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Impact of Heavy Hydrocarbon Concentration on Natural Gas Flow through Transportation Pipelines

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Abstract. In this work, binary, ternary, quaternion, and quinary natural gas mixtures were evaluated including methane, ethane, propane, butane, and pentane to highlight their impact on pipeline performance and thermophysical properties of natural gas. The results presented that all the heavy hydrocarbons have a negative impact on natural gas phase envelope. For binary mixtures, methane/propane recorded the widest two-phase envelopes while the quinary mixtures generally formed the widest two-phase envelopes over the other mixtures. Besides, the heavy hydrocarbons content of different mixtures increased the critical pressures and critical temperatures in comparison to pure methane. The highest temperature drop of 6.495 ℃ was recorded by the binary mixture and the lowest temperature drop of 6.341 ℃ was by quinary mixture. The highest pressure drop of 4.964 bars was caused by the quinary mixture, while the lowest pressure drop of 4.1 bars was by the binary mixture. In addition, the results showed that natural gas density controlled by methane content caused increasing the methane content resulting in reducing the density of natural gas mixture. The viscosity of natural gas is a sensitive parameter to the content of the heavy hydrocarbon concentrations and all heavy hydrocarbons increased the viscosity of natural gas in comparison to pure methane.

Keywords. Heavy Hydrocarbon, Transportation pipelines, Natural gas , viscosity, Methane.

1. Introduction

Natural gas is a pivotal source of fuel for modern society. During the last 50 years of the twentieth century, natural gas provided around 25% of the total energy demand in the United States [1]. During 2012, the United States produced 24,062,889 million cubic feet of total dry natural gas and imported approximately 3,137,811 million cubic feet [1]. Worldwide, it is predicted that natural gas consumption will increase by 40% between 2018 and 2050 [2]. In China, natural gas production has been increased by 500% in 16 years (2000 to 2016). However, the growth in natural gas demand which recently increased by 850% exceeded the production capacity over the same period [3]. In Brazil, the total local production of natural gas was 27.7 billion cubic meters and the import amount was 10.7 billion cubic meters during 2018 [4]. This extensive growth for natural gas demand underlines the need for feasible natural gas infrastructure. Commonly, natural gas trade passes through several stages namely production, treatment, enrichment, sweetening, transmission, storage, and distribution. Natural gas transmission is a critical step of the process owing to massive economic damages and significant environmental devastation that may caused by any failure. Natural gas pipeline construction gained great attention for economic growth and development. In 2014, it has been mentioned that 663.9 billion cubic meters was transferred using pipelines around the world which represents 66.5% of the total natural gas trade at that period [5]. Generally, the pipelines are divided into transportation pipelines and distribution pipelines. The transportation pipelines are employed to transport natural gas from the production areas to the distribution points. The transportation network usually works with high pressure more than 70 bars in an attempt to transport a huge amount of natural gas for long-distance. It has been reported that the common range of the operating pressure of natural gas transportation pipeline is between 3.45 to 9.65 Mpa with a diameter ranging from 0.6 to 0.9 meter [6]. On the other hand, the distribution pipelines provide natural gas to the customers and work with low and moderate pressures lower than 4 bars. Abd et al. (2019) reported that China performed around 62,000 km of pipelines for transportation of natural gas by the end of 2013 [7], whereas during 2015, China manufactured around 100,000 km [8]. In the United Kingdom, the National Grid operates 7660 km of natural gas pipeline network at high pressure of 85 bars and a diameter ranging from 0.063 to 1.2 meter [9]. Meanwhile, the distribution pipelines network is 267,750 km with a diameter ranging from 0.3 to 0.6 meter [9]. The materials of pipelines construction mainly depend on the operating conditions which are cast iron, steel, or plastic. More explicitly, the transmission pipelines are constructed from mild steel owing to the high operating pressure while the distribution pipelines are manufactured using polyethylene [10]. Many factors control the efficiency of natural gas pipelines such as pipeline length, physical properties, the environment surrounding the pipeline, and the compositions of the fluid. Chaczykowski et al. (2018) reported that the identification of natural gas compositions can result in accurate evaluation of flow assurance through pipelines [11]. Natural gas compositions relate mainly on the time of the extraction, the production resources, and the level of purifications. These parameters robust impact the octane number of natural gas mixture. Natural gas principally includes methane as the main contributor with percentage of ethane up to 14%, 5% propane, and some other heavy hydrocarbons such as i&n-butane, and i&n-pentane. Also, natural gas contains traces of other non-hydrocarbons components such as CO_2, H_2S, H_2, N_2, H_2O, O_2, He, and Ar. The impact of non-hydrocarbons components on the heating value of natural gas and the flow assurance has been investigated by Abd et al. (2020) [12]. Kayadelen et al. (2017) mentioned that natural gas compositions have a direct impact on the flame temperature and the thermophysical properties of natural gas [13]. The variation of natural gas compositions influences the mixture properties like the viscosity, density, phase envelope, and critical properties which in turn impact on the flow assurance of pipelines. Thus, the efficient evaluation of the mentioned properties can optimize the pipeline performance. Additional research to completely estimate the key tenets of the effect of heavy hydrocarbons content on the flow assurance through the transmission pipelines is necessary. This work seeks to investigate the impact of heavy hydrocarbons content in natural gas mixtures such as ethane, propane, n&i butane, n&i pentane on the thermophysical properties and the flow assurance through transmission pipelines. The evaluation will be in terms of natural gas properties like viscosity, density, phase envelope, and pipeline performance like temperature drop and pressure losses. The design specifications of the simulation pipeline are captured from real pipeline project owned and operated by FluxSwiss and Swissgas AG. This paper offers a significant opportunity to understand the effect of heavy hydrocarbons content on natural gas flow in the pipeline with respect to properties and operating conditions.

2. Methodology and simulation assumptions

Aspen Hysys version 9 was employed to model the impact of some common heavy hydrocarbons at maximum allowable concentrations on the flow assurance of natural gas through pipelines (see Table 1). The study includes various properties such as pressure drop, heat transfer, density and viscosity of natural gas mixture, phase envelope, and critical properties. Peng-Robinson fluid package has been chosen to estimate the mentioned properties owing to the compatible performance regarding the heavy hydrocarbons [7]. For the gain of confidence, the simulation has been validated using Aspen Plus simulator; the results were closed with minor errors in an acceptable range which are not reported in this study. The pipeline specifications are similar to the string of Rodersdorf to Lostorf pipeline with

55000 m length operated by FluxSwiss and Swissgas AG (see Table 2). This pipeline string is chosen to avoid the impact of the boosting station. The feed stream pressure and temperature are 67.5 bars and 55 ℃ to ascertain that the mixture feed is in a supercritical state. The material of the pipeline is mild steel as suggested by McCoy et al., (2007) based on their study for constructing a high corrosion resistance pipeline [14]. Some assumptions have been specified to simplify the simulation complexity i.e I) the gas flow is one dimension and the pipeline length is not divided II) the flow is steady state III) natural gas consumption and the impact of hydrates are neglected IV) the soil temperature is assumed to be constant.

