Material Balance Calculations Using the Excel Spreadsheet

Introduction

Material balance is a fundamental petroleum reservoir engineering tool that can be used to provide an understanding of a reservoir and the influence of any connecting aquifer. The basic requirements for the application of material balance to a reservoir include:

1) The hydrocarbon and water production from all wells producing from a reservoir must be summed to provide a total reservoir production history.

2) Some knowledge of the average reservoir pressure history must be known. Utilizing the average pressure history of the reservoir suggests that material balance is best applied in reservoirs where relatively small pressure gradients exist.

3) PVT properties must be expressed with sufficient accuracy using a so-called "Black Oil" model. Solubility of gas in oil and oil formation volume factor must be expressed as a simple function of pressure. Gas is assumed to be insoluble in water. This requirement typically eliminates volatile oil and rich gas condensate reservoirs from consideration for material balance calculations.

The ability to express the pressure and production history in this so-called "tank" model often allows an accurate estimation of initial hydrocarbons in place and/or the productivity and size of any connecting aquifer. Material balance can often be applied fairly early in the life of reservoir before it is fully delineated by drilling which can aid in selecting new well locations and spacing once the drive mechanism is understood.

The use of material balance by practicing reservoir engineers has recently fallen from favor with the development of reservoir simulation. This loss of knowledge and experience is unfortunate when the simplicity of material balance calculations is considered compared to reservoir simulation. Indeed, all the data required for a material balance analysis is collected for any reservoir simulation study. It is the experience of this reservoir engineer that if material balance is successful in characterizing the aquifer and initial hydrocarbons in place, that the time required for the history matching process in a reservoir simulation project may be shortened by an order of magnitude! Furthermore, if material balance is unsuccessful in those reservoirs that can be described by a tank model, problems with the data are indicated and any reservoir simulation is doomed to failure!

While various commercial material balance programs exist, the purpose of this endeavor wa

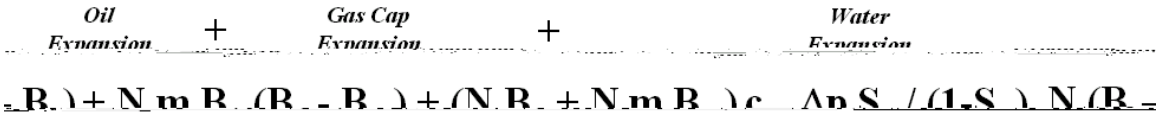
values of initial hydrocarbons in place and aquifer properties to calculate a pressure history for comparison to any historic measured values of pressure. This is in contrast to the method of using the measured pressure data in the calculations to estimate water influx in a stair-step fashion usually utilized in a method commonly referred to as an "XY" plot. This commonly used XY plot can provide excellent results when the input data includes regularly recorded bottom-hole pressures over relatively short time intervals. The accuracy of the XY plot method must be called into question, however, as the time between measured pressure values increases and the pressure data becomes more sporadic.

For example, consider a problem that has a measured pressure after two years of production. Assume that the reservoir was produced for the first year at 10,000 BOPD and 30,000 BOPD/day the second year. In the common XY plot method, the water influx calculations would be identical if instead the reservoir had been continuously produced at 20,000 BOPD for two years, *or even if it had been produced at 40,000 BOPD for the first year and then shut-in for the second!* Clearly the approximations required for water influx calculations can yield erroneous results as the pressure data becomes sparse and the production rates become erratic.

