

EVALUATION OF RESERVOIR PROPERTIES FROM WIRELINE FORMATION
TEST IN MULTILAYER RESERVOIR

Miss Duenpen Palasarn

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Petroleum Engineering

Department of Mining and Petroleum Engineering

Faculty of Engineering

Chulalongkorn University

Academic Year 2006

ISBN 974-14-3004-3

Copyright of Chulalongkorn University

การประเมินคุณสมบัติของแหล่งกักเก็บจากการทำไวรัสไลน์ฟอร์มชันทดสอบในแหล่งกักเก็บหลายชั้น

นางสาวเดือนเพ็ญ ปาลสาร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาวิศวกรรมปิโตรเลียม ภาควิชาวิศวกรรมเหมืองแร่และปิโตรเลียม

คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2549

ISBN 974-14-3004-3

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

490327

เดือนเพ็ญ ปาลสาร : การประเมินคุณสมบัติของแหล่งกักเก็บจากการทำไวร์ไลน์ฟอร์มเมชัน
 เทสต์ในแหล่งกักเก็บหลายชั้น (EVALUATION OF RESERVOIR PROPERTIES FROM
 WIRELINE FORMATION TEST IN MULTILAYER RESERVOIR) อ.ที่ปรึกษา : ผศ.
 ดร. สุวัฒน์ อธิชนากร, อ.ที่ปรึกษาร่วม : ดร. สายฝน (ดวงแก้ว) สิริมงคลกิตติ, 135 หน้า,
 ISBN 974-14-3004-3

การศึกษานี้ ใช้การสร้างแบบจำลองของแหล่งกักเก็บทั้งแบบชั้นเดียวและแบบหลายชั้น
 จำลองพฤติกรรมของความดันในชั้นหินเมื่อมีการทำไวร์ไลน์ฟอร์มเมชันเทสต์ จากนั้น ใช้โปรแกรม
 ประเมินค่าจากการทำทดสอบหลุมมาประยุกต์ใช้ในการประเมินค่าคุณสมบัติของชั้นหิน กรณีศึกษา
 เบื้องต้น เป็นการศึกษาโดยใช้แบบจำลองของแหล่งกักเก็บชั้นเดียว ทำการศึกษาผลกระทบของ
 ระยะเวลาในการทดสอบ ตำแหน่งของอุปกรณ์ในการเก็บข้อมูล และค่าความสามารถในการซึม
 ผ่านของของไหลในชั้นหิน จากนั้นทำการศึกษาโดยใช้แบบจำลองของชั้นหินหลายชั้น ศึกษา
 ผลกระทบในลักษณะเดียวกันกับที่ได้กล่าวมาแล้ว แบบจำลองประกอบด้วยชั้นหินที่มีความหนา
 เท่ากัน จำนวน 2 ชั้น โดยแต่ละชั้นจะตั้งค่าความสามารถในการซึมผ่านไว้ต่าง ๆ กัน เพื่อศึกษา
 เพิ่มเติมเกี่ยวกับ ผลกระทบของความแตกต่างของค่าความสามารถในการซึมผ่านของแต่ละชั้น
 หลังจากนั้น ค่าเฉลี่ยความสามารถในการซึมผ่านของแหล่งกักเก็บที่ประกอบด้วยชั้นหินหลายชั้น
 จากวิธีการเฉลี่ยแบบต่างๆ ก็ถูกนำมาศึกษาและเปรียบเทียบเช่นกัน เพื่อประเมินว่าค่าคุณสมบัติ
 ต่างๆ ที่ได้จากการทำไวร์ไลน์ฟอร์มเมชันเทสต์นั้นสามารถให้ค่าที่ยอมรับได้ ณ สภาวะการณ์ใดบ้าง
 ภายใต้ความสามารถของอุปกรณ์

ภาควิชา วิศวกรรมเหมืองแร่และปิโตรเลียม
 สาขาวิชา วิศวกรรมปิโตรเลียม
 ปีการศึกษา 2549

ลายมือชื่อนิสิต... *Ducnpen Palasarn*.....
 ลายมือชื่ออาจารย์ที่ปรึกษา... *Dr. Omit*.....
 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม... *Dr. Sunyapatt*.....

