# 俞启泰

# 油田开发论文集

# PROCEEDINGS ON OILFIELD DEVELOPMENT BY YU QITAI

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## 内 容 提 要

本论文集共108篇，这些论文的绝大多数是关于注水开发油田的理论和方法，主要内容有：注水油田开发方法、注水油田开发分析方法、注水油田开发调整、注水油田剩余油研究、改善注水油田开发效果方法、油田开发指标预测理论与方法、注水油田开发技术、油田开发的原则与战略等。可供油田现场、科研、石油院校的有关人员参考和使用。

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# 作者简介

俞启泰，1940年11月生，男，汉族，浙江绍兴人。现为中国石油天然气集团公司石油勘探开发科学研究院教授级高级工程师。1963年毕业于北京石油学院油田开发系油气田开采专业。1963年至1975年在玉门油区石油沟油田、采油科学研究院所、鸭儿峡油田从事油田开发的管理和研究工作。1975年至1980年在吉林油区红岗油田从事油田开发的管理工作。1980年至今在中国石油天然气集团公司石油勘探开发科学研究院油气田开发研究所从事油田开发研究工作。曾获部级科学技术进步奖4项，局级科学技术进步奖24项。公开发表论文100余篇，其中有14篇被俄罗斯的《文摘杂志》、日本的《科学技术文献速报》、美国的《石油文摘》、《化学文摘》摘要介绍。曾被评为全国油气田开发地质先进工作者。

# About the author

Yu Qitai, born in Shaoxing, Zhejiang province in November 1940, works as a professor of engineering in Scientific Research Institute of Petroleum Exploration and Development of CNPC in China. He graduated from the oilfield development and production department of Beijing Petroleum College in 1963, was responsible for the management and research work of oilfield development in Shiyougou oilfield, Oil Production Research Institute and Yaerxia oilfield in Yumen from 1963 to 1975, and was in charge of management responsibility for oilfield development in Honggang oilfield in Jilin from 1975 to 1980. From 1980 on, he has been conducting research work on oilfield development in the oilfield development center in Scientific Research Institute of Petroleum Exploration and Development of CNPC in China. He won the ministerial scientific and technological advance awards for four times and the departmental scientific and technological advance awards for 24 times. More than 100 articles were publicly issued, of which 14 were collected and introduced by Russian Abstracts, Japanese Current Bibliography on Science and Technology, American Petroleum Abstracts and Chemical Abstracts. He was once selected as one of the national model workers in the area of oil and gas field development and geology.

# 序

70年代我担任吉林省油田管理局副指挥兼总地质师时，俞启泰同志是下属的红岗油田的地质师。他根据对油田的分析和研究，提出了不少有价值的措施和建议，为合理开发油田和完成生产计划作了大量的工作。在油田全体职工的努力下，当时红岗油田的油田开发和生产管理都是相当不错的。从我和他的接触中，我感到，俞启泰同志是一位热爱祖国石油事业、具有很强的敬业精神和解决实际问题能力的油田开发工作者。记得一次在全局的油田开发分析竞赛会上，俞启泰同志代表红岗油田所作的开发分析获得了第一名，他提出的低渗透油田注水开发后产生的局部高压现象是由特低渗透层引起的新颖观点给我留下了深刻的印象。

