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# Correlative Comparison of Gas CO2 Pipeline Transportation and Natural Gas Pipeline Transportation

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## Abstract

Carbon capture, utilization and storage technology (CCUS) is considered to be one of the most important technical pathways for greenhouse gas emission reduction. $CO_2$ pipeline transportation technology in China started late, with more $CO_2$ pipeline transmissions operating in the gas-phase. At present, the main reference for the design of $CO_2$ gas transmission pipeline is the standard of natural gas pipeline. Because of the differences of physical properties between $CO_2$ and natural gas, there are many problems in pipeline design. This paper makes a comparative analysis of $CO_2$ and natural gas related physical properties and transport parameters in china. The results showed that compared with natural gas, $CO_2$ has a mutation in the density, viscosity, heat capacity and liable to phase changes, so the temperature and pressure in the process of conveying should be strictly controlled. At the same time, compared with natural gas, the explosion of $CO_2$ is relatively safe, but the $CO_2$ has strong corrosion at the existence of water, so in the design of $CO_2$ pipeline the difference of the safety level and corrosion should be considered. Under the same conditions, the gas phase transport of $CO_2$ mixture is more likely to generate hydrate than natural gas. The study provides some suggestions for the construction of $CO_2$ pipeline transportation in China.

## Key words

$CO_2$, natural gas, pipeline transportation, specification

## 1. Introduction

Natural gas is a cleaner and environmentally friendly energy source that has been seen as a promising alternative energy source in the future [1-5]. Compared to other fossil fuels, natural gas has relatively lower carbon intensity and higher fuel efficiency in power production [6]. The process of burning fossil fuels such as coal, oil or natural gas by power plants and other industrial processes produce the atmospheric pollutant carbon dioxide ($CO_2$), which is responsible for climate change and global warming [7]. Carbon dioxide Capture and Storage (CCS) can significantly reduce the climate causing effect of particularly electricity production with coal, natural gas and oil fuelled power plants [8]. Natural gas and $CO_2$ are mostly transported via pipelines for the $CO_2$ near its pure form. The most obvious difference between natural gas and $CO_2$ pipelines is the higher operation pressure required in supercritical phase by the latter [9]. Natural gas is a combustible gas that is a mixture of simple hydrocarbon compounds and contains primarily methane (CH4) and can constitute up to 97% of natural gas. It also contains small amounts of ethane, butane, pentane, and propane [10].

In engineering design, both natural gas and carbon dioxide are regarded as dangerous chemicals. In China the carbon dioxide pipeline transportation standards, laws and regulations are imperfect. It is only by improving the design of the pipeline safety level that will ensure the safety of carbon dioxide pipeline transportation which will enhance effective standards, laws and regulations [11]. Although Sinopec launched the preparation of industry standard which named "Carbon dioxide pipeline engineering design criteria", the main references for several gas carbon dioxide pipeline transportation project carried out in the early stage in China are GB 50251-2015 ‘Code for design of gas transmission pipeline engineering’ [12] and GB 50350-2015 ‘Code for design of oil-gas gathering and transportation systems’ [13]. Some standards are based on the development of flammable and explosive gas, which have high security level requirements, but did not consider the impact of $CO_2$ physical properties on the delivery process, anti-corrosion technology, etc. Therefore, it is of great significance for the development of $CO_2$ pipeline construction in China to compare the properties of $CO_2$ and natural gas and analyze the problems existing in the design of $CO_2$ pipelines.

## 2. Current situation of $CO_2$ pipeline transportation in China

Global warming caused by carbon dioxide emissions has become the focus of world attention. In order to promote the development and application of CCUS technology, many countries in the world have launched a large-scale program to promote the development and demonstration of CCUS technology, and actively promote the development of CCUS in the global scope [14-16]. By the end of 2014, the number of large-scale CCUS projects in the world which planning and have been put into operation have reached 55, of which China has a large number of CCUS projects accounted for 20% [17].

Compared with foreign countries, the $CO_2$ pipeline transportation technology in China started late, the scale is small, and there is no mature long-distance transportation pipeline. Individual fields use of their own advantages of the $CO_2$ source is close, transport the $CO_2$ to the site of injection wells in the gaseous or liquid phase, to achieve the ultimate objective of improving oil recovery.

