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Integrated Petroleum Engineering Simulation and Decision Making Teaching Program

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Abstract

A course of exercises has been developed that trains the student in the different steps involved in discovering and evaluating the economic worth of an oil field. The objective is for the course to act as a link for several different aspects of petroleum engineering - seismic analysis, drilling and completion, logging, well testing, reservoir evaluation and economic analysis - that the student has been taught in detail in the specialist courses that he/she has attended during the course of his/her petroleum engineering education.

To do this, a fictitious oil field has been invented, and its details incorporated into a simulator that allows drilling, logging and other operations to be carried out so that the student gradually learns about the properties of the field during the course of a series of "hands on" exercises. Once the investigation is complete, the student has enough information to make an economic evaluation of the field, and is in a position to determine the necessary economic criteria - investment required, net present value, return on investment etc. - that will allow the "company" owning the lease to decide whether to go ahead with developing the field.

Introduction

Petroleum Industry Technical Managers have often expressed the view that although new engineering graduates entering the industry from a university have extensive technical knowledge, it tends to be held in isolated blocks that reflect the disciplines in which it was taught, rather than being available as a means for solving problems that require the combination of information from several different sources. For example, although the graduate may have an extensive knowledge of fluid mechanics, electrical engineering and materials science, he/she has never been exposed to the process whereby elements from each of these disciplines are brought together to make an efficient and effective design for an electric pump.

With this in mind, we have developed a course for petroleum engineering students that guides the student through various steps that are involved in discovering and evaluating a petroleum reservoir. The course consists of a series of eleven exercises, each of which deals with a different engineering topic, and which together lead from the early discovery of the field through to the decision to develop it or not. The exercises make extensive use of a computer-based drilling simulator (1) that allows a "hands on" feel so that, for example, the costs of drilling a well are partially determined by the skill of the student in controlling the drilling process. The simulator also allows wells to be logged so as to get information on the extent and type of hydrocarbons in the well, and the porosity and water saturation of the surrounding formations.

Since each exercise deals with a separate area of knowledge, but only comprises less than ten percent of the course, it is not possible to treat each area with the degree of detail that it might need for the student to understand it fully. Instead, only the material necessary to solve the immediate problem is presented, and it is left to the student to research the necessary background. Indeed, it is hoped that by the time the student is taught this course, he/she will already have taken a range of specialty courses in drilling, logging, reservoir engineering and so on, and the background material should already be entirely familiar. In this way, the course will fulfill its intended function, to act as a "capstone" experience, where knowledge from all the separate specialty courses is brought together in a logical whole.

In order to make the material transportable between different instructors, it has been assembled in the form of an instruction manual with printed versions of the exercises and their solutions, together with the necessary software.

Construction of the oil field

The field to be evaluated is loosely based on the Railroad Gap field in Kern County, California (2, 3). The field geology is in the form of an elongated dome. It contains two reservoirs, one vertically above the other. These are the "Carneros" and the "Phacoides" reservoirs, that are, respectively about 6,400 x 2,000 and 6,400 x 1,800 ft. across at their oil-water contacts. Both have gas caps. The Carneros reservoir top is at approximately 5,858 ft depth, while that of the Phacoides is at 7,754 ft. To simplify the calculations, the strata were made to have the form of an inverted parabola along the narrow axes of the reservoirs, and to be straight in the orthogonal direction. To obtain closure, it was postulated that there is a "fault" that allows one half of each reservoir to dip down at seven degrees from the fault in a north westerly direction, and at ten degrees down from the fault in the south easterly direction. **Fig. 1** shows a representation of the sealing layer on one half of the Carneros reservoir.

The device of choosing a field with two reservoirs that are broadly similar but not identical helps the teaching process, as in many of the exercises, the student can be shown a worked example for one reservoir, and then be assigned a parallel exercise on the second reservoir as homework.

In order to make a meaningful project, all the physical properties of the field had to be made self-consistent as far as possible. This means that, for example, the depths of various features seen on the seismic sections have to correspond in depth with those that are encountered while drilling. This includes the intervals between hard and soft drilling strata, that can also be "seen" in the seismic sections, the position of an oil-gas contact that appears both in the logging data and the seismic sections and so on. It was also essential that the depths of the various reservoir cap rock strata, and the depths of the oil-gas and oil-water contacts have to correspond in each of the wells that the student drills so as to allow the determination of the extent of each reservoir and its geometry. More subtle effects had to be included. For example, the physical chemistry of the oil and gas in each reservoir had to be consistent with the density, phase behavior and flow characteristics of the fluids as "reported" in the well tests, and as needed for calculating reservoir engineering data such as the oil-gas ratio, the oil formation factor and the likely recovery.