4671603821 : MAJOR PETROLEUM ENGINEERING

KEY WORD : /PERMEABILITY/WIRELINE FORMATION TEST/

MULTILAYER RESERVOIR

DUENPEN PALASARN. THESIS TITLE : EVALUATION OF
RESERVOIR PROPERTIES FROM WIRELINE FORMATION TEST IN
MULTILAYER RESERVOIR. THESIS ADVISOR : ASST. PROF. SUWAT
ATHICHANAGORN, Ph.D., THESIS CO-ADVISOR : SAIFON
(DAUNGKAEW) SIRIMONGKOLKITTI, Ph.D. 135 pp. ISBN 974-14-3004-3

In this study, a reservoir simulator was used to determine pressure responses from wireline formation tests for single-layer and multilayer reservoirs. Then, a well test interpretation software was used to estimate reservoir parameters. A single layer homogenous reservoir was used as a base case to investigate the effect of test duration, probe position, and formation permeability. Next, multilayer models were simulated and interpreted in order to obtain reservoir properties under different conditions. A reservoir model consisting of two layers of an equal thickness but with different values of permeabilities was constructed in order to determine the effect of the contrast permeability between layers and its order. The averaged permeabilities of multilayer reservoirs based on three averaging techniques were compared to the interpreted results. All the investigations were performed to determine whether the results from WFT conducted in multilayer systems can provide satisfactory information under different reservoir scenarios and tool limitation.

Department: Mining and Petroleum Engineering

Field of Study: Petroleum Engineering

Academic Year: 2006

Student's Signature: *Duenpen Palasarn*

Advisor's Signature: *Suwat Athichanagorn*

Co-advisor's Signature: *Saifon Daungkaew*

Acknowledgement

I would like to express my graceful thank to Dr. Suwat Athichanagorn, my thesis advisor, for useful discussion and invaluable advice for this work. I also am grateful to Dr. Saifon (Daungkaew) Sirimongkolkitti, Reservoir Domain Champion (Schlumberger BMP.), my co-advisor, for creative suggestion and invaluable advice.

I would like to gratefully thank Mr. Paul Griffin, Mr. Jim Stuart, Paradigm Geotechnology B.V. and Walailuk University for providing reservoir simulation and interpretation software (SimBestII and Interpret2005), data, and guideline used in this work.

I would like to give my special thank to all my classmates in petroleum engineering program, especially Miss Rossawan Chandakaew, for invaluable discussions, encouragement, and friendship.

I wish to thank the thesis committee members for their comments and recommendations.

I would like to express my deep appreciation to my family and my friends who give me their sympathy, endless love, encouragement, and support.

Contents

	Page
Abstract (in Thai)	iv
Abstract (in English).....	v
Acknowledgement.....	vi
Contents.....	vii
List of Tables.....	ix
List of Figures.....	x
List of Abbreviations.....	xv
Nomenclature	xvi
1. INTRODUCTION	1
1.1 Objective.....	1
1.2 Methodology.....	2
1.3 Thesis Outline.....	2
2. LITERATURE REVIEW	3
2.1 Well Test	3
2.2 Wireline Formation Test (WFT)	6
3. THEORY AND CONCEPT.....	10
3.1 Well Test and Wireline Formation Test Interpretation	10
3.2 Pressure Transient Analysis (PTA)	11
3.2.1 Well Test Concept.....	11
3.2.2 Wireline Formation Test Concept	12
3.3 Radius of Investigation.....	14
3.4 Type Curve for Wireline Formation Test.....	15
3.5 Flow Regime	15
3.5.1 Spherical Flow.....	15
3.5.2 Radial Flow	17
3.5.3 Hemispherical Flow.....	18
3.6 Multilayer Reservoir.....	20
3.6.1 Commingled System	20
3.6.2 Crossflow System.....	20