The $CO_2$ transmission pipeline in China have the following characteristics:

Mainly distributed in the periphery of the oil field, which is used for oil displacement and enhanced oil recovery. (2) The transmission distance is short and the output is small. (3) The main transport process is gas transmission.

The main CO2 transportation pipelines data in China is shown in Table 1 [18].

**Table 1.** Main $CO_2$ transportation pipelines in China

| Position | Gas transmission rate/($10^4\,t \cdot a^{-1}$) | Pipe length/km | Transportation phase |
|---|---|---|---|
| Shengli Qilu oilfield | 62.1 | 70 | Gas |
| Jilin oilfield | 50 | 8 | Gas |
| Daqing Xushen oilfield | 14.8 | 35 | Gas |
| Daqing Yu Shulin oilfield | 7 | 5~6 | Liquid |
| East China bureau of Huangqiao | | 5.4×2 | Liquid |

Different from conventional oil and gas pipelines, $CO_2$ has many kinds of transportation phases, and the difference of density, viscosity and specific heat are very large in different phases, which can be transformed into each other under certain conditions. But the specification of $CO_2$ pipeline design in China is less. Related standards of $CO_2$ pipeline in China are shown in Table 2 [18].

**Table 2.** Related standards of $CO_2$ pipeline in China

| The name of the standards | Analysis of the applicability |
|---|---|
| GB 50251-2015 ‘Code for design of gas transmission pipeline engineering’ | Apply to the long-distance transportation of natural gas pipeline project design. No consideration has been given to the characteristics of $CO_2$ in terms of transportation technology, phase calculation, pipe and accessories selection, wall calculation, etc. |

| | |
|---|---|
| GB 50350-2015 ‘Code for design of oil-gas gathering and transportation systems’ | Apply to the onshore oil and gas fields of natural gas gathering, processing and transportation engineering. There is no consideration of special physical and chemical properties in the $CO_2$, $CO_2$ transport process, the phase behavior calculation |

## 3. Comparison of physical properties between $CO_2$ and natural gas

Similar to natural gas, it is necessary to regulate the purity of $CO_2$ and the type and content of impurities in $CO_2$ during its transport. For both natural gas and $CO_2$ transport, but most especially the latter, for optimum operation of the pipeline, it is expected that, the gas composition meet the requirements of the transport process, avoidance of fluid phase changes and blockages, and impurity levels kept low to enhance the normal operations of pipelines and ancillary transport equipment. This therefore brings to the fore, the importance to understand the difference between $CO_2$ and natural gas properties and their significance to especially new $CO_2$ pipeline design.

### 3.1 Selection of equation

The PR state equation was proposed by Peng-Robinson in 1976, and it is widely used to study the thermo-physical properties of $CO_2$ and nature gas. The expressions are shown in Eqn. (1) to (6) [19].

$$p = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)+b(V-b)} \tag{1}$$

$$a(T) = a(T_c)\alpha(T_r, \omega) \tag{2}$$

$$a(T_c) = 0.45724\frac{R^2T_c^2}{p_c} \tag{3}$$

$$b = 0.07780\frac{RT_c}{p_c} \tag{4}$$

$$\sqrt{\alpha} = 1 + m\left[1 - \left(\frac{T}{T_c}\right)^{0.5}\right] \tag{5}$$

$$m = 0.37464 + 1.54226\omega - 0.26992\omega^2 \tag{6}$$

Where : $p$ - system pressure, kPa.

$V$ - molar volume, $m^3$/mol.

$R$ - universal gas constant, 8.3143kJ/ (kmol/ k).

$p_c$ - critical pressure, kPa.

$T$ - system temperature, K.

$T_c$ - critical temperature, K.

$T_r$ - contrast gas temperature, $T_r = T / T_c$ .

$\omega$ - eccentric factor.

## 3.2 Component parameters

In this paper, the typical component parameters of gas pipeline transportation are studied. The component parameters of nature gas and $CO_2$ mixture are shown in Table 3.

