Petroleum 3 (2017) 273–279

Contents lists available at ScienceDirect

Petroleum

journal homepage: www.keaipublishing.com/en/journals/petlm

# On the evaluation of steam assisted gravity drainage in naturally fractured oil reservoirs

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A R T I C L E I N F O

*Article history:*
Received 14 August 2015
Received in revised form
2 January 2016
Accepted 12 January 2016

*Keywords:*
SAGD
EOR
Naturally fractured reservoir
Operational parameters

A B S T R A C T

Steam Assisted Gravity Drainage (SAGD) as a successful enhanced oil recovery (EOR) process has been applied to extract heavy and extra heavy oils. Huge amount of global heavy oil resources exists in carbonate reservoirs which are mostly naturally fractured reservoirs. Unlike clastic reservoirs, few studies were carried out to determine the performance of SAGD in carbonate reservoirs. Even though SAGD is a highly promising technique, several uncertainties and unanswered questions still exist and they should be clarified for expansion of SAGD methods to world wide applications especially in naturally fractured reservoirs. In this communication, the effects of some operational and reservoir parameters on SAGD processes were investigated in a naturally fractured reservoir with oil wet rock using CMG-STARS thermal simulator. The purpose of this study was to investigate the role of fracture properties including fracture orientation, fracture spacing and fracture permeability on the SAGD performance in naturally fractured reservoirs. Moreover, one operational parameter was also studied; one new well configuration, staggered well pair was evaluated. Results indicated that fracture orientation influences steam expansion and oil production from the horizontal well pairs. It was also found that horizontal fractures have unfavorable effects on oil production, while vertical fractures increase the production rate for the horizontal well. Moreover, an increase in fracture spacing results in more oil production, because in higher fracture spacing model, steam will have more time to diffuse into matrices and heat up the entire reservoir. Furthermore, an increase in fracture permeability results in process enhancement and ultimate recovery improvement. Besides, diagonal change in the location of injection wells (staggered model) increases the recovery efficiency in long-term production plan.



## 1. Introduction

Enhanced Oil Recovery (EOR) is a promising improvement technique for oil production. Application of EOR methods on oil fields has received a significant attention due to the increase of oil price as well as oil consumption, in recent years [1,2]. Average oil recovery factor for most of oil fields is less than 40%. This means that a large amount of Original Oil in Place (OOIP) remains entrapped in host reservoir rocks [3]. Based on the type of reservoirs' rock and fluid type, different EOR methods should be

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Peer review under responsibility of Southwest Petroleum University.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.petlm.2016.01.003

implemented on oil fields to extract more oil and increase recovery factors [4,5]. Chemical, gas injection, water flooding and thermal methods are the main EOR categories. In general, thermal methods are applied on heavy oil reservoirs to increase the oil mobility ratio and pushing more oil towards producing wells. In spite of huge amount of heavy oil resources, the recovery factor of these reservoirs does not normally exceed 10% implementing primary and secondary recovery; therefore, applying thermal methods on these fields, provides more oil production and recovery factor.

Huge amount of global heavy oil resources exists in carbonate reservoirs which are mostly naturally fractured reservoirs. Global oil consumption in recent years reveals the importance of fractured reservoir development for the future of oil supply. Different thermal methods are being employed in heavy oil production including, Continuous Steam Injection [6,7], Cyclic Steam Injection [8,9], In-situ Combustion and Steam Assisted Gravity Drainage (SAGD) [10–12]. Complexity of fractured reservoirs reduces the efficiency of classic steam injection methods. One of the most efficient thermal methods used in heavy oil recovery and bituminous sands is known as Steam Assisted Gravity Drainage which was invented by Butler in the 1970s [13]. This method which benefits from a pair of injection/production horizontal wells ensures a stable and uniform expansion of steam, resulting in economical oil production rates [11]. During the process, the heated oil moves approximately parallel to the steam-saturated zone interface, called steam chamber [14]. The entrapped oil due to more contact with steam, exchanges heat with the steam more efficiently, leading to a considerable reduction of oil viscosity and better oil displacement in reservoir rock. As it is well-known, viscosity plays a key role in any EOR process [15–18]. Fig. 1 schematically illustrates the SAGD mechanism. In the first stage, the steam chamber rises vertically in the reservoir rock; and oil production increases steadily [19,20]. In the next stage, after the steam chamber touches the top of the reservoir, lateral expansion of steam chamber begins and this expansion starts controlling the oil production. Although SAGD is an assuring method for fractured reservoirs especially for those with heavy oil reserves, few studies have been carried out to investigate the applicability of this method in these types of reservoirs.

