

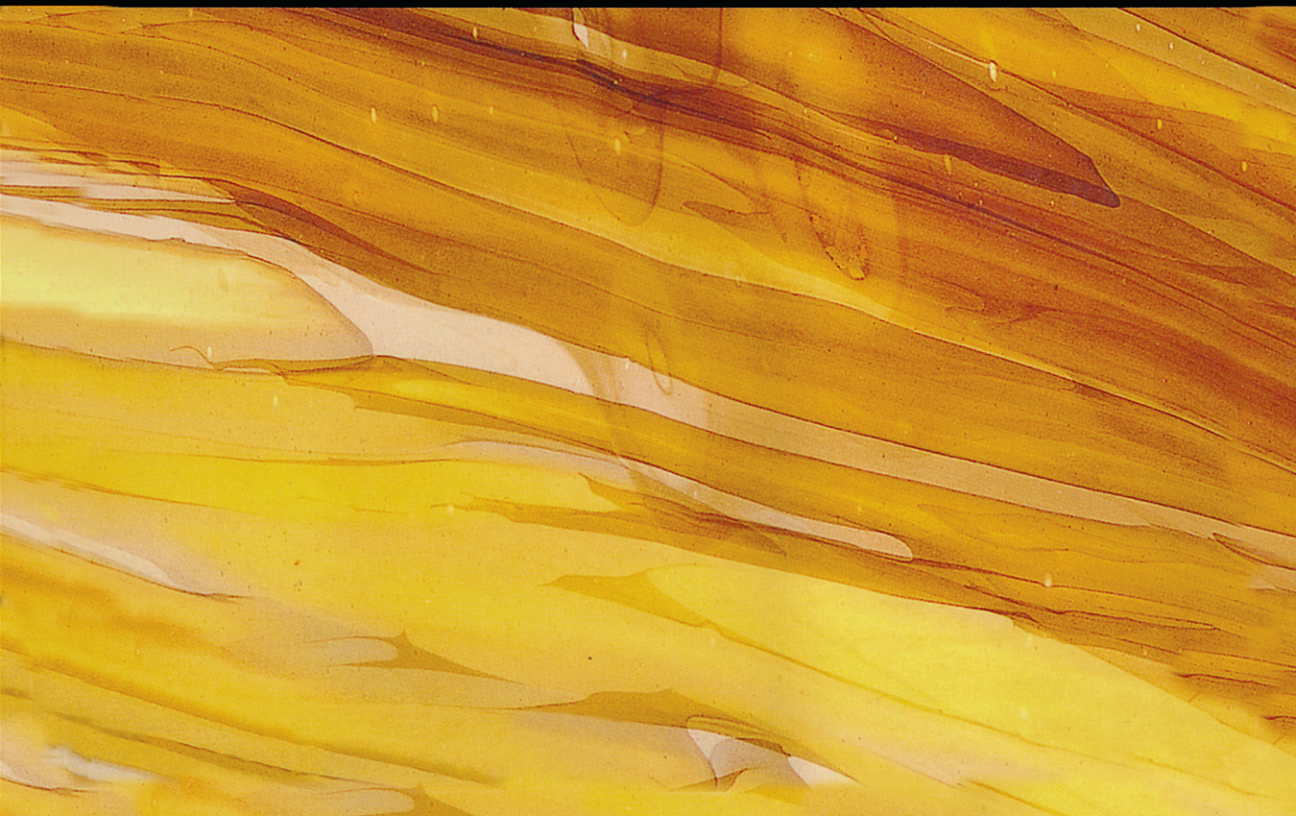


DEVELOPMENTS IN
PETROLEUM SCIENCE

36

**THE PRACTICE OF
RESERVOIR
ENGINEERING
(REVISED EDITION)**

L.P. DAKE





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L.P. DAKE †



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FOREWORD TO THE REVISED EDITION

This revised edition presents a series of small text improvements throughout the book and a certain revision of the text of chapter 4 which was required to enable a better understanding of some physical explanations.

A more important change was carried out in subchapter 5.9 in relation to “the examination of water drive performance”, where an excellent demonstration for a new procedure was developed for two real field cases. All elements of design, such as injection pressure, oil rate, and recovery prediction are explained in detail and illustrated with two field examples: one in the North Sea and another one in East Texas.

