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Selective dehydration of high-pressure natural gas using supersonic nozzles

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ABSTRACT

Supersonic separators are proposed in this paper as a compact high-pressure processing system capable of selectively removing water from high-pressure natural gas streams without affecting the hydrocarbon content. A computer simulation linked to a thermodynamic property package is presented to predict the water removal efficiency and to compare the proposed system with conventional techniques. Some of the advantages of the proposed system include compactness, self-induced refrigeration, high gas velocity in the nozzle and low risk of hydrate deposition. Selective water removal with the proposed method can be achieved by controlling the design parameters: e.g., increasing the inlet pressure with constant temperature, increasing the inlet temperature with constant outlet pressure, and controlling the backpressure.

1. Introduction

The dwindling high quality crude oil reserves and increasing demand for natural gas has encouraged energy industries further towards the discovery of remote offshore reservoirs. Consequently, new technologies have to be developed to efficiently produce and transport stranded natural gas to consuming markets. Compactness of production systems is the most challenging design criteria for offshore applications. From the gas quality perspective, water vapour is the most common impurity in natural gas mixtures. The demand for natural gas has motivated the oil and gas industry to discover natural gas reservoirs in remote and harder to reach locations. The global need for less-carbon and potentially no-carbon content fuels (such as hydrogen) is motivated by environmental concerns. Natural gas is, at present, the only hydrocarbon energy source that will lead to major reductions in green house gases and other pollutants. Natural gas, produced from the reservoir is not a single-component mixture, rather a mixture of hydrocarbons, which may include heavier-than-methane hydrocarbon constituents (C_2^+) or natural gas liquids (NGLs), reservoir water, and various impurities such as inert gases, carbon dioxide, and hydrogen sulphide. Natural gas needs to be processed before being used in the supply network. The impurities such as nitrogen, carbon dioxide, hydrogen sulphide, and heavy hydrocarbons can be removed in a central plant [1]. However, some other impurities such as sand and free water should be removed near the wellhead.

Produced natural gas, in most cases, is in a supercritical dense phase. During natural gas processing it is likely that the water and the hydrocarbon components condense and form a liquid phase. This phase behaviour can be explained using the equilibrium phase diagrams known also as phase envelopes. The presence of water in natural gas decreases its heating value and if condensed can cause major operational problems such as corrosion, excessive pressure drop, hydrate formation and consequently the slug flow and reduction in gas transmission efficiency. The possibility of pipe obstruction due to the formation of hydrate within the flow lines is one of the most serious problems in the gas industry. The point at which gas hydrate forms and therefore becomes a source of trouble depends on gas pressure, temperature, and composition. Within the transportation system and at very high pressure of the gas, hydrate can form even at relatively high temperatures (close or above 20 °C). Therefore, it is important to assure that hydrate does not form as the gas is transported from the wellhead to a processing facility. Line heating, injection of hydrate inhibitors, and dehydration are commonly practiced to meet this requirement [2].

In processes such as transmission of gas in high-pressure pipelines and the gas storage in high-pressure containers for land or marine transportation of gas in compressed form, in certain specific pressure and temperature conditions, the presence of heavier hydrocarbons in natural gas is favourable [3]. As the heavier hydrocarbons (C_2^+) are introduced in the gas stream, the gas gravity increases and the compressibility factor decreases. Retaining

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the heavier hydrocarbons in the gas also eliminate the need for dewpointing and NGL recovery units. This may be considered as an advantage especially if the reservoir is in hard to reach environment, examples are arctic gas or gas in deep ocean or very cold environments where construction and running of large gas processing facilities may not be justified. The gas under such circumstances needs to be prepared to a “transportable” quality rather than a “pipeline” quality and therefore the removal of heavier hydrocarbons might not be an absolute necessity. Hydrate should however be handled properly no matter where the gas is produced from.

Natural gas can be dehydrated using the following different methods:

- Absorption using liquid desiccants.
- Adsorption using solid desiccants.
- Dehydration with calcium chloride.
- Dehydration by refrigeration.
- Dehydration by membrane permeation.
- Supersonic dehydration.

Extensive literature is available on common gas dehydration systems including solid and liquid desiccant and refrigeration-based systems [4,5]. Glycols are very good absorbers for water because the hydroxyl groups in glycols form similar associations with water molecules. The contact between a wet gas and glycol can be made in any gas–liquid contact device. Liquid desiccant systems are very established dehydration systems. They are relatively simple to operate and maintain and it is possible to automate them for unmanned operations [4,6]. This technology needs a large facility and due to the need for glycol, there is a possibility for some operational problems such as corrosion, foaming in contactor device, fouling of heat transfer surfaces, glycol contamination and loss.