Table 1. The maximum allowable concentrations of natural gas. Adopted from Bloch and Soares (2001) [15].

Components, mol%	Minimum	Maximum
CH_4	75	------
C_2H_6	-----	10
C_3H_8	-----	5
C_4H_{10}	-----	2
C_5H_{12} and heavier	-----	0.5

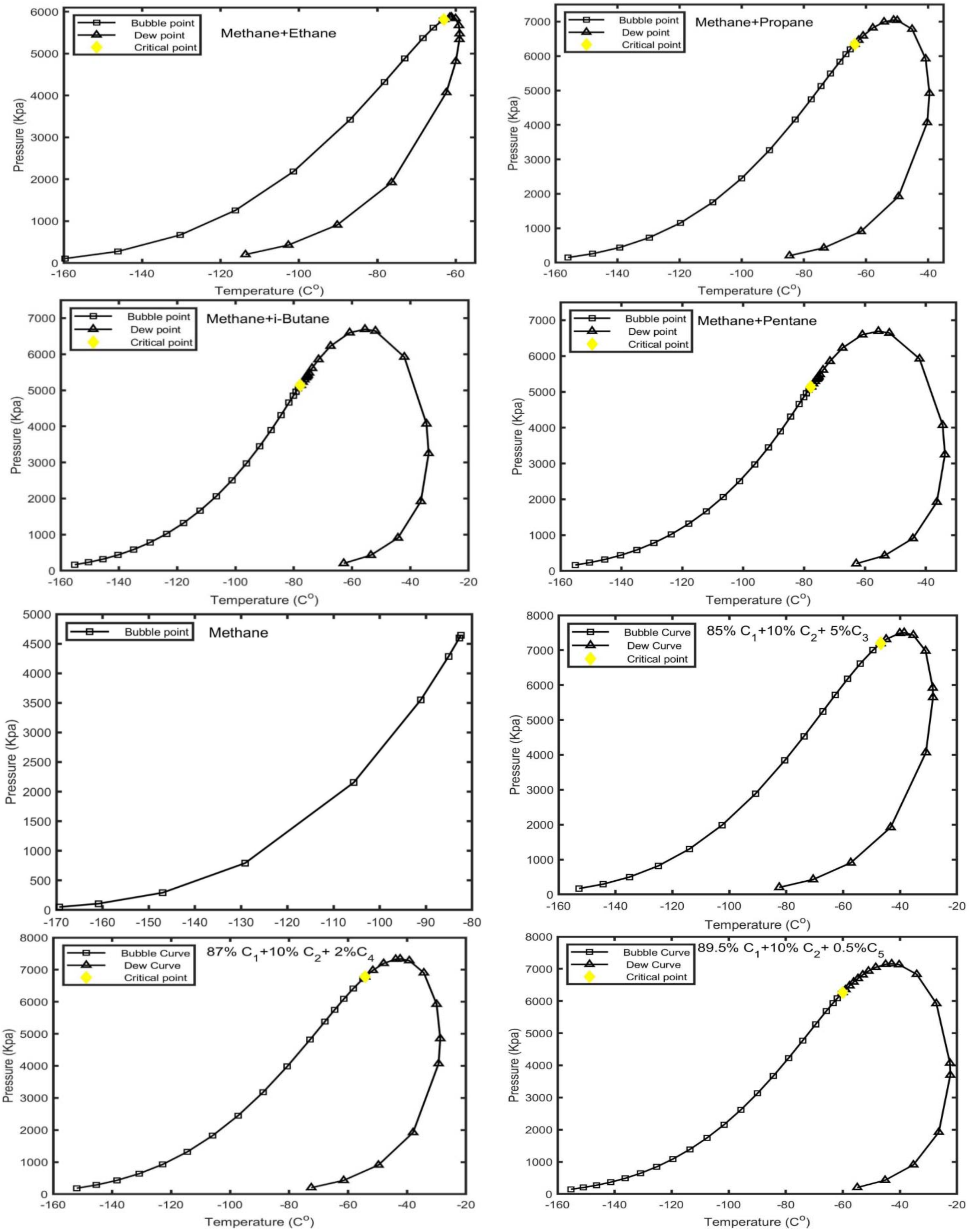
Table 2. The pipeline specifications adopted from Transitgas Pipeline System [16] and feed specification.

Length	55 km	Thermal conductivity	45 w/m.k
Inner diameter	875.4 mm	Material of construction	Mild steel
Outer diameter	900 mm	Feed temperature	55 °C
Roughness	4.572×10^{-5} m	Feed pressure	67.5 bars
Pipeline elevation	Horizontal	Feed flowrate	3038.32 kgmol/h

3. Results and discussion

3.1. Phase diagram of natural gas mixtures

Understanding the phase envelope of natural gas mixture is necessary for efficient assessment of natural gas transmission. The phase envelope of natural gas is the relation between temperature against pressure that estimates whether the mixture exists in single or two phases at the given operating temperatures and pressures. The phase diagram mainly consists of two curves namely bubble and dew curves and the intersection point called the critical point. Many efforts have been deployed to predict the phase behavior of various natural gas mixtures using different equations of state. Martinez and Hall (2006) compared Redlich-Kwong/ Peng–Robinson, Patel–Teja, and PC-SAFT using ten experimental data of synthetic natural gas [17]. Their findings concluded that Redlich-Kwong/ Peng–Robinson can estimate the phase behavior superior to the other equations of states. A two-phase flow is produced when fluid is in the gas phase and the other in the liquid phase. Mokhatab et al. (2015) reported that the phase envelope on natural gas is significantly influenced by the content of the heavy hydrocarbon content [18]. In addition, the phase envelope of natural gas strongly is related to the production resources [19]. May et al. (2001) mentioned that the dew point is highly sensitive to any tiny concentrations of heavy hydrocarbons [20]. A simulation study has been performed to investigate the effect of heavy hydrocarbons content in natural gas on the phase behavior and pipeline performance. The study starts using binary mixtures mainly methane and one heavy hydrocarbon at the maximum allowable concentration based on common pipeline specifications. Later, the study extends to investigate the effect of different natural gas mixtures on the phase envelope, and critical properties. Fig. 1 displays the phase behavior of different natural gas mixtures where the upper line represents the bubble curve, and the lower line represents the dew curve. The results show, for binary mixtures, that 2% of butane produced the widest two-phase envelope while 10% of ethane recorded the smallest two-phase envelope, where the rating exhibited was based on the area under the curve. It is interesting to notice that increase in methane content and decrease in propane content can create the widest phase envelope for the ternary mixtures. To conclude, the phase envelope strongly relates to the concentrations of the heavy hydrocarbons in natural gas and all the heavy hydrocarbons have a negative impact on the phase envelope of natural gas.



