CHAPTER - 2

LITERATURE SURVEY

CHAPTER - II

2. LITERATURE SURVEY

In this chapter a critical review of the literature published on multiphase flow through chokes is presented. Since choke can be installed either at the wellhead or at the end of the tubing string, the survey includes the studies on subsurface safety valves and bottomhole chokes. Studies on choke size selection and multiphase vertical flow correlation employed in oil industry have also been reviewed. As the objective includes the study of commingling flow using bottomhole chokes, investigations on commingling flow have also been incorporated.

2.1 MULTIPHASE FLOW THROUGH CHOKES

The published literature on multiphase flow through chokes is divided into two groups for the purpose of comparison. One, theoretical correlation which consider the physical properties of fluids and the other, empirical correlation which do not consider the physical properties of fluids.

2.1.1 THEORETICAL CORRELATIONS

Most of the published literature on two phase flow through chokes are for critical flow because of the extensive use of chokes at critical flow conditions. Very few studies in sub-critical and critical-subcritical boundary regimes have been reported in the literature. The first theoretical development in the area was published by Tangren and co-workers [(1)] in 1949. They developed equations for the prediction of surface choke performance based on basic fluid mechanics principles assuming liquid to be incompressible, gas to be ideal with no mass transfer between phases. The study mainly deals with critical flow through a converging -diverging nozzle.

Gilbert [2] extended the work of Tangren assuming the liquid phase to be homogeneously dispersed as droplets in a continuous gas phase. He agreed with Tangren's assumption of uniform velocity at the throat. His assumptions include polytropic gas expansion and negligible potential energy differences. He postulated that mist flow occurs at the entry of the choke and the slippage at the end of the choke throat can be neglected, and wall friction can be ignored if the length of the choke is short.

Ros [3] reported equations for the prediction of flow rate through chokes. Poettmann and Beck [4] modified the Ros equations in terms of oilfield units. This equation is only for critical flow and independent of choke downstream pressure. The equation is expressed in terms of liquid rate as a function of choke size, gas liquid ratio, and fluid physical properties. The equation is given below

$$q^{*}_{L} = \frac{86400\, A_c\, C_d}{\rho_m} \; \frac{9273.6\; P_1}{V_L\left(1+0.5\,\rho_{mL}\right)} \; \frac{0.4513\,R \;+\; 0.7660}{\left(R+0.5663\right)} \qquad \text{..................(2.1)}$$

where

$$\rho_m = 5.614\,\rho_{Lsc} \;+\; 0.0765\,\rho_g\, R_p \qquad \text{....................(2.1a)}$$

$$R = \frac{0.0504\; T_1\; Z_1\; \left(R_p \;-R_{s1}\right)}{P_1\; B_{o1}} \qquad \text{....................(2.1b)}$$

$$R = \frac{v_{sg1}}{v_{sL1}} \qquad \text{....................(2.1c)}$$

$$m_L = \frac{1}{\left(1+R\left(\rho_{g1}/\rho_{L1}\right)\right)} \qquad \text{....................(2.1d)}$$

$$v_L = \frac{m_L}{\rho_{L1}} \qquad \text{....................(2.1e)}$$

Using equation (2.1) and an empirical correlation for determining R_{s1} and B_{o1}, Poettmann and Beck[4] generated working nomographs for pure crude oil gravities of 20, 30 and 40 degrees API. A gas gravity of 0.6 and temperature of 85 degrees Fahrenheit were assumed in constructing the charts. They compared the field measured oil production rates with the chart results for 108 tests covering a wide range of choke sizes and upstream pressures. They reported that the charts predicted the production data with a mean error of +6.5% and a standard deviation of 26.4%.