3.7	Averaging Techniques.....	21
3.7.1	Arithmetic Mean.....	21
3.7.2	Geometric Mean.....	22
3.7.3	Harmonic Mean.....	22
3.8	Reservoir Simulation Concept.....	23
3.9	Numerical Solution and Analytical Solution.....	23
3.10	Wireline Formation Test Tools.....	24
3.11	Wireline Formation Test and Interpretation Procedure.....	28
4.	SIMULATION STUDIES.....	32
4.1	Simulation of Single Layer Homogenous Reservoir.....	33
4.1.1	Base Case.....	33
4.1.2	Effects of Test Duration.....	43
4.1.3	Effects of Probe Positions.....	47
4.1.4	Effects of Formation Permeability.....	54
4.2	Simulation of Two-layer Reservoir.....	59
4.2.1	Case I: Horizontal permeability of 10 and 100 mD.....	60
4.2.2	Case II: Horizontal permeability of 100 and 10 mD.....	77
4.2.3	Case III: Horizontal permeability of 10 and 1000 mD.....	92
4.2.4	Case IV: Horizontal permeability of 1000 and 10 mD.....	102
4.3	Real Data.....	113
5.	CONCLUSIONS AND RECOMMENDATIONS.....	115
5.1	Conclusions.....	115
5.2	Recommendations.....	117
	References.....	118
	Appendices.....	123
	Vitae.....	135

List of Tables

	Page
Table 4.1: Grid sizes of the single layer radial model.....	35
Table 4.2: Reservoir conditions of simulation model.	40
Table 4.3: Comparison between input parameters and estimates from test interpretation.....	42
Table 4.4: Interpreted results for different test durations.	44
Table 4.5: Interpreted results from different probe positions.....	53
Table 4.6: Interpreted results of extended test duration of tests conducted in a reservoir with horizontal permeability of 1 mD.	55
Table 4.7: Interpreted results of tests conducted in a reservoir with different permeabilities.	58
Table 4.8: Interpreted results of extended time when the probe is at 5 feet above the middle of the formation.....	64
Table 4.9: Spherical and horizontal permeabilities using different averaging techniques for case I.	74
Table 4.10: Interpreted results of tests conducted in a reservoir with different probe positions for case I.....	75
Table 4.11: Spherical and horizontal permeabilities using different averaging techniques for case II.....	89
Table 4.12: Interpreted results of tests conducted in a reservoir with different probe positions for case II.	90
Table 4.13: Spherical and horizontal permeabilities using different averaging techniques for case III.	99
Table 4.14: Interpreted results of tests conducted in a reservoir with different probe positions for case III.	100
Table 4.15: Spherical and horizontal permeabilities using different averaging techniques for case IV.	110
Table 4.16: Interpreted results of tests conducted in a reservoir with different probe positions for case IV.....	111

List of Figures

	Page
Figure 3.1: Inverse problem (Horne, 1995).....	10
Figure 3.2: Type curve for wireline formation test.	15
Figure 3.3: Schematic of spherical flow.....	16
Figure 3.4: Pressure change and pressure derivative of spherical flow.	16
Figure 3.5: Schematic of radial flow.	17
Figure 3.6: Pressure change and pressure derivative of radial flow.....	18
Figure 3.7: Schematic of hemispherical flow.....	19
Figure 3.8: Pressure change and pressure derivative of hemispherical flow.	19
Figure 3.9: Commingled system (Horne, 1995).....	20
Figure 3.10: Crossflow system (Horne, 1995).	20
Figure 3.11: Simulation and Well test interpretation software flow geometries for WFT.....	24
Figure 3.12: Schematic of wireline formation test tool.....	27
Figure 3.13: Schematic of WFT test.....	29
Figure 3.14: Pressure and flowrate history of WFT.....	29
Figure 3.15: Repeated drawdown and buildup tests.....	30
Figure 3.16: Wireline formation test and interpretation.....	31
Figure 4.1: Comparison between different gridding methods.....	34
Figure 4.2: 3D view of a single layer radial model.	36
Figure 4.3: Top view of a single layer radial model.....	37
Figure 4.4: Cross section of a single layer radial model.	38
Figure 4.5: Side view of a single layer radial model.....	38
Figure 4.6: Schematic of a single layer homogenous reservoir.....	39
Figure 4.7: Pressure history of a single layer homogenous reservoir (base case).....	41
Figure 4.8: Diagnostic plot for a single layer homogenous reservoir (base case).....	41
Figure 4.9: Regression for a single layer homogenous reservoir (base case).	42
Figure 4.10: Schematic of a single layer reservoir with different test durations.....	43
Figure 4.11: Diagnostic plots for different test durations.....	45
Figure 4.12: Schematic of different probe positions.	47