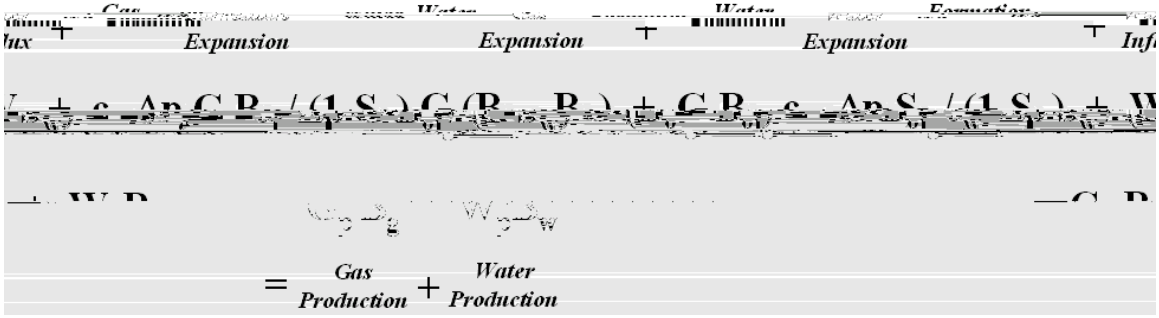
A very powerful feature of this program is that in addition to initial hydrocarbon in place and aquifer properties, other parameters that may not be known with confidence can also be varied. For example, the initial pressure of the reservoir may not be exactly known and is extremely important in the calculations. Formation compressibility may not be known and a value for it can be determined that yields a best fit. Any combination of parameters can be fixed or varied. A particularly useful application fixes the initial hydrocarbons in place at the volumetric value determined from the initialization of a simulation model to allow the determination of appropriate aquifer properties for the model.

Material Balance Concept

The development of the general oil material balance equation can be found in any petroleum reservoir engineering textbook including Applied Petroleum Reservoir Engineering (B. C. Craft and M. F. Hawkins, revised by R. E. Terry) and Fundamentals of Reservoir Engineering (L. P. Dake). This equation simply states that as the pressure in the reservoir falls, the oil, gas and water must be allowed to expand. The volume of this expansion in reservoir barrels, along with a reduction in pore volume and any fluid injection, must be equal to the total fluid production also expressed in reservoir barrels. Although not its most simple algebraic form, the oil GMBE can be written as follows allowing each term in the equation can be readily identified:



Similarly, the gas GMBE can also be written in a form that allows each term expressed in reservoir barrels to be readily identified:



While the current reservoir pressure in the above equations is only explicit in the “Δp” found in the formation and water expansion te

at the best history match, some effort is first spent manually attempting to determine the match. Although arguably this seems like an inefficient use of time, it is primarily done for three reasons: 1) bad data points can usually be readily identified and excluded from the ultimate Solver solution, 2) Solver can be unstable and providing it with starting values that are close to the ultimate best fit values can improve stability and decrease calculation time, and 3) perhaps most importantly, manual manipulation of the problem can provide an important insight into the sensitivity of the model to changes in the input parameters providing a level of confidence in the uniqueness of the history match.