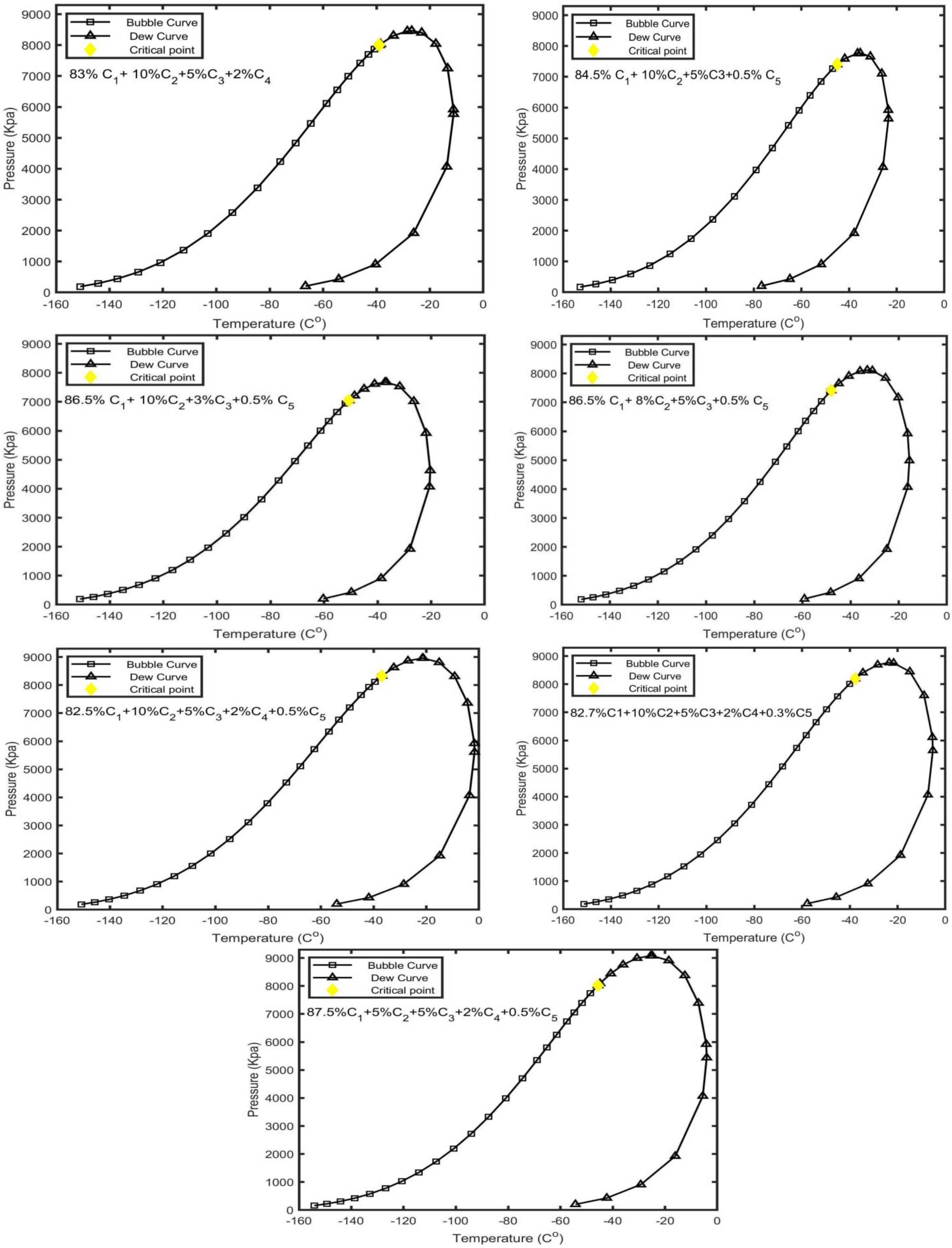


Figure 1. Phase envelope of binary, ternary, quaternion, and quinary natural gas mixtures at different concentrations.

The presence of heavy hydrocarbons in natural gas increases the possibility of two-phase flow in the transmission pipelines as the operating pressure and temperature decrease during the transmission process. Therefore, all the heavy hydrocarbons in natural gas come with negative impacts of consisting two-phase regions. To challenge this problem, the pressure and temperature of the mixture should be above the critical temperature and critical pressure by managing the pressure losses through boosting stations and the heat transfer to environment by insulation. The compression process or in some cases the heating process is costly where low critical pressure results in low compression and subsequently low energy penalty. Generally, the operating pressure of the transmission pipelines are vetted to be somewhat higher than the critical pressure of natural gas. Therefore, the component that elevates the critical pressure of natural gas mixture can turn in more energy required to keep the flow at supercritical state. As well as the supercritical temperatures of natural gas mixtures range reduce at the point that the critical temperature increases. A simulation study was performed to examine the effect of heavy hydrocarbons content on the critical pressure of natural gas mixtures. Table 3 shows that all heavy hydrocarbons increase the critical pressure of all the mixtures above which contain pure methane. For binary mixtures, 5% of propane recorded the highest increase in both critical pressure and critical temperature in comparison to pure methane by 25.28% and 23.59% respectively. On the other hand, 0.5% of pentane recorded the lowest increase in both critical pressure and critical temperature by 10.75% and 5.7% respectively. The remarkable results can be noticed is that the critical properties are controlled by the content of propane over all the mixtures. Also, it is interesting to highlight that further number of components in natural gas mixture result in increasing the critical properties of the mixtures.

Table 3. The critical temperature and pressures of different natural gas mixtures.

Binary mixtures	Critical pressure (kPa)	Critical temperature (°C)
100% C1	4640.674	-82.45114
90% C1+ 10% C2	5813.8628	-63
95% C1+ 5% C3	6344.628	-63.6218754
98% C1+ 2% C4	5804.5528	-71.725
99.5% C1+ 0.5% C5	5139.7	-77.75179
Ternary Mixtures		
85% C1/10% C2/5% C3	7195.598	-46.84
87% C1/ 10% C2/2% C4	6776.415	-54.229
89.5% C1/10% C2/0.5% C5	6266.17425	-60.0438
Quaternion mixtures		
83% C1/10% C2/5% C3/2% C4	7998.4	-39.013
84.5% C1/ 10% C2/5% C3/0.5% C5	7404.135	-44.87
Quinary mixtures		
82.5% C1/ 10% C2/5% C3/2% C4/0.5% C5	8325.2154	-36.8464167683175
82.7% C1/ 10% C2/5% C3/2% C4/0.3% C5	8195.84065528277	-37.7109206454788
87.5% C1/ 5% C2/5% C3/2% C4/0.5% C5	8019.99263154541	-45.6441559297691