**Table 3.** Component parameters of nature gas and $CO_2$ mixture

| | $CH_4$ | $C_2H_6$ | $CO_2$ | $N_2$ |
|---|---|---|---|---|
| Nature gas | 92.3% | 1.8% | 3.3% | 2.6% |
| $CO_2$ mixture | 3.5% | — | 96.1% | 0.4% |

## 3.3 Thermodynamic properties

### 3.3.1 Characteristic of phase diagram

$CO_2$ can exist in the gas, liquid, solid ('dry ice') and supercritical phases. $CO_2$ in the supercritical phase has properties of both a gas and liquid, in that it occupies all available volume, but it can dissolve materials like a liquid. Small changes in temperature or pressure can have a large impact on the state and density of the fluid [20].

Natural gas is a gas at all expected pipeline conditions. Natural gas is a colorless, tasteless, odorless, and non-toxic gas. Because it is odorless, a powerful chemical called mercaptan is added to the gas, in very small amounts, to give the gas a distinctive smell of rotten eggs. This strong smell can be helpful in detecting the source of any gas leak. Natural gas is about 40% lighter than air, so should it ever leak, it can dissipate into the air. Other positive attributes of natural gas are a high ignition temperature and a narrow flammability range, meaning natural gas will ignite at temperatures above 1,100 degrees and burn at a mix of 4–15% volume in air. Under certain conditions, the natural gas will be liquid state [21-23].

The fundamental physical properties of pure $CO_2$ and CH4 are listed in Table 4.

**Table 4.** Properties of pure $CO_2$ and $CH_4$

| Property | | $CO_2$ | $CH_4$ |
|---|---|---|---|
| Molecular weight | g/mol | 44.01 | 16.04 |
| Critical pressure | bar | 73.7 | 45.9 |

| | | | |
|---|---|---|---|
| Critical temperature | ℃ | 31.1 | -82.6 |

In one sense, transmission of methane is potentially much more dangerous than $CO_2$. Methane is lighter than air and highly flammable, so any leak from a pipeline is likely to ignite, causing gas burn injuries or fatalities and major damage to the pipeline. In contrast, $CO_2$ is heavier than air and not flammable. Exposure to $CO_2$ at 3-10 vol% causes $CO_2$ intoxication, which can be distressing and potentially debilitating, but is reversible by treatment with 100% oxygen. Exposure to $CO_2$ at more than 17 vol% is fatal [20].

In the pipeline transportation process, $CO_2$ and CH4 exist in the form of mixture. A comparison of the phase diagram of pure $CO_2$, pure CH4, natural gas and $CO_2$ mixture is shown in Figure 1.

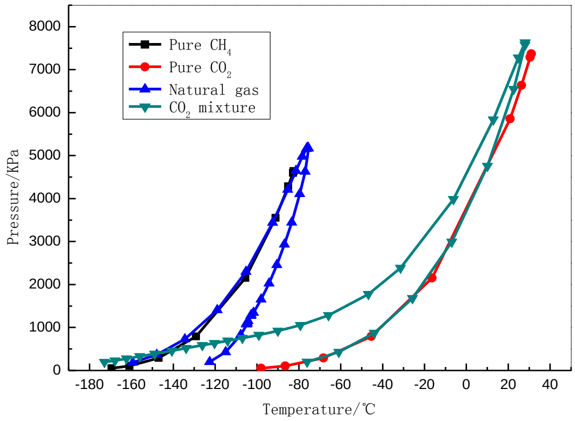


Fig.1. Comparison of phase diagrams of $CO_2$ and natural gas

Figure 1 shows that the critical temperature of natural gas is lower than the pipeline operating temperature (0~30 ℃). So it is not easy for natural gas to change phase in the process of pipeline transportation. The critical temperature of $CO_2$ mixture is close to the pipeline operating temperature. When the conveying pressure is high, the gas-liquid two-phase flow is easy to be produced, so the pressure should not be too high to avoid exceeding the critical pressure. For example, some carbon dioxide pipeline, in the design of alternative provisions, the maximum operating pressure of low pressure gas pipeline does not exceed 4.8Mpa [24].

### 3.3.2 Characteristic of density

The mutation of the medium density affects the stability of the pipeline transportation, and influences the service life of the pipeline. $CO_2$ mixture and natural gas density change with temperature and pressure curves are shown in Figure 2 to Figure 4.

