DEVELOPMENT OF AN ANALYTICAL MODEL FOR CYCLIC STEAM INJECTION AND STEAM DRIVE METHODS

By

Mohamed Fathy Salem Atwa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Petroleum Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

Prof. Dr. Mohamed Helmy Sayyouh

……..

Professor
Petroleum Engineering Department
Faculty of Engineering, Cairo University

Prof. Dr. Ahmed Hamdy El Banbi

……..

Professor
Petroleum Engineering Department
Faculty of Engineering, Cairo University

Dr. Mohamed Samir

……

Operations General Manager, Sahara Oil
and Gas for Exploration and Production

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Approved by the
Examining Committee

_____
Prof. Dr. Mohamed Helmy Sayyouh, Thesis Main Advisor

_____
Prof. Dr. Ahmed Hamdy El Banbi, Advisor

_____
Prof. Dr. Mahmoud Abu El Ela Mohamed, Internal Examiner

_____
Eng. Nabil Salah Gaber, External Examiner
- Deputy chief executive officer for production - Egyptian General Petroleum Corporation

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Engineer's Name: Mohamed Fathy Salem Atwa
Date of Birth: 15/10/1991
Nationality: Egyptian
E-mail: Mo.fathy.salem@gmail.com
Phone: 00201095177176
Address: 13 El Marwa, Tur Sinai

Registration Date: 1/10/2014
Awarding Date: …./…./2019
Degree: Master of Science
Department: Petroleum Engineering Department

Supervisors:

Prof. Dr. Mohamed Helmy Sayyouh
Prof. Dr. Ahmed Hamdy El Banbi
Dr. Mohamed Samir

Examiners:

Eng. Nabil Salah Gaber (External examiner)
- Deputy chief executive officer for production - EGPC

Prof. Dr. Mahmoud Abu El Ela Mohamed (Internal examiner)
Porf. Dr. Mohamed Helmy Sayyouh(Thesis main advisor)
Porf. Dr. Ahmed Hamdy El Banbi (Advisor)

Title of Thesis:

Development of an Analytical Model for the Prediction of the Performance of both Cyclic Steam Injection and Steam Drive Methods.

Key Words:
EOR; Cyclic Steam Injection; Steam Drive; Analytical Predictive Model; Heavy Oil Recovery

Summary:
A computer program has been developed to predict the performance of both cyclic steam injection and steam drive methods. The program uses methods for the first time along with those found in the literature for cyclic steam injection method. In case of steam drive, a model was developed. The program was validated against ECLIPSE along with actual field data. It can predict the performance with acceptable accuracy in shorter time than numerical simulators with fewer input data.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Mohamed Fathy Salem Atwa Date:

Signature:

Dedication

I dedicate this work to my parents; Fathy Salem and Mona Abd El Aziz.

Acknowledgments

The completion of this work is attributed to the ornate and harmonious mixture of major and minor roles of many people and entities. Therefore, I'd like to narrate and acknowledge each one of them as a sign of my deeply felt waves of gratitude for their unbounded support.

Walking through this research, lots of hardships would have caused depression to obstruct its completion. My supervisors, however, didn't let that take over me at any point of the research period. Despite the concrete dead-ends we used to hit, they have always pushed me through and taught me to fly over and steer around the impenetrable walls. Professor Mohamed Helmy Sayyouh has given this thesis its beating heart by relentlessly igniting my passion whenever it went dim. His guidance and pieces of advice have illuminated a distinct path for every technical problem. Professor El Sayed Ahmed El Tayeb has always brought everything to perfection. I cannot count how many times my presentations and documents have received compliments because of his acute contemplation and directions. His ideas have paved the path for structuring the research point and granting it a value for its generalized nature. Besides, Professor Ahmed El Banbi and Dr. Mohamed Samir have fueled this work by their exquisite experience and scientific mindset. Scheming this work, engraving its details and drawing its milestones were forged through their thoughtful ideas. Pridefully, I have dealt with such ideas as priceless gifts from a master of that sort of gifts.

