ENGINEERING ECONOMICS TOPICS IN HYDROCARBON SUBSURFACE

A BIBLIOGRAPHICAL REVIEW HANDBOOK

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Introduction

Many articles and books have been published about the economic evaluation of the various phases relative to hydrocarbon-related projects: from the early exploratory phases to the end-point delivery of the production to the markets. They treat the related subjects in different degrees of depth and cover individual areas of the overall "hydrocarbon business", as well as entirely different phases of it.

However, I must say that in all I have read over the last 50 years of professional activity on the subject, I do not recall going through such a thorough and practical collection of the topics related to the proper evaluation of a hydrocarbon-related project, in any of its phases, be it exploration, production, maintenance, operation, operating-arrangements, equipment upgrading, salvage and abandonment, and many others.

In addition to offering an overview on each of the related topics, this text under the title - Engineering Economics Topics in The Hydrocarbon Subsurface Industry – uses the unique feature of providing not only working practical examples, but sharing with the reader the simplest available tools to meet the challenge associated to the economic decision process in each case. This has required an enormous effort to achieve, and will make the text extremely useful to the reader – from beginners to experienced professionals handling often concepts that could be subject to different interpretations.

After following the author´s professional career development for the last 50 years, I consider it a privilege to be asked to introduce to other readers this exceptionally useful piece of work. This is a privilege that I rarely accept, because it requires to dedicate the time to read in detail the work, and this is specially demanding in case of technical work as this is.

After such in-detail reading, now I would like to thank the author for the rare opportunity he has provided me to participate in the final lap of this huge effort. In the process I have learned more than I have contributed, and my initial expectations from the product have been exceeded in every respect.

In the end, after recommending it to readers of a variety of fields and specialties, I commit to support as strongly as possible all efforts to publish the text in a practical format and vehicle that will make it available to the largest possible audience.

Rolando has made an exceptional contribution to the readers in and out of the hydrocarbon industry.

Caracas October 10, 2022

Dr. Martin Essenfeld

Notes to the Readers

The material is basically a bibliographic review about Engineering Economics in the hydrocarbon industry with emphasis on topics and examples related to the subsurface environment. The review can be considered a basic course up to and including Chapter 4 and advanced from Chapter 5 onwards; therefore, some concepts are repeated so that the courses can be independent.

It is not necessary to read the chapters in order. Readers with basic knowledge can select the sections or chapters they need because the topics are clearly indicated in the Table of Contents.

Some themes or concepts are re-emphasized and become more complex as the chapters progress. For example, the topic of Net Present Value (NPV), given its importance, begins in the first chapters explaining the concept. The topic is then reinforced with more complexity after considering the concepts of risk and probability. In other words, for the calculation of the NPV, risk and its probabilistic variation are included rather than a single number as a way of presenting concepts incrementally.

The other intention of some concepts spanning multiple chapters is to serve as a refresher for the readers so they do not have to go back to previous chapters.

Technical chapters are included in addition to the economic ones to highlight that the approval of projects must pass two requirements, it must be technically feasible and economically profitable.

All economic parameters are calculated using Excel spreadsheets that are included as part of this bibliographical review. This is to emphasize that what is important is not the arithmetic of the calculation process but the understanding of the concepts.

In the first examples using the Excel spreadsheet, in addition to presenting the parameter that is discussed at that moment, the spreadsheet also calculates other parameters that have not been explained yet; but the readers can return to them once they learn the use of those parameters. For example, when the NPV calculation is first presented, the IRR calculation also appears, although this parameter has not been explained up to that moment, because the Excel sheet calculates everything at once.

In other cases, the same example is used as an input to explain different concepts and thus learning is intertwined. The "expansion" of the concepts is shown, for example, with the topic of Capital Budgeting, which is presented in two sections given the importance of the topic as part of the budget and then as a key for the selection of projects, whether they are independent , dependent or mutually exclusive, because the selection will depend on the money available for projects.

