CHAPTER II

LITERATURE REVIEWS

In 1941, Schilthuis[1] presented a general form of a material balance equation. The use of the Schilthuis' form in predicting future performance was proved to be laborious in that one generally has to make several estimates at each step of the trial and error calculation before reaching a check of the hydrocarbon in place.

In 1954, Tracy[2] presented a method for expediting the calculations. The Schilthuis' form of the material balance was rearranged into a more useable form. In using the material balance to predict the future performance of a reservoir, it had become common practice to estimate the incremental hydrocarbon production for each step of the calculation which corresponded to a given pressure reduction.

As it is known that reservoir pressure in the material balance equations, as well as the associated water influx equations, is generally an implicit term. Hurst[3] presented in 1958, another approach to the problem, whereby the reservoir pressure which was an implicit term could be isolated by mathematical procedure to relate that parameter with all the factors contributing to its change.

In 1964, Cook and Johnson[4] presented that two probable sources of appreciable error in conventional material balance calculations were inaccurate measuring and accounting for produced gas, and assuming that average data obtained during bottom-hole pressure surveys is equal to the average reservoir pressure.

Spivak and Dixon[5] presented their paper in 1973 describing a new method for simulating gas-condensate reservoirs. The simulator accounts for both retrograde condensation and vaporization of condensed liquid as well as arbitrary field shapes, well patterns, and heterogeneities. The formulation of the simulator is based upon a formation volume factor which is analogous to that used in black-oil simulation models.

In the gas-condensate analogy, mass transfer between the gas and liquid hydrocarbon phases is handled by an " r_s " term which has a unit of STB liquid/MSCF dry gas and is similar to the " R_s " term in black-oil simulation. Fluid properties for black-oil simulation models are usually obtained from laboratory PVT cell depletion data. This type of model is of questionable reliability in special cases such as volatile-oil reservoirs where the reservoir pressure and temperature are close to the critical pressure and temperature of the oil. One would expect that gas-condensate reservoirs could be treated by a formation volume factor approach with fluid properties determined from laboratory depletion data. The simulator described in the Spivak and Dixon's paper also employs such an approach. The simulator handles three phases and consists of numerical solution of the continuity or mass balance equations for gas, hydrocarbon liquid, and water in one, two, and three dimensions.

Brigham and Morrow[6] presented their paper in 1977 about p/z behavior for geothermal steam reservoirs. The results show that the presence of boiling water phase will have a considerable effect on the pressure behavior of such systems. Furthermore, the porosity of the system will have a marked effect. Extrapolations of early data on the p/z plot will be optimistic if the porosity is low and pessimistic if the porosity is high. In all cases, the steam zone will remain at the original temperature, though the temperature of the boiling water drops as the pressure declines.

In 1981, Collier, Monash, and Hultquist[7] developed a mathematical model and tested for the production of natural gas with water encroachment and gas entrapment. The model was built on the material and volumetric balance relations, the Schilthuis' water drive model, and a gas entrapment mechanism by assuming that the rate of gas entrapment was proportional to the volumetric rate of water influx. This model represents an alternative to the large grid models because it has low computer, maintenance, and manpower costs.

In a normally pressured volumetric gas reservoir, the gas is produced by gas expansion. In an abnormally pressured gas reservoir, sand grain expansion, rock compact, and water expansion are also significant in addition to gas expansion. For an abnormally pressured, depletion type gas reservoir, a conventional plot of p/z versus cumulative production yields two distinct slopes. The extrapolation of the initial slope to a p/z of zero yields the apparent GIIP, which may be significantly different from the true GIIP. The problem is that the conventional p/z plot in abnormally pressured reservoirs must be adjusted for rock and water compressibility to obtain reasonable estimates of GIIP.

Ramagost and Forshad[8] presented a paper in 1981 about a new technique for predicting performance of an abnormally pressured gas reservoir. This method maintains the old straight line relationship for conventional p/z's in normally pressured reservoirs and allows direct extrapolation of GIIP in abnormally pressured reservoirs by accounting for rock and water compressibility in the adjustment factor term. Thus, in case of abnormally pressured reservoirs, the method of Ramagost and Forshad can be used to yield reasonable results.

Concerning turbulence in gas reservoirs, Lee, Logan, and Tek[9] presented their paper in 1987 about the effect of turbulence on transient flow of real gas through porous media. Their paper represented the first effort in quantifying the "turbulence intensity" as related to deliverability from gas wells. A new dimensionless number called the Forchheimer number, N_{f0}, had been proposed along with a generalized expression of turbulence coefficient. Applications include a new concept called "inverse productivity index, J_i," proposed as an alternative to classical back pressure plots for characterizing gas well performance.

In 1987, Prasad and Rogers[10] presented a paper about p/z behavior for superpressured gas reservoirs. They reviewed pressure decline data from 21 superpressured gas reservoirs in the Gulf Coast to determine the characteristic slopes of the p/z plots. They rewrote the gas law equation for a superpressured gas reservoir (gas/aqifer reservoir) in a generalized form with additional coefficients included the fluid and rock compressibility changes with pressure and gas liberating from solution. The p/z plot calculated by the generalized model departs from a straight line, and curves downwards depending on the compressibilities and aquifer size. The generalized equation can be solved analytically or with numerical computer methods to fit both the shape and position of the decline data.

In 1987, Ambastha and Aziz[11] used a reservoir simulator for studying the phenomena of gas percolation and gravity segregation, and their effects on reservoir performances. The comparison of their simulation results with the Tarner's method shows that the latter predicts faster reservoir pressure and oil saturation decline, and thus, underpredicts the reservoir producing life and recovery. They proposed new material balance method to predict the performance of thick, homogeneous, depletion-drive reservoirs. Their method accounts for the vertical pressure and saturation gradients, and the secondary gas cap. The thickness of the secondary gas cap can be estimated with good accuracy using an idealized saturation profile. The idealized saturation profile is also used to develop pseudo-functions to simplify the simulation of solution-gas-drive reservoir with gravity segregation.