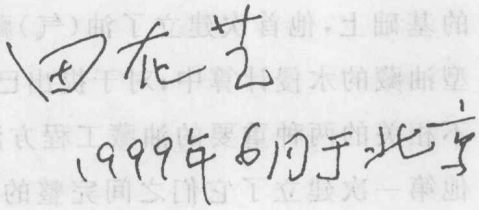
俞启泰同志在大学期间就参加了大庆石油会战，毕业后又在玉门油田和吉林油田的现场和研究所工作，长期从事油田开发的管理和研究，积累了大量的生产经验。进入石油勘探开发科学研究院专门从事油田开发和油藏工程的研究后，他经常去河南、中原、华北、辽河、吉林、大庆、胜利等油田开展研究工作。与此同时，他也注意了学习和借鉴国内外先进的理论和技术，使他有条件把理论和实际较好地结合起来。因此，这些年来他公开发表的有关油田开发和油藏工程的论文一方面有较高的学术水平，同时也有较大的实际应用价值，其中不乏玑珠之作。这些论文的绝大多数是关于注水开发油田的理论和方法。在油藏工程方法、油田开发参数和指标的计算和预测理论、油田开发分析方法、高含水期油田开发调整方法等的研究和应用方面，俞启泰同志都有所创新和贡献。例如，在传统的物质平衡方程的基础上，他首次建立了油(气)藏的物质平衡微分方程，并成功地应用于各种类型油藏的水侵计算中；对于提出已达四五十年，但长期以来各自独立进行研究、互不相关的两种重要的油藏工程方法——水驱特征曲线法和递减曲线法，在国内外他第一次建立了它们之间完整的联系，发现了对应 Arps 指数、双曲、调和递减的水驱特征曲线；他首次提出了一种在性能上远远超过前苏联4种重要水驱特征曲线的广义水驱特征曲线；他建立了一种新的油藏工程方法——增长曲线法，从而为油藏工程方法大家族又增添了一个新的成员；他建立了一套先进的、完整的、包括油田开发分析、剩余油研究、调整方法研究为内容的高含水期油田开发方法系统，并应用于双河油田 $\text{Ⅳ}_{1-4}$ 层系、濮城油田南区沙二下$_{1-5}$层系的开发调整中，取得了成功，具有很大的推广价值。这些领先于国际水平的研究成果，丰富了我国的油田开发理论体系，在实际应用中也取得了较大的成效。这些论文体现了中国油

田开发科学工作者赶超世界先进水平的追求和努力，这也是它们的真正价值之所在。

油田开发的工作对象是深埋在地下的油层，不同的油田具有不同的、固有的天然性质，这是客观存在。油田开发工作者的任务就是采用各种方法，将原油最大限度地、经济地开采出来，这是主观努力。因此，一个油田成功的开发固然表现在油田具有高的采收率和高的经济效益上；但达到这一目标的关键是开发工作要有先进的开发理论的指导和开发方法符合油田实际、具有很强的针对性。我国油田广泛采用了先进经济的注水开发方法，经过艰苦的探索，形成了以大庆油田为代表的、适合我国陆相沉积油田条件的、系统的注水开发理论和方法，成功地开发了许多油田，使我国成为了世界石油大国。但是目前我国油田大都已进入高含水期和特高含水期开采，油田平均采收率还不高，仅为 33.2%；而开采强度相当大，储采比只有 10；开发形势相当严峻。在即将来临的 21 世纪，如何大大改善油田开发效果，深入挖掘油田潜力，保持石油工业的继续发展，难度是很大的。我们每个油田开发工作者肩上的担子很重，必须用科学探索和知识创新去迎接这个严重的挑战。

俞启泰同志把他这些年来发表的论文汇编成集出版，可以看作是一名油田开发工作者向 21 世纪石油工业的献礼，是一件很有意义的事情，我向他表示祝贺，并相信他在今后的研究工作中，必将取得更多更好的研究成果。

中国科学院院士



# Foreword

Mr. Yu Qitai worked as a geologist of Honggang oilfield under Jilin Petroleum Administration Bureau in 1970s when I was Vice Director and General Geologist of that Bureau. He proposed lots of valuable measures and suggestions based on his analysis and research, and conducted a great deal of practical works for the rational development of the oilfield and the fulfillment of production plans. With the common efforts of all staff in the oilfield, the development and production management of Honggang oilfield was fairly good. Through my personal contact with him, I feel that Mr. Yu Qitai is such a person in the area of oilfield development who loves our country's petroleum industry, has a strong spirit of hardwork and high capabilities of solving real problems. I can remember that in a competition match of oilfield development analysis throughout the whole Bureau, the analysis presented by Mr. Yu Oitai on behalf of Honggang oilfield was selected as the best. I was deeply impressed by his new explanation that the phenomenon of partial high pressure appearing after water injection in the oilfield of low permeability is caused by the super-low permeable layers.

