Journal of Petroleum Science and Engineering 137 (2016) 125–133

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

A pseudo-SAGD scoping model for evaluating economic viability of heavy oil projects

Dayanand Saini *, Ivan Jimenez [1], Christopher D. Reedy [2], Mark Houghton [3]

Department of Physics & Engineering, California State University, Bakersfield, 93311 CA, USA

ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form
24 October 2015
Accepted 25 November 2015
Available online 26 November 2015

Keywords:
Pseudo-SAGD
Jones Model
Sawhney
Liebe, and Butler model
Project economics
Cash flow analysis

ABSTRACT

Unlike the Canadian heavy oil and bitumen resources, which are mainly produced using steam assisted gravity drainage (SAGD) process, production from many of the US heavy oil reservoirs relies on steam injection through vertical wells. To utilize existing vertical injection wells and other surface infrastructure, conventional steam flooding projects may be modified to operate in a pseudo-SAGD mode that use vertical steam injection and horizontal production wells. However a preliminary feasibility study is necessary to reliably analyze a single well pair as a stand-alone project before launching comprehensive simulation studies. For this purpose, a reservoir scoping model coupled with economic analysis template that is easy to apply and use by individual reservoir engineers, was developed. The scoping model was then used to evaluate the economic viability of a heavy oil lease in California.

The scoping model developed in the present study is based on two well-known models namely the Jones model and the Sawhney, Liebe, and Butler model. The model results are comparable with the reported performance of two heavy oil horizontal well projects in the San Joaquin Valley, California, that used vertical steam injection scheme. The economic template is capable of handling a multitude of different scenarios. Any variable can be readily changed to allow users not only to forecast specific scenarios but also to see what variables will have greatest impact on project viability.

The scoping model results suggest that the studied heavy oil lease can be effectively produced in pseudo-SAGD mode. Steam flood application with vertical injection wells at a rate of 246 barrels of cold water equivalent (BCWE/D) per well is determined to effectively promote oil production in a horizontal well at rates over 500 barrels per day (BOPD) for several years. The life span of the project is expected to be to 10 years with an initial capital investment of 6.5 million dollars. Even at relatively high minimal acceptable rate of return (MARR) of 42.5%, the project remains an economical venture with minimum oil price of $84/barrel at the beginning of the project with an annual increase of 2.5% in oil price during the project span. In a downside scenario of $50/barrel crude oil price and 40% tax on income, project can be still economically viable, if 22% or less MARR is acceptable.

1. Introduction

Total resources of heavy oil in known accumulations around the world are 3396 billion barrels of original oil in place (OOIP) and total natural bitumen resource in known accumulations amounts to 5505 billion barrels of oil originally in place (Meyer et al., 2007). Out of these vast resources, over 52% of the heavy oil can be found in North America (19%) and South America (33%). The United States has around 145 billion barrels of heavy oil and bitumen resources (Herron and King, 2004) and around 100 billion barrels of OOIP is in the form of heavy oil (Advanced Resources International (ARI), 2006). According to ARI report (ARI, 2006), the domestic heavy oil resource is primarily located in California (42 billion barrels), Alaska (25 billion barrels), and Wyoming (5 billion barrels). In case of California, nearly, two-thirds of California crude has a gravity under 20° (IPAA, 2015) requiring use of thermal oil recovery processes to exploit it. The use of steam flooding, which is one of the most commonly used thermal oil recovery processes in the world, has enabled California oil industry to economically produce its heavy oil resources. In conventional steam flooding operations (cyclic or continuous), some vertical wells are used as steam injection wells and other vertical wells are used as oil producers.

The recent advancements in drilling technology have resulted in the development of several new heavy oil recovery processes including the Steam-Assisted Gravity Drainage (SAGD). Butler et

* Corresponding author.
E-mail address: dsaini@csub.edu (D. Saini).
[1] Current address: California Resources Corporation, Bakersfield, CA, USA.
[2] Present address: Naftex Operating Company, Bakersfield, CA, USA.
[3] Current address: Ramsgate Engineering, Inc., Bakersfield, CA, USA.

http://dx.doi.org/10.1016/j.petrol.2015.11.019
0920-4105/

Nomenclature

g	gravitational acceleration, m/s^2
h	reservoir height above well, m
k	absolute permeability, m^2
k_s	reservoir permeability to steam, darcies
L_i	initial effective length of production well, m
m_2	dimensionless parameter (Eqs. (2)–(3))
q	volumetric flow rate, m^3/s
t	time, day
T	temperature, °C
T_R	initial temperature of reservoir, °C
T_S	temperature of steam, °C and °F
α_o	thermal diffusivity of oil, ft^2/h
ΔS_o	difference between initial (or current) oil saturation and residual oil saturation
μ_s	steam viscosity, cp
ν	kinematic viscosity of oil at T, m^2/d
ν_R	kinematic viscosity of oil at T_R, m^2/d
ν_s	kinematic viscosity of oil at T_S, m^2/d
ρ_o	density of oil, lbm/ft^3
ρ_s	density of steam, lbm/ft^3