After explaining what the risks are, the use of economic hurdles is re-exposed for the examples on fracturing and enhanced recovery, but incorporating risk and technical uncertainties. Again, to emphasize the technical and economic double yardstick, in addition to considering the probability that something unforeseen may appear, a section on probabilities is included, which serves to evaluate the probability of variation of the NPV or reserves. Key chapters have summary sections at the end of each. Again, to emphasize the key ideas and concepts.

Engineering Economics Topics in Hydrocarbon Subsurface
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Chapter 1 Introduction to the Hydrocarbon Business

Learning Objectives Chapter 1

Having worked through this chapter the reader will be able to:

- Describe general organization and financial aspects of the petroleum industry
- Identify the main characteristics of the hydrocarbon business
- List financial parameters or statistics that may be used to explain or to monitor the performance of a petroleum company
- Describe five of these statistics or parameters
- List and describe the five principal sectors of petroleum activity
- Describe the typical production steps in the life of an oil project

Introduction: Basic Definitions or Descriptions as Starter

The concepts defined in the following paragraphs will be expanded along the chapters. The idea of presenting these concepts here is to serve as an introduction for some of the most common terms in the hydrocarbon industry.

Characteristics of Hydrocarbon Business:

- The hydrocarbon products have several uses for modern economic and military systems
    - **Transportation**: Oil is one of the basic sources of energy used in transportation. Gasoline/petrol, diesel, kerosene, liquefied petroleum gas (LPG), jet fuel, and marine fuel are the major transportation fuels obtained from oil
    - **Power generation**: A thermal power plant uses petroleum for electricity generation. Although coal is the major source of electricity generation, oil also accounts for significant power generation
    - **Lubricants**: Almost all industries use lubricants for the proper functioning of machinery. Lubricants reduce friction in vehicles and industrial machines. Lubricants are even used in cooking, bio-applications on humans, ultrasound and medical examinations.
    - **Pharmaceuticals**: Certain by-products like mineral oil and petrolatum are used in the manufacture of topical medicines. The complex organic molecules used in pharmaceuticals are linked to simple organic molecules of petroleum byproducts.
    - **Agriculture**: Ammonia, which is a source of nitrogen in agricultural fertilizers, is manufactured from oil, some pesticides are produced from petroleum. Machinery for ploughing etc. also works on oil products.
    - **Chemical industry**: The raw materials of several chemical companies are by-products of an oil refinery. Chemical fertilizers, synthetic fibers, insecticides, synthetic rubber, nylon, plastics, pesticides, perfumes, dyes, paints etc. are the significant products manufactured using the major by-products like naphtha, grease, petroleum jelly, wax, butadiene etc.

  - **Domestic uses**: Household products like detergents, vaseline, wax etc. are by-products derived from oil. Kerosene is used in many countries for cooking, lighting and other domestic purposes.
- From production to processing the stages are highly capital intensive
- Investment is affected by a variety of risks
- Distribution of subsurface resources is uncertain
- Investment may be undermined by exploration success elsewhere. Therefore, competition and profitability are unpredictable
- There is a continuous effort to control elements of the market, to reduce costs, competition and investment risk

A Vertically Integrated Petroleum Company

It means that it is involved in the whole process, from exploration, through to marketing of refined and manufactured products.

Upstream

It relates to the sector of the business for discovery and the production of oil and gas.

Downstream

- It relates to refining and manufacturing of chemical products. The transition is generally a point of sale, which may be:
  - The wellhead
  - A specific offshore loading buoy
  - An export terminal. The price at this point is identified as "***<u>FOB</u>***" meaning "free on board"

The transition phase between upstream and downstream is called "midstream".