Mr. Yu Qitai participated in the early exploration and development of Daqing oilfield while he was receiving his university education. After graduation, he ever worked at oilfield sites and research institutes of Yumen and Jilin oil areas for a long time and gained a great deal of production experience regarding to management and research of oilfield developments. After being transferred to the Scientific Research Institute of Petroleum Exploration and Development and initiating his career exclusively on the research on oilfield developments and oil reservoir engineering, he has been to Henan, Zhongyuan, Huabei, Liaohe, Jilin, Daqing and Shengli oilfields for many times to perform research work. In the meantime, he has also paid attention to the learning and utilization of domestic and foreign advanced theories and technologies so that he has the advantage of combining very well the practical experience and the advanced theories. Therefore, the articles on oilfield development and oil reservoir engineering that he has publicly issued in recent years are not only of high academic value, but also of remarkable practical application value. Some of them are fairly good. Most of the articles are on the theory and methodology of oilfield development by water injection. With regard to the methodology of oil reservoir engineering, the

calculation and forecast theory on oilfield development parameters and indicators, the performance analysis methodology for oilfield developments, the research and application of the adjustment methods for the oilfield development in the stage of high water cut, Mr. Yu has also made important contributions. For example, it is he who, basing upon the traditional material balance equation, first sets up the differential calculus equation for the oil (gas) reservoir material balance and puts it into the calculation of oil invasion for different types of oil reservoirs. In respect of the two key oil reservoir engineering methods — the water flooding characteristic curve method and the decline curve method—which were proposed 40 to 50 years ago, but have been studied separately with no relevance found between them, it is he who first builds up in the world the complete relationship between the two methods, finds the correspond Arps exponential, hyperbolic, harmonic declining water flooding characteristic curves. It is he who first proposes the generalized water flooding characteristic curve that far exceeds in the terms of function the four important Russian water flooding characteristic curves. He has established a new kind of oil reservoir engineering method—increase curve method, adding a new member to the family of oil reservoir engineering methods. He has set up a set of advanced, complete development method system for the oilfield development stage of high water cut, including oilfield development performance analysis, residual oil and adjustment methodology studies, and successfully applied it in the development adjustments of $\mathrm{N}_{1-4}$ of Shuanghe oilfield and $\mathrm{S\,II}_{1-5}$ of southern section of Pucheng oilfield. This system has been proven to be of high value for extensive application. These internationally advanced research achievements have enriched the oilfield development theory system in our country and brought about fairly good results in their practical application. These articles represent the efforts made by the Chinese oilfield development researchers in their strive to catch up with and surpass the world advanced level. This is where their value lies.

The working object of the oilfield development is the oil-bearing layer lying deep in the ground. Different oilfields have different intrinsic natural properties. These are the objective facts in oilfield developments. The task for those working for oilfield developments is to economically maximize crude oil production from the ground through different methods. These are the subjective efforts in oilfield developments. Therefore, the successful development of an oilfield is obviously shown by the high recovery factor and high economic return, but the key

to realize the task is that the development work should be guided by advanced development theories and the development method should be in conformity with and strongly catering to the actual situation of the oilfield. Advanced and economic development methods through water injection have been widely used in our oilfields. With enormous hard work made by our people, our country has witnessed the coming into being of the systematic water flooding development theories and methods, which are represented by Daqing oilfield and appropriate to our oilfields for continental deposit, and the successful developments of many oilfields have set our position as one of the major oil producers in the world. However, most of our oilfields have entered into the development stage of high or super high water cut, with a relatively low average oilfield recovery factor of being 33.2%, but the reserve-production ratio is as low as 10. This means that the development situation is highly challenging. In the coming 21st century, it will not be easy for us to funther improve the oilfield development efficiency, fully utilize the oilfield potential and ensure the sustainable development of the whole petroleum industry in our country. The task is very heavy for all people working for our oilfield developments. We must meet this challenge by means of science probe and knowledge innovation.