3.2. Heat exchange

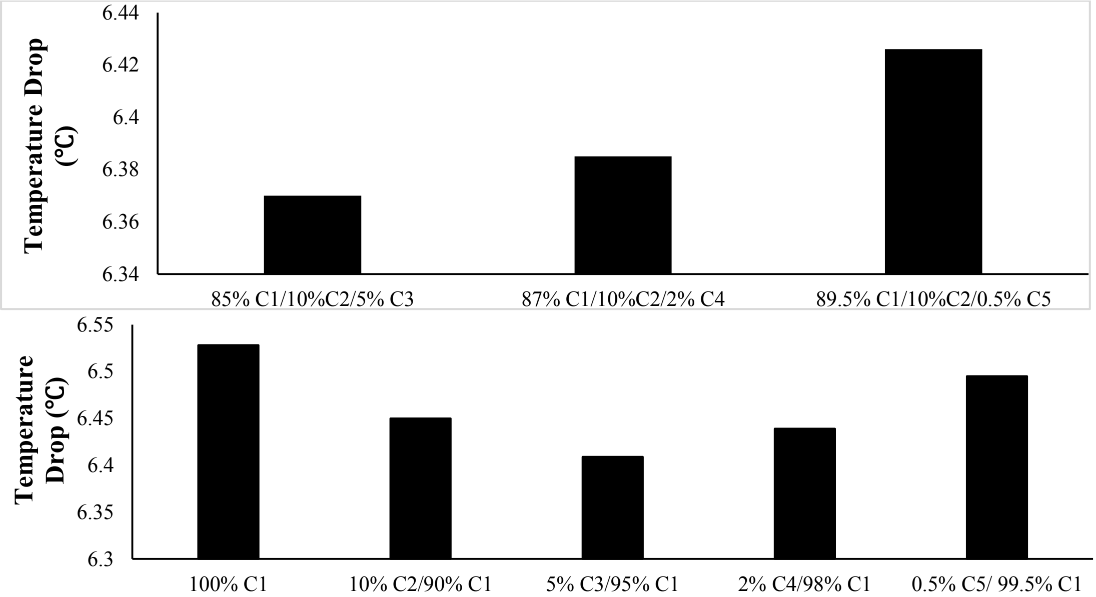
As natural gas mixture flows lengthways the pipeline, natural gas will be unavoidability affected by the friction between the fluid and the inner wall of the pipeline and turned into losing heat through the pipeline wall to the surrounding. The highest temperature of natural gas mixture records after the compression stage. In some cases, the heat transfer between the gas into pipelines and the surrounding can result in environmental issues. For example, pipelines transferring high-temperature fluid can result in elevating the temperature of the surrounding soil and may in turn change the moisture content of the soil [21]. Also, high temperature drop from natural gas flows in a pipeline may cause a formation of wax and hydrates [22]. Dongjie et al. (2011) designed a hydrodynamic model to evaluate the impact of different parameters on the pipeline performance [23]. Their results stated that both the surrounding temperature and the elevation have a direct impact on the pressure drop. Drescher et al. (2013) reported that the amount of heat transfer over the pipelines through flow type and the physical properties will control the cooling/heating rate [24]. Zhou and Adewumi, (1997) investigated the impact of soil temperature on the flow assurance and stated that as the pipeline is long enough, the temperature of the gas will be almost in equilibrium with the surrounding [25]. Generally, the heat exchange between natural gas mixture and soil will be analyzed in four stages: 1) Forced convection from natural gas mixture to the inner wall of the pipeline owing to the pump-action , 2)Conduction across the pipeline thickness to the surrounding soil , 3) Conduction through the soil from the outside the wall of the pipeline to the soil, 4) Natural convection from the soil to the environment. The calculation of the heat losses by forced convection depends on the used correlation that estimates the heat transfer coefficient (h) in Eq. (1) which is mainly a function of Reynold's number and Prandtl number. Reynold's number is a function of mixture kinematic viscosity, mixture velocity, and the pipeline diameter. While Prandtl number is a function of mixture velocity, mixture viscosity, and thermal conductivity of mixture.

$$q = h\,(T_{Sin} - T_{\infty}) \tag{1}$$

where, h is the convection heat transfer coefficient of natural gas mixture W/m^2.K, T_{Sin} the temperature of the internal surface of the pipeline, and T_{∞} is the temperature of natural gas in the middle of the pipeline. For heat losses by conduction is shown in Eq (2), where k is the thermal conductivity of the pipeline material and dT/dx is the rate of change in temperature over x.

$$q = K\frac{dT}{dx} \tag{2}$$

A simulation study has been performed to analyze the impact of various natural gas mixtures on the temperature drop over a transmission pipeline. It is observed by Fig. 2 that all the heavy hydrocarbons reduce the operating temperature in comparison to pure methane. For binary mixtures, 5% of propane records the lowest temperature drop which is 6.409 ℃ along the pipeline. On the other hand, 0.5% of pentane recorded the lowest reduction of temperature drop which is 6.409 ℃ in comparison to pure methane as shown in Fig. 2. It is observed that the methane concentration is the main contributor of the temperature drop and 89.5% C1, 10% C2, and 0.5% C3 mixture records the highest temperature change of 6.426 ℃ for ternary mixtures. The remarkable results that illustrate in Fig. 2, the 84.5% C1, 10% C2, 5% C3, and 0.5% C5 and 86.5% C1, 8% C2, 5% C3, and 0.5% C5 mixtures reaches same temperature drop of 6.358 ℃. For quinary mixtures, reduction of propane content results in increasing the temperature drops where 85.5% C1, 10% C2, 2%C3, 2%C4, and 0.5% C5 records the highest temperature drop of 6.341 ℃. The highest temperature drop recorded for binary mixture with 6.495 ℃ followed by quaternary mixture with 6.441 ℃, ternary mixture with 6.426 ℃, and quinary mixture with 6.341 ℃. To conclude, all the heavy hydrocarbons in natural gas reduce the temperature drop over the transmission pipeline compared to pure methane.