Joint Ownership

It reflects the strategy of spreading risk, particularly in the exploration phase. As fields mature, investment risk diminishes and companies may seek to rationalize their interests. Having a larger percentage share of a smaller number of projects is probably more efficient use of resources. Furthermore, larger companies may be more suited to the development of new opportunities and may therefore wish to transfer mature assets to smaller organizations, which specialize in such projects.

Capital Expenditure

CAPEX relates to the creation of a useful or productive system and equates with "invests".

Operating Expenditure

OPEX is that expenditure required to operate and to maintain the productive system.

Capital Intensive

The world of hydrocarbon industry invests more than US$ 100 billion per year. An oil company might produce 2 million barrels of crude oil and sell more than 6 million barrels of refined products every day. However, to maintain productivity and operating efficiency, the company could invest, annually more than $10 billion in new field development, downstream facilities or infrastructure.

Upstream Investment

Large, integrated petroleum companies invest predominantly in the upstream sector of the business with the following characteristics:

- It is expensive
- It is long term
- It is affected by several sources of risk
- It may be very profitable

A single exploration well can cost from less than US$ 1 million to more than US$100 million, with some 75% chance of failure.

An oilfield development can cost thousands of millions of dollars and may then generate revenues for half a century.

Financial performance of a company is derived directly from its investments, the larger the project and the longer its life expectancy, the more important the decision. Decisions to make these investments are always taken in an environment of uncertainty. Recoverable reserves are only confirmed, when they have been recovered and technology often must survive in extreme conditions. Tomorrow, the price of oil will be different and somewhere government policy will have changed.

Finding Cost

It relates to exploration expenditure per barrels discovered. This depends on several factors, such as geological complexity, well location and technology. Time is a particular problem in developing any average relationship between reserve barrels and cost of discovery.

Reserves

These are those volumes of hydrocarbons in the reservoirs remaining to be produced. Since commercial status may not be confirmed for five or more years and because of varying calculation procedures, it is difficult to use finding cost to make meaningful comparison between companies.

Measuring a Hydrocarbon Company Performance

Usually, a group of parameters are used to describe corporate activity and to measure corporate performance. For example:

- **Prices**: Hydrocarbon corporations trade in different currencies therefore are affected by exchange rates. Gas and oil prices are complex parameters because particularly oil price has shown fluctuations over time, reflecting changes in the market. Supply disruption, shortage and uncertainty cause price to increase. In some other cases such as exploration success or economic depression may cause the price to fall
- **Operational Details**: Replacement of reserves is a measure of exploration success; greater than 100% means discoveries exceed production. Finding and development cost records the unit cost of new fields and reflects geographical location, technological advance and corporate efficiency
- **Financial Activity**: It includes measures of financial activity.
    - Turnover is a measure of company sales revenue; it reflects variation in prices and in rates of production
    - Capital investment is money spent on new projects
    - Finance Debt is money borrowed from banks and financial institutions and for some companies it could represent about 25% of its available capital. Increased borrowing increases corporate risk
- **Measures of profitability**: It must conform to recognized accounting standards. For example, in the USA, the standards are:
    - The Generally Accepted Accounting Principles (GAAP’s)
    - Historical Cost Profit is the standard, accountants’ measure of performance that correlates strongly with prices
    - Return on Average Capital Employed (ROACE) is profit, as a proportion of capital employed (a measure of total corporate funding). It is also called Profit to Investment Ratio (**PIR**)
    - Dividend is the annual distribution of profit to shareholders
    - Share price reflects market perception of the performance and potential of the company. It also reflects attitude to the stock market in general and to other forms of investment

Investment in Hydrocarbon Business

From exploration, through retailing gasoline, the hydrocarbon industry consists of several business layers. Expenditure is divided in Capital and Operating.