The philosophy introduced by Laurie Dake in chapter 5.9 concerns the key to understanding the reservoir fractional flow technique by the appreciation that the Buckley-Leverett theory is dimensionless and thus represents the simplest statement of the material balance for water drive.

In this book, containing the basic material and modifications prepared by the author Laurie Dake, any Petroleum Engineer will find the essential basis not only for understanding a gas or oil field, but also for predicting the future behaviour of a reservoir. It represents one of the most precious heritages of one of the most brilliant minds who dedicated his life to the advancement of Petroleum Science and Engineering.

Prof. Dr. T.D. van Golf Racht
Petroleum Department
Trondheim University

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PREFACE

The *Practice of Reservoir Engineering* has been written for those in the oil industry requiring a working knowledge of how the complex subject of hydrocarbon reservoir engineering can be applied in the field in a practical manner. The book is a simple statement of how to do the job and is particularly suitable for the hard pressed reservoir/production engineers in its advice, illustrated with 27 examples and exercises based mainly on actual field developments. It should also be useful for those associated with this central subject of hydrocarbon recovery, from geoscientists and petrophysicists to those involved in the management of oil and gas fields.

Reservoir engineering is a complex subject for two reasons. In the first place, we never see enough of the reservoirs we are trying to describe. Therefore, it is difficult to define the physics of the system and, therefore, select the correct mathematics to describe the physics with any degree of certainty. The second problem is that even having selected a sensible mathematical model there are never enough equations to solve for the number of unknowns involved. The latter problem extends across the broad spectrum of the subject, from material balance application to well test interpretation and leads to an inevitable lack of uniqueness in describing reservoirs. Given these basic limitations, the only approach to the subject must be one of simplicity and such is the theme of the book. In fact, the basic tenet of science: Occam's Razor, applies to reservoir engineering to a greater extent than for most physical sciences — that if there are two ways to account for a physical phenomenon, it is the simpler that is the more useful.

Chapter 1, *Introduction to Reservoir Engineering*, is a description of the subject and of the main themes of the book. It was inspired on reading the excellent history of the industry *The Prize (The Quest for Oil, Money and Power)* written by Daniel Yergin and published by Simon and Schuster in 1991. Rather surprisingly, in the extensive index to this 880 page treatise the word "Reservoir" does not appear and, therefore, neither does "Reservoir Engineering", practitioners of which will appreciate is the most important subject in the whole industry. Chapter 1, therefore, attempts to redress the balance with a statement of the meaning of reservoir engineering. It includes a description of the main activities and the role of engineers, particularly in offshore developments, which is a topic that has received little attention in the literature. The history and future of reservoir engineering are considered and the chapter ends with a description of the basic physical principles involved in its application.

Chapter 2, *The Appraisal of Oil and Gas Fields*, focuses on the appraisal stage of field development, which is particularly relevant to offshore projects. Subjects covered include: PVT-fluid properties, with particular emphasis on sample collection and the correction of laboratory data to match field conditions, the estimation of

hydrocarbons in place and the contentious issue of equity determination. The chapter concludes with a description of pressure–depth relations and, in particular, RFT-interpretation, the purpose and practice of appraisal well testing (DSTs) and the design of extended well tests (EWTs). The chapter is written in such a manner as to serve as a useful introduction to field appraisal for all disciplines involved in this activity.

Chapter 3, *Material Balance Applied to Oilfields*, is on the application of material balance to fields influenced by a variety of different drive mechanisms. In the author's opinion, the subject has become as dead as the Dodo in recent years, the general belief being that it has been superseded by the more sophisticated technique of numerical simulation modelling. Nothing could be further from the truth, however, since material balance is the fundamental physical statement of reservoir engineering, not only explaining the mechanics of reservoir behaviour but also being the basic principle of the mechanics of fluid displacement (Buckley-Leverett). The chapter points out that material balance and simulation should not be regarded as competitive modes of describing field performance but must instead be fully supportive. The former is the ideal tool for history matching field performance, the results of which are used to construct a simulation model for the purpose of prediction. Such has been the neglect of material balance, however, that younger engineers have neither experience nor confidence in its application. To overcome this, the chapter contains six fully worked examples of material balance application to real field developments.