This need for self-consistency frequently required the exercises to be constructed in a "first backwards, then forwards" manner, i.e. to get a self-consistent answer, it was necessary to start from a desired, physically reasonable answer, to work back to the geological or other conditions that would produce that answer, and then develop the teaching exercise in the "forward" direction, knowing that the answer to be obtained would be of the correct magnitude. This applied not only to issues of the physical chemistry of the reservoir fluids mentioned above, but also, for example, to the assignment of values for the rock strength and abrasivity, the properties of drill bits and the drilling rig rental rates that would allow the finding of "reasonable" lives for drill bits, and reasonable costs for drilling and logging each well.

Finally, efforts were made to bring an element of challenge into the exercises. This was done by introducing a degree of choice on the part of the student. This could easily be done, for example, in some of the drilling exercises where the students are free to choose the drilling parameters, casing depths and so on in an attempt to minimize the cost of each well. Unfortunately, there are limits to this process if the set of possible "solutions to exercises" is not to expand without limit.

The Exercises

We now briefly describe each of the exercises in order to indicate the range of activities that are covered and the sequence of operations that lead to the economic evaluation of the field.

Introduction.The first exercise serves as a frame and introduction to the course. The lease boundaries are set as a rectangle of sides 12,000 ft in an east-west direction by 8,000 ft north-south. This defines a local coordinate system to which all field operations subsequently refer. There is a description of the regional geology that mentions a series of folds whose dips run approximately NE-SW, and “reports of oil strikes” in adjacent leases.

Seismic exercise. Based on the existence of the folding, a seismic section running approximately NE-SW (i.e. along the direction of folding) is authorized and obtained (**Fig 2**). This shows a clearly defined anticline, and in the center, the horizontal trace of an oil-gas contact. The students are expected to recognize this, and then, using some information on the average speed of sound as a function of depth, to find its approximate depth. They must also estimate the lateral extent of the contact, infer which reflector is the sealing layer, and then estimate the depth to the top of the reservoir.

Having found strong evidence for the presence of hydrocarbons by virtue of the gas-oil contact, "authorization is obtained" to make another seismic section, orthogonal to the first, running through the highest point of the anticline. This reveals that the strata in this direction are unfolded, but that closure is obtained by a fault that causes the strata to dip down at seven degrees to the north west of the fault, and at ten degrees toward the south east of the fault. Again, evidence for the gas-oil contact is found, consistent with the data from the first section.

This allows an approximate mapping of the extent of the gas cap on the Carneros reservoir, and a request for authorization to drill a wildcat well.

Planning the Wildcat. Exercise three requires the student to estimate the cost of drilling the wildcat well. Compiling an AFE is a difficult exercise to make interesting, as the student has to be told how much each operation or type of goods costs, and it is not easy to make the exercise more challenging than the task of entering data into a spreadsheet. Nonetheless, there is scope for the instructor to discuss how rig rates, for example, might vary between different locations, how many drill bits of each size might be needed, and how severe the environmental constraints might be. Alternatively, students may be asked to estimate all values for themselves by calling local oil companies, although the scope for variability is very large. These data may be used to start a useful discussion on the relative costs of operations in different parts of the world.

Drilling the Wildcat. This exercise uses the drilling simulator to drill a wildcat at the intersection of the two seismic lines. A typical depth-time plot generated by the simulator is shown in **Fig. 3**. The lithology corresponds to that "seen" in the seismic sections, and allows a correction to the speed of sound in the strata as a function of depth. It also allows an accurate identification of the depth of the Carneros reservoir. Logging the well allows the discovery of the Phacoides reservoir, whose existence until now was only hypothetical.

The exercise also serves to instruct the students in the choice of casing depths. Initially, the only objective is to drill the well to as great a depth as possible. To this end, each casing is set as deep as it can be. However, once the depth of the Phacoides reservoir is known, and it is decided to drill no deeper than that, an improved casing design can be developed, based on a "bottom up" design that sets each casing only as deep as it needs to be to reach TD. This results in the casing costs dropping from $648,000 to $516,000.