Typical activities for an oil company are:

- Exploration and appraisal
- Field development and operation
- Transportation
- Refining
- Distribution and marketing

Exploration and Appraisal

Exploration is the first stage in the process of producing oil. Money is spent on seismic surveys and drilling of exploratory wells. Discoveries are made, tested and eventually added to reserves. However, many unsuccessful wells are drilled and the standard practice is to consider the cost of successful wells as **CAPEX** and the cost of unsuccessful wells as **OPEX**. This is known as “successful efforts” accounting. It is, however, permissible to record all exploration expenditure as CAPEX (full cost accounting).

Field Development

Once a commercial decision is taken, investment (**CAPEX**) is required in wells, structures, production facilities and export. The cost of development varies from one environment to another (onshore, offshore) and the cost of technology that evolves over time. Development cost per barrel is variable and may be calculated in different ways; therefore, caution is required with interpretation and comparison between companies.

When production starts, expenditure (**OPEX**) is required to operate the system and produce petroleum. OPEX per barrel is sometimes called “***Lifting Cost***”; this benefits from economies of scale and increases over time as rate of production diminishes.

Taxation varies depending on the country and many regimes include specific field related, or upstream or production taxes. In the case of oil, the basis of these taxes is normally the market price for crude oil. If a field or oil project can be delineated, it is possible to define profit, relating to it. Profit is generally based on the residual of crude oil selling price less exploration, development, lifting costs, and taxes.

Transportation

Transfer from oilfield to refinery may be direct, by pipeline, or by a series of stages and owners involving pipeline, storage, export terminal and tanker. Transportation infrastructure may be owned by the user (oil producer), or leased on a per-journey, per-year or per-barrel basis.

Ownership implies that the company has invested (CAPEX), whereas leasing implies payment of tariffs (OPEX).

Refining

Refineries buy crude oil at market (***CIF***) price (cost, insurance and freight price). It is the price of the oil (in this case) delivered at the frontier of the importing country, including any insurance and freight charges incurred to that point.

If the refinery is owned by the oil producer, this "transfer" price may differ from market price. Refineries are designed to produce a range of synthetic products and therefore generate revenue reflecting the weighted-average market price of these products. The difference between unit selling and unit purchase price is sometimes called the ***gross refining margin***. This is the revenue available per barrel to meet refinery operating costs and give a return on the capital investment. ***Net refinery margin*** is gross margin minus refinery operating cost (energy plus materials plus labor etc.). Refinery activity gives rise to general corporate taxes and profits. Detailed analysis of refinery economics is beyond the scope of this handbook.

In the extra heavy oil business, it could be an intermediate operation between the field and the refinery and it is called an ***upgrader***. Upgrading is a process by which bitumen or extra heavy oil is transformed into light oil by fractionation and chemical treatment, removing virtually all traces of sulphur and heavy metals. Upgraders usually have five basic operational units:

1. Diluent recovery
2. H:C ratio upgrading through hydrogen addition or carbon rejection
3. Fractionation or cracking of heavy oil into light oil
4. Impurity removal
5. Product blending

Distribution and Marketing

Refinery output may be feedstock for other downstream processes, or may be transferred directly into a distribution system for sale to consumers. All the large oil companies have access to service stations selling gasoline, their most important product. Service stations may be owned by an oil producer and refiner, by a refiner or by a retail organization. If the retailer is independent of the refiner, the product is purchased on a wholesale market.

Project Proposals and Classifications

Projecting cash flows is the most important and difficult step in the analysis of a capital project. Typically, a capital project will initially require investment expenditures and later produce annual net cash inflow. A great many variables are involved in forecasting cash flows, and many individuals ranging from engineers to cost accountants and marketing people participate in the process.

In a typical oil and gas company, many ideas for capital investment will be advanced. Since some ideas will be feasible and some other not, procedures are usually established for screening projects. Corporations generally classify projects as either ***profit-adding*** or ***profit-maintaining***.