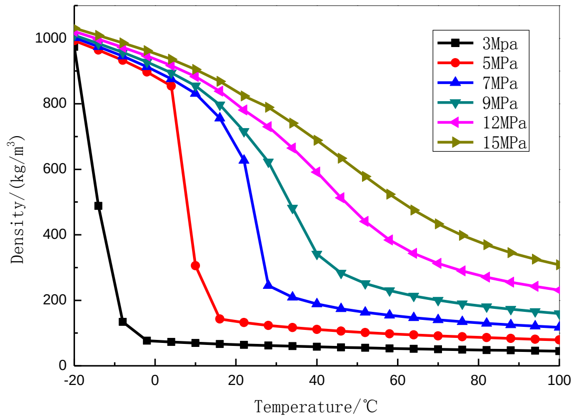


Fig.2. Density change curve of $CO_2$ mixture with temperature and pressure

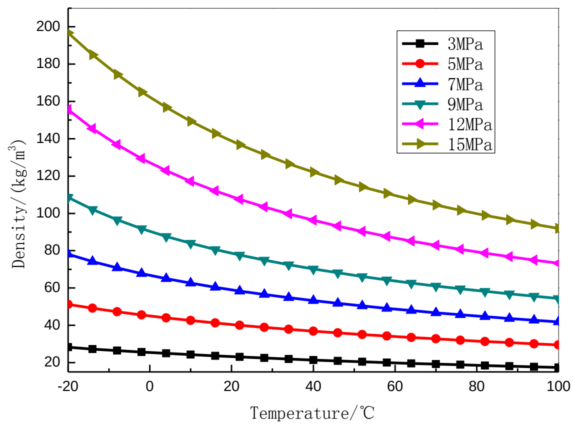


Fig.3. Density change curve of natural gas with temperature and pressure

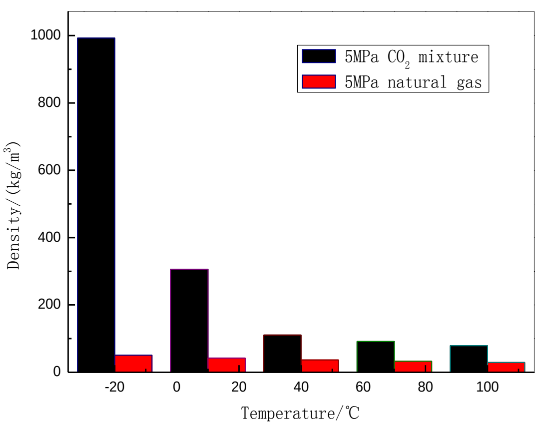


Fig.4 . Density change curve of $CO_2$ mixture and natural gas with temperature under the pressure of 5MPa

Figure 2 to Figure 4 show that the density of $CO_2$ mixture is more sensitive to temperature and pressure, and the density of $CO_2$ mixture may change abruptly in a small temperature range. And under low temperature, the density of $CO_2$ mixture is much greater than that of natural gas. Nature gas density mutation does not occur when the temperature changes, and the density changes with temperature, pressure change is small. Therefore, in the process of transporting $CO_2$ mixture, the temperature and pressure should be strictly controlled.

### 3.3.3 Characteristic of viscosity

Energy changes will occur in the transport process of $CO_2$ mixture and natural gas, and viscosity characteristic is an important parameter affecting energy changes. $CO_2$ mixture and natural gas viscosity change with temperature and pressure curves are shown in Figure 5.

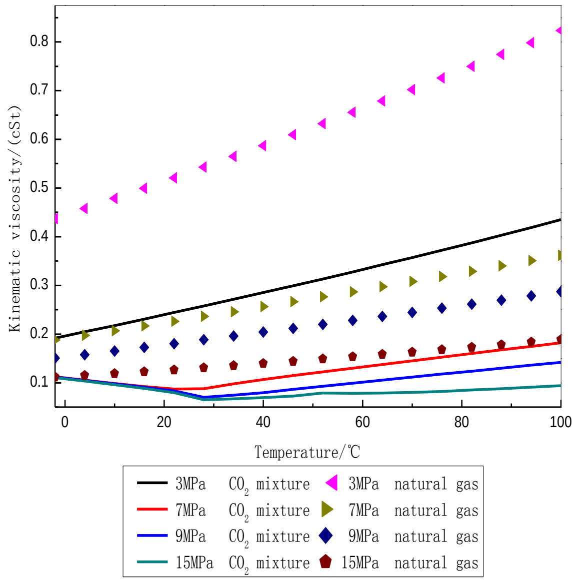


Fig.5. Kinematic viscosity change curve of $CO_2$ mixture and natural gas with temperature and pressure