Once the casing plan is fixed, each section of the well can be drilled repeatedly while experimenting with different choices of drill bit, mud and hydraulics parameters, and operating parameters. With a little perseverance, the student will see the cost of the well drop from about $ 1.2 million to $ 836,000.

Casing and Drill String Design. This exercise concentrates on the design of the drill pipe and the casings required in a typical well in this field. The design could be carried out for the wildcat well, but by now the project team will have decided that they must drill some evaluation wells to check the extent of the reservoir. The simulator is therefore used to drill and log another well, and this is used for the casing and drill pipe design exercises.

The casing designs follow a simple methodology based on resistance to collapse, burst and tension. **Fig. 4** shows the design diagram for the 13 3/8" casing. The required design parameters are derived from the well data as it is drilled. In a similar manner, the strength necessary for the drill pipe is calculated for each section, based on depth and hole diameter. The latter, of course, determines bit size and thence the number and weight of collars required.

In each of these operations, the student is given the design method and a worked example for one section of the well, and is then asked to make a design for another section. There is thus always an example to follow.

Cementing. In a similar manner, the next exercise concerns the design of a cementing operation. Another well is chosen for this purpose, with the objective of accumulating additional information concerning the reservoir on the way. As in the case of the previous exercise, the cementing exercise proceeds by giving an example of the calculation for the 20" casing, and the student is asked to follow that example to design the 13 3/8" casing cement job (**Fig.5**). Again, the student is required to log the well and thereby gather important information on the reservoir properties.

Logging. The course now turns away from drilling engineering towards logging and reservoir engineering. The next exercise requires the student to evaluate the log data from a new well and combine it with information obtained during the drilling of the wildcat and other wells. The student must first examine the logs of the four wells that were drilled so far to determine the heights of the reservoir tops and the oil-gas and oil-water contacts. Next he/she must interpret the wireline data to determine porosity (obtained directly from the logs) and hydrocarbon saturation. In the latter case, a simple method is used employing Archie's law (4), and assuming that the lower part of each reservoir (the water zone) has no oil saturation so as to be able to determine the water salinity. No corrections are applied for changes in temperature, "shaliness" or other effects that are required in more sophisticated evaluations. The porosity and hydrocarbon saturation information gathered from this exercise will later be used to estimate the gas and oil initially in place.

The Well Test. The well test is an essential part of the reservoir evaluation process. The student is told that a well test has been carried out on the wildcat well, and is given the pressure-time data (**Fig 6**). A brief summary of the theory of the drawdown test is given, although it is assumed that the student is already familiar with one or more of the classic texts on this subject.

The student is expected to analyze the test results, and to derive values for the skin and permeabilities from the early-time (transient) data, and the drainage area and the Dietz shape factor (5), from the semi-steady state results. As usual, the exercise takes the form of a worked example, in this case, using the data from the Carneros reservoir, while the student is expected to solve the equivalent problem for the Phacoides reservoir. The method employed is very similar to that given by Dake (6).

Solution of this exercise gives the important results that for the Carneros reservoir, the permeability, at 25 mD, is sufficient to produce an adequate flow if we install production wells, and the drawdown area is about 30 acres, thus indicating that the wells can be spaced a reasonable distance apart. The corresponding data for the Phacoides reservoir are 0.25 mD and 9.3 acres, which make a less attractive prospect.

Oil and Gas in Place. The next essential step is to determine the overall dimensions of the Carneros and Phacoides reservoirs, and to calculate the oil and gas in place. To do this, the student must drill and log a number of delineation wells, making a total of thirteen in all, that will give an adequate view of the geometry of the reservoir. It would of course be possible to have the student drill each of the wells using the simulator, but by now it is assumed that he/she has had enough exercise in drilling, so the positions of the reservoir tops and gas-oil and oil-water contacts are simply tabulated. From this information, and the known positions of the delineation wells on the lease map, the student must determine the shape of the reservoir and the volume of hydrocarbons. It would be possible to do this by drawing a series of contour maps, but since our reservoirs have a very straightforward geometry, we can make the simplifying assumption that they can be approximated to parts of cones on an elliptical base (**Fig 1**). This allows the student to carry out an exercise in solid geometry, and to determine the reservoir volumes analytically.