Profit-adding projects:

- Expansion projects
    - Include expenditures to increase production and profits by:
        - Exploitation of new reservoirs or fields
        - Reaching new markets
        - Providing facilities to meet current or forecasted production
    - Decisions regarding new projects are ultimately based on whether the expected cash inflows from the production of new wells/reservoirs/fields are large enough to warrant the investment in equipment and working capital and the other costs required to produce the hydrocarbon. Where working capital means the amount carried in cash, account receivables, and inventory that is available to meet day-to-day operating needs
- Product-improvement projects
    - This class includes expenditures intended to improve the marketability of existing production
- Cost-improvement projects
    - This class includes projects designed to:
        - Reduce costs and expenses of existing operations at current yearly production volume
        - Avoid future cost increases
    - An example is the decision to buy equipment to automate an operation now done manually. The expected future cash inflows from this investment would be the savings resulting from lower operating costs

Profit-maintaining projects

These projects have as primary purpose not to reduce cost or increase production but simply to maintain ongoing operations. They include:

- Replacement projects
    - Required to replace existing but obsolete or worn-out assets
    - Failure to implement these projects results in a slowdown or shutdown of operations
    - Additionally, the future expected cash inflows from replacement projects could be the cost saving resulting from lower operating costs, or the revenues from additional volume produced by the new equipment, or both
- Necessity projects
    - These projects are made from necessity, rather than based on an analysis of their profitability

- Necessity projects yield intangible benefits because their economic advantages are not easily determined or are nonexistent. For example, pollution-control equipment, installation of safety devices, and capital expenditures that must be made to comply with statutory requirements possibly to avoid penalties

In practice, projects may contain elements of more than one of these categories. Such projects are often classified according to their primary purpose.

Field Development and Associated Costs

The final cost of a field development is affected by several factors, for example:

1) Location

Geographical location is probably the main determinant of cost. A field, which is onshore and accessible, is going to be more economical to develop, than a comparable reservoir offshore in deep water. The cost of fixed structures increases exponentially with water depth. Distance to shore and to suitable landfall are relevant to the cost of export facilities

2) Reservoir

Reservoir geology and geometry has an impact on the cost of drilling development wells. The deeper the reservoir, the longer and more expensive the individual wells. The deeper the reservoir, the higher the temperature and pressure, which will be encountered, adding to the engineering complexity and cost.

However, shallow reservoirs may give rise to well geometry problems, if drainage must be achieved through a single location. The lower the temperature the higher the viscosity that will reduce productivity.

Reservoir shape, quality, layering and discontinuity will influence the number of development wells which must be drilled and geological complexity will increase the probability that individual wells may be unsuccessful

3) Reservoir fluids

The composition and properties of reservoir fluids have an impact on development cost. Light oil is cheapest to develop. It moves freely in pipes and creates few problems. Heavier and more viscous crudes are more difficult and expensive to move around.

Gas has a greater volume, for comparable value, so gas production and gas separation facilities are more expensive. Condensate fluids present a greater engineering challenge, to prevent liquid drop-out and maximize recovery. This normally involves recycling large volumes of gas, thereby adding significantly to cost

Non-hydrocarbon chemistry is important and some components, such as carbon dioxide and hydrogen sulphide (H_2S) can be problematic and dangerous. The special materials required to resist the attack of H_2S add significantly to cost

4) Technology

The hydrocarbon business has experienced considerable technological changes due by fluctuations in oil prices and developments in electronics and information technology. Technological change can have several objectives:

i) Cost Savings

Substantial cost savings have been achieved, for example in fixed structures, by using more effective designs and through a greater degree of standardization

ii) Creating new opportunities

Developments in sub-sea and floating technology, although expensive, have made it economically possible for the industry to move out into deeper water

iii) Improving safety and reliability
iv) Increasing productivity and efficiency

Horizontal wells are more expensive than equivalent vertical wells, but if properly applied, are more productive and give engineers more control over the reservoir

v) Reducing uncertainty

More is now spent on collecting geophysical information, but with the benefit of much better reservoir description and higher expected recovery factors