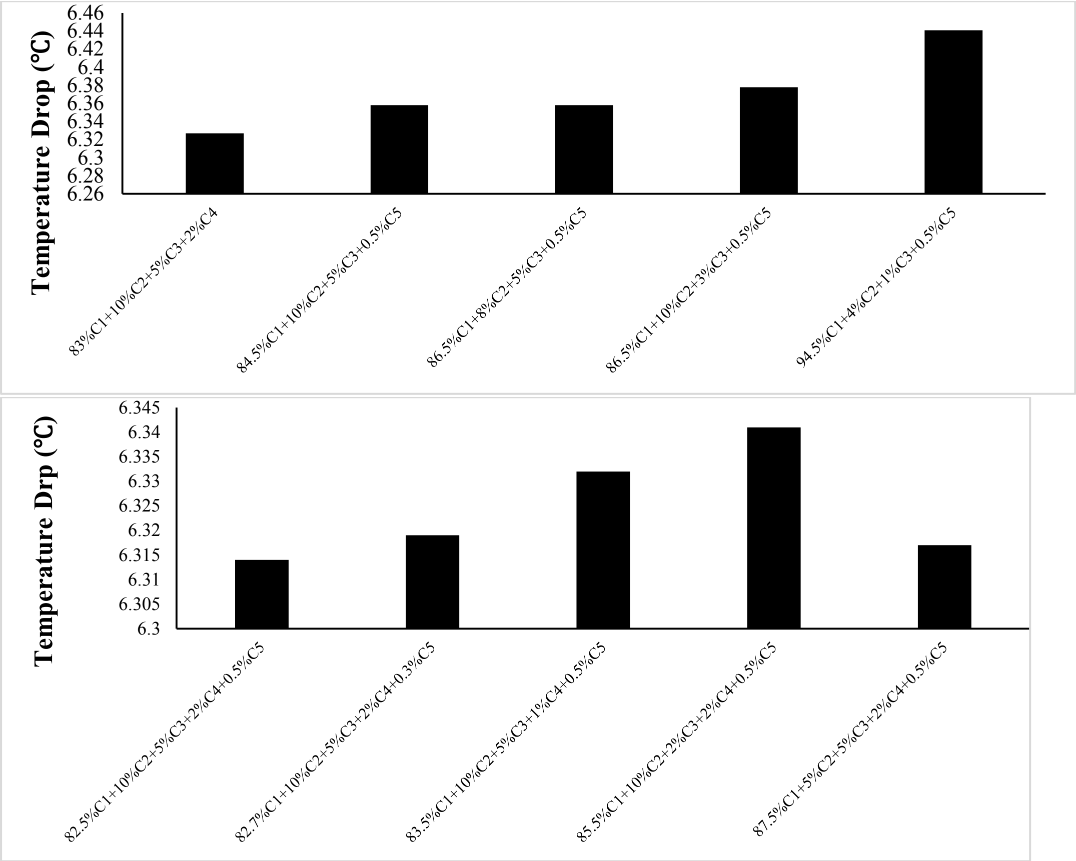


Figure 2. Temperature drop of binary, ternary, quaternion, and quinary natural gas mixtures at different concentrations over transmission pipeline.

3.3. Pressure losses

Pressure drop is mainly dependent on the density and viscosity of the mixture and the velocity to a great extent. Koga et. al. (2005) addressed, at the supercritical operating conditions, pure gases with liquid state densities and low gaseous state viscosities [26]. Generally, natural gas transports long travel distance from the production areas to the customers. Boosting stations are employed to ensure that the gas pressure matches the customers' specifications. Liang et al. (2018) mentioned that the pressure boosting process consumes up to 5% of the energy demand through transportations [27]. The fluid velocity plays a crucial role in the evaluation of pressure drop along a pipeline. The lighter mixture results in a higher pressure drop in the horizontal pipeline compared to the denser mixture at the same mass flowrates. This can be attributed to the high velocity of lighter mixture. For non-horizontal pipelines, the mixture density can outbalance the impact of the flow velocity owing to the height change parameter. Chandel et al. (2010) mentioned the main equation to calculate the pressure drop [28]:

$$\Delta p = \frac{f\, \rho\, l u^2}{2\, D} + \rho\, g\, \Delta z \tag{3}$$

Where Δp is pressure losses, f is friction factor, l is the length, u is velocity, D is the pipeline internal diameter, ρ is the fluid density, g is acceleration and Δz is change in elevation. The total cost of natural gas pipelines increases when the pressure losses increase due to the need for more boosting stations to maintain the pressure up to the customer specifications. A simulation study has been performed to examine the effect of heavy hydrocarbons on the pressure losses over the transmission pipeline. For binary mixtures, 5% of propane has the highest pressure drop of 4.3 bars while 0.5% of pentanes have the lowest pressure drop of 4.1 bars in comparison to pure methane as shown in Fig. 3. It is worth noting that an increase in methane concentration can result in minimizing the pressure drop over all the ternary mixtures. Interestingly, decrease in the propane content can in turn reduce pressure drop for ternary mixture and the lowest pressure losses. On the other hand, increase methane content for the quaternion mixture leads to decrease the pressure losses over different mixtures. The most remarkable results can emerge from Fig. 3 that the highest pressure drop records by the quinary mixture of 4.964 bars. Increase the pressure losses means natural gas mixture will flow for shorter distance in the horizontal pipeline before the compression stations thereby increasing the cost of the transmission process. Therefore, the presence of high heavy hydrocarbon concentrations can cause high pressure losses.