Figure 5 shows that under the same conditions, the viscosity of natural gas is larger than $CO_2$ mixture, and the change of viscosity is stable under the same pressure. With the change of temperature, the viscosity of $CO_2$ mixture will mutate with the change of temperature under the same pressure, and the higher the pressure, the higher the temperature is.

### 3.3.4 Characteristic of heat capacity

The mass heat capacity directly affects the change of the medium temperature during the pipeline transportation. $CO_2$ mixture and natural gas mass heat capacity change with temperature and pressure curves are shown in Figure 6.

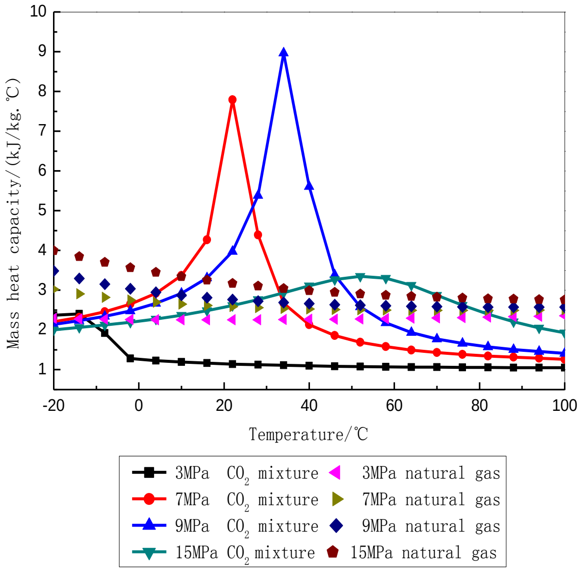


Fig.6. Mass heat capacity change curve of $CO_2$ mixture and natural gas with temperature and pressure

Figure 6 shows that under the same pressure, the mass heat capacity of $CO_2$ mixture will mutate with the change of temperature, while change of natural gas of mass heat capacity with temperature is relatively stable. $CO_2$ mixture in the gas phase transport state relative to the supercritical transport has a smaller mass heat capacity, so the process of transport greater impacted by the ambient temperature.

## 4. Comparison of pipeline parameters of $CO_2$ and natural gas transportation

The change of the parameters in the pipeline transportation has a direct impact on the safety and economy of transportation. Based on the transport conditions of $CO_2$ mixture, the changes of CO2 mixture and natural gas transport parameters under the same transport conditions are studied.

## 4.1 Variation of temperature and pressure along the line

Temperature and pressure along the line are the important parameters of transport. The changes of the temperature and pressure of $CO_2$ mixture and natural gas pipeline along the line are shown in Figure 7.

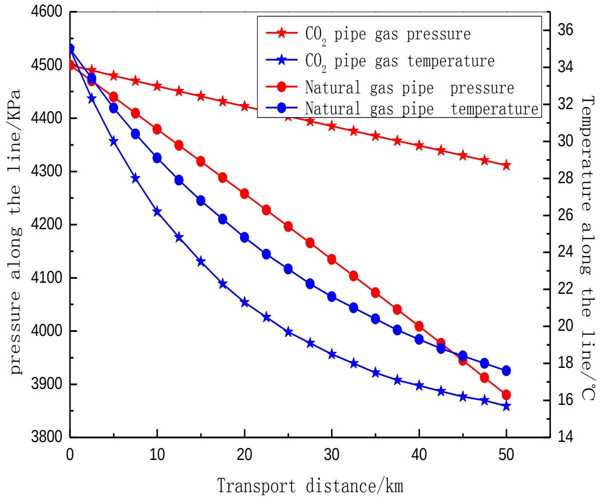


Fig.7. The changes of the temperature and pressure of $CO_2$ mixture, natural gas pipeline along the line

Figure 7 shows that under the same conditions, the gas phase transport of the $CO_2$ mixture has a relatively small pressure drop and a relatively large temperature drop than natural gas. In the design of the pressurization station and the heating station, the difference between the two transport states should be fully considered.