5) Infrastructure

The oil and gas industry has been active for more than a century with operations in thousands of fields. Many of these are connected to land-based oil or gas terminals by pipelines to shore. The cost of a petroleum development can be significantly reduced, if it is able to benefit from existing infrastructure of platforms and pipelines. Some fields are entirely dependent on an existing platform for all services; others use pipelines; others may simply require access to a regular supply of gas for power or artificial lift. In these circumstances, the capital cost is normally replaced by a per-barrel tariff. It is to be assumed that when such an arrangement has been made, it is to the benefit of the project paying the tariff. Otherwise, there is no incentive to sign the contract

Infrastructure has a limited life and are exposed to the elements. Therefore, it is important to consider the life expectancy of any facilities, which are being considered as part of the development strategy for a new project

6) External Factors

Development cost is subject to several external influences (external meaning independent of the project). Two are particularly important, namely supply markets and regulatory authorities

i) Supply Markets

Oilfield technology is built from steel and other components, including oil-derived products and energy. The cost of the finished, installed systems are sensitive to price changes in any relevant market for materials and labor, and structural changes in the various manufacturing industries

ii) Regulatory Authorities

Oil field development is subject to Government approval and systems must conform to current regulation particularly related to the environment. There are cost implications for both existing and planned projects

7) Project Taxation

The hydrocarbon industry is subject of a wide range of fiscal charges at all stages, from royalties on exploration to duty on the sale of products. Even though, taxation is out of the scope of this bibliographical review, some related terms were included in this chapter because of the relation between taxation and projects economic analysis. For example, for the cash flow model royalties and taxes are included as expenses

8) Royalties

Oil and Gas royalties refer to funds received from the production of oil or gas, free of costs, except taxes. Oil and gas royalties are also the cash value paid by a lessee to a lessor or to one who has acquired possession of royalty rights, based on a percentage of gross production from the property, free and clear of all costs

The word "royalty," as used in connection with oil and gas leases, means a share of the products, or proceeds are reserved to the owner of land for permitting another to use the property.

Usually, the net oil royalties and taxes payable by a producer are calculated by multiplying the royalty by the average net value before taking applicable deductions. Each producer’s royalty for a well is calculated by multiplying the oil royalty by the daily or monthly production volume, pro-rated based on the producer’s ownership percentage. Depending on the country the oil royalty rate may vary between 0 percent and 40 percent, and is conditioned by:

- The production volume
- The origin of the oil (Crown or freehold)
- The kind of oil the well produces (new oil, old oil, third tier oil, or heavy oil)

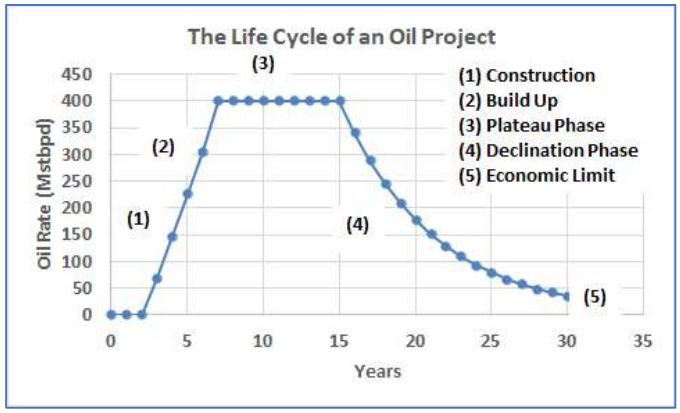
Besides Royalties other forms of taxations are: License Fees, Corporation Tax, Capital Gains Tax, Withholding taxes, Indirect taxes, etc.

The Typical Life of an Oil Project

Before identifying the elements of the cash flow, it will be presented the typical sources of inflows and outflows associated to the life of an oil project.

