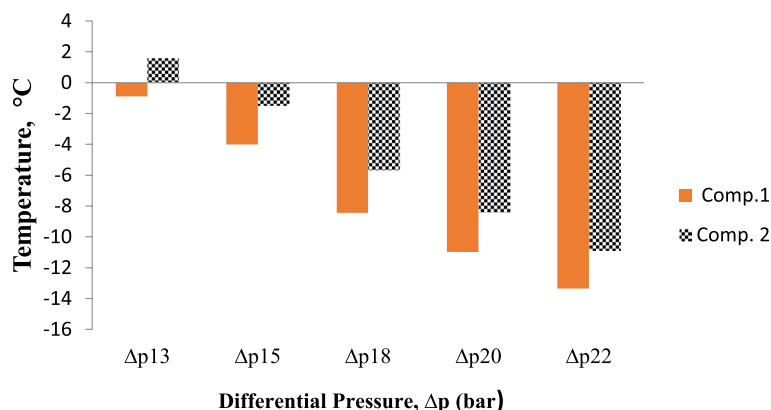


Fig. 3 Effect of (J–T) valve differential pressure (Δp) on hydrocarbon dew point using different composition of natural gas, C1 and C2

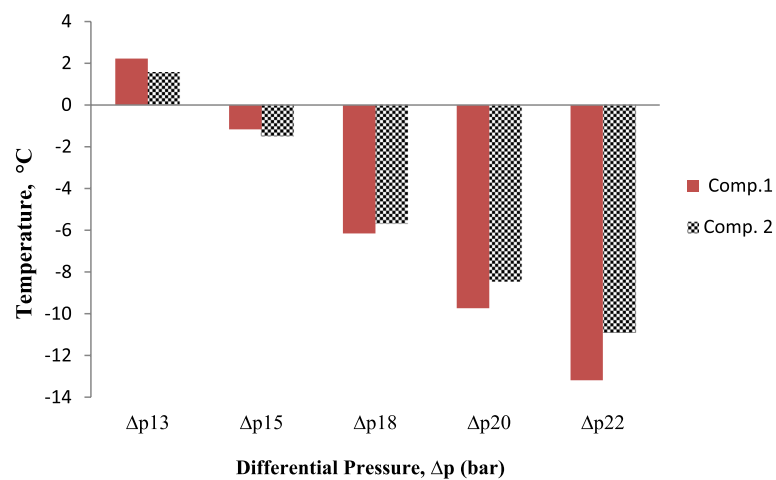


Fig. 4 Effect of (J-T) valve differential pressure (Δp) on water dew point using different composition of natural gas, C1 and C2

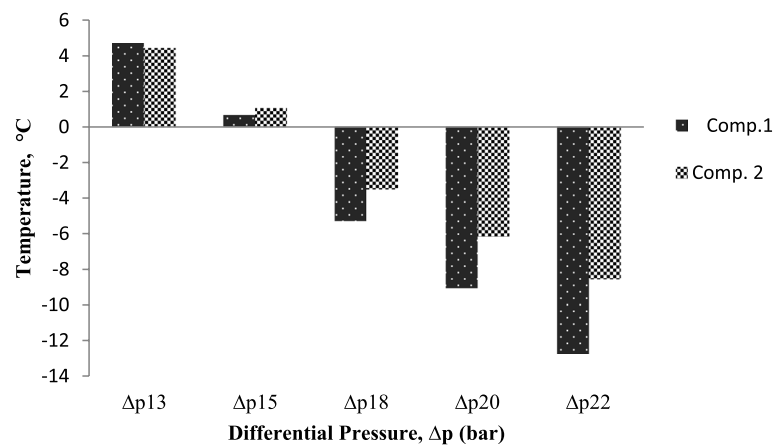


Fig. 5 Effect of (J-T) valve differential pressure (Δp) on cricondenthem using different composition of natural gas, C1 and C2

Table 3 Hydrocarbon dew point, water dew point, and cricondenthem using different compositions (C1 and C2)

	C1	C2
J-T valve differential pressure, (Δp), bar	15	15
Hydrocarbon dew point, °C	−4.0	−2.0
Water Dew Point, °C	−1.2	−1.80
Cricondenthem, °C	0.50	1.0

15 bars, the estimated values of hydrocarbon dew point, water dew point, and cricondenthem using composition (C1) are -4.0°C , -1.2°C , and 0.5°C , respectively, whereas those obtained using composition (C2) are -2.0°C , -1.80°C , and 1.0°C , respectively. All these results meet pipelines specification of natural gas transmission.