This compilation of the articles written by Mr. Yu Qitai in many years can be regarded as a gift to the petroleum industry in the next century by a researcher of oilfield development. It is very meaningful. I here by would like to express my sincere congratulations to him and believe that he will achieve more better research results in the coming years.

Member of Chinese Academy of Sciences
Tian Zaiyi,
Beijing, June 1999

# 前　言

从1958年进入北京石油学院油田开发系上学至今，我从事油田开发的学习、工作和研究已有40年了。这期间，结合实际工作，我发表了一些论文，现汇集成此论文集，谨献给祖国的石油事业。

这些论文的绝大多数是我进入石油勘探开发科学研究院专门从事油田开发研究工作后写的。但是应该说，在此之前，在油田现场工作17年的经历，使我受益匪浅，因此对我的研究工作帮助很大。主要有两方面：第一是对油田开发资料数据有了深刻的认识。首先，使我知道了这些数据是无数油田开发工作者付出很大的辛劳甚至血汗取得的。我不会忘记在石油沟油田深夜的戈壁滩上，冒着漫天大雪，我一个人到百米外的集油站去量油的紧张心情；也不会忘记在鸭儿峡油田我为取得114井长时间关井的压力恢复资料，爬上高高的井架，由于盘根盒没有松好，井架险些被通井机拉倒的惊险场面。所以这些数据对我来说不再是枯燥的数字，因为在这些浩如烟海的油田开发数据中，就有我亲自取得的和计算的。我深知它们的价值，因而分外珍惜。其次，资料数据是油田开发生产和研究工作的基础，根据它们，我们才能总结规律、验证成果、编制方案、预测变化。因而正确地使用它们是非常重要的，否则将会产生错误的结果和做出不正确的决策。由于我知道它们录取和计算的方法和过程，对它们的出处、准确性、可靠程度、适用范围、取舍标准都心中有数，在使用它们时，就能更充分合理和得心应手。第二是油田现场工作的经历，加深了我对石油和石油事业的热爱，对油田开发工作者最关心的问题有了深切的体会。在现场，他们最关心的是什么呢？就是原油产量和安全生产这两个问题。我不会忘记在油矿调度室值夜班，由于没有发生事故和完成了计划，一夜平安，在早上交班时的轻松和舒畅；不会忘记在石油沟油田，为了增产原油，用手摇绞车一次几十公斤甚至几公斤的从井中捞油的情景；也不会忘记在油矿地质室，为完成生产计划，“斤斤计较”地、一口一口井地分析产量变化原因度过的不眠之夜。这些切身体会使我感受到作为一名油田开发工作者应负的责任，从而全身心地投入去担负起它们。油田现场生产的实践，不仅使我掌握了油田生产的全过程和各个环节，积累了大量的经验，而且对油田在提高产量、改善开发效果、提高采收率工作中最迫切和急需解决的问题有了比较深刻的了解，使我对研究工作不仅重视它的理论意义，而且更注重它在油田生产中的实用价值，以便与油田生产结合得更加紧密。以上这些都是一个潜移默化的过程，不经过现场工作的实践是不能得到的。