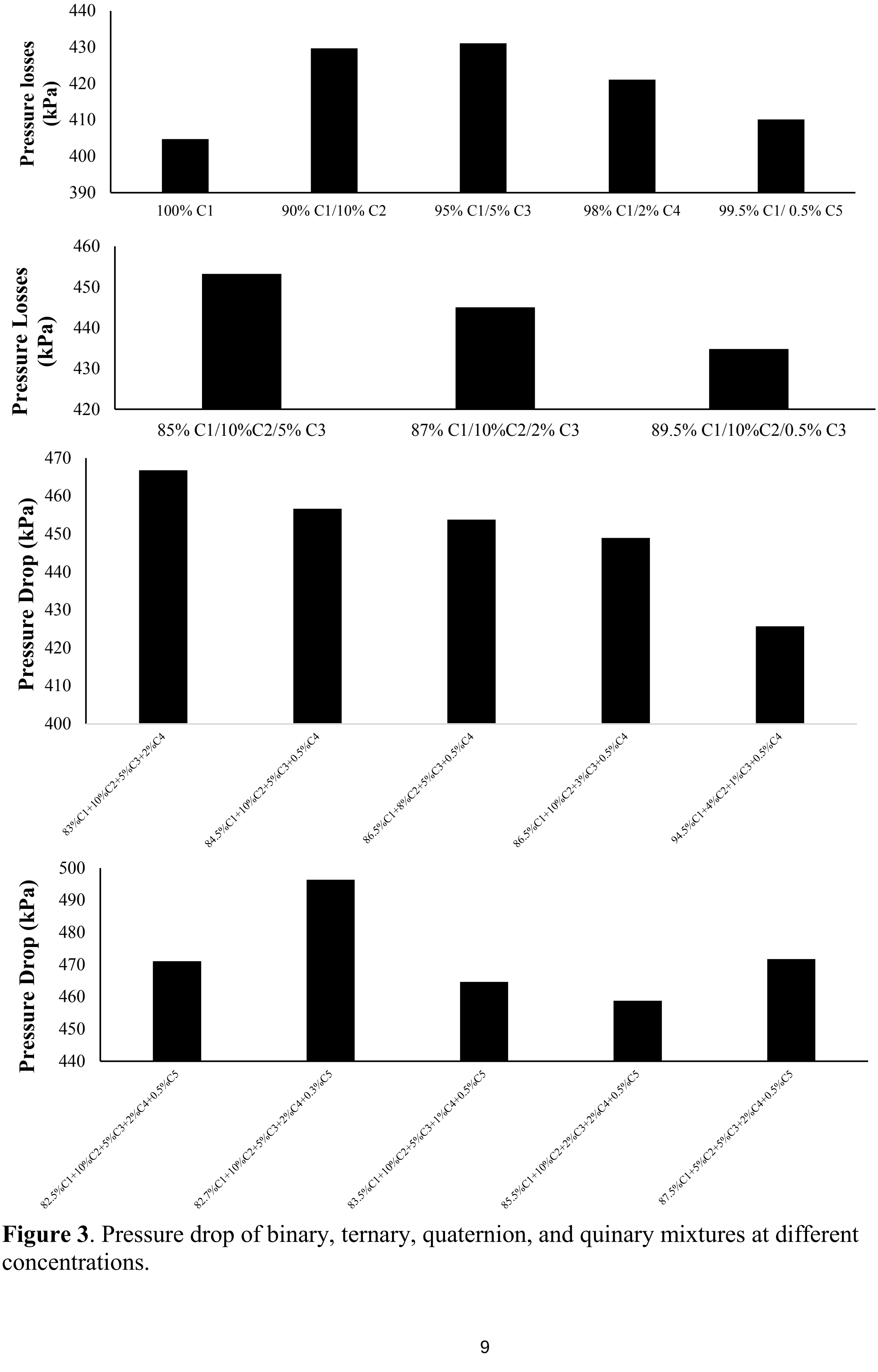
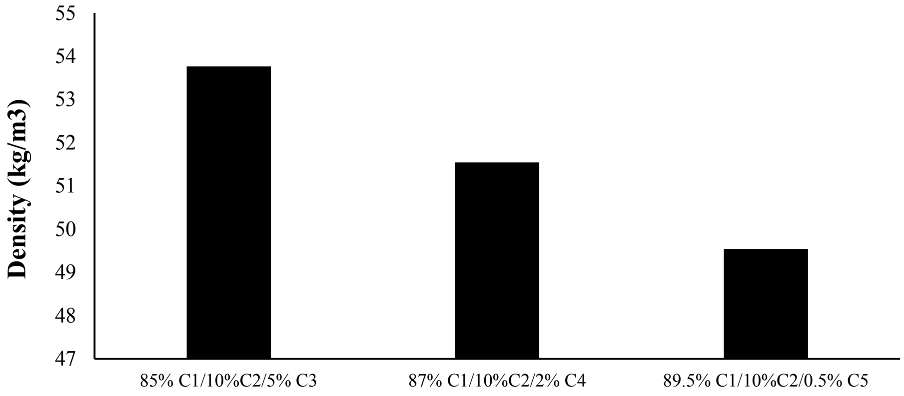
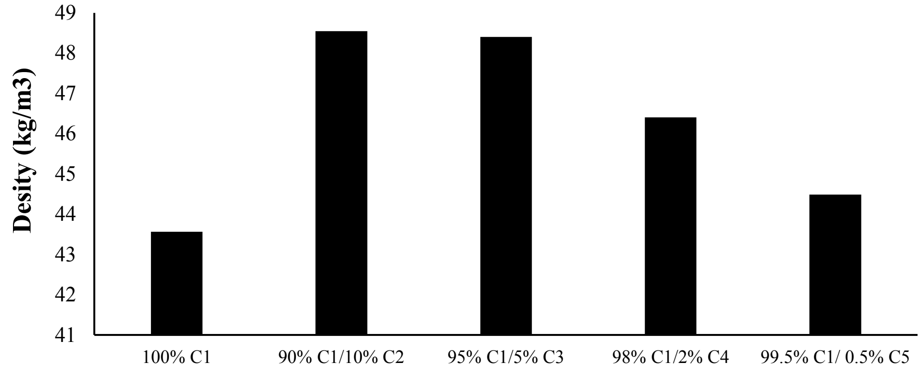


Figure 3. Pressure drop of binary, ternary, quaternion, and quinary mixtures at different concentrations.

3.4. Natural gas density

Gas density can be defined as the number of gas molecules in the volume of material and it is important natural gas property. Density of the gas mixture has a positive relation with pressure and a negative relation with temperature. The gas density influences several gas handlings such as resource recovery, above-ground, transportation, and storage of natural gas. Nevertheless, gas density varies to a great extent with operating conditions (pressure and temperature) and compositions of natural gas [29]. Khosravi et al. (2018) mentioned that many correlations have been proposed to estimate natural gas density and all these correlations require natural gas compositions [30]. Patil et al. (2007) studied the impact of pressure on the density of natural gas mixture with methane content up to 90% [31]. Their results revealed that the gas density increases on the point that the pressure elevates over a wide range of temperatures ranging from 270 k to 340 k where the density was 101.844 kg/m^3 at 340 k and 138 bars. All the hydrocarbons manipulate the density according to their molecular weights and the impact of other mixture components. For binary mixtures, it is observed by Fig. 4 that 10% of ethane recorded the highest increase in density, while 0.5% pentanes recorded the lowest increase in mixture density in comparison to the pure methane density. It is interesting to notice that increase in methane and decrease in propane concentrations can in turn decrease the mixture density for ternary mixtures. For quaternion mixtures, the mixtures densities are almost close ranging from 47.4 to 56.9 kg/m^3 and the density decreases on the point of increase methane and reduce propane concentrations. The most striking results to emerge from Fig. 4 is that for 85.5% C1, 10% C2, 2% C3, 2% C4, and 0.5% C5 mixture records the lowest density with reference to the other natural gas mixtures which can be attributed to the reducing of propane content. To conclude, the component that increases the density of natural gas decreases the pressure losses through a pipeline. The highest density of natural gas recorded for quinary mixture up to 58.1 kg/m^3 followed by quaternion mixture with 56.9 kg/m^3, ternary mixture with 53.77 kg/m^3, and binary mixture of 48.545 kg/m^3 respectively.





