A Review of Pipeline Transportation Technology of Carbon Dioxide

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Abstract. CO2 from industrial production is captured and stored to be buried underground or used for driving oil or gas (CCS). The CCS technology can be used not only to mitigate environmental pollution and reduce the anthropogenic greenhouse effect, but to improve economic efficiency. CO2 transportation is imperative, and pipeline transportation is the most economical and convenient way for CO2 transportation because of its features such as large-throughput, long-distance and reliable-operation. According to the different phases, CO2 pipeline transportation can be divided into gas phase, liquid phase, dense phase and supercritical transportation. In this paper, the characteristics and application ranges of three kinds of pipeline transportation process were analyzed, finally in a design influence factors of pipeline transportation were analyzed, and faced currently of problems were shown.

1. Introduction
CO2 produced from oil and gas fields or fossil fuels burning can be captured and stored to be buried underground or used for enhancing oil recovery (EOR). The CCS technology can be used not only to solve the problem of environmental pollution, but to produce more economic benefit. Therefore, the transportation of CO2 from sources to the oil field or stored formation, has extremely significant to the development of oil fields, even to the economic development and environment[1-3]. Three CO2 transportation ways can be used by pipeline, ship and tanker. For large-scale and long-distance transport tasks, pipeline transportation is the most economical method[4]. For the CO2 critical parameters (critical temperature is 304.25 K, critical pressure is 7.38MPa) and extremely easy changes of CO2 phase, pure carbon dioxide is transported by pipelines, in gas, liquid, dense or supercritical phase[5-7]. Hence, CO2 piping process is different from oil or gas pipelines for its own characteristics.

2. Properties of Carbon Dioxide
The phase diagram for pure CO2 is shown in Figure 1. It contains two distinct features which are a “triple point” at 0.52MPa, 217.15K; and a “critical point” at 7.38MPa, 304.25 K. At the triple point CO2 can exist as one of three phases, solid, liquid, or gas[8-10]. The curve connecting the triple point and the critical point in Figure 1. is the vapor-liquid line separating the gaseous and liquid phases. The “critical temperature” is the vapor temperature at the critical pressure. The region above the critical temperature and critical pressure is labeled as “supercritical region”, while the region above the critical pressure, but below the critical temperature, is called the “dense phase region”[11-13].
Figure 1. Phase diagram for pure CO$_2$

In the supercritical region, CO$_2$ no longer exists in distinct gaseous and liquid phases. In the supercritical phase, CO$_2$ has a similar density to the liquid phase but a similar viscosity to the gas phase. Increasing pressure, it can’t be changed into liquids when exceeding the critical temperature. In the dense phase region, CO$_2$ density increases with decreasing temperature[14]. The most efficient way in terms of cost and throughput of transporting CO$_2$ by pipeline is in its supercritical or dense phase.

3. CO$_2$ pipeline transportation process

The CO$_2$ pipeline system is similar to the natural gas or products pipeline system, including of pipes, (compressor or pump) stations and ancillary equipment and instruments.

3.1. CO$_2$ gas pipeline transportation

As seen from figure 2, the CO$_2$ is kept in gas phase in the CO$_2$ pipeline transportation, and its pressure is enhanced by compressors, named as gas transportation. The pipelines need the thermodynamic calculation to determine whether they are laid with insulation layer. Most of the CO$_2$ is in a supercritical phase in the gas well, before entering the pipes it needs to be throttled and depressed its pressure to meet with the requirements of the pipeline. Similarly, when CO$_2$ pressure is enhanced, its pressure needs to be controlled to avoid CO$_2$ into the supercritical state. For example, the Scurry Area Canyon Reef Operators (SACROC) oilfield carbon dioxide pipeline in the United States, in the design of its alternatives, the highest operating pressure in gas pipeline can’t exceed 4.8MPa[15]. Therefore, gas phase transportation pipe has lower operating pressure and higher operation security; For gas compressibility, gas transportation is fit for different throughput, but CO$_2$ gas pipe diameter is larger, and its investment is higher, so it is suitable for low throughput, short-distance pipeline and for CO$_2$ from gas phase source, and it is more suitable for the densely populated area compared with supercritical transportation.
3.2. CO₂ liquid pipeline transportation

As figure 3 shown, in this process CO₂ is kept in liquid phase in the pipe, by pumped up its pressure to overcome the friction and the terrain elevation difference. Whether pipeline is laid insulation layer also needs to be determined by thermodynamic calculation. Usually, to get the liquid phase, CO₂ needs to be cooled, the most common method is throttling CO₂ source at the wellhead to depress pressure and refrigeration. In order to protect the booster pump, CO₂ must have been transformed into liquid before entering pump. After pumps, CO₂ is still necessary to be cooled by heat exchangers. Liquid CO₂ pipeline has lower operation pressure, and usually needs insulation layer, so the investment cost is higher. It fits for low throughput, and short-distance gathering pipelines in the oil field, or CO₂ source is in liquid phase.