在工作中我还体会到，要搞好科学研究工作，必须做到以下两点：第一是做任何研究前，一定要充分了解当前国内外的最新水平。这样做一方面是为了保证科

学研究的高水平，另一方面也是为了从中学习和借鉴。俗话说，“开卷有益”。调研文献总是或多或少地受到教益。美国和前苏联在长期的油田生产实践中，各自形成了比较先进的、独特的、完整的油田开发理论体系，有力地指导了它们各自的油田开发工作。但它们之间的交流还很不够，就拿用生产数据预测油田开发指标的两种重要的油藏工程方法——水驱特征曲线法和递减曲线法来说，水驱特征曲线法在前苏联和俄罗斯得到了深入而广泛的研究和应用，而递减曲线法研究和应用状况则差得多；美国则相反，对递减曲线法进行了极为深入的研究和应用，水驱特征曲线法的研究和应用状况则差得多。我们国家得天独厚，可以不带任何偏见地兼容并蓄，对国外优秀的东西为我所用，做到后来居上。现在在我们国家，水驱特征曲线法和递减曲线法都得到了广泛而深入的研究、应用和发展，从借用阶段进入到了创造阶段，这两种方法的研究水平在很多方面已经超过了美国和俄罗斯。第二是研究工作必须把创新放在第一位，因为创新是科学研究的灵魂。作为一名中国的科学工作者，必须在自己的研究中充分体现我们赶超世界先进水平的信心和能力。前苏联有 Максимов 水驱特征曲线，美国有 Arps 递减曲线，这是他们研究水平的标志和骄傲。我们中国也应该有自己的曲线，应该以建立中国自己的、先进的、科学的、完整的油田开发理论体系为己任。我的这本论文集也可以说是对这项巨大工程的一个极其微薄的贡献。

在 20 世纪中，石油生产在社会生活、经济、军事等诸多领域发挥了十分巨大的、不可替代的作用，对人类文明进步作出的贡献也是不可估量的。在人类文明史上有“石器时代”、“青铜时代”、“铁器时代”，20 世纪是否能称为“石油时代”呢？在即将来临的 21 世纪，石油工业对国民经济的发展、人类文明的进步仍将起着重要作用。石油开采工业的兴起和衰落，只是历史长河中很小的一段，且不说它对人类文明的巨大贡献，就油田开发这门学科本身来说，它对世界科学发展所做的贡献也是巨大的，在世界科学史中占有重要地位，例如渗流力学理论、指标预测理论等的研究成果，对其他学科当今和今后的发展都有重要作用。所以，每个油田开发科学工作者，都不应妄自菲薄，而应充分认识到自己工作的意义，这就是，我们都在为人类伟大的科学大厦添砖加瓦。

最后，我要深深感谢 40 年来我的老师、领导、亲人、同事对我的教诲、关心、爱护、支持和帮助；还要特别感谢发表我的论文的杂志社和石油工业出版社的各位领导、编辑付出的辛劳和心血。恕我不一一列举他们的名字，但我将永远铭记他们的好意。

俞启泰

1999 年 6 月于北京

# Preface

I engaged in the area of oilfield development in 1958, about forty years ago, when I was enrolled into the oilfield development department of Beijing Petroleum College. I would like to compile into a book the articles that I have written druing this period and dedicate it to our petroleum industry.

Most of the articles were written after I started my full-time job as a researcher of oilfield development in the Scientific Research Institute of Petroleum Exploration and Development. However, I should say that my 17 years of experience working in the oilfield before this has contributed a lot to my research work. The contribution can be summarized as follows:

*A deeper understanding of oilfield development data.*

First, I have come to recognize that these data result from the hard work of infinite workers in the area of oilfield development. I will not forget the nervous mood with which I went out alone against the heavy snow in the deep night to do oil metering in the oil battery more than one hundred meters away, on the desert beach in Shiyougou oilfield. I will neither forget the dangerous scene that the high derrick was almost pulled down by the tractor hoist due to the improper unloosing of the stuffing box when I climbed the derrick to obtain the pressure build-up data after well No. 114 in Yaerxia oilfield had been shut for a long time. Therefore, to me, these data will not be dull data any longer because some of the immense oilfield development data were collected and calculated by myself. I know their value and the difficulty in getting them. Thus I much treasure them.

Secondly, data are the basis for oilfield production and research work. Only based on these data can we summarize general rules, test results, work out programs and predict changes. Therefore, the correct use of them is of high importance. Otherwise it yields erroneous results and wrong decision making. Due to my knowledge of the method and process of data acquisition, their sources, accuracy, reliability, application scope and the standard for acceptance or rejection, I can easily and reasonably use these data.