Figure 4.13: Diagnostic plot of the pressure response obtained from a well test interpretation software.	48
Figure 4.14: Schematic of pressure response.	49
Figure 4.15: Diagnostic plot when the probe is 8 feet above the middle of the formation.	50
Figure 4.16: Diagnostic plot when the probe is 5 feet above the middle of the formation.	51
Figure 4.17: Diagnostic plot when probe position at 0.5 foot above the middle of the formation.	52
Figure 4.18: Schematic of a single layer reservoir with varying permeability.	54
Figure 4.19: Diagnostic plot of a test conducted in a reservoir with horizontal permeability of 1 mD.	55
Figure 4.20: Diagnostic plot of test conducted in a reservoir with horizontal permeability of 10 mD.	56
Figure 4.21: Diagnostic plot of test conducted in a reservoir with horizontal permeability of 100 mD.	57
Figure 4.22: Diagnostic plot of test conducted in a reservoir with horizontal permeability of 1000 mD.	58
Figure 4.23: Schematic of a two-layer formation with different probe positions.	59
Figure 4.24: Schematic of a two-layer formation with horizontal permeabilities of 10 and 100 mD.	60
Figure 4.25: Diagnostic plot when the probe is 8 feet above the middle of the formation.	61
Figure 4.26: Diagnostic plot when the probe is 5 feet above the middle of the formation.	62
Figure 4.27: Diagnostic plot when the probe is 5 feet above the middle of the formation for extended test duration.	63
Figure 4.28: Diagnostic plots when the probe is 2 feet above the middle of the formation.	65
Figure 4.29: Diagnostic plot when the probe is 1 foot above the middle of the formation.	66

Figure 4.30: Diagnostic plot when the probe is 0.5 foot above the middle of the formation.....	67
Figure 4.31: Diagnostic plot when the probe is 0.5 foot below the middle of the formation.....	68
Figure 4.32: Diagnostic plot when the probe is 1 foot below the middle of the formation.....	69
Figure 4.33: Diagnostic plot when the probe is 2 feet below the middle of the formation.....	70
Figure 4.34: Diagnostic plot when the probe is 5 feet below the middle of the formation.....	71
Figure 4.35: Diagnostic plot when the probe is 8 feet below the middle of the formation.....	72
Figure 4.36: Chart comparing spherical permeability for case I.....	76
Figure 4.37: Chart comparing horizontal permeability for case I.....	76
Figure 4.38: Schematic of two layer with horizontal permeabilities of 100 and 10 mD.....	77
Figure 4.39: Diagnostic plot when the probe is at 8 feet above the middle of the formation.....	78
Figure 4.40: Diagnostic plot when the probe is at 5 feet above the middle of the formation.....	79
Figure 4.41: Diagnostic plot when the probe is at 2 feet above the middle of the formation.....	80
Figure 4.42: Diagnostic plot when the probe is at 1 foot above the middle of the formation.....	81
Figure 4.43: Diagnostic plot when the probe is at 0.5 foot above the middle of the formation.....	82
Figure 4.44: Diagnostic plot when the probe is at 0.5 foot below the middle of the formation.....	83
Figure 4.45: Diagnostic plot when the probe is 1 foot below the middle of the formation.....	84
Figure 4.46: Diagnostic plot when the probe is 2 feet below the middle of the formation.....	85