Fortunati [5] developed correlation for both critical and sub-critical flow and the boundary between these regimes assuming no slippage between phases. He also pointed out that there will be no slippage only when the mixture velocity is greater than 10 m/sec. (32.78 ft/sec.) and the Froude number of the mixture is greater than 600. He presented the following equation for flow rate prediction :

$$q_L = A\,B\left(1-\lambda_{g2}\right) C_d\, v_{m2f}\, \frac{P_2}{P_{2f}} \qquad \text{....................(2.2)}$$

Where

$$n = \left(1-\lambda_{g2}{}^{3}\right)^{0\,38} \qquad \text{....................(2.2a)}$$

$$v_{m2} = v_{m2f} \left({P_2}/{P_{2f}} \right)^n \qquad \text{.....................(2.2b)}$$

The flow coefficient (C_d) suggested by Fortunati was unity for critical flow and for sub-critical flow from 1.020 to 1.035 depending upon the choke size. His model is valid if the choke downstream pressure exceeds 1.5 atmosphere (152 kpa). The properties of the fluid were calculated at downstream conditions.

Fortunati[5] also stated that sonic or critical flow occurs only when the Mach number is greater than one. He presented the following equation for critical velocity

$$v^* = \left(144\, k\, P_g / \lambda_g\, \rho_n\right) \qquad \text{.....................(2.2c)}$$

$$\text{Where } k = \frac{\left((1-X)\, C_{vL} + C_{pg}\right)}{\left((1-X)\, C_{vL} + XC_{vg}\right)} \qquad \text{.....................(2.2d)}$$

Ashford [6] presented a study for critical flow through choke beans extending the work of Ros [3]. Assumptions made in developing the correlation are

a) Polytropic expansion of gas phase.

b) Critical pressure ratio of 0.547 and

c) Discharge co-efficient of 1.04

The equation reported by him is

$$q = \frac{0.858\, C\, \beta\, d_c^2}{A/P_1 + 0.56} \; \frac{\left(A + 0.76\, P_1\right)}{\left(B + 0.01353\rho_g R_p\right)^2 \left(B + 0.01353\rho_g R_s\right)^{-1}} \qquad \text{.....................(2.3)}$$

Where

$$A = 5.04 \times 10^{-3} \quad T_1 Z_1 \left(R_p - R_s\right) \qquad \text{.....................(2.3a)}$$

$$B = 62.4 \left(\rho_{osc} + \rho_{wsc}(WOR)\right) \qquad \text{.....................(2.3b)}$$

$$\beta = \frac{1}{\left(B_o + (WOR)\right)} \qquad \text{.....................(2.3c)}$$

Using field data from 14 flowing well tests he calculated discharge co-efficient necessary to predict the production data from these wells. The calculated discharge co-efficient varies from 0.765 to 1.218 for choke sizes 16/64 inch to 40/64 inch.

A thorough analysis on two phase flow measurements with orifices was published by Murdock [7] in 1962. He developed an equation based on a highly idealized model of two phase flow. His assumptions include negligible slip between phases, a coefficient of contraction of 1.0, frictionless flow and total incompressibility of both the phases.

Ashford and Pierce [8] developed a model for subcritical flow through subsurface safety valves assuming the following :-

- **the gas expansion through choke is polytropic.**
- **flow through the choke is frictionless adiabatic.**
- **there is no slippage between gas and liquid phases and**
- **liquid is incompressible.**

The model developed by them is,

$$q_0 = C_d \; 3.51 \, d_c^{\,2} \; \alpha_{10} \; B_{10} \qquad \text{....................(2.4)}$$

Where

$$\alpha_{10} = \left(B_o + Fwo\right)^{-0.5} \qquad \text{.....................(2.4a)}$$

$$B_{10} = \frac{(n/n-1)T_1Z_1(R-R_s)(1-E)^{(n/n-1)} + 198.6P_1(1-E)}{(198.6+T_1Z_1(R-R_s)E)^{-1/n}} \frac{(\rho_o + 0.000217\rho_g R_s + F_{wo}\rho_w)}{(\rho_o + 0.000217\rho_g R + F_{wo}\rho_w)}$$

....................(2.4b)

The experiments were conducted using OTIS 22 J037 safety valve fitted with 14/64, 16/64 and 20/64 inch chokes cover the following range of variables.