Chapter 4, *Oilwell Testing*, is devoted to the examination of the purpose, practice and interpretation of well tests in both appraisal and development wells. Since the early 1980's, the subject has been dominated by the philosophy of attempting to solve the *inverse problem*: using mathematics to define the physical state of a system. With the exception of developments at the forefront of physical science, this is an unconventional approach in practical physical/engineering disciplines and amounts to little more than curve fitting, which suffers from a severe lack of uniqueness. The chapter attempts to persuade the engineer that the only rational approach to test interpretation is to first define the physical state of the system under test by comprehensive observation of all relevant reservoir/mechanical data and then reach for the appropriate mathematical model (if it exists) to analyse the test. This is a much more difficult approach but, bearing in mind the importance of the field development decisions based on well test interpretation, is one that is mandatory.

In examining the history of well testing, the author has had cause to revise some of the earlier, simplifying assumptions that have dominated the subject. The most pervasive is that of *transience* (infinite acting behaviour) which, on account of its mathematical simplicity, has long prevailed in the subject and is still enshrined in many modern texts and computer software for test interpretation. Removal of this assumption on fifteen occasions, from the conventional presentation of the subject, confronts the engineer with a completely different perspective on test interpretation; in some respects more restrictive, in others more liberating but always more realistic.

In spite of the burgeoning use of log–log pressure plotting since the early 1980's, by far the most popular means of pressure buildup interpretation remains the

Horner semi-log plot (1951). Yet the most widespread error in the whole subject lies in its interpretation: where should the straight line be drawn and what does it mean? To overcome this, the author has resurrected and extended application of the simpler form of buildup analysis technique of Miller, Dyes and Hutchinson (MDH-1950) and demonstrated that it is capable of matching anything that Horner analysis can do — and a little bit more, in a simpler and less error prone manner. Use of the technique suggests that perhaps we waste too much time and money indulging in lengthy pressure buildups, when a few hours of closure is all that is ever required. Examining Horner and MDH time derivative plots in conjunction is presented as a *guaranteed* method for defining the correct straight line on semi-log buildup plots.

Chapter 5, *Waterdrive*, describes the most widespread form of secondary recovery technique: engineered waterdrive. Some of the description relates to the development of North Sea fields, the majority of which operate under this condition. This is not chauvinistic because the argument is made that the North Sea has been the biggest laboratory ever for the study of waterdrive.

The chapter starts with a description of the practicalities of waterdrive with particular emphasis on matching the capacities of surface facilities for injection/production of liquids to the reservoir performance. Next, the basic theory of waterdrive (Buckley-Leverett) and its components are examined in detail. These consist of relative permeabilities and the concept of the fractional flow of water. It is argued that the former have little relevance in themselves and it is the fractional flow relationship that predominates in the subject. In fact, it is the main purpose in writing the chapter to try and re-assert the importance of fractional flow, which, like material balance, has practically disappeared from reservoir engineering in recent years simply because the concept has never (or only recently) been incorporated in the construction of numerical simulation models — and, therefore, it has ceased to exist. Data requirements and their interpretation and incorporation in the calculation of vertical sweep efficiency in heterogeneous reservoir sections are described, all using pseudo fractional flow functions in Welge calculations. The chapter finishes with an account of methods for history matching and predicting the performance of *difficult* waterdrive fields, which sometimes defy the use of numerical simulation due to their sheer complexity.

Chapter 6, *Gas Reservoir Engineering*, covers three aspects of gas reservoir engineering: material balance, immiscible gas drive and dry gas recycling in retrograde gas condensate reservoirs. Gas material balance is probably the simplest subject in reservoir engineering, yet the universal use of p/Z -plots in isolation leads to some alarming errors in overestimating the GIIP, the worst example noted by the author being an excess of 107%. Surely we can do better than that — and indeed we can. A more rational and sensitive approach to material balance application, to be used in conjunction with p/Z -plots, is suggested and its use illustrated.