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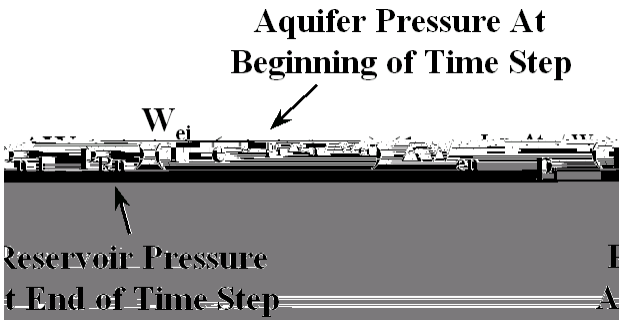
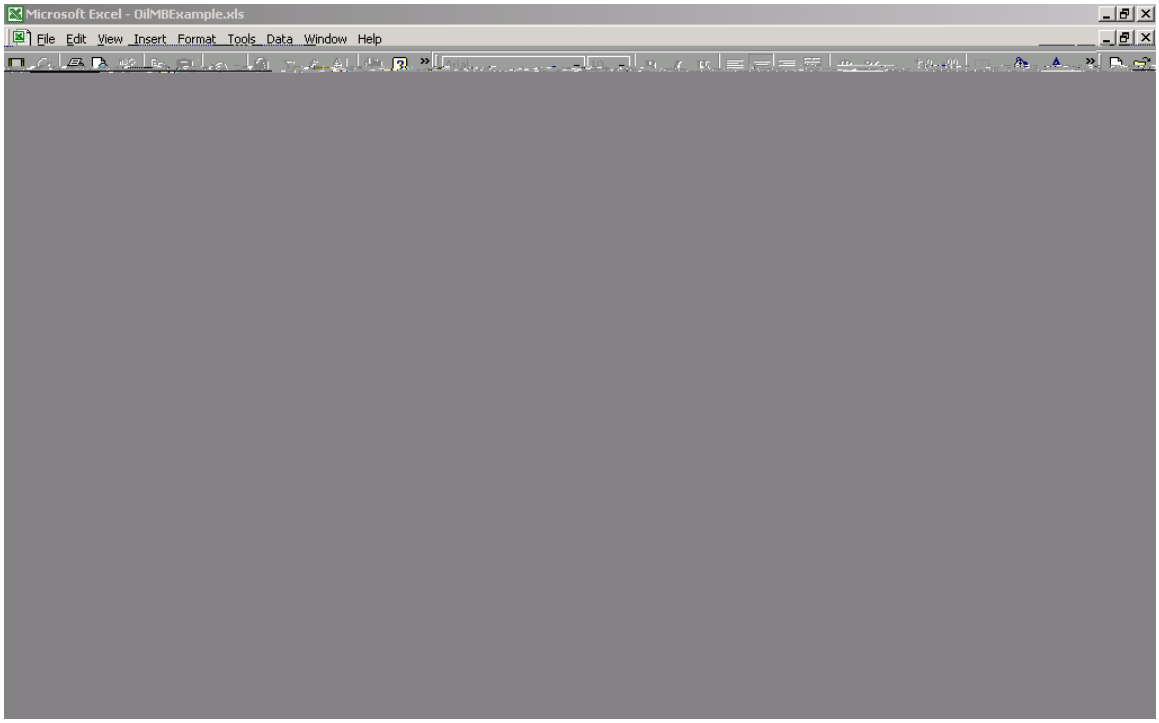
(see Dake page 328 for example calculations), *typically less is known about the aquifer than the reservoir being studied*. For this reason, the aquifer productivity index and the encroachable water term discussed previously are used in this program as history matching values to describe the aquifer.

Fetkovich algebraically manipulated and integrated these equations to arrive at an expression describing the water influx for a constant pressure drop and a specified time. Theoretically, this equation requires tedious superposition in a manner similar to that required by the Hurst and van Everdingen method. Fetkovich's most significant contribution was to determine that his solution could be applied in a stepwise fashion using the equation to the right. This eliminated the need for superposition while providing approximate results of acceptable accuracy.



It is not the intention of this narrative to replace the complete discussion of the Fetkovich aquifer found in most reservoir engi