Flow rate	**- 334 - 559 Bbls/day**
Gas Liquid Ratio	**- 429 - 478 (V/V)**
Upstream pressure	**- 1161 - 1226 psi**

They have suggested different discharge coefficients for different orifice sizes as given below :

Orifice size (inch)	**Discharge Co-efficient (C_d)**
8/64	**1.20**
12/64	**1.20**
14/64	**1.1510**
16/64	**1.0564**
20/64	**0.9760**
24/64	**0.95**
32/64	**0.95**

They claimed that the flow rate calculated using their equation will be within 15 to 20 % error.

Gould [9] plotted Fortunati's curve using Ashford's approach for comparing the critical pressure ratio for different specific heat ratios, k and showed that different values of polytropic exponent yield different boundaries.

Wallis [10] showed that the sonic velocity of a homogeneous mixture passes through a minimum at $\lambda g = 0.5$ and reported the following equation for critical velocity.

$$v^* = \left(\left(\lambda_g \rho_g + \lambda_L \rho_L\right)^2 \left(\left(\frac{\lambda_g}{\rho_g V_{g'}}\right) + \left(\frac{\lambda_L}{\rho_L v_{L'}}\right) \right) \right) \qquad \text{......................(2.5)}$$

API 14B [11] presents algorithms for calculating the following :

a) Pressure drop across a choke for a given flow rate and downstream pressure.

b) Pressure drop across a choke for a given flow rate and upstream pressure.

c) Choke diameter to yield a desired pressure drop for a given flow rate and upstream pressure for sizing of subsurface safety valves.

Beggs and coworkers [12] have presented an improved technique for predicting subcritical pressure drop across velocity controlled subsurface safety valves OTIS J and Camco A-3.

Omana [13] conducted experiments on flow through surface chokes with carefully controlled flow tests covering the following range of variables :

Upstream Pressure	: 400 - 1000 psig
Downstream Pressure	: 300 - 900 psig
Choke size	: 4,6,8,10,12 and 14/64 inch
Gas flow rate	: 0-7 MMScf/D (0.611 gas gravity)
Liquid flow rate	: 0 - 800 STB/D (water)

Dimensional analysis was made that yielded eight dimensionless groups. Liquid holdup was not considered since it was not measured. A multiple regression analysis was made that yielded the following empirical correlation for critical flow involving five dimensionless groups.

$$N_{qL} = 0.263\, N_{\rho}^{-3.49}\, N_{p1}^{3.19}\, Q_{d}^{0.657}\, N_{d}^{1.8} \qquad \text{.....................(2.6)}$$

Where

$$N_{d} = 120.872\, d \left(\frac{\rho_L}{\sigma_L}\right)^{0.5} \qquad \text{.....................(2.6a)}$$

$$N_{\rho} = 1.84\, q_L \left(\frac{\rho_L}{\sigma_L}\right)^{1.25} \qquad \text{.....................(2.6b)}$$

$$\mathbf{N_{p1} = 1.74 \times 10^{4}\ P_1} \left(\frac{1}{\rho_{L1}\,\sigma_{L1}}\right)^{0.5} \qquad \text{.....................(2.6c)}$$

$$\mathbf{Q_d} = \frac{1}{(1+R)} \qquad \text{.....................(2.6d)}$$

$$\mathbf{R} = \frac{N_{gv}}{N_{Lv}} \qquad \text{.....................(2.6e)}$$

$$\mathbf{R} = \frac{v_{sg1}}{v_{sL1}} \qquad \text{.....................(2.6f)}$$

$$N_{\rho} = \frac{R_g}{\rho_L} \qquad \text{.....................(2.6g)}$$

It is reported that when the volumetric gas liquid ratio (R) is less than or equal to one, the deviation observed was more than 10 percent irrespective of the pressure ratio employed. The effect of viscosity number did not correlate with other independent groups. He arbitrarily deemed the flow to be critical when the ratio of downstream to upstream is less than 0.546 and when superficial gas velocity exceeds the superficial liquid velocity.