1. Build Up

Build up is the phase of production from start to peak. It is the time when development wells are being drilled and new wells are coming on stream. The outcome depends on:



- The rate at which wells are drilled and brought on stream
- The performance of these wells as they come on stream

Speed of buildup may be improved by pre-drilling of wells and by ensuring that early wells intersect the most productive parts of the reservoir. Speed of buildup is diminished by mechanical drilling problems or by unforeseen geological problems in the reservoir

2. Plateau Phase

The peak years can dominate the economic performance of a project and must therefore be properly planned. In the case above, eight years at 400,000 barrels per day represents more than fifty percent of reserves. In principle, the higher the peak, the sooner average oil is produced and the higher its discounted value. However, below factors may constrain the optimum rate:

- Higher rate means higher system capacity, more wells, larger pipes and vessels, more platforms and more cost. There is a balance between rate and reserves to ensure optimal economics
- Higher system flow-rate results in higher fluid flow-rate within the reservoir itself. Depending on geological architecture, this can cause fluid bypass (gas or water) and lead to reduced recovery of oil
- A higher rate of production implies more fluid to sell and therefore more customers to find. With oil this may not present a problem; however, gas markets are more restrictive and may constrain production. In general, gas fields produce at a lower peak rate to accommodate to market conditions

Development plans must be approved by Government, who may have views about development plans, which may have a detrimental effect on recovery factors. Government may also have a policy on general rates of depletion

3. Decline Phase

Once production falls off plateau, it enters a phase of natural decline, the shape of which depends on reservoir characteristics and energy. A compartmentalized low permeability and isolated reservoir will decline faster than one continuous and pressure supported. In general, the reservoir performance depends on the skill of the subsurface engineering team to understand the reservoir, to drill infill wells and to apply appropriate pressure maintenance, artificial lift technology, and to develop the best asset development and depletion plan

4. Economic Limit

Petroleum production normally comes to an end before the reservoir is fully depleted. Depending on the nature of the reservoir and the fluids, recovery may be as low as 10%, or as high as more than 50%. Typically, the production terminates for economic reasons

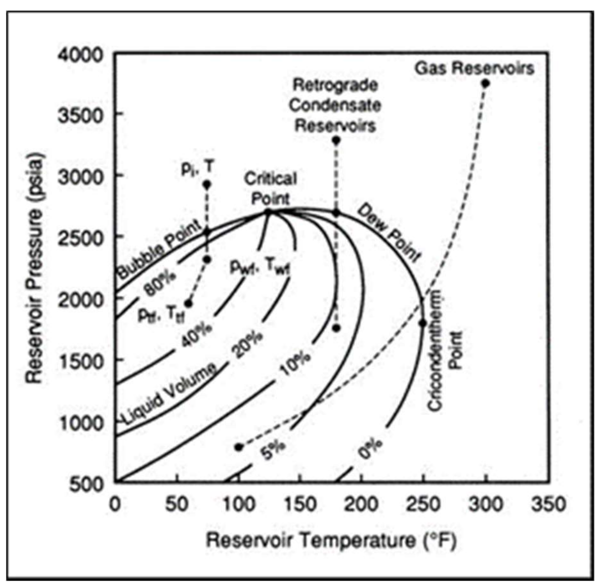
The primary issue is the balance between cost and revenue. Over time, revenue declines, with declining production, whereas some elements of OPEX will remain intact. The result is that, at some moment, the cost of running the project for another unit of time (year) becomes greater than the revenue generated in that unit of time. In other words, "***Marginal Cost***" exceeds "***Marginal Revenue***". "Marginal" in this context means avoidable, in the sense that if a decision were taken to terminate, these cash flows would not arise. Complications may appear, because of abandonment expenditure and associated tax recovery

Hydrocarbon Reservoir Fluids and Fields Classification

Hydrocarbon fluids occur naturally as complex mixtures, which may form separate liquid and gaseous phases in the subsurface. Once produced, most petroleum forms liquid and gaseous phases at atmospheric conditions.