Having found the volume of the gas and oil parts of each of the reservoirs, and knowing the porosity of each reservoir, the student must determine the volume of gas under standard conditions, and the stock tank oil initially in place (STOIIP).

These calculations use data concerning the known pressure, temperature and molecular composition of the gas and oil phases in the reservoir, all of which are given to the student as "data obtained from lab tests". However, the lab test data are not fully reduced, so the student must actually calculate pseudo critical temperatures and pressures, the solution gas-oil ratio, the oil formation factor and other values from the lab data.

Economic Analysis. At this point, the student has sufficient information to make an assessment of the economic worth of the two reservoirs. This is simply carried out by making a spreadsheet analysis. Input information includes the number of wells that will be needed to drain the reservoir, and the cost of each well. The total number of wells (13) is based on the calculated drainage area of each well, (derived from the analysis of the drawdown test). However, the student will have to take into account that four of those wells miss the Carneros formation, and 7 miss the Phacoides formation.

Ultimate recovery is estimated from Arps's correlations (7), taking into consideration the physical properties of the oil and reservoir rocks as well as an assumption that the reservoir is pressurized by solution gas, a gas cap and an active water drive from below.

An assumption must be made as to the likely productivity of each well, and this can again be derived from the well test data. It is further assumed that after the go-ahead is given, the necessary production wells can be drilled in two years. Finally, the cost of the wells is obtained from the results of the drilling exercises. These are estimated to cost one million dollars each.

Various economic assumptions must now be made, concerning the rates of interest and inflation, tax rates and so on. From these data, a spreadsheet can be constructed to show any of the common economic yardsticks such as Return On Investment (ROI), Net Present Value (NPV), Discounted Profitability Index (DPI) etc. Graphs can also be constructed to show cash flow as a function of time (**Fig 7**) and other data.

Naturally, however, it is a simple matter to change values in the spreadsheet to investigate the results of changes in the financial parameters such as the rates of inflation and interest. It is also instructive to investigate the merits of making changes to the investments in the field, by, for example, increasing the number of wells to increase the production rate. Each of these proposals can be simulated by making adjustments to the spreadsheet and then discussed by the class.

Conclusions

The above notes give a brief overview of a training course that covers most of the technical elements involved in the discovery and evaluation of a typical oil field. Since the course was designed to fit into the time available in a typical university semester, it has not been possible to enter into as much detail as may be applied in the evaluation of a real reservoir in the industry. However, it was not the purpose to go into exhaustive detail in each technical field. Indeed, it is hoped that students taking this course will already have greater knowledge of the basic petroleum engineering disciplines than are treated here.

Rather, the objective has been to bring together the components in a way that illustrates the influence that each brings to the other, and to illustrate the sequence of operations that is necessary in the rational development of an oil field. In addition, it is hoped that the use of computer simulation, the ability to try different scenarios and to learn by trial and error will prove interesting and challenging to future students.

References

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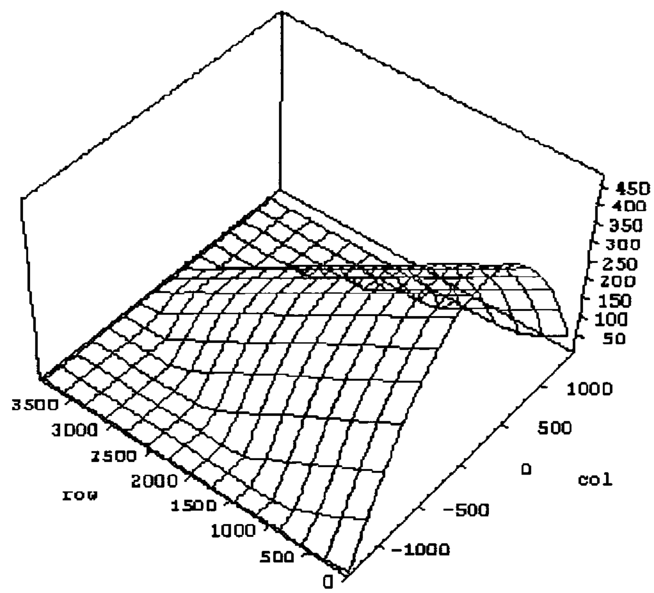

Fig 1. View of the sealing layer above the NW section of the Carneros reservoir.

