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Original article

Technical and economic feasibility study of flue gas injection in an Iranian oil field

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ABSTRACT

Nowadays, the non-hydrocarbon gases are the main sources for gas injection projects in different countries. The main advantages of the flue gas injection are low cost, readily available sources (which consists mainly of N_2 and CO_2) and low compressibility in comparison with other gases like CO_2 or CH_4 (for a given volume at the same conditions). In addition, it occupies more space in the reservoir and it is an appropriate way for CO_2 sequestering and consequently reducing greenhouse gases. In the aforementioned method, N_2 and/or CO_2 is injected into the oil reservoir for miscible and/or immiscible displacement of remaining oil.

Moreover, a key parameter in the designing of a gas injection project is the minimum miscibility pressure (MMP) which is commonly calculated by running simulation case or implementing conventional correlations. From technical viewpoints, the lower MMP values are more flavor for miscible gas injection process due to lower injection pressure and consequently lower maintenance and lower injection costs.

The main aim of this research is to investigate various gas injection methods (N_2, CO_2, produced reservoir gas, and flue gas) in one of the northern Persian gulf oil fields by a numerical simulation method. Moreover, for each scenario of gas injection technical and economical considerations are took into account. Finally, an economic analysis is implemented to compare the net present value (NPV) of the different gas injection scenarios in the aforementioned oil field.

1. Introduction

It's well known that EOR projects have been strongly influenced by economics and oil prices. EOR methods can be classified into thermal methods, that are mostly intended for heavy oils and non-thermal methods such as gas and chemical injection [1]. In the U.S., the number of chemical and thermal EOR projects were in constant decline from mid-1980's to 2005 (Fig. 1). EOR gas injection project statistics remained constant from mid-1908's and exhibited a growing trend from 2000, especially with the increase in CO_2 projects. In 2002, EOR gas injection projects outnumbered thermal projects for the first time in 30 years [2]. Economical issue is the main obstacle to developing EOR technologies, there is increasing interest in gas injection because it is relatively easy to apply, and comparatively inexpensive.

Flue gas, which consists of a considerable amount of N_2 and CO_2, is a gas that can be used for EOR. The recovery mechanisms associated with flue gas injection are generally same as those observed for pure CO_2 and pure N_2 injection [3–8] but it is based on a readily available gas. The availability of flue gas (and the resulting lower cost) can be a major advantage for this gas injection method.

Furthermore, the escalating concern for reduction of greenhouse gas emissions has led researchers to invent or review and revise all possible means of CO_2 sequestration. By injection of

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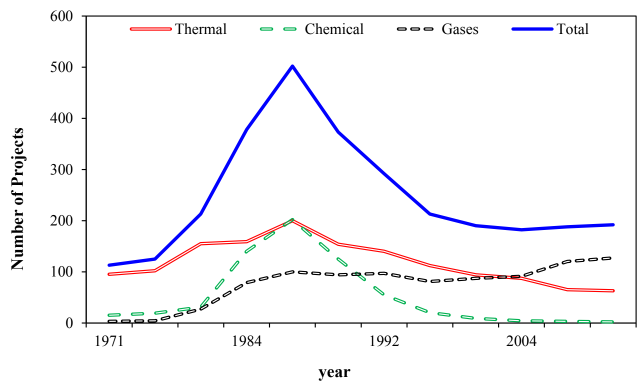

Fig. 1. Evolution of EOR projects in the United States [2].

flue gas into depleting hydrocarbon reservoirs, CO_2 present in the flue gas can be safely stored.

The objective of this paper is to investigate the performance of flue gas injection compared to N_2, CO_2 and natural gas injection in an Iranian oil reservoir. This evaluation is based on experimental determination of MMP via slim tube test, full field simulation of the reservoir and an economic evaluation.

2. Literature review

Nitrogen flooding has been an effective recovery process for high-pressured light oil reservoirs that are located in deep formations. It's been proposed that in such reservoirs, increased oil recoveries result under miscible conditions that favor vaporization of light fractions of light oils and condensates [3]. While N_2 flooding can increase recovery at miscible conditions for light oil reservoirs, immiscible N_2 injection has also been used for pressure maintenance, cycling of condensate reservoirs, and as a drive gas for miscible slugs [4]. Because of high capital and operational costs associated with N_2 injection, interest in this recovery process has lowered. Even so, high pressure and high temperature light oil reservoirs are still selected for N_2 injection if other gas sources are unavailable [5,6].