## 4.2 The formation of corrosion products and hydrate along the line

Natural gas at typical pipeline conditions, does not possess serious problems for corrosion as no compounds are formed. Common use of corrosion inhibitors are always effective in controlling corrosion. However, $CO_2$ in the presence of small amount of water forms the compound known as carbonic acid. Carbonic acid is extremely corrosive, especially in the presence of water. In such situations it requires measures to keep the gas extremely dry or stainless steel pipe and equipment. The propensity of $CO_2$ in forming corrosive products influences commissioning and start-up procedures on $CO_2$ pipelines.

Pipeline transportation is one of the main ways of gas transportation. With the rapid development of natural gas industry and CCUS technology, pipeline transportation is becoming more and more important. The longer the pipeline and the more complex the environment, the greater the risk of gas hydrate formation, then the greater the hazards to the safe operation of the pipeline. In order to effectively control the formation of hydrate, hydrate formation conditions must be grasped along the pipeline. $CO_2$ mixture and natural gas hydrate formation is shown in figure 8.

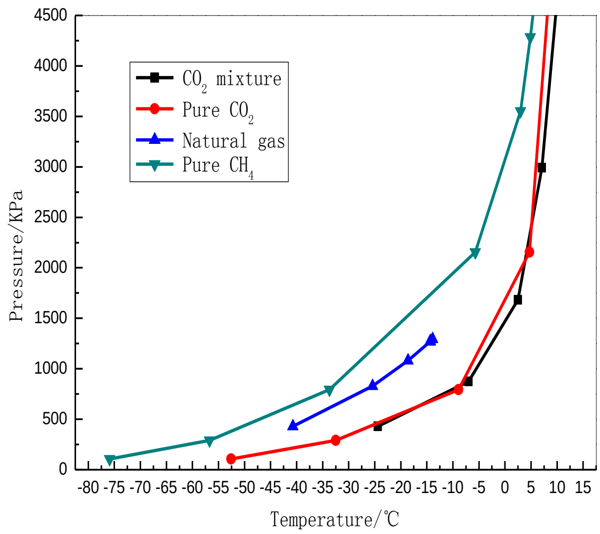


Fig.8. The hydrate formation of $CO_2$ mixture and natural gas

From figure 8 we can see that, under the same conditions, the gas phase transport of $CO_2$ mixture is more likely to generate hydrate than natural gas. Therefore, in the process of pipeline transportation of $CO_2$ mixture, we should strictly control the conveying temperature and pressure, avoid the temperature being too low.

## 5. Conclusion

The transportation parameters and related physical properties of $CO_2$ natural gas in pipeline in china has been investigated. Through the comparative analysis of related physical property and pipe transmission parameters of $CO_2$ and natural gas. It is concluded that critical temperature of natural gas is lower than the pipeline operating temperature (0~30℃), so it is not easy to change phase in the process of pipeline transportation for natural gas. The critical temperature of $CO_2$ mixture is close to the pipeline operating temperature. When the conveying pressure is high, the gas-liquid two-phase flow is easy to be produced, so the pressure should not be too high to avoid exceeding the critical pressure. Also, the density, viscosity and mass heat capacity of $CO_2$ mixture will mutate with the change of temperature, thus affecting the pipeline safety and economy, so the temperature and pressure should be controlled strictly in the transportation process. Furthermore, compared with natural gas, the explosion of $CO_2$ is relatively safe, but when there is water $CO_2$ has strong corrosion at the existence of water, so in the design of $CO_2$ pipeline should consider difference of the safety level and corrosion. At last, under the same conditions, the gas phase transport of $CO_2$ mixture is more likely to generate hydrate than natural gas. Therefore, in the process of pipeline transportation of $CO_2$ mixture, we should strictly control the conveying temperature and pressure, avoid the temperature is too low.

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