The mobility ratio for immiscible gas–oil displacement is very unfavourable, making the process intrinsically unstable, unless the gravity term in the gas fractional flow is dominant. The section concentrates on the vetting of reservoirs for their suitability for gas drive and provides an example of gas drive efficiency calculations.

In considering dry gas recycling, much of the analysis in the literature is focused on compositional effects and what is overlooked is that the process is basically unstable. The section describes the influence of heterogeneity and gravity on the efficiency of recycling, which is illustrated with an example.

Acknowledgements. I should like to thank all those who have helped me during the course of writing this book. Foremost are all those engineers with whom I have worked or who have attended my lecture courses in reservoir engineering. I am particularly indebted to Scottish Enterprise (formerly the Scottish Development Agency) for their support and Enterprise Oil of London for their continual assistance. My thanks are also due to the staff of the Department of Energy, London (now the Department of Trade and Industry) and also to members of the staff of The Danish Energy Agency in Copenhagen. Particular thanks also to my colleague Professor Th. van Golf Racht of Paris for his advice.

Laurie Dake

IN MEMORIAM: LAURENCE P. DAKE

In the family of reservoir and petroleum engineers it was always so natural and rewarding to talk about “Laurie” (the name he preferred to his official one, Laurence Patrick Dake) about his point of view, and about his acceptance of, or opposition to, certain ideas or procedures. Today, sitting in front of a blank sheet of paper, I understand for the first time how difficult, how sad, and how impossible it is for any of his friends to talk about Laurie in *memoriam*. The only way to proceed is by remembering Laurie’s life and his contribution to our petroleum engineering profession, and in evoking his exceptional creative spirit.

I remember the unforgettable conversations during the long winter nights of 1985 in my Norsk Hydro Oslo Office, when Laurie elaborated on the key objective of reservoir engineering: The capacity to turn the time-mirror around, so that a coherent image of the future prediction of an oil field can in return give us valuable insight into today’s understanding of the same field, in order to ensure that every statement about the future behaviour of the reservoir is not accompanied by a long series of “ifs”, “buts” and an avalanche of “maybes”.

It was during this period that Laurie began using this approach to lay the foundations for the book “Practice of Reservoir Engineering”.

Laurence Dake was born *11 March 1941* on the Isle of Man. He received his education at King Williams College and graduated in Natural Philosophy at the University of Glasgow in *1964*.

Recruited by Shell in *1964*, he joined Shell International as a Petroleum Engineer. Following a thorough training program at the Shell Training Center in The Hague, he participated as Petroleum Engineer in a variety of field operations in Australia, Brunei, Turkey and Australia until *1971*, when he was once again called back to the Shell Training Center in The Hague. For seven years, from *1971 until 1978*, he taught the subject of Reservoir Engineering to Shell graduates.

In *1978* Laurie Dake left Shell after 14 years of service, at which time he made two significant steps which would determine his further professional career:

(1) He joined the newly established State Oil Company BNOG (British National Oil Cooperation) as Chief, Reservoir Engineering. In this function he participated in the discovery, development and deciphering of the secrets of the large North Sea reservoirs. His contribution during the early days of the UK offshore industry was so significant that in *1987* he received the OBE recognition for his Reservoir Engineering services to the UK industry. In these days this recognition not only honoured him for his exceptional work, but also indirectly honoured the reservoir engineering profession for its potential to influence the results of the oil and gas industry.

(2) In *1978* Laurie Dake published his first book with Elsevier on reservoir engineering under the title “*The Fundamentals of Reservoir Engineering*”. In this work he introduced a modern vision on Reservoir Engineering based on the

synthesis between rigorous physics and applied science, necessary in any field operative work. The exceptional success of this book with the entire petroleum world resulted from:

- its utility for Petroleum Engineers in applying simplified procedures to complex problems of hydrocarbon reservoirs;
- its utility as fundamental text for students at almost every University where the scientific basis of the reservoir discipline is combined with a large amount of field applications and examples.