al. (1981) have provided the detailed discussion on the theory of SAGD process. In Canada, use of SAGD process that consists of a pair of two horizontal wells (one injection and one producer) has resulted in more efficient recovery of bitumen and heavy oil from shallow (up to 2000 ft) reservoirs. In an update review of enhanced oil recovery, Alvarado and Manrique (2010) have pointed out that though SAGD pilots have been reported in China, U.S. and Venezuela, commercial application of this EOR process have been reported in Canada only. They further state that among Canadian SAGD projects, only those developed in McMurray Formation (reservoir depth <1500 ft) operate commercially. The analysis presented by Alvarado and Manrique (2010) also suggests that the Canadian SAGD projects with reservoir depth greater than 1500 ft (e.g. Clearwater Formation) have been proved to be uneconomic. The deepest formation for a SAGD operation in the Western Canadian Sedimentary Basin is the Lindbergh Formation (Akram, 2010), with a target bitumen zone at 1675 ft below surface.

On the other hand, California's oil producers have successfully used horizontal producing wells in cyclic steaming operations that primarily use vertical wells for steam injection and oil production. Berry Petroleum Company used horizontal producing wells in the Midway-Sunset field (Morach Formation) to improve production performance and thermal efficiency of existing cyclic steaming operations (McKay et al., 2003). It is noted here that these horizontal wells were also cyclically steamed shortly after they were originally completed and then were placed on production. The offset vertical wells were used to keep the reservoir heated later in the project's life.

Cline and Basham (2002) reported the application of horizontal producing wells with vertical steam injectors in the Tulare and Amnicola reservoirs in the Cymric and McKittrick fields located in the southwestern portion of the San Joaquin Valley, California. According to them, the application of horizontal producing wells with vertical steam injectors has proven to be an economic alternative to a conventional vertical steamdrive operation in the field. The schemes used in the Midway-Sunset field and the Cymric and McKittrick fields seems to resemble the initial version of SAGD process that relies on a series of vertical injection wells, injecting steam above another horizontal producing well (Medina, 2010).

The above mentioned studies demonstrate the successful use of SAGD technology in existing steamflooded heavy oil fields of California. Given the abundance of densely spaced vertical wells (e.g. 1/4 acre well spacing (Chona et al., 1996) and availability of other surface infrastructure in extensively steamflooded heavy oil fields of the San Joaquin Valley, California, use of SAGD technology (vertical injection wells, injecting steam above another horizontal producing well) is an attractive option to improve the oil recovery. The use of existing and new vertical injection wells and other surface infrastructure along with the application of horizontal wells have been found to be an economically viable option (Hayat and Echols, 2005) in arresting the decline in the base production in marginally economic areas developed using pattern steam flooding (e.g. five-spot pattern configurations of vertical steam injection and oil production wells).

However, in the case of difficult to produce heavy oil reservoirs (e.g. the Newcastle Sandstone formation at LAK Ranch in Eastern Wyoming (Grills et al., 2002) or the need for detailed simulation study to optimize the performance of horizontal infill producers in already steamflooded fields (e.g. Chona et al., 1996; Chiou et al., 2000; Hayat and Echols, 2005) necessitates a preliminary feasibility study to reliably analyze a single well pair as a stand-alone project before launching comprehensive simulation studies which rely either on sophisticated commercially available simulators (e.g. Chiou et al., 2000) or proprietary software (e.g. Hancioglu et al., 2013) that may not be necessarily available to small operators.

The needs of such studies also arise from the past uneconomic field experience(s) involving with pseudo-SAGD mode (one vertical injector – one horizontal producer) design. For example, the Kern River vertical-shaft and horizontal-well steam pilot (Dietrich, 1988) which effectively pseudo-SAGD mode design was terminated because of unfavorable economic. The design of this pilot test relied on a pre-SAGD era thermal reservoir simulation tools.

The present study reports on the development of a reservoir scoping model coupled with economic analysis template that is easy to apply and use by individual reservoir engineers. The scoping model is based on two well-known models namely the Jones model (Jones, 1981) and the Sawhney, Liebe, and Butler model (Sawhney et al., 1995). The developed model uses a vertical steam injection-horizontal oil production well pair similar to initial version of SAGD technology hence is termed as pseudo-SAGD scoping model. The model results were then used to evaluate the economic viability of a single well pair as a stand-alone project in pseudo-SAGD mode. A detailed discussion on steam injection (vertical well) and oil production modeling (horizontal well) procedure, associated economic analysis, and efforts made to ensure the reliability of input reservoir parameters is given next.

2. Steam injection modeling (vertical well)

The vertical well steam injection model incorporated in the pseudo-SAGD scoping model uses the steam injection-rate optimization model developed by Jones (1981). In the developed model presented here, steam properties are calculated via the Van Lookeren model (Van Lookeren, 1983). Using the Van Lookeren model, a steepest-ascent hill-climbing algorithm was used to find the maximum vertical conformance factor.

2.1. The Jones model

The Jones' steam injection-rate optimization model utilizes a simple iterative local search algorithm. As such, it performs