Study of SAGD method can be conducted in two main approaches including investigation of reservoir parameters and investigation of operational parameters. Reservoir parameters are the main criteria in selection of EOR methods [4]. In naturally fractured reservoirs, fracture characteristics such as fracture orientation, fracture permeability and fracture size and spacing have important roles in selection of SADG method. Therefore, fracture characteristics as well as reservoir parameters need to be investigated. Bagci [21], through an experimental and numerical study on SADG process in conventional and fractured models, found that the shape of steam chamber in fractured models is elongated, while the conventional steam chamber is almost round. Nasr et al. [22] investigated the effect of vertical permeability in CDOR (calendar day oil rate) and SOR (steam oil ration), and found that the reduction of vertical permeability produces a remarkable decrease in CDOR and SOR. Sola and Rashidi [11] studied the effects vertical and horizontal fractures on SAGD performance. They stated that an increase in vertical fracture density causes the steam chamber to inflate more effectively, while the rise of the level of horizontal fractures adversely affects steam chamber expansion. Chen et al. [23] also investigated the effect of heterogeneities including vertical and horizontal fractures. They came up with the conclusion that the case of vertical fracture produces more oil in the first stage of production than any of horizontal fracture and base case. Llaguno et al. [24] performed a study on SAGD screening methodologies and found that accumulation parameters (porosity, thickness, oil saturation) have more impact on SAGD performance than fluid parameters (permeability, oil viscosity, reservoir pressure and API). Several other studies have been carried out on the effect of oil pay thickness on SAGD performance; all of the investigators unanimously, stated that the higher the reservoir thickness, the better the SAGD performance [25–27]. Shanqiang and Baker [28] reported that an increase in API results in a decrease in SAGD performance. Very recently, Hashemi-Kiasari et al. [29] showed that reservoir dip adversely affects SAGD performance due to overriding effects.

Several studies have been carried out to identify the effects of operational parameters on SAGD performance. Gates and Chakrabarty [30] observed that the quality of injected steam should be as high as possible due to the fact that any condensate in the injected fluid that drops due to gravity from the injector approaching the producer and through this cause an insignificant quality of heat to be sent to the oil sand. Ong and Butler [31] investigated the effect of well length and found that it does not have significant impact on gravity head in comparison with well size. Very recently, Hashemi-Kiasari et al. [29] reported that in thin reservoirs injector/producer and injector/top of the reservoir spacing, need to be optimized to get the best performance. More details about the effect of operational and reservoirs parameters on SAGD were thoroughly reviewed elsewhere [29].

Unlike clastic reservoirs, very few studies were conducted to identify the performance of SAGD in carbonate reservoirs. Although SAGD is a highly promising technique, many uncertainties and unanswered questions still exist and they should

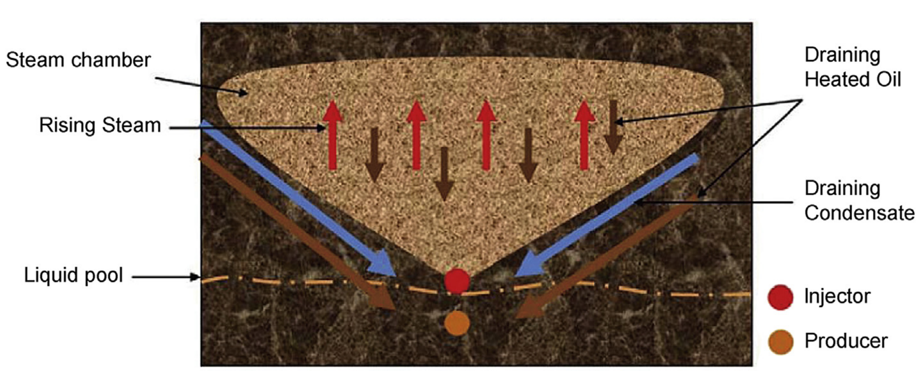


**Fig. 1.** Essential feature of the SAGD process [19].