In 1982 Laurie Dake left BNOOC at the time of its privatisation and started as an independent consultant, based in Edinburgh. His comprehensive activities were divided among:

- a “direct consulting activity” with medium and large companies where Laurie made a substantial contribution to the appraisal and development of over 150 world wide oil and gas fields, *between 1982 and 1994*. He became one of the most appreciated international petroleum consultants, and was consulted by very large companies (BP, Agip, Norsk Hydro, Statoil, etc.) and banks (Bank of Scotland – Edinburgh, BankWest Perth, Australia, etc.);
- an important collaboration with the Petroleum Department of the Heriot—Watt University, where he started initially (*after 1978*) as an external examiner and where he later became a “Honorary Professor”;
- the elaboration of his second book “The Practice of Reservoir Engineering”, published by Elsevier in 1994. In addition to many field operative concepts, the text included specific procedures and analyses developed by Laurie and proven successful in various fields studied by him.

In the middle of these exceptional activities, his real help to the entire petroleum engineering family through his books and courses, his consulting activities and his advice to the Financial World and Petroleum Companies, Laurie Dake’s death on *July 19, 1999* left us disoriented. All of us who appreciated him, who admired his work and loved him for his exceptional qualities and distinction suddenly felt impoverished.

However, if we now look back to the horizon opened by Laurie, knowing that there exists an accepted horizon — visible but sterile, and another ... an imaginative and creative one, we may change our point of view. Knowing that the creative horizon in a sense defines the boundaries between spirit and matter, between resources and platitude, we start to understand the role played by Laurie Dake — who disregarded the customary procedure and fought to grasp the real meaning of reservoir behaviour.

He has been able with his intelligence to enlarge the opened horizon by combining the will of creativity with the knowledge of reality versus the size of possibility ... , all of which we find in the solutions proposed by him.

It is this enlarged horizon which Laurie left to all of us as a splendid heritage ...

Prof. Dr. T.D. van Golf Racht
Petroleum Department, Trondheim University

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NOMENCLATURE

A	area (sq.ft)
B_g	gas formation volume factor: gas (rcf/scf) : oil (rb/scf)
B_o	oil formation volume factor (rb/stb)
B_w	water formation volume factor (rb/stb)
c	isothermal compressibility (1/psi)
c_f	pore compressibility (1/psi)
c_o	oil compressibility (1/psi)
c_w	water compressibility (1/psi)
C_A	Dietz shape factor (dimensionless)
C'_A	Larsen shape factor (dimensionless)
D	vertical depth (ft.ss)
e	exponential
ei	exponential integral function
E	gas expansion factor (scf/rcf)
$E_{f,w}$	term in the material balance equation accounting for connate water expansion and pore compaction (rb/stb)
E_g	term in the material balance equation accounting for the expansion of the gas cap (rb/stb)
E_o	term in the material balance equation accounting for the expansion of the oil and its originally dissolved gas (rb/stb)
f_g	fractional flow of gas (dimensionless)
f_w	fractional flow of water (dimensionless)
F	underground withdrawal of fluids (rb)
G	gas initially in place (scf)
G	gravity number in the fractional flow equation (dimensionless)
G_p	cumulative gas production (scf)
h	formation thickness (ft)
k	permeability (mD)
k_r	relative permeability (dimensionless)
k'_r	end point relative permeability (dimensionless)
\bar{k}_r	pseudo relative permeability (dimensionless)
l	length (ft)
L	length (ft)
m	ratio of the initial hydrocarbon pore volume of the gascap to that of the oil column (material balance) (dimensionless)
m	slope of the early linear section of semi-log plots for well test interpretation psi/log cycle