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Nomenclature

Symbol	Representation	Unit
A_{st}	Steam zone are	ft^2
C_{avg}	Average oil compressibility	psi^{-1}
C_o	Oil specific heat	Btu/lb. °F
C_r	Dry rock specific heat	Btu/lb. °F
C_w	Water specific heat	Btu/lb. °F
D	Depth	ft
f_p	Fraction of injected heat produced	Fraction, Dimensionless
H	Thickness	ft
h_{fs}	Specific enthalpy of liquid water at steam temperature	Btu/lb
h_{fr}	Specific enthalpy of liquid water at formation temperature	Btu/lb
H_{last}	Remaining heat from the previous cycle	Btu
H_{loss}	Heat losses	Btu
h_{ps}	Pump shoe depth	ft
h_{st}	Average steam zone thickness	ft
h_{static}	Static fluid level	ft
H_{st}	Steam injected heat	Btu
k	Permeability	md
k_{ann}	Annulus thermal conductivity	Btu/ft.day.^{o}F
K_f	Formation thermal conductivity	Btu/ft.day.^{o}F
k_{ins}	Insulation thermal conductivity	Btu/ft.day.^{o}F
K_{ov}	Overburden thermal conductivity	Btu/ft.day.^{o}F
k_{ro}	Oil relative permeability	Fraction, Dimensionless
k_{rw}	Water relative permeability	Fraction, Dimensionless
L_w	Wellbore losses	Btu
L'_w	Wellbore losses per feet	Btu/ft
L_v	Specific enthalpy of liquid water at average heated zone temperature	Btu/lb
M_o	Oil heat capacity	Btu/ft^3.°F
M_t	Total volumetric heat capacity	Btu/ft^3.°F
M_w	Water heat capacity	Btu/ft^3.°F
P'	Average reservoir pressure	psi
P_f	Initial formation pressure	psi
P_h	Maximum bottomhole flowing pressure	psia
P_i	Steam injection pressure	psia
P_{wf}	Downhole pressure	psi
q_o	Oil production rate	STB/day
Q_{max}	Maximum amount of supplied heat	Btu
Q_{st}	Steam injection rate	bpd
q_w	Water production rate	STB/day
R_c	Volumetric Heat Capacity of Rock	Btu/ft^3.^{o}F
R_e	Drainage radius	ft
R_h	Heated radius	ft

R_{hi}	Initial heated radius at the beginning of the cycle	ft
r_{ic}	Casing inside radius	ft
r_{ins}	Insulation radius	ft
r_{oc}	Casing outside radius	ft
r_{ot}	Tubing outside radius	ft
R_w	Wellbore radius	Ft
S_o	Oil saturation	Fraction, Dimensionless
S_{oi}	Initial oil saturation	Fraction, Dimensionless
S_{ors}	Residual oil saturation to steam	Fraction, Dimensionless
S_{orw}	Residual oil saturation to water	Fraction, Dimensionless
S_w	Water saturation	Fraction, Dimensionless
S_{wi}	Initial water saturation	Fraction, Dimensionless
S_{wc}	Critical water saturation	Fraction, Dimensionless
t	Time	day
T_{avg}	Heated zone average temperature	^oF
T_c	Casing temperature	^oF
T_f	Formation temperature	^oF
t_{inj}	Injection period	day
T_{ins}	Insulation temperature	^oF
T_{ov}	Overburden temperature	^oF
T_r	Reservoir temperature	^oF
t_{soak}	Soak period	day
T_{sur}	Surface temperature	^oF
T_s	Steam temperature	^oF
x'	Average downhole steam quality	Fraction, Dimensionless
x'_{surf}	Average surface steam quality	Fraction, Dimensionless
v_r	Unit solution in the radial direction	Dimensionless
V_s	Steam zone volume	ft^3
V_{spec}	Specific volume of steam	ft^3/lb
v_z	Unit solution in the vertical direction	Dimensionless

Greek

Symbol	Representation	Unit
α	Thermal Diffusivity	ft^2/day
β	Formation volume factor	Bbl/STB
$\emptyset$	Porosity	Fraction, Dimensionless
μ	Viscosity	cp
$\in$	Emissivity	Dimensionless
ε	Thermal Efficiency	Fraction, Dimensionless
ρ	Density	lb/ft^3
δ	Correction factor	Fraction, Dimensionless