With the rising concerns for lowering CO_2 emissions, CO_2 injection is now generally considered for EOR with its dual advantage of CO_2 sequestration and improving oil recovery. But while CO_2 injection can increase oil recovery and maintain reservoir pressure, it has a rapid breakthrough due to its low minimum miscibility pressure [7]. Furthermore, since natural sources of CO_2 are usually far from oil reservoirs and considering the costs associated with CO_2 injection (capture, compression and transportation), this kind of gas injection process may not be economically reasonable in the absence of incentives for CO_2 storage [8]. Moreover, another method for storing CO_2 is carbonated water injection into depleting hydrocarbon reservoirs as a secondary and/or tertiary enhanced oil recovery method [9,10].

Another gas EOR method is recycling of produced hydrocarbon gas, which is referred to the injection of produced hydrocarbon gases back into the oil reservoir. This gas injection technique increases oil recovery by the pressure maintenance mechanism. Considering the high costs of gas transportation and the occasional difficulties with selling gas, produced gas will in many cases be a hassle. For this reason, many operators prefer to use the gas in the field. The usual option is to implement a continuous hydrocarbon gas injection scheme. It seems this method is better than N_2 and CO_2 injection due to compatibility and miscibility of injected gas with reservoir fluid [11]. However, injection of hydrocarbon gas back into the reservoir will mean that benefiting from a considerable amount of the reservoir's natural gas will be delayed until gas recycling ceases. Furthermore, as the producing reservoir is depleted, hydrocarbon gas injection is generally unable to achieve complete pressure maintenance.

The advantages of previous techniques can be potentially combined by injection of a mixture of CO_2 and N_2, which are the main constituents of flue gas (flue gas consists of 85–88% N_2 and 15–12% CO_2) [12]. Injection of such mixture should delay the gas breakthrough compared to a pure N_2 injection, and enhance CH_4 production due to displacement by CO_2. Since flue gas is readily available as power plant exhaust, its injection eliminates costs of pure CO_2 separation [13].

Based on the previous researches, flue gas injected into an oil reservoir displaces light oil by a mass transfer mechanism in which intermediate hydrocarbon components transfer from the rich oil phase into the injected flue gas. The process is followed by condensation of heavier intermediate oil components from the enriched gas phase into the liquid phase. Therefore, flue gas injection is a multi-contact process involving a combined vaporizing-condensing gas drive mechanism [14]. From an experimental approach, results show that with increase of the CO_2 fraction in flue gas, the flooding efficiency increases. This is theoretically justified because compared to N_2, CO_2 has a superior ability to dissolve and extract and it causes swelling in crude oil [15].

Gas injection is more efficient when the gas is nearly or completely miscible with in-situ reservoir oil [16]. Various studies have investigated miscibility in gas floods [16–18]. Therefore, it's important to determine whether injected gas is miscible with in-situ reservoir oil. This is done by study of the MMP. The slim tube is generally used for determination of MMP [19–24]. Various equations of state (EOS) can be used to model the process, but the Peng-Robinson EOS is a popular method [25].

3. Governing equations

It is worth to mention that in this study we employed the black oil model to simulate different gas injection scenarios. The Darcy equations are used in the black oil model formulation as expressed in eqs. (1) and (2). Fluid flow formulation in the black oil model can be expressed as follows:

$$u_o = -\frac{KK_{ro}}{\mu_o}(\nabla P_o - \rho_o g) \tag{1}$$

$$u_g = -\frac{KK_{rg}}{\mu_g}(\nabla P_g - \rho_g g) \tag{2}$$

$$\rho_o = \frac{\rho_{so} + \rho_{gs} \cdot R_{so}}{B_o} \tag{3}$$

$$\rho_g = \frac{P \cdot Mw}{ZRT} \tag{4}$$

$$-\nabla(\rho_o q_o) = \frac{\partial}{\partial t}[\varnothing \rho_o S_o] \tag{5}$$