Solid desiccant dehydration is also known as dry-bed dehydration. It uses a solid reagent to remove water. Adsorbents also known as desiccants are high capacity materials for water removal; examples include alumina, silica gels, and molecular sieves. Desiccants have limited capacity for water, become saturated soon, and therefore should be regenerated to restore their adsorptive capacity. The regeneration is usually accomplished by heating. Dry-bed dehydration is a semi-continuous process for which at least two parallel vessels filled with the adsorbent are required. In this arrangement, one vessel is adsorbing while other is regenerating [4–6]. Solid anhydrous calcium chloride ($CaCl_2$) which forms various $CaCl_2$ hydrates when combined with water can be also used as desiccant to dehydrate natural gas. As water absorption continues, brine solution will be formed. In this unit calcium chloride pellets are placed in a fixed bed. The units might show poor performance under some conditions if $CaCl_2$ pellets bond together and form a solid bridge in the tower [4]. These units produce a waste stream that has to be taken care of appropriately.

Refrigeration through external vapour recompression is the simplest and most common process for natural gas dew point control (i.e., control of NGLs and water content of natural gas). In external or mechanical refrigeration systems the cooling is supplied by a vapour recompression cycle that typically uses propane or other common refrigerants as the working fluid. The refrigerant boils off and leaves the chillers as a saturated vapour [4,7]. If the gas inlet pressure is high enough, there will not be a need for external cooling and the expansion refrigeration that is known as low temperature extraction (LTX) or low temperature separation (LTS). This process applies the Joule–Thompson (JT) effect to reduce the gas temperature upon expansion in order to condense water and hydrocarbon and recover condensate with or without hydrate inhibition. A valve is used to throttle the high-pressure gas stream and generate the self-cooling, The JT effect in this process induces “self-refrigeration” as opposed to “external refrigeration” used in vapour recompression cycles discussed before. This technique requires a large pressure drop so it is used when a high-pressure gas is available. Turbine expansion can also be used for self-refrigeration instead of JT valves. In this case the lost energy could be substantially recovered by connecting the turbine shaft to a compressor [6].

Membranes have been successfully used to remove acid gases from natural gas. They have also been successfully used for dehydration of air. They are also being promoted by suppliers of membrane technologies for water removal [8]. They are relatively expensive (especially for large gas flow rates) and can be easily fouled by gas contaminants. They also need high pressure for efficient operation. However, they have a low-pressure drop through the process and do not need any chemical reagents. The installation and change of the membrane cartridges are relatively easy and the maintenance cost is low. The membranes' capability to remove water vapour is not selective and part of the gas is always wasted through co-permeation.

Most of the previously mentioned methods may have good dehydration performance but they have some disadvantages including the need for relatively large facilities, a considerable investment, complex mechanical work, and the possibility of having a negative impact on the environment. Supersonic gas processing systems were introduced to overcome some of the disadvantages of the alternative processes for dehydration [9]. The main part of a supersonic system is a supersonic (converging–diverging) nozzle. Supersonic nozzles are simple in design and do not contain any moving parts. In a supersonic nozzle both condensation (or solidification of hydrate) and separation occur at supersonic velocities, which leaves hydrate no time to deposit on the wall surfaces due to the short residence time and the high velocity of the fluid. Supersonic nozzles have been commercialized for dew point control applications [10]. The simplicity of this device makes it suitable for unmanned operation for underwater or remote gas production applications. As a result, it is claimed that the gas in this system can be dehydrated in a smaller, lighter, cheaper, more environmentally friendly, and less complex facility [9,11].

In a supersonic unit, the gas temperature is lowered based on gas expansion principles without the need of any refrigerant. The compactness of this design is a major advantage over traditional means of dehydration particularly for offshore applications. The gas velocity in this device is very high which prevents fouling or deposition of solids and ice. Refrigeration is self-induced therefore no heat is transferred through the walls and unlike external refrigeration systems, no inhibitor injection and inhibitor recovery system are necessary. The major drawback of this system is the pressure loss due to the expansion in the nozzle. The system is also very sensitive to variation of pressure and gas flow rate, therefore the turn-down ratio can also be limited. Most of the traditional means of dehydration remove water and hydrocarbon simultaneously and are not selective to any one chemical alone. At certain conditions of pressure and temperature, presence of heavy hydrocarbons (C_2^+) increases the gas gravity and reduces the compressibility factor, which results in an increase in the pipeline mass flow capacity [3]. Furthermore, the compactness and reliability of the process equipment are very important especially for offshore applications where the foot print area is at a premium. To remove water selectively natural gas should be kept in a single phase and hydrocarbon condensation should be avoided. This may require high pressures to keep the hydrocarbon in the supercritical state.