Using his critical flow data Omana compared his correlation with those of Poettmann and Beck[4] and Gilbert [2]. He reported that Gilbert correlation predicted the two phase flow data with a deviation of 64 percent and Poettmann and Beck with a deviation of 36.20 percent whereas his correlation best predicted the results with a deviation of 14.98 percent.

He also reported the following limitations of his correlation :

Pressure	: 400 - 1000 psig.
Flow rate	: 800 B/D max.
Choke size	: 4/64 to 14/64".

He claimed that his correlation can be used in sizing small surface as well as bottomhole chokes.

Sachdeva [14] conducted experiments using kerosene-water and air and gathered data for 223 critical, 220 subcritical and 110 boundary regimes for five choke sizes: 16,20,24,28 and 32/64 inch. He presented the following equations for calculating the flow rate through a choke

$$G_2 = C_d \left(2 g_c \, 144 \, P_1 \, \rho_{m2} \left(\frac{(1-x_1)(1-y)}{r_L} + \frac{x_1 \, k}{k-1} \left(V_{g1} - y V_{g2} \right) \right) \right) \quad \text{.....................(2.7)}$$

Where

$$G_2 = \frac{M_{g2} - M_{L2}}{A_c} \qquad \text{......................(2.7a)}$$

$$V_{g2} = V_{g1}\, y^{\frac{-1}{k}} \qquad \text{......................(2.7b)}$$

$$\frac{1}{\rho_{m2}} = x_1 V_{g1}\, y^{\frac{-1}{k}} + (1 - x_L) V_L \left(\frac{k}{k-1}\right) + \frac{(1 - x_1) V_1 (1 - y)}{x_1 V_{g1}} \qquad \text{............(2.7c)}$$

$$Y_c = \left[\frac{\left(\frac{k}{k+1}\right) + \frac{(1-x_1)V_1(1-y)}{x_1 V_{g1}}}{\left(\frac{k}{k-1}\right) + \frac{n}{2} + \frac{n(1-x_1)V_L}{x_1 V_{g2}} + \frac{n}{2}\left(\frac{(1-x_1) V_L}{x_1 V_{g2}}\right)^2}\right]^{\left(\frac{k}{k+1}\right)} \qquad \text{...................(2.7d)}$$

$$Y = \frac{P_2}{P_1} \qquad \text{......................(2.7e)}$$

When $Y_c \le Y_{actual}$, critical flow exists

When $Y_{actual} > Y_c$, subcritical flow exists.

The experiments cover the following range of variables

Mass flow rate	**- 1340 Bbls/day**
Maximum gas rate	**- 136.6 Mscf/day**
Maximum pressure	**- 105.5 psi**
Choke size	**- 16/64 - 32/64"**

Based on the experimental data he concluded that his model predicts the flow rate better than the other existing models. He recommended that the discharge coefficient of 0.75 for elbow type chokes and 0.85 for the chokes where there is no elbow.

In 1990, Perkins[15] published a model developed based on the basic thermodynamic principles assuming at any point in the system :

a) all phases are at the same temperature.

b) all components are moving in the same velocity.

c) the liquids have negligible compressibility compared to gas.

d) the flow process is adiabatic and frictionless.

The following is the model presented by him :-

$$W_t = \frac{A_2 v_2}{\left(f_g V_2 + \frac{f_o}{\rho_o} + \frac{f_w}{\rho_w}\right)} \qquad \text{.....................(2.8)}$$