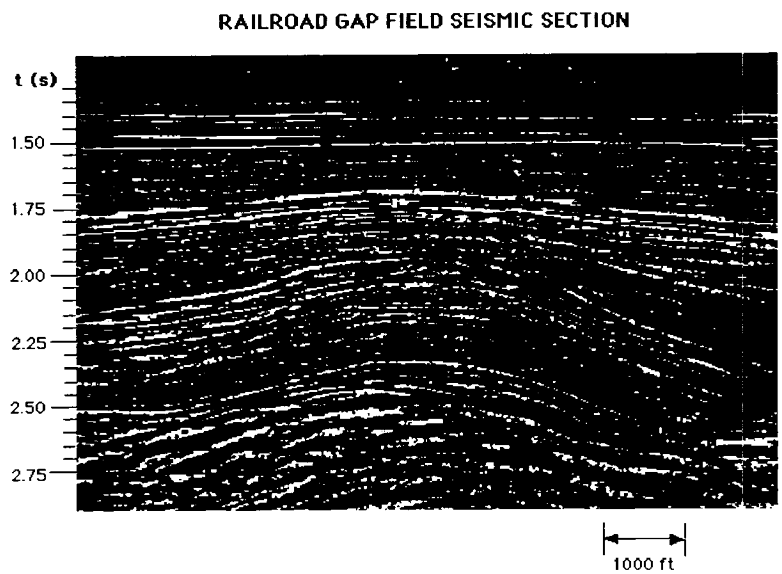

Fig. 2. The first seismic section. Note the horizontal trace at approximately 2.15 seconds that indicates an oil-gas contact.

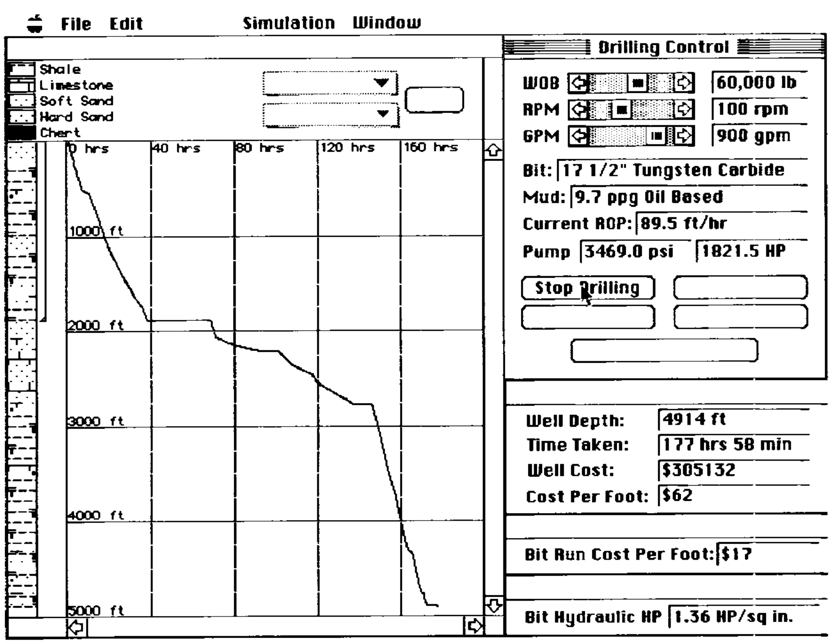

Fig. 3 Typical depth-time simulator screen, showing the drilling control panel and diagnostics windows, the depth-time plot, the "mud log" showing the rocks that have been penetrated, and a casing symbol showing that one casing has been set.

