Research on CO₂ Quality Pipeline Transportation Based on Yanchang Oilfield CCUS

Yongchao Yang 1, Hongsheng Tao1, Jinghua Yang1, Qinghua Shang1 and Shuangge Cao2

1Yanchang Oil Field co., LTD, Research Center of Exploration and Development, Shannxi Yan’an, China
2Xi’an Shiyou University, School of Mechanical Engineering, Shaanxi Xi’an 710065, China
740293171@qq.com

Abstract. CO₂ capture, utilization and storage (CCUS) is now recognized as an important technology in the global scope of CO₂ emission reduction, pipeline transportation is the main center to connect the capture point and the use storage point, the first issue to CO₂ pipeline transportation is to solve CO₂ source quality research. Yanchang Oilfield has the advantages of CCUS, its coal chemical capture of CO₂ contains different impurities. In the CO₂ pipeline transportation, the impurity content in CO₂ is based on its end use and the actual situation of pipeline. The impurities will affect the efficiency of CO₂-EOR, the choice of CO₂ state equation, the changes of CO₂ phase diagram and the capacity of pipeline transportation.

Keywords. CO₂ quality, pipeline transportation, CO₂-EOR

1 Introduction

CCUS (CO₂ capture, utilization and storage) is a new technology, which has the potential of large-scale CO₂ emission reduction, is expected to achieve low carbon utilization of fossil fuels, which is widely considered to be one of the important technologies to deal with global climate change and control greenhouse gas emissions [1]. CO₂-EOR is the most important part of CCUS, it refers to that CO₂ is separated from the industrial or energy production, then transported to some oilfields to enhanced oil recovery, at the same time, sequesters some CO₂ [2]. According to the geology evaluation, there are 10 billion tons of petroleum geological reserves are suitable for CO₂-EOR in China. If they all used for CO₂-EOR, it is expected to increase the recoverable reserves of 700 million tons to 1400 million tons, which provides a broad prospect for CO₂-EOR. The first problem to used CO₂-EOR to achieve industrial applications is to solve pipeline transportation, CO₂ from capture contains such as CH₄, H₂S, N₂ and other impurities, so CO₂ must need to be need to be purified, then transported by long distance pipeline to the injection point for EOR. According to the data, there are more than 65 million tons CO₂ for CO₂-EOR each year in America, it increases more than 15 million tons oil [3]. CO₂ pipeline construction and operation experience has been more than 40 years in America, which contains impurities CO₂ pipeline’s experience is 20 years, however, CO₂ pipeline transportation in China has just started, building a large scale containing impurities CO₂ pipeline and ensuring safety and stable operation, the research of CO₂ quality is the first step.

2 The advantages of Yanchang Oilfield to carry out CCUS

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Yanchang oilfield has coal, gas and oil resources in the same area, the natural conditions lays the foundation for the comprehensive development of the CCUS work. Domestic modern energy and chemical base has been formed, especially Coal-to-Oil and Coal-to-Olefins as the representative capture large numbers of high concentrations CO₂. There are more than 9.5 million tons CO₂ had emitted by coal chemical projects every year, of which about 60%, the concentration is above 85%. the use of CO₂ for EOR to reduce CO₂ emissions in Northern Shaanxi means that the coal utilization rate is higher than other areas and it’s also the important module of coal chemical industry in Northern Shaanxi [4]. In recent years, there are a total of about 10 million tons of high pure CO₂ capacity in Northern Shaanxi, of which Yanchang oilfield has been formed a huge capture scale that is early 400000t CO₂, mid 700000 CO₂ and forward 4 million tons CO₂, this huge CO₂ capture is the prerequisite for the development of CO₂-EOR.

Yanchang oilfield is extra-low permeability reservoir, which has low oil recovery, CO₂-EOR can efficiently enhance oil recovery, this can ensure the long-term stable production of the oilfield; water resources in North Shaanxi is deficient, CO₂-EOR saves a large amount of water;according to the abroad experience of CO₂ pipeline and the characteristics of CO₂, the CO₂ pipelines are laid away from the crowd, sparsely populated of northern shaanxi for CO₂ pipeline provides a good geographical conditions.