$m(p)$	pseudo pressure (psi ² /cp)
M	end point mobility ratio (dimensionless)
n	number of lb moles
N	stock tank oil initially in place (stb)
N_p	cumulative oil recovery (stb)
N_{pd}	dimensionless cumulative oil recovery (PV)
N_{pD}	dimensionless cumulative oil recovery (HCPV)
p	pressure (psia)
p_b	bubble point pressure (psia)
p_D	dimensionless pressure
p_e	pressure at the external boundary (psia)
p_i	initial pressure (psia)
p_{sc}	pressure at standard conditions (psia)
p_{wf}	wellbore flowing pressure (psia)
p_{ws}	wellbore static pressure (psia)
p_{wsl}	static pressure on the early linear trend of a semi-log buildup or two rate drawdown plot (psia)
\bar{p}	average pressure (psia)
p^*	specific value of p_{wsl} at infinite closed-in time (Horner plot) (psia). (See also Z^* .)
q	liquid production rate (stb/d)
q_{wi}	water injection rate (b/d)
Q	gas production rate (MMscf/d)
r	radial distance (ft)
r_e	external boundary radius (ft)
r_{eD}	aquifer/reservoir radius ratio (dimensionless)
r_o	reservoir radius (ft)
r_w	wellbore radius (ft)
R	producing (instantaneous) gas oil ratio (scf/stb)
R	universal gas constant
R_p	cumulative gas oil ratio (scf/stb)
R_s	solution or dissolved gas oil ratio (scf/stb)
S	skin factor (dimensionless)
S_g	gas saturation (PV)
S_{gr}	residual gas saturation (PV)
S_o	oil saturation (PV)
S_{or}	residual oil saturation (PV)
S_w	water saturation (PV)
S_{wbt}	breakthrough water saturation (PV)
S_{wc}	connate water saturation (PV)
S_{wf}	shock front water saturation (PV)
\bar{S}_g	thickness averaged gas saturation (PV)
\bar{S}_{gd}	thickness averaged dry gas saturation (PV)
\bar{S}_w	average water saturation (PV)

t	time hours to years, as appropriate
t_D	dimensionless time
t_{DA}	dimensionless time ($t_D r_w^2 / A$)
Δt	closed-in time (pressure buildup) (hours)
Δt_s	closed-in time during a buildup at which p_{wsl} extrapolates to p_i or \bar{p} on an MDH plot
T	absolute temperature (degrees Rankin)
U	aquifer constant (bbl/psi)
v	velocity (ft/d)
V	volume (cu.ft)
W	width (ft)
W_D	dimensionless cumulative water influx
W_e	cumulative water influx (bbl)
W_i	cumulative water injected (bbl)
W_{id}	dimensionless cumulative water injected (PV)
W_{iD}	dimensionless cumulative water injected (HCPV)
W_p	cumulative water produced (bbl)
Z	Z-factor (dimensionless)
Z^*	alternative symbol to replace p^* in Horner buildup analysis (psia)

GREEK

α	volumetric sweep (dimensionless)
γ	specific gravity (liquids: relative to water = 1, gas: relative to air = 1, at standard conditions)
γ	exponent of Euler's constant (1.781)
Δ	difference
θ	dip angle (degrees)
μ	viscosity (cp)
ρ	density (lb/cu.ft)
σ	coefficient in well testing equations = $7.08 \times 10^{-3} \text{ kh}/q\mu B_o$

SUBSCRIPTS

b	bubble point
bt	breakthrough
d	differential (PVT analysis)
d	dimensionless (PV)
d	displacing phase
D	dimensionless (pressure, radius, time)
D	dimensionless (HCPV)
DA	dimensionless (time)
e	production end of a system
f	flash separation

f	flood front
g	gas
i	cumulative injection
i	initial
o	oil
p	cumulative production
r	relative
r	residual
s	solution gas
sc	standard conditions
t	total
w	water
wf	wellbore, flowing
ws	wellbore, static

ABBREVIATIONS

CTP	constant terminal pressure
CTR	constant terminal rate
CVD	constant volume depletion
DST	drill stem test
EOR	enhanced oil recovery
EOS	equation of state
EWT	extended well test
FIT	formation interval tester
FVF	formation volume factor
GDT	gas down to
GOC	gas oil contact
GOR	gas oil ratio
HCPV	hydrocarbon pore volume
IARF	infinite acting radial flow
JOA	joint operating agreement
KB	kelly bushing
MDT	modular formation dynamic tester
MGV	movable gas volume
MOV	movable oil volume
OWC	oil water contact
PV	pore volume
PVT	pressure, volume, temperature
RF	recovery factor
RFT	repeat formation tester
SCAL	special core analysis
SIP	sequential inflow performance
WUT	water up to

Chapter 1

INTRODUCTION TO RESERVOIR ENGINEERING

1.1. ACTIVITIES IN RESERVOIR ENGINEERING

Reservoir engineering shares the distinction with geology in being one of the great “underground sciences” of the oil industry, attempting to describe what occurs in the wide open spaces of the reservoir between the sparse points of observation — the wells. In applying the subject, it is possible to define four major activities, which are:

- Observations
- *Assumptions*
- Calculations
- Development decisions

and these can be described as follows.