King[12] presented his paper in 1990 about the development of two material balance methods for unconventional gas reservoirs. One method is appropriate for estimating GIIP while the second is appropriate for making future reservoir predictions. These techniques differ from the material balance methods for conventional gas reservoirs, in that, the effects of adsorbed gas are included. Both methods were developed using the assumptions traditionally associated with the material balance approach. For estimating GIIP, the additional assumption of equilibrium between the free and adsorbed gas phases is required (i.e., gas desorption is assumed to be strictly pressure dependent).

In 1991, Humphreys[13] developed a modified form of the material balance equation for a hot and high-pressured gas-condensate reservoir by accounting for water vaporization effects. Failure to account for them can result in erroneous predictions of GIIP, and hence reserves. It may also lead to incorrect identification of reservoir drive mechanisms.

In 1991, Gilicz[14] analyzed different forms of the material balance and gave highlights of advantages and drawbacks of them. According to one of the main conclusions of Tehrani[15] that before applying the material balance equation it is not recommended to transform it into the form of a straight line as severe calculation errors can be introduced into the calculations, it is recommended to use the material balance in a form of a plane because this gives the high resolving power. The drawback of this treatment, however, is that it does not provide the useful graphic abilities as does the Havlena-Odeh method.

Fetkovich and Reese[16] presented a paper in 1991 about a derivation of a general gas material balance that has particular application to high-pressured gas reservoirs. The material balance is valid for both normal-pressured and over-pressured (geo-pressured) reservoirs. Its main application is to calculate GIIP and assist in calculating remaining recoverable gas from pressure-production data. High-pressured gas reservoirs typically have curved p/z plots (concave downward). Incorrect extrapolation of early data may result in serious overestimation of GIIP and remaining recoverable gas. The proposed form of the gas material balance equation provides a method to linearize the p/z plot and thereby predict the true GIIP. A method is suggested to determine GIIP by analyzing the behavior of cumulative effective compressibility backcalculated from pressure-production data.

Fetkovich and Reese also showed that the effect of pore collapse on high-pressured gas reservoirs was generally positive, providing additional pressure support. There is not a clear discontinuity in the behavior of p/z-Gp where pore collapse occurs, and pore collapse tends to flatten a p/z-Gp curve at lower pressures. The proposed gas material balance by Fetkovich and Reese is applicable to any high pressure gas reservoir with an appreciable volume of associated water.

In 1992, Alvarado, *et al.*[17] generated a new and improved material balance method by which the original dry gas in place and the original condensate in place can be calculated for a retrograde gas condensate reservoir. This new material balance equation (MBE) is a result of theoretical research that is validated using experimental data. Ultimate validation of the new equation can be made with field cases by using a laboratory B_c (condensate formation volume factor). The new MBE requires a modified PVT procedure to determine B_c. This variable is currently rarely in use in the industry and hence is rarely being measured in current PVT lab procedures. A basic assumption in the new MBE is that no reservoir condensate is produced. Additionally, the new MBE assumes normal pressure, volumetric conditions, and existence of the reservoir at the dew point. After the validation of the new MBE (basic equations), Alvarado, *et al.* made modifications to accommodate water influx and rock and water compressibilities.

In 1993, Hwan[18]resented a new material balance calculation by coupling a statistics based history matching program with a material balance program. The procedure is to match the historical reservoir pressure data with the calculated pressures obtained from the material balance program. The combination of the history matching and material balance programs was proved to be a simple and powerful tool for material balance calculations. This is because the new procedure is based on the pressure match method which is known to be applicable to all types of reservoirs (i.e., oil or gas reservoir with or without gas cap and/or aquifer) with accurate results. The obtained results from the new material balance calculations are comparable to or better than those of using the material balance program alone. Moreover, the matches were obtained in only a few number of runs.

West and Cochrane[19] presented their paper in 1994 about the merit of two new methods of reserve evaluation which address problems generally occurred for tight shallow gas reservoirs. The first method applies type curve matching which combines the analytical pressure solutions of the diffusivity equation (transient) with the empirical decline equation. The second method is an extended material balance which incorporates the gas deliverability theory to allow the selection of appropriate p/z derivatives without relying on pressure data.

In 1994, Sills[20] presented an improved material balance formulation for determining original hydrocarbon-in-place in water-drive oil and gas reservoirs. The improved formulation reduces the number of unknowns in the regression analysis through the definition of a combined reservoir and aquifer expansion term (CET). It can be concluded from the Sills'study that the CET material balance formulation provides several advantages over existing regression analysis techniques.

In 1996, Payne[21] presented his paper about material-balance calculations in tight-gas reservoirs. He mentioned that the basic tank assumption(used for the straight-line p/z plot) which reservoir pressure gradients are small can be violated, even with long shut-in period. It was also demonstrated that a reasonably straight-line p/z decline did not necessarily indicate that the reservoir behaved as a tank. The communicating reservoir(CR) model was presented as a simple, yet much more accurate, method of performing material-balance calculations in tight reservoirs. The results of the application of the CR model to the Waterton gas field were used to illustrate the success and large impact that could be obtained by examining the pressure behavior more closely than simply plotting p/z.

From all above studies, it is found that nobody has fully studied the topic of GIIP and reserves evaluation for single- and multi-layered gas reservoirs by using material balance methods. Therefore, it is decided, for this study, to investigate this topic in detail.