The nature conditions of Yanchang oilfield provided a successful foundation for CCUS: (1) It makes CO₂ emission reduction successful and the benefits from enhanced oil and gas recovery can make up for the cost of CCUS. (2) It saves a lot of water resources, these advantages are the key reason that America and China choose Yanchang oilfield as demonstration base of CCUS [5].

3 Requirements of CO₂-EOR for CO₂ Quality

The requirements of pipeline transportation for CO₂ quality are considered its final use: enhance oil recovery. For EOR applications, CO₂ flow must has a high purity, which generally provides the minimum content of CO₂ is 95% and the average content of CO₂ is about 98.45%–98.72% in foreign countries, which is to ensure that CO₂ and oil are mixed in the suitable geothermal basin.different impurities in CO₂ flow has different effects on CO₂-EOR. H₂S can increase the solubility of CO₂ in the oil and reduce the mixed phase pressure, increase the water solubility in CO₂, so H₂S is favorable for CO₂-EOR. Therefore, the restriction on H₂S is based on security perspective, the recommended of H₂S concentration is below 0.02% [6], but in the actual operation, the concentration is determined according to the actual operation situation eventually;CH₄ can affect the minimum miscible pressure , and it is an important factor for affecting the mixing capacity, the volume concentration of CH₄ is 2% in EOR applications; while N₂ and other non-condensable species have a negative effect on the miscible capacity, density and viscosity of CO₂ flow [7,8]. In conclusion, the impurities content in the CO₂ flow is considered by having a minimal on EOR applications.

4 Requirements of Pipeline Transportation for CO₂ Quality

The pipeline system is very sensitive to the impurities in CO₂ flow, which will affect many parts of CO₂ pipeline transportation. The impurities will affect the phase change of the whole CO₂ flow, pipeline transport process, pipeline transport capacity, pipeline crack propagation and pipeline corrosion and protection, etc.

4.1 Requirements of pipeline transportation for water content

The impact of free water on the transport pipeline is mainly reflected in the following two aspects: (1) CO₂ will lead to the electrochemical reaction between carbon steel and water, then make the pipeline and equipment corrosive and corrosion rate is high; (2) The free water will form hydrates to block the pipes and even damage equipment. So, before entering the pipeline systems, CO₂ must be dehydrated.

Under super-critical conditions, the solubility of water in pure CO₂ is 0.0026kg/m³ and it has been determined that the water content is less than 60% saturation (0.0015kg/m³), and carbon steel will not corrode. For super-critical CO₂,
along with the increase in pressure and temperature, the solubility of water in CO₂ increased. In addition, the existence of free water also can cause hydrogen embrittlement or hydrogen brittleness, because the free water can cause the hydrogen atoms diffusing to the metal substrate to form hydrogen molecules, resulting in local internal pressure decreased the ductility and tensile strength of steel [9,10].

The formation of hydrate is not the main problem but it is a problem to be solved. The concerns about hydrates are mainly from the aspects of the flow protection, hydrate in the pipeline may cause the pipe blockage and flow content reduction and plug the pipeline system and accessories then causing accidents. In addition, if there is some water in CO₂ flow, it is easy to generate hydrate in pipeline restart [11,12]. In order to avoid the occurrence of corrosion, the water content in current CO₂ pipeline is far less than 60%, and the operation of these pipelines are safe, so in our country designing CO₂ pipeline is also to meet this requirement. If in transit appear free water, there is no definite response, the International Petroleum Exchange gives the suggestion is that using ethylene glycol or corrosion inhibitor [13, 14].