(a) Observations

These include the geological model, the drilling of wells and the data acquired in each: cores, logs, tests, fluid samples. Following the start of field production, the oil, gas and water rates must be continuously and accurately monitored together with any injection of water and gas. Frequent pressure and production logging surveys should also be conducted throughout the lifetime of the project. The importance of data collection is a subject that is frequently referred to throughout the book and is perhaps best illustrated in Chapter 3 when describing material balance which is so fundamental to reservoir engineering. It is pointed out that the material balance equation can easily contain eight “unknowns” and failure to collect the essential rate, pressure and pressure–volume–temperature (PVT) data to give oneself a “sporting chance” of attaining a meaningful solution of the equation can make the application of quantitative engineering impossible. The author has seen many fields in which the data collection was so inadequate that it would have been dangerous to attempt to apply any quantitative reservoir engineering technique and the alternative: guesswork, although occasionally unavoidable, is something to be shunned as much as possible. Thorough data acquisition is expensive (very expensive) and it is the duty of practising reservoir engineers to convince those who hold the purse strings of the necessity of the exercise. To do this, it is important that the engineer knows exactly to what use the data will be put and in this respect it is hoped this book will prove helpful in advising on the matter.

Once the data have been collected and verified, the engineer must interpret them very carefully and collate them from well-to-well throughout the reservoir and adjoining aquifer. This is a most delicate phase of the whole business of understanding reservoirs, in which it can prove dangerous to rely too much on automated techniques. It is fine to use computer programs to interpret well tests, for instance, but to apply sophisticated numerical methods to generalise about formation properties by such means as generating statistical correlations and use of regression analysis should be reduced to a minimum. Reservoir performance is so often dominated by some particular physical feature (the bit in the corner), which may be a weakness or strength, that can be completely overlooked through the smudging effect inherent in the application of number crunching methods. In this respect, three examples of the dangers of “statistical smearing”, which adversely affect the calculation of sweep efficiency in waterdrive or gas-drive projects, as described in Chapters 5 and 6, respectively are.

- The evaluation of formation heterogeneity using probability distributions of permeability. This totally neglects gravity and therefore disregards Newton’s second law of motion.

- Application of convoluted petrophysical transforms to generate permeability distributions across formations. Considering the expensive errors this leads to, it is much cheaper to core “everything”.

- Plotting core permeabilities on a logarithmic scale when viewing their distribution across a reservoir section. Darcy’s flow law specifically states that the velocity of advance of a fluid is proportional to the permeability of a layer: not the logarithm of its permeability.

These are not small, fastidious points. Together they have cost international operators billions of dollars in lost and deferred production in secondary recovery projects worldwide. Most of the difficulties mentioned would be overcome by adherence to the basic laws of physics in the interpretation and collation of reservoir data.

The most valuable reservoir engineers are those who *see* the clearest and the most and who know what they are looking for.

The last comment implies the need for experience, which may be a bit discouraging to newcomers to the subject but there has and always will be a very large element of *deja vu* associated with reservoir engineering.

(b) Assumptions

Now the main difficulty arises: having thoroughly examined and collated all the available data, the engineer is usually obliged to make a set of assumptions concerning the physical state of the “system” for which an appropriate mathematical description must be sought. For instance:

- The oil or gas reservoir is or is not affected by natural water influx from an adjoining aquifer.

- There will or will not be complete pressure equilibrium across the reservoir section under depletion or waterdrive conditions.

– The late-time upward curvature of points in a pressure buildup survey results from: the presence of faults, dual porosity behaviour or the breakout of free gas around the wellbore.