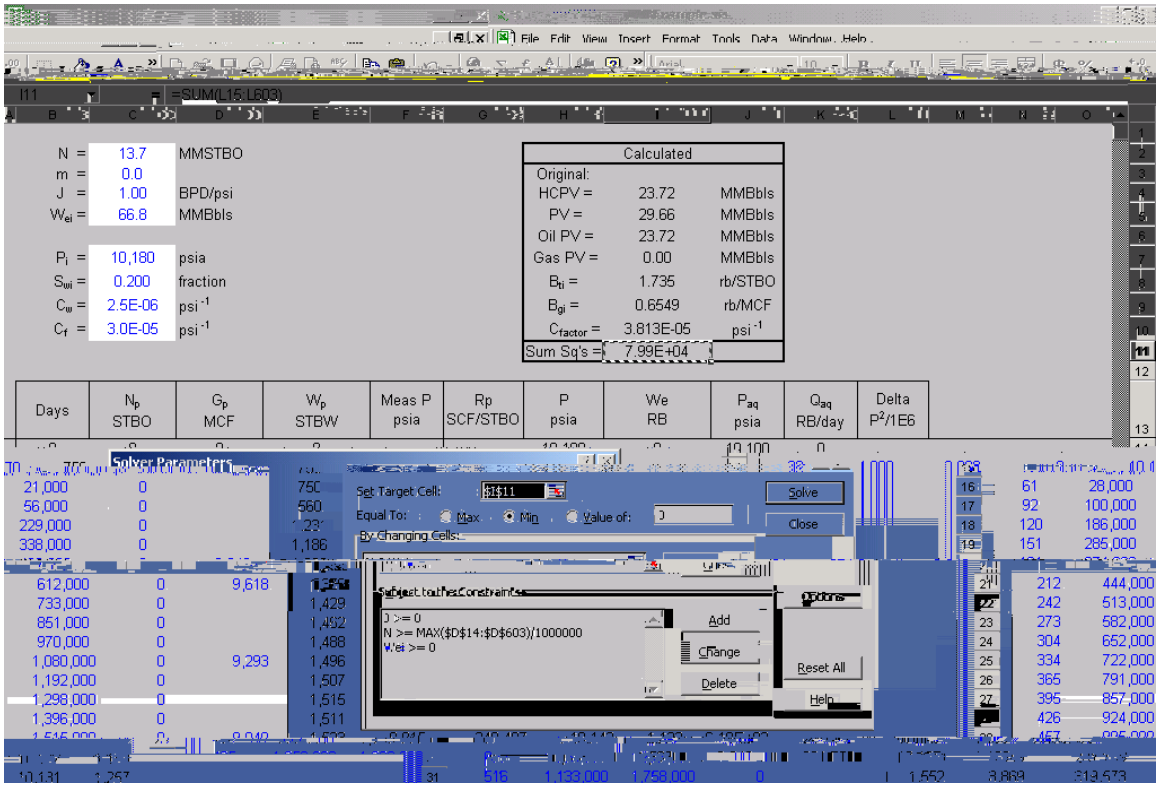
hydrocarbons in place and aquifer properties. The first worksheet, tabbed “Z Factors”, from the example oil material balance problem is shown below:



sheet tabbed “Calculations.” Note that the column for water production can be viewed as a “net” value and can be negative in situations where water injection is present. Considering the inaccuracies of water production measurements, water formation volume factor was assumed to equal unity. If it is desired to include B_w, adjust the input water production to reservoir barrels prior to inputting the values to the spreadsheet.

Initial guesses for initial hydrocarbon in place should obviously be larger than cumulative production. Initial guesses at aquifer properties can vary widely. It is often useful to assume an infinite acting aquifer by entering an extremely large value for W_{ei}, say 1E9 reservoir barrels, and a limited value for productivity index, perhaps on the order of 1 BWPD/psi. Manual attempts at history matching the aquifer properties usually show that early time data is influenced strongly by aquifer productivity and later time pressure is more strongly influenced by aquifer size.

The value of “m”, the ratio of gas cap volume to oil volume, should be set to zero for initially undersaturated oil problems. iti900345.0205 Tw 12 0 720 0 12 90 223.500 Tm(volum)Tj1234.7



Depending upon the complexity of the problem, Solver can require a fairly significant amount of computer time for its calculations. Its progress can be observed in the lower left hand corner of the spreadsheet. By default, it will pause after 100 seconds and prompt whether to continue, and it will also pause after 100 iterations. These defaults can be changed under the “options” button if desired, along with such things as convergence criteria and the calculation method employed. Most problems typically converge in around five minutes with less than ten iterations. It may be wise to change the maximum iterations from 100 to perhaps 20 since the process is likely unstable if convergence is not rapidly achieved and 100 iterations could take an hour or more to complete.

As previously mentioned, Solver can become unstable and it is best to start the calculations with values at least close to the final solution. It is highly recommended that the spreadsheet be saved prior to the use of Solver. The Newton-Rhapson method employed in the material balance program usually converges in less than five iterations. It also can occasionally become unstable and will halt after 100 iterations and display a message that it is experiencing convergence