4.2 Requirements of pipeline transportation for other impurities

The impurities affect the density, compressibility and viscosity of the whole CO₂ flow. These thermodynamic parameters affect the physical properties of the fluid and the pipeline transport properties, they can determined by the equation of state. The most popular used to predict the CO₂ phase diagram are: Peng-Robinson (PR) equation, Soave-Redlich-Kwong (SRK) equation, Benedict-Webb-Rubin-Starling (BWRS) equation and GERG-2008 equation. The differences of impurities content and kinds make the equation of state’s more difficult, so the equation of state for CO₂ pipeline design has not yet reached a consensus, currently used for simulation of the impurities in the CO₂ state equation are based on the published experimental data available in the literature to evaluate, DNV RP J202 Design and Operation of CO₂ Pipelines recommended PR equation is used for CO₂ containing impurities. PR equation has higher accuracy, however, in the process of calculation, the equation of state needs use the experimental data to adjust and to assess the calculation of uncertainty.

Impurities affect the phase behavior of the whole CO₂ gas flow and then affect the process of pipeline transportation. Figure 1 show the phase diagram of CO₂, compared the different impurities on the critical point and phase curve of CO₂.

![Fig. 1. CO₂ phase diagram](image-url)
The critical point of pure CO2 is T=31.4, P=7.38MPa, which has a lower critical point. Because super-critical CO2 has good flow characteristics and transmission characteristics, it has high transmission efficiency in the process of conveying. So all foreign operation of CO2 pipelines are using super-critical CO2. Figure 1 shows that different kinds of impurities make CO2 phase diagram in a two phase region and changed CO2 critical point, this influences the operation scope and transportation way of pipelines. With the increasing of impurities, critical pressure increases and critical temperature decreases [15], this means compared with transporting pure CO2, CO2 containing impurities need higher pressure, so in the pipeline transportation, determining the types and contents of impurities in the CO2 flow is the first step for determining the operating conditions.

Impurities will also affect the transport capacity of the pipeline, it can consume additional compression, and with the increase of impurities, the pipeline transportation capacity will be reduced. It has been shown that [16, 17], for example, in the same transport conditions, compared with pure CO2, if the content of CH4 is 5% or 10%, the pipeline transport capacity decreased by 9.4% and 16%, if the content of N2 is 5%, the pipeline transport capacity decreased by 12.6%, which is due to the impurities reduce the volume of the pipeline transport capacity.

Impurities can also affect the design of pump and compressor, which is based on CO2 components such as NOX, H2S, CO, SOX, etc. The existence of such impurities increase the pipeline leakage risks; Impurities can affect the use of the pipeline infrastructure. Above all, the impurities in CO2 flow influence multiple aspects of the pipeline, so it must control the content of impurities reasonably and effectively during the process.

5 Conclusions and Recommendations

Compared with natural gas pipelines and other hazardous liquids pipelines, few accidents happened at the current CO2 pipelines in America. Throughout the CO2 pipeline technology, it can be seen that CO2 pipeline transportation is not really difficult to overcome, so large-scale and long-distance CO2 transmission pipeline will be fully realized in China.

1. Yanchang oilfields as CCUS demonstration project implementation in China, CO2 capture needs combine with CO2-EOR, and explore the best way to capture for CO2-EOR.

2. It must be to do a good job of dehydration and removing impurities before CO2 flow into the whole pipeline system and monitor the water content in the entrance to ensure the saturation limit of moisture content below 60%; Impurities also can affect the critical point of CO2, pipeline transport process and transport properties, so it should be strictly controlled the content of impurities and monitored carefully.

3. The research on CO2 pipeline transportation needs to combine American’s 40 years of experience in CO2 pipeline transportation and China’s experience in rich natural, gas oil pipelines, then develop a suitable standard for China’s large-scale CO2 transmission pipeline.

4. Capture, transportation, storage, injection, separation, detection, monitoring of high pressure and large impurity CO2, CO; anti-corrosion technology and equipment need to be tested research and optimized.

5. With the development of experimental and industrial applications, the government and related enterprises should take into account the planning and construction of the CO2 containing impurities transport pipeline in due time.

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