Table 4 Mass balance of low temperature separation train streams

	Feed gas		Sales gas		Condensate	
	C1, mass %	C2, mass %	C1, mass %	C2, mass %	C1, mass %	C2, mass %
N ₂	0.24	0.07	0.24	0.07	0.00	0.00
CO ₂	0.93	0.56	0.95	0.58	0.14	0.10
Methane	80.66	75.51	82.77	77.35	4.62	5.33
Ethane	6.24	6.79	6.38	6.92	2.05	2.63
Propane	4.33	7.37	4.38	7.43	5.04	9.77
i-Butane	1.85	3.23	1.84	3.19	5.26	10.23
n-Butane	1.48	2.67	1.44	2.60	5.94	11.84
C ₅ ⁺	2.87	2.49	2	1.84	76.89	60.00
H ₂ O	0.35	0.33	0.00	0.01	0.00	0.00
Methanol	1.05	0.97	0.00	0.01	0.05	0.10

Table 5 Conditions of low temperature separator train unit

	Feed gas		Sales gas		Condensate	
	C1	C2	C1	C2	C1	C2
Vapor fraction	0.99	0.99	1.00	1.00	0	0
Temperature, °C	30.72	30.67	0.62	2.00	0.62	2.00
Pressure, bar	51.00	50.89	35.97	36.77	35.97	36.77
Molar flow, kg mole/h	2692.34	2801.5	2675.6	2783.36	9.11	10.34
Mass flow, kg/h	48783.57	52802.52	47918.75	51928.34	605.08	608.91
Liquid volume flow, m ³ /h	151.36	160.32	150.12	159.03	0.98	1.03

Mass Balance of LTS Train

Mass balance of each stream of low temperature separation train unit is listed in Table 4 for each composition C1 and C2. The conditions of each stream are listed in Table 5.

Effect of (J–T) valve differential pressure on sale gas gross calorific value using different composition of natural gas, C1 and C2

Gross calorific value of sale gas ranges from 1092 Btu/SCF to 1078.5 Btu/SCF using composition C1 whereas it varies from 1137 Btu/SCF to 1122 Btu/SCF using composition C2 as Δp increases from 12 bar to 25 bar. These values meet the specification of sale gas listed in Table 1.

Conclusions

The hydrocarbon and water dew points may cause concerns in gas pipelines during transportation. The problem comes from the possibility of liquid condensation in pipelines, leading to issues in metering, pressure drop, and safe operation. It must be controlling hydrocarbon dew point, water dew point, and cricondentherm to meet the specification of pipelines and avoid various problems. Hydrocarbon dew point is a function of gas composition and pressure. The natural gas composition includes the lighter hydrocarbons that reduce the values of hydrocarbon dew point and vice versa. Controlling water

dew point can be achieved by elimination of water condensation through pipelines. It is necessary to control the dew points to be below the pipeline operating conditions to prevent two-phase flow and hydrate formation in the system. Natural gas process simulation is very important to get the optimum operating condition that meet the specification of the pipeline as follows: hydrocarbon dew point lower than 5°C at pressure < 70 bars and water dew point equals 0 at 70 bars. Lower values of hydrocarbon dew point, water dew point, and cricondentherm temperature are obtained using raw natural gas composition contains lower content of heavier hydrocarbons whereas the presence of heavier hydrocarbon causes an increase in the hydrocarbon dew point. Also, the optimal operation conditions to meet the specification of pipelines are obtained at differential pressure (Δp) of Joule–Thomson ranging from 14 to 24 bars.

Abbreviations

BCM	Billion cubic meter unit
BTU	British thermal unit
CNG	Compressed natural gas
CHP	Combined heat and power
CCHP	Combined cooling, heat, and power
NGL	Natural gas liquids
J-T	Joule–Thomson
LTS	Low temperature separation
SCF	Standard cubic feet

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Authors' contributions

MA wrote up the manuscript and conducted the HYSYS results. NA and AR supervised the HYSYS results, edited, read, and approved the final manuscript. The authors read and approved the final manuscript.

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Availability of data and materials

The datasets supporting the conclusions of this article are included within the article.

Declarations

Competing interests

The authors declare that they have no competing interests.

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