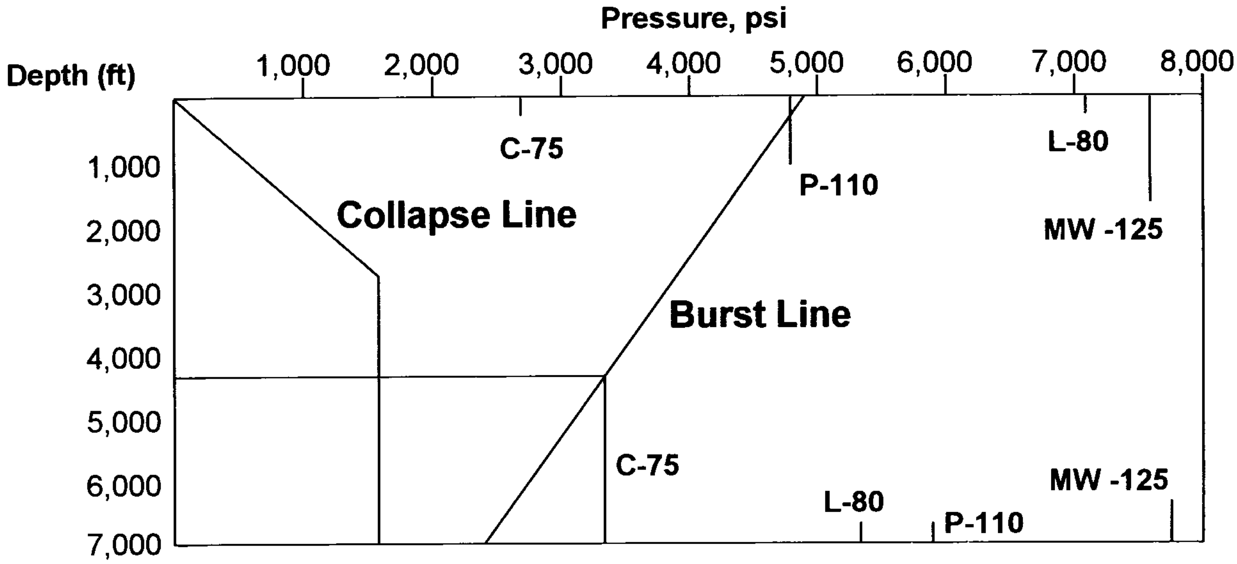

Fig 4. Casing design diagram for a 9 5/8" casing.

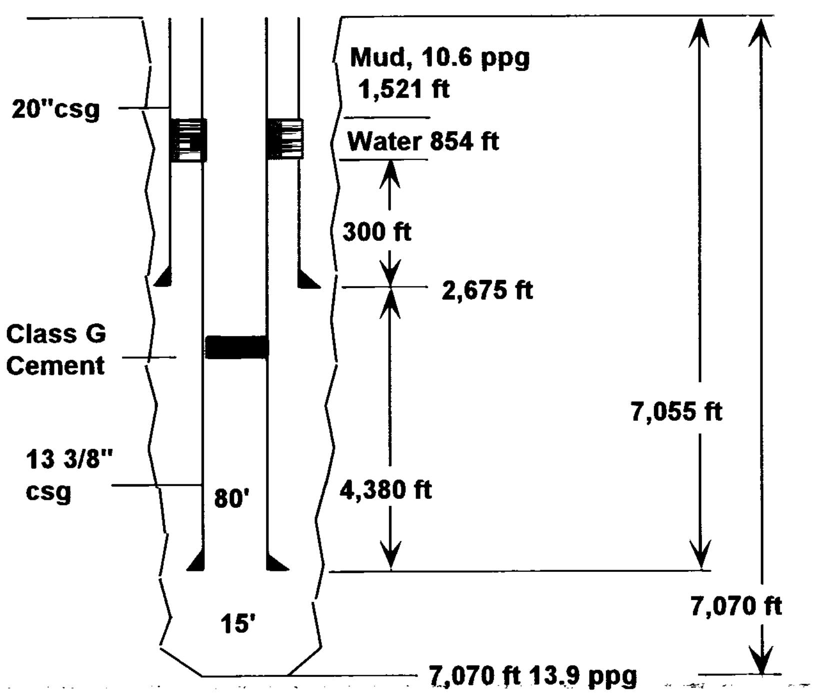

Fig 5. Cementing planning diagram for designing the cementing of a 13 3/8" casing.