3.3. Supercritical CO₂ pipeline transportation

In figure 4, CO₂ in the transportation pipelines keeps the supercritical phase (temperature and pressure are higher than the critical value), the pressure is enhanced by the compressor unit. Insulation layer needs to be laid on the pipe to keep its temperature above CO₂ critical point[16]. Before entering the compressor, CO₂ phase in the pipe must be changed from the dense phase into dilute gas phase. CO₂ revaporation is realized by increasing the temperature through the heat exchangers. Unlike gas transportation, supercritical transportation needs to set the minimum pressure to keep its dense phase in the pipeline. Attentionally, for changes of operating conditions, when temperature of CO₂ in pipe is reduced to 304.25K, CO₂ phase can be changed from supercritical to dense[17]. In supercritical transportation, the pipeline has higher operation pressure, lower investment, and does not need to be heated, and hold different throughput; Supercritical transportation is suitable for larger throughput longer distance transmission pipeline, and operation safety coefficient of the pipeline is lower, it is
suitable for along some lower population density areas. Most of the CO₂ pipelines have been built are adopted supercritical transportation mode.

![Figure 4. Process flow diagram of supercritical CO₂ transportation](image)

For above-mentioned three CO₂ transport processes, the optimal flow state of gaseous CO₂ in the pipe is in drag square area and that of supercritical/liquid CO₂ in the pipe is in hydraulic smooth area. By comparing the three kinds of pipeline technology, supercritical transportation and liquid transportation are obviously superior to gas transportation in economy and technology. However, whether the liquid or supercritical transportation is more economic remains to be further studied.

The fluid transportation method can be directly determined by both the pipeline pressure and temperature, it can affect the efficiency and cost of the pipeline[18]. Therefore, when the CO₂ transportation system is designed, a variety of factors should be considered, such as its temperature, pressure and impurity composition. Supercritical transportation system has higher operation pipeline pressure, lower investment than others.

The performance parameters of CO₂, such as specific heat, density viscosity, transfer-heat rate, diffuse coefficient and entropy etc., change with the variety of the temperature and pressure, some parameters changes dramatically, data analysis need to be carried on before detail design to ensure accuracy and operability of the design. The impurities in the CO₂ can influence the CO₂ vapour pressure and region partition of CO₂ phase state envelope, and also effect on pipeline fracture control and pipeline throughput. So the influence of the impurities content of CO₂ to transportation need to be analyzed to select one corresponding transport method.

4. The special of CO₂ pipeline transportation

Compared with other gas or liquid pipeline transportation, the properties of CO₂ result in some specials in the following aspects.

(1) Density of gaseous CO₂ is higher than air, leading to be easily gather in the low hollow place, when the physical volume density is extended to 10%, CO₂ can affect the surrounding environment, even causing death for asphyxia.

(2) CO₂ occurs phase change easily. When pipeline is vented, the pressure sharply descends, and CO₂ phase is changed, leading to the temperature decrease sharply. Furthermore, it causes easily the damage of metal or nonmetal pipes and valves; there is decompression wave in the pipeline when there have been corrosion or crack, result in influence to the crack extend.

(3) CO₂ gas is acidic gas, it usually contains some water and has corrosive action on metals[19]. In the liquid and supercritical CO₂ pipeline, for higher operation pressure, it is easy for CO₂ to change its phases, then which cause to nip the piping material or aggravate corrosion points. Therefore,
choosing materials for pipeline, even blow-down pipeline and its valves need to be specially considered.

5. Summary
(1) There are three kinds of CO₂ pipeline, liquid, gas, and supercritical transmission. Compared the three kinds of transportation mode, gas transmission is simple, safe, but not economic; liquid transportation is also safe and need larger investment than gas transportation, thus two transportation modes are suitable for low throughput and short distance transportation. Supercritical pipeline transportation has higher operation pressure, lower investment, and does not need to heat preservation, and fits different throughput, thus it is suitable for large throughput, and long distance, but it is more complex and dangerous.

(2) Because of the higher density, prone to phase transition and acid characteristics of carbon dioxide, the projects such as the transmission method, pipeline material, equipments and valves need be synthetically analyzed and evaluated on the specific situation of the whole system.

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