Where

$$V_2^2 = \frac{\left(288 g_c \left(\lambda P_1 V_1 \left(1 - P_r^{(n-1)/n}\right)\right) + \left(\frac{f_0}{\rho_o} + \frac{f_w}{\rho_w}\right) P_1 \left(1 - P_r\right)\right)}{\left(1 - \frac{A_2}{A_1}\right)^2 \left(\frac{f_g + \alpha_1}{f_g P_r^{-1/n} + A_1}\right)^2} \qquad \text{.....................(2.8a)}$$

$$P_r = \frac{P_2}{P_1} \qquad \text{.....................(2.8b)}$$

$$P_1 V_1^n = P_2 V_2^n \qquad \text{.....................(2.8c)}$$

$$\left(1-\frac{A_2}{A_1}\right)\left(\frac{f_g+a_1}{f_gP^{-1/n}+a_1}\right)^2\left(f_gP_r^{-1/n}+a_1\right)\left(\lambda\,\frac{n-1}{n}\,P_r^{-1/n}\;+\;a_1\right)=\left(2\lambda\left(1-P_r^{(-1+n)/n}\right)\right)+$$

$$2a_1\left(1-P_r\right)\left(1-\left(\frac{A_2}{A_1}\right)^2\right)\left(\frac{f_g+a_1}{\left(f_gP_r^{-1/n}+a_1\right)^2}\right)\left(f_gP_r^{-(1+n)/n}\right)\;+$$

$$\left(\frac{A_2}{A_1}\right)\frac{f_g}{n}\left(\frac{\left(f_g+a_1\right)^2P_r^{-(1+n)/n}}{\left(f_gP_r^{-1/n}+a_1\right)^2}\right) \qquad \text{.....................(2.8d)}$$

$$n \;=\; \frac{f_g\,k\,C_{vg}\;+\;f_o\,C_{vo}\,f_w\,C_{vw}}{f_g\,C_{vg}+f_o\,C_{vo}+f_w\,C_{vw}} \qquad \text{.....................(2.8e)}$$

$$a_1 \;=\; \frac{1}{V_1\left(\dfrac{f_o}{\rho_o}+\dfrac{f_w}{\rho_w}\right)} \qquad \text{.....................(2.8f)}$$

He also presented a computer based methodology to calculate the flow rate through a given choke size when upstream conditions and physical properties of fluids are known. He analyzed 1432 sets of literature data comprising both critical and sub-critical flow and suggested a best average value of 0.826 for discharge co-efficient.

2.1.2 EMPIRICAL CORRELATIONS

In addition to the above theoretical approaches, numerous empirical equations to calculate Tubing head pressure also exist. Gilbert [(2)] derived an empirical equation from the simplest equation for pressure drop across the choke given by

$$\Delta P = C \frac{q'_L \sqrt{R}}{A_c} \qquad \text{.....................(2.9)}$$

He arrived at the following equation

$$P_{tf} = C \frac{q'_L \sqrt{R}}{d_c^2} \qquad \text{.....................(2.10)}$$

where C is a constant whose value depends on the units of P_{tf}, q'_L, R and d_c.

He found that the equation (2.10) gave larger deviations compared to other models. Hence, he modified the exponents of this equation to fit his experimental data and reported the following form of equation.

$$P_{tf} = \frac{A\, q'_L\, R^B}{d_c^C} \qquad \text{.....................(2.11)}$$

Where P_{tf} **= tubing head pressure in psi.**
q_L **= liquid flow rate bbls/day.**
R = gas liquid ratio scf/bbl.
d_c **= choke diameter 1/64 th of an inch.**

Ros [3] and Mach [16] have developed variations of the equation proposed by Gilbert[2] to match with their test results. Sachdeva[14] presented equations developed by Pilhevari and Baxendell in his comparative study while Kermit. E. Brown [17] in his book presented the equation developed by Achong. The following table shows the values of A, B and C in Gilbert equation suggested by various investigators.

Correlation	A	B	C
Gilbert	10.00	0.546	1.84
Ros	17.40	0.500	2.00
Baxendell	09.56	0.546	1.93
Achong	03.82	0.650	1.88
Mach	15.81	0.500	2.00
Pilehvari	46.67	0.313	2.11

A1-Attar[18], Abdul-Majeed [19], Surbey [20], Josip [21], Osman and Dokla [22], James [23], Henry and Fauske [24], Moody [25], Starkman [26], Baker [27] and Surbey and coworkers [28] conducted studies on two phase flow through chokes and suggested various equations depending upon the experimental results or based on the particular field production data.