This is the crucial step in practical engineering, so much so that the word *assumptions* is highlighted (page 1) to signify that once they have been made that is effectively the end of the reservoir engineering. The third activity, calculations, is entirely dependent on the nature of the assumptions made as is the fourth, development decisions, which rely on the results of the calculations. It is therefore necessary to be extremely cautious when making physical assumptions and the most convincing reservoir studies are those containing the least number. In this respect, the application of material balance is strongly recommended (oil, Chapter 3; gas, Chapter 6), in history matching field performance, as being one of the safest techniques in the business for the simple reason that it requires fewer (far fewer) assumptions than the alternative technique, numerical simulation modelling, which should therefore be used as a logical follow-up (Chapter 3, section 3.5). Assumptions can usually be confirmed only by observation, not calculation, but this can be problematical. In the first two examples listed above, for instance, the observations necessary to confirm the influence of an aquifer or the degree of pressure equilibrium across a reservoir can only be made some time after the start of continuous field production, which causes difficulties in offshore developments, as described in section 1.2d. Finally, considering the importance attached to assumptions, it is mandatory that they be listed and rationalized right at the start of any study report — if for no other reason than to permit the reader the choice of whether to explore the text further or not.

(c) Calculations

While the above comments may seem to denigrate the importance of calculations, that is only meant to be relative to the physical assumptions upon which any mathematical model selected for use is entirely dependent. Once a physical condition has been defined (assumed) then calculations are an absolute must and it should be remembered at all times that we reservoir engineers receive our salaries to perform calculations rather than merely express opinions.

Since the 1960's mathematics has been awarded a much more exalted status in the business than ever before for the simple reason that now, with our sophisticated computers, we can do it, whereas previously we could not, or only with great difficulty. With each passing year and each improved mathematical model, there is a great danger that numerical modelling is becoming a subject in its own right in which there is a tendency for it to evolve in a direction that removes it ever further from the requirements of reservoir engineering. Hence the fairly new title in the Industry of "Simulation Engineers". There should be no such thing, only reservoir engineers who happen to have simulation packages at their disposal for use, amongst other tools, as and when required.

Engineers, and particularly those entering the subject, should be aware of this pitfall and not become too mesmerised by mathematical models — no matter how

user-friendly. It is not entirely unusual, for instance, to find a group of engineers slaving away in the back room for months with their computers only to emerge with the pronouncement that — “the model is great but there seems to be something wrong with the reservoir.” The majority of a reservoir engineer’s time should be spent looking at things very carefully and only then deciding on the correct approach to the problem rather than bombarding it with different mathematical models in the hope that one of them might fit. The approach to avoid is that noted recently by the author in which up to 600 computer runs were budgeted for in a study to history match the performance of a field. This sort of planning makes you wonder whether it was a reservoir engineering study or a lottery.

The requirement of the engineer is to assess in advance, through sound physical judgement, which of the runs is liable to be correct — and why. If mathematics is used carefully and correctly then we should have a great advantage over our predecessors in this subject but if it is abused by relying on mathematics to define physics, then reservoir engineering is itself in danger.

(d) Development decisions

Every action contemplated, planned and executed by reservoir engineers must lead to some form of development decision — otherwise it should not be undertaken in the first place.

1.2. BASIC THEMES OF THE TEXT

(a) Simplicity

Even if we could see in complete detail all the complications of the reservoir geology and its fluid contents, trying to describe it mathematically would be a daunting task. But since we hardly see anything of the systems we are attempting to describe and even when we formulate equations they contain far too many unknowns to provide a unique solution, then the situation begins to look grim. Under these circumstances, this book advocates that all problems be approached in a simple fashion, in fact, there seems to be an inverse law applicable to reservoir engineering that the more complex the system, the more appropriate is the attempt at simplicity and the more convincing. It is virtually impossible, for instance, to construct a reliable simulation model for waterdrive in a complex delta top reservoir, with criss-crossing channels that do not seem to correlate from well to well, for the simple reason that you cannot model what you cannot see — although it does not prevent people from trying.

The alternative approach (as illustrated in Chapter 5, section 5.9) is to apply the simple concept of material balance to match waterdrive history and make a reasonable attempt at prediction. This will provide an understanding of the physics of the system which enables sound operating judgements to be made, even though it may not yield exactly correct results which, by the very nature of the subject,