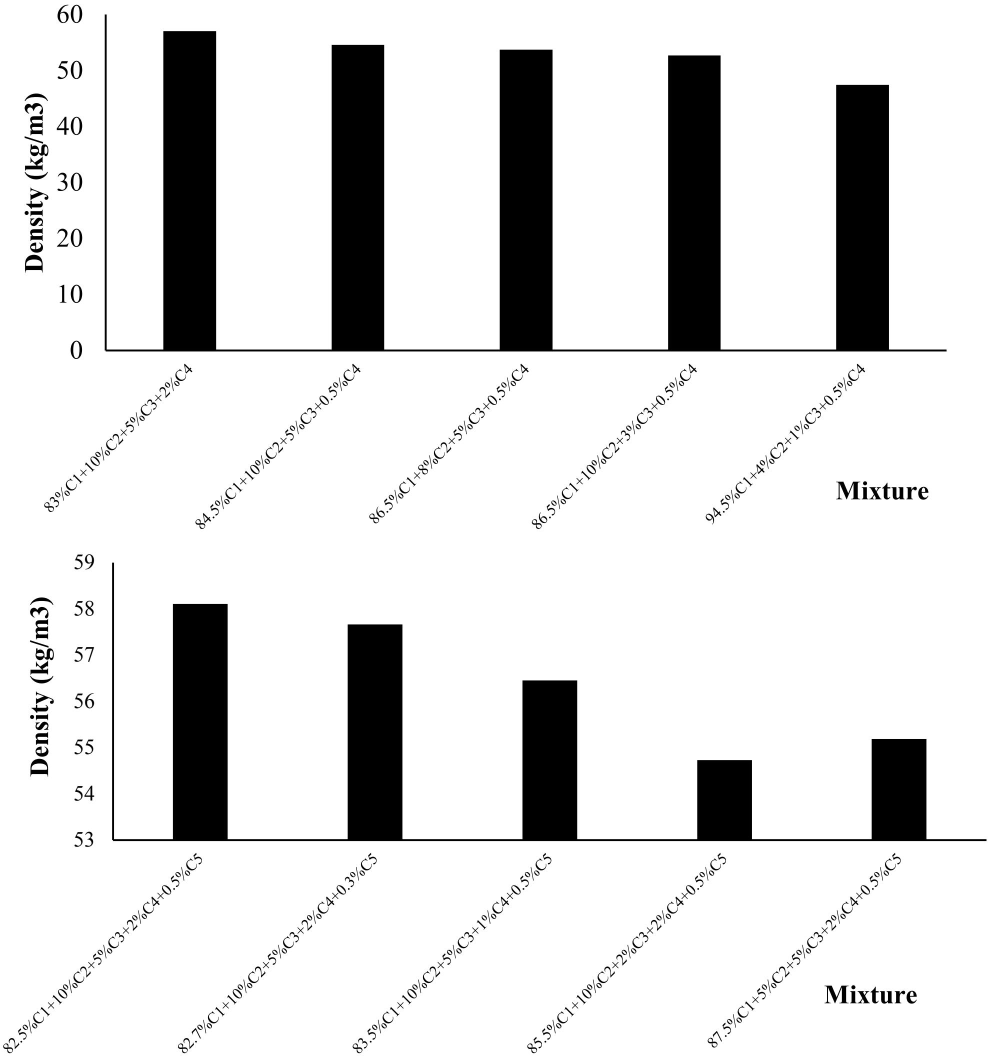


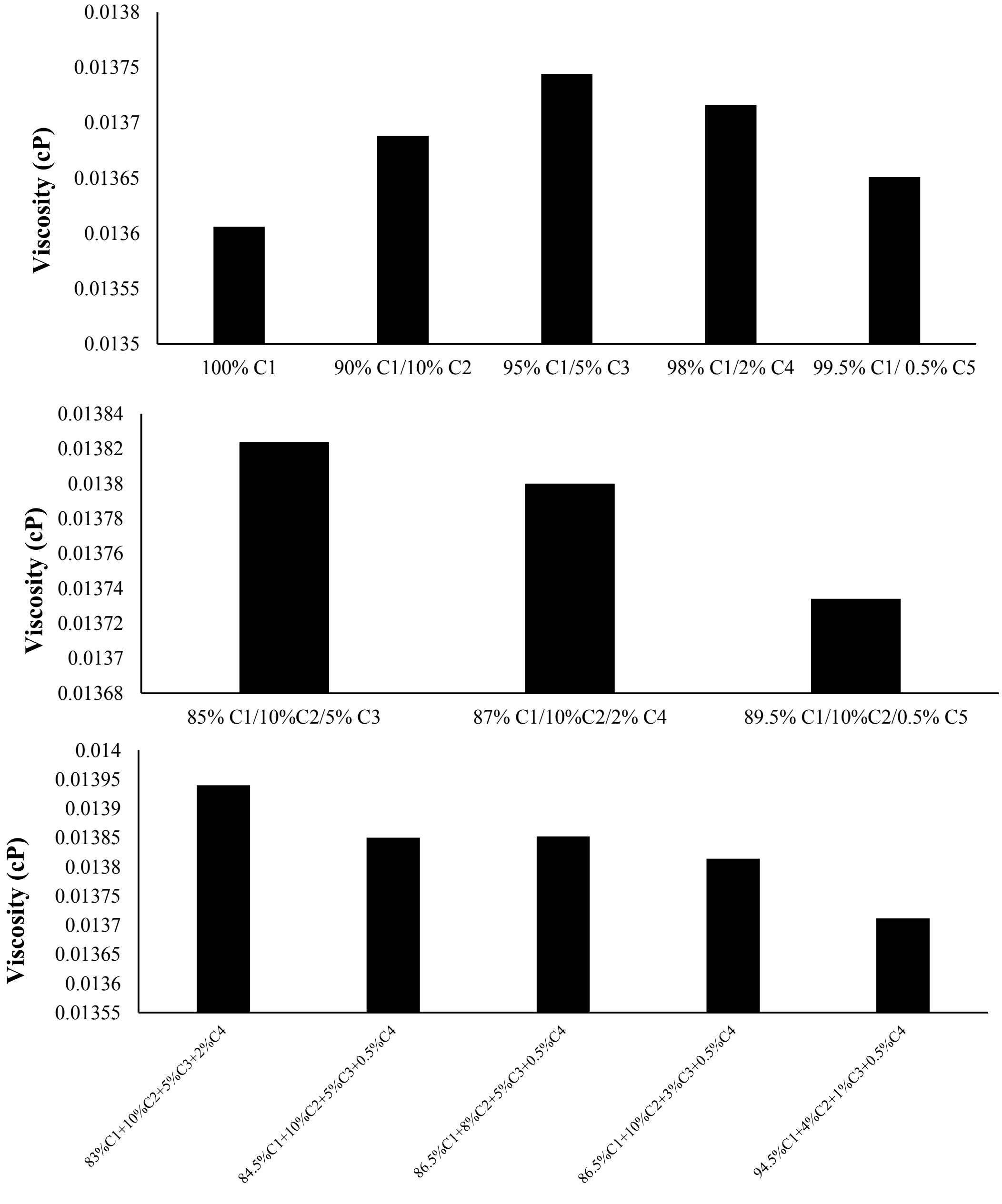
Figure 4. Density of binary, ternary, quaternion, and quinary natural gas mixtures at different concentrations.