Figure 4.47: Diagnostic plot when the probe is at 5 feet below the middle of the formation.....	86
Figure 4.48: Diagnostic plot when the probe is at 8 feet below the middle of the formation.....	87
Figure 4.49: Chart comparing spherical permeability for case II.....	91
Figure 4.50: Chart comparing horizontal permeability for case II.....	91
Figure 4.51: Schematic of two layer reservoir with horizontal permeability of 10 and 1000 mD.....	92
Figure 4.52: Diagnostic plot when the probe is at 8 feet above the middle of the formation.....	93
Figure 4.53: Diagnostic plot when the probe is at 5 feet above the middle of the formation.....	94
Figure 4.54: Diagnostic plots when the probe is 2 feet above the middle of the formation.....	95
Figure 4.55: Diagnostic plot when the probe is 1 foot above the middle of the formation.....	96
Figure 4.56: Diagnostic plot when the probe is 0.5 foot above the middle of the formation.....	97
Figure 4.57: Diagnostic plots comparing a single layer and the two layers with different probe positions for case III.....	98
Figure 4.58: Chart comparing spherical permeability for case III.....	101
Figure 4.59: Chart comparing horizontal permeability for case III.....	101
Figure 4.60: Schematic of two layer reservoir with horizontal permeabilities of 1000 and 10 mD.....	102
Figure 4.61: Diagnostic plots comparing a single layer and the two layers with different probe positions for case IV.....	104
Figure 4.62: Diagnostic plot when the probe is 0.5 foot below the middle of the formation.....	105
Figure 4.63: Diagnostic plot when the probe is 1 foot below the middle of the formation.....	106
Figure 4.64: Diagnostic plot when the probe is 2 feet below the middle of the formation.....	107

Figure 4.65: Diagnostic plot when the probe is 5 feet below the middle of the formation.	108
Figure 4.66: Diagnostic plot when the probe is 8 feet below the middle of the formation.	109
Figure 4.67: Chart comparing spherical permeability for case IV.	112
Figure 4.68: Chart comparing horizontal permeability for case IV.	112
Figure 4.69: Real data of spherical flow regime and a high permeable zone acts as a constant pressure boundary.....	113
Figure 4.70: Real data of the changing mobility.	114

List of Abbreviations

DST	drillstem test
FIT	formation interval tester
FMT	formation multi-tester
FT	formation tester
MDT	modular dynamic formation tester
MST	multiset formation sampler
PTA	pressure transient analysis
RCI	reservoir characterization instrument
RDT	reservoir description tool
RFS	repeat formation sampler
RFT	repeat formation tester
SFT	selective formation tester
SFTT	sequential formation tester
WFT	wireline formation test

Nomenclature

B_{wi}	water initial formation volume factor
c_t	total compressibility
G	geometric mean
H	harmonic mean
k	formation permeability
k_{xyz}	spherical permeability
k_{xy}	horizontal permeability
k_z	vertical permeability
k_z/k_{xz}	vertical to horizontal permeability ratio
n	number of samples
p_i	initial reservoir pressure
q	flowrate
r_{inv}	radius of investigation
r_s	probe radius
S_p	probe skin factor
t	time
w	weight
\bar{x}	arithmetic mean
x_i	samples

GREEK LETTER

μ	fluid viscosity
ϕ	porosity
Δ	difference operator

SUPERSCRIPTS

i	number of samples
n	all number of samples

SUBSCRIPTS

<i>inv</i>	investigation
<i>p</i>	probe
<i>sc</i>	standard condition
<i>t</i>	total
<i>w</i>	water
<i>x</i>	x-direction
<i>y</i>	y-direction
<i>z</i>	z-direction