*My experience on the oilfield site has deepened my love of petroleum and petroleum industry and offered me the deep understanding of the questions much*

*concerned to those working in the area of oilfield development.*

On the oilfield site, what are the most concerned quesions? They are crude oil production and safe production. I will never forget the ease and pleasure when I transferred my duty to another shift in the morning after having been on duty at night in the oilfield controlling room with no accident happening and the work plan completed. I will neither forget the work scene that we were using hand winches to lift oil from several kilograms to several dozens of kilograms of oil so as to increase oil production in Shiyougou oilfield. I will neither forget the sleepless nights busy with analyzing the changes of oil production well by well for the purpose of completing our production plan when I worked in the oilfield geological room. These personal experiences made me realize the due responsibility of a person working in the area of oilfield development and therefore I devoted myself to taking this responsibility. The practical work on the oilfield site not only made me get familiar with the whole process of oilfield production and gain a lot of experience, but also deepened my understanding of the most urgent problems to be solved for increasing production, improving development efficiency, raising recovery factor. It also let me recognize the importance to emphasize both the theoretical significance and the implication value in the actual oilfield production of my research work and to closely connect the two aspects. The acquisition of all these is a gradual process and cannot be realized without the practical work on the oilfield site.

From my work I have recognized that the following two points are very important for a good scientific research program. First, it is necessary to thoroughly understand the prevailing most advanced level at home and abroad before the start of any research program. To do this has two objectives: one is to assure the resulting high level of the scientific research program; the other is to make full use of the existing research achievements. There is a Chinese saying: Reading books is always beneficial. The consultation of existing literature can always improve ourselves more or less. Through the long period of oilfield production practice in the USA and former Sovier Union, relatively advanced, unique and complete theory systems on oilfield development have been formed, and provided

useful guidance to their respective oilfield developments. But the exchange of the two different theory systems is not sufficient. Taking as example the two oil reservoir engineering methods of predicting oilfield development parameters by using production data-the water flooding characteristic curve method and the decline curve method, the former has been deeply and extensively studied and applied in the former Soviet Union and Russia with few efforts on the latter lacks. In contrast, USA has deeply and extensively studied and applied the latter with fewer efforts on the former. Our country is in a unique advantageous position to use both of them without any prejudice. Now the water flooding characteristic curve method and the decline curve method have been extensively and deeply studied, applied and developed and arrive at the innovation stage from the imitation stage. Our research levels in many aspects of these two methods have surpassed those of the USA and Russia. Secondly the research work should have innovation as priority because innovation is the key to the research work. As a Chinese scientific researcher, our confidence and capacity to catch up with and surpass the most advanced level in the world should be represented in our research work. The former USSR has Maksimov water flooding characteristic curve while the USA has Arps decline curve. These are indications of their research levels and pride. Chinese should have our own curves. We should devote to the formation of our own advanced, scientific and complete oilfield development theory. I hope that this book of mine can contribute a little to this huge project.

The twentieth century has witnessed the huge and irreplaceable role of petroleum production in the social life, economy and military area. The contribution of petroleum production to the human civilization can never be over-assessed. In the history of human civilization, there are "stone era", "bronze era" and "iron era". Can the twentieth century be called the" petroleum era"? In the coming twenty-first century, the petroleum industry will continue to play a highly important role in the development of national economy and the advance of human civilization. Although the rise and fall of the petroleum exploitation sector covers only a small part in the long river of history, putting aside the huge con-

tribution to the human civilization by the petroleum exploitation sector, the science of petroleum exploitation itself has also made remarkable contribution to the advance of the world science. For example, the research achievements on seepage mechanics and parameter forecasting are and will be of significance to the development of other sciences. Therefore, every scientific worker in the oilfield development area should recognize the value of his work. That is to say we are also doing our own part in the construction of the human scientific building.

Finally I would like to sincerely thank my teachers, superiors, relatives and colleagues who have given me inspiration, encouragement and help in the past 40 years. I really appreciate the hard work made for my articles by superiors and editors of the magazines publishing my articles and the Petroleum Publishing House. Unfortunately I cannot list all those that have helped me, but I will never forget their goodwill.

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Beijing, China

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