3.5. Natural gas viscosity

Gas viscosity plays a vital role in the predictions of the pressure drop of natural gas pipelines by resisting the mixture flow. Natural gas viscosity is classified as one of the major transportations and thermophysical properties. Viscosity is significantly important for effective prediction of efficient gas utilization, gas reserves, reservoir modeling, reservoir transmission, and characterization [32]. According to Newton's theory, the shear stress and the velocity gradient are proportional perpendicular to the layers of fluid and can be presented as:

$$\tau = \mu \frac{\partial u}{\partial y} \tag{4}$$

Where the μ is the dynamic viscosity, and $\frac{\partial u}{\partial y}$ is the velocity gradient. The gas viscosity is strongly influenced by temperature, pressure, and gas compositions in the case of the mixture. Viscosity is the main parameter in the evaluation of pressure drop in the act of calculating the friction factor that depends on the estimation of Reynold's number which is a function of viscosity. At low and moderate pressures, the gas viscosity increases at the point of elevating the temperature; however, the gas viscosity approaches liquid density at high pressure [33]. Jarrahian et al. (2015) developed a new model to calculate natural gas viscosity at high operating temperature and pressure with different mixture compositions [34]. The proposed model is compatible for the estimation of natural gas viscosity over pressures ranging from 103 to 1380 bars and temperature up to 171 °C. Besides, they stated that elevating the pressure at constant temperature can in turn increase natural gas viscosity. The impact of the heavy hydrocarbons content on the viscosity of natural gas for different mixtures are shown in Fig. 5. For the binary mixture, 5% propane /95% methane recorded the highest viscosity of 0.01374 cP in comparison to other mixtures, followed by 2% butane, 10% ethane, and 0.5% pentane. The remarkable observation to emanate from Fig. 5, for the ternary mixture that more methane content results in reducing the mixture viscosity at a constant concentration of ethane. For the quaternion mixture, it is worth highlighting that decreasing the ethane content by 2% and increasing methane content by 2% can result in close natural gas viscosity of 0.01385 cP. To conclude, all the hydrocarbons for all the mixtures elevated the viscosity of natural gas with reference to pure methane. An increase in the mixture viscosity increases the friction between the fluid molecules and the inside wall of the pipeline and results in higher pressure losses.



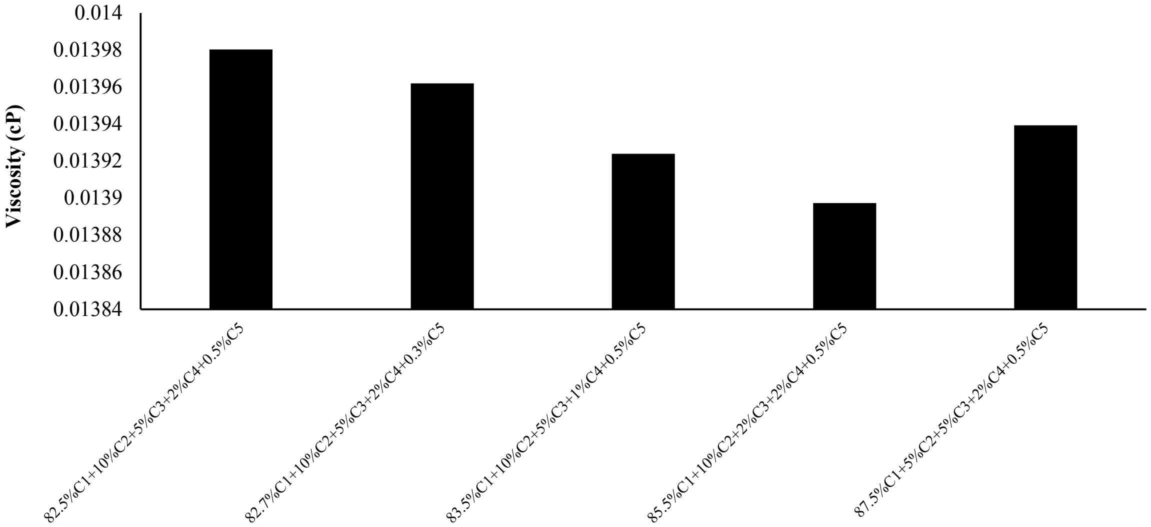


Figure 5. Viscosity of binary, ternary, quaternion, and quinary natural gas mixtures at different concentrations.

4. Grading of heavy hydrocarbons

All the heavy hydrocarbons in natural gas minimize the total molar volume of natural gas by taking up a part of the total volume. The heavy hydrocarbons graded from the highest to the lowest negative effect on natural gas based on the study parameters. The grading will perform based on the binary mixture only to clarify the direct impact of each component on the methane behavior.

Phase envelope* [a]*: Pentane, Butane, Propane, and Ethane.

Critical temperature: Ethane, Propane, Butane, Pentane.

Critical pressure: Propane, Ethane, Butane, Pentane.

Temperature drop: Pentane, Ethane, Propane, Butane.

Pressure drop: Propane, Ethane, Butane, Pentane.

Density: Ethane, Propane, Butane, Pentane.

Viscosity: Propane, Butane, Ethane, Pentane.

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a, the grading based on the area under the curve.

5. Conclusion

This paper analyses the effect of heavy hydrocarbons content at maximum allowable concentrations in natural gas on the thermophysical properties and flow assurance through transmission pipelines. The study covers common heavy hydrocarbons in natural gas namely ethane, propane, butane, and pentane. The evaluation includes the impact of heavy hydrocarbons content on the phase envelope, pressure loss, temperature drop, and viscosity and density of natural gas. All the hydrocarbons have at least one negative impact on natural gas flow assurance through the transmission pipeline. The phase envelope is influenced by the heavy hydrocarbons content in natural gas to a great extent. All the heavy hydrocarbons enhance the possibility of a two-phase flow. The pressure losses change for different mixtures. For binary mixtures, the heavy hydrocarbons increase the pressure drop in comparison to pure methane and the highest drop was recorded by 5% propane of 4.311 bars. Furthermore, all the heavy hydrocarbons increase the pressure drop in comparison to the pure methane. Besides, the results revealed that the presence of heavy hydrocarbons reduces the temperature drop over the pipeline in comparison to the pure methane. Also, the presence of heavy hydrocarbons results in increasing the density and the viscosity of natural gas. The findings of this research can be employed to predict the effect of heavy hydrocarbons on the thermophysical properties and the transmission pipeline performance. For example, low concentrations of heavy hydrocarbons in natural gas mixture can help in reducing the temperature drop and at the same time elevating the pressure losses. It is, therefore, important to balance their concentration. This work can serve as a guide in the design and optimization of natural gas transmission pipelines owing to the illustration of the negative and positive effects of hydrocarbons content. Hence, it is advisable to pay attention to the effect of heavy hydrocarbons concentrations on the flow assurance and the performance of the pipeline.

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