2.2. SYSTEM ANALYSIS - CHOKE SIZE SELECTION

The pressure drop across the choke is substantial when the flow through the choke is critical. When the choke is placed at the bottom of the tubing string (bottomhole choke) it is very important to calculate the down stream pressure of the choke and the pressure drop in the tubing string so as to find out the tubing head pressure. Consequently it requires a complete system analysis for selecting an optimum choke size for a particular well conditions.

The objective of the system analysis is to combine various components of the oil or gas well in order to predict optimum flow rates and to optimize the various components in the system. An approach was discussed by Mach, Proano and Brown [29] . This approach analyses the complete well system from the outer boundary of the reservoir to the sand face, across the perforation and completion section to the tubing intake, up the tubing string including any restrictions and downhole safety valves, the surface choke, the flow line and separator.

Brown and Beggs [17] discussed two types of solution procedures, one starting node from the top of the well and the other from bottom of the well.

Employing system analysis approach API - 14 B [30] presents design of subsurface safety valves and Beggs [31] and Brown [32] presented a design procedure for the velocity operated subsurface safety valves. For calculating the pressure drop across the subsurface safety valve, they adopted the recommendations of Beggs and Brill[33] .

2.3 VERTICAL FLOW CORRELATIONS

Many correlations for predicting the pressure drop in vertical and inclined conduits have been reported in the literature. Among them the well known correlations in the oil industry are Poettmann and Carpenter [34] , Duns and Ros [35] , Baxendell and Thomas [36] , Fancher and Brown [37] , Hagedorn and Brown [38] , Orkiszewaski [39] , Beggs and Brill [40] , Aziz and coworkers [41] and Chierici and coworkers [42] . A comparative study of these models has been done by Lawson and Brill [43] , and Browne [44] . Lawson and Brill tested these correlations using 427 field trial test data and reported that the Hagedorn and Brown correlation best predicted the pressure drop. The average percent error and standard deviation obtained by them are -1.3 and 26.1 for Hagedorn and Brown, -17.8 and 27.6 for Beggs and Brill and - 8.6 and 35.7 for Orikiszewski models respectively. A comparison of multiphase flow correlation with measured data of vertical and deviated oil wells of India was

done by Rai [45]. He also reported that the correlation of Hagedorn and Brown and Orkiszewski performed well among the existing correlations.But the correlation reported by Hagedorn and Brown takes into account the slip between the phases but does not consider the flow regimes.

2.4 COMMINGLING FLOW

Commingling reservoirs can be divided into two groups one layered reservoir with cross flow, in which layers hydrodynamically communicate with each other at the contact planes and the other, layered reservoir without cross flow, in which layers communicate only through well bore. Initially, the interpretation of the pressure buildup data for a layered reservoir was made using the method adopted for a single homogeneous reservoir. The three most common graphical techniques used to interpret pressure buildup behavior in a single homogeneous layer are the methods of Muskat[46,47],Miller-Dyes-Hutchinson [48] and Hornor [49]. Ramey and Cobb [50] reviewed the methods adopted for the interpretation of pressure buildup data and also presented a method for the interpretation of fractured reservoirs. In recent years many authors including Gringarton [51], Earlougher [52], Cino-L [53,54], Prijambodo [55], Bilhartz [56], and Streltsova [57,58] conducted studies on wells with commingled fluid production from two or more non-communicating zones. Lefkovits and coworkers [59] presented identical rigorous solutions that describe the pressure behavior of a constant-termina-rate well producing from a bounded, non-communicating multilayer reservoir with similar properties. Both Lofkovits and coworkers and Papadopulos [60] have presented pressure behavior of infinitely large multilayer reservoirs.

Mathews [61], Lefkovits [62], Kazemi [63] and Russel [64] reported that the earlytime pressure drawdown of a multilayerd reservoir system with or without cross flow yields a straight line on the semilog pressure build up plot. Raghavan and coworkers [65] presented a technique for estimating the