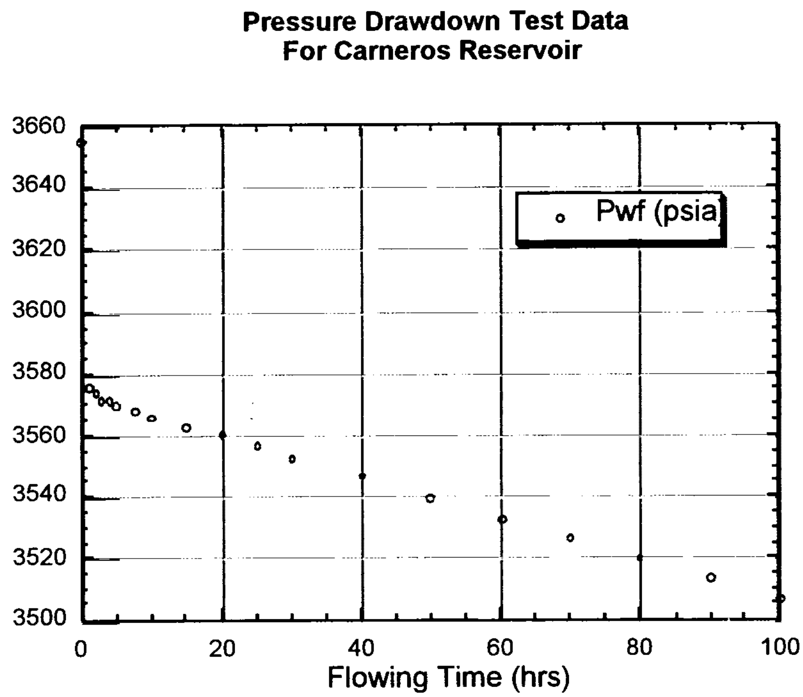

Fig 6. Drawdown test data for the Carneros reservoir performed at the wildcat.

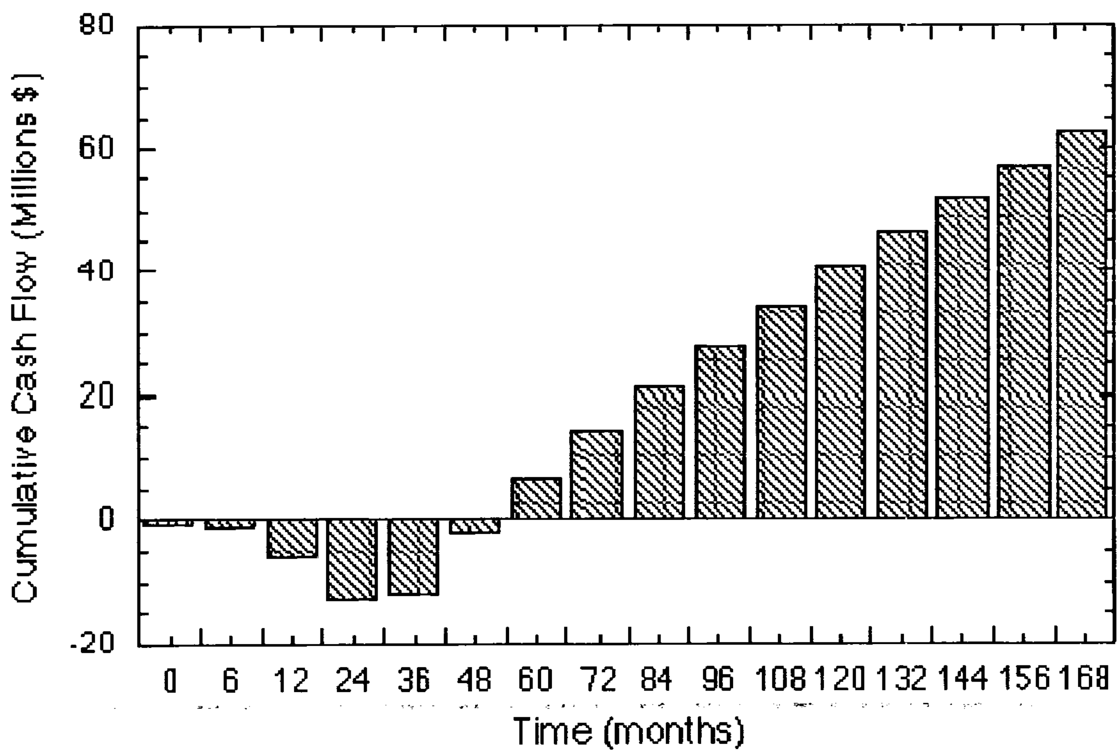

Fig 7. Economic Analysis: Cash flow for the Railroad Gap Field Carneros Sand.