From the engineering definitions, not the legal point of view, hydrocarbon reservoir fluids can be related to the API gravity (°API = (141.5/(sp. gr.@ 60° F)) - 131.5) and classified into five types:

- Black oils
  - Black oils are made up of a variety of components including large, heavy, and non-volatile hydrocarbons. The stock tank gravity is lower than 40 °API
- Volatile oils
  - Volatile oils contain fewer heavy molecules and more intermediate components (ethane through hexane) than black oils. Volatile oils generally have initial



gas-oil ratios in the 2000 to 3300 scf/stb range, and the stock tank gravity is usually 40° API or higher

- Retrograde gas condensates
  - Condensate gas is very similar to volatile oils in terms of gravity (40° to 60° API) of the produced oil. However, at reservoir conditions where a volatile oil is a liquid at original reservoir pressure and temperature, a condensate gas is a gas. As pressure is reduced in a condensate gas reservoir, the fluid will pass through the dew point and large volumes of liquid will condense in the reservoir
- Wet gases (Rich Gas)
  - Natural gas that contains significant heavy hydrocarbons such as propane, butane and other liquid hydrocarbons is known as wet gas or rich gas. The general rule of thumb is if the gas contains less methane (typically less than 85% methane) and more ethane, and other more complex hydrocarbons, it is identified as wet gas. Wet gas exists solely as a gas in the reservoir throughout the reduction in reservoir pressure. Unlike retrograde condensate, no liquid is formed inside the reservoir
- Dry gases
  - Natural gas that occurs in the absence of condensate or liquid hydrocarbons, or gas that had condensable hydrocarbons removed, is called dry gas. It is primarily methane with some intermediates. The hydrocarbon mixture is solely gas in the reservoir and there is no liquid (condensate surface liquid) formed either in the reservoir or at surface

Each type of fluid is produced by different engineering techniques and costs. The type of fluid is critical to production decision and therefore must be determined early in the life of a reservoir. The reservoir fluid determines the:

- Method of sampling
- Laboratory tests used in analyzing the samples
- Surface equipment type and sizes
- Procedures for determinizing oil and gas in place
- Techniques for predicting oil and gas reserves
- Processes for predicting production rates
- Development and depletion plan
- Selection of secondary or enhanced recovery methods

In terms of petroleum fields, the previous five types of hydrocarbon fluids are grouped in three types of fields:

a) Oil Field (Black Oil)
   - An oil field is one in which the dominant produced fluid is liquid. Many oil fields also produce associated gas. If the quantity of associated gas is small, recovery

and transportation may be uneconomic, resulting in re-injection or flaring. Larger quantities will justify recovery and sale. In some cases, natural gas liquids (NGL) may be recovered from the gas

- NGL are components of natural gas that are separated from the gas state in the form of liquids. This separation occurs in a field facility or a gas processing plant through absorption, condensation, or other methods. NGL typically refers to ethane, propane, butanes, and natural “gasoline” (pentanes). NGL’s are hydrocarbons removed (condensed) as a liquid from a hydrocarbon stream that is typically in a vapor phase (i.e., natural gas) They are kept in a liquid state for storage, shipping and consumption
- In normal black oil fields, the oil and gas are produced together with a difference in revenue. For example, oil revenue could be based on $50 per barrel and gas on $4 per Mcf (dollars per thousand of cubic feet). This indicates the relative economic importance of oil and gas to the project

b) Gas Field

- A gas field is one in which the dominant produced fluid is gas. However, many gas fields also produce some liquid (NGL)

c) Intermediate Field (Volatile oils, Retrograde gas condensates or Wet Gases)

- An intermediate field is one, which produces economically significant quantities of both liquid and gas. In some cases, the liquid is a condensate. Gas is produced for sale and to be re-injected to maintain reservoir pressure. In these cases, both liquid and gas are economically important to this project and either could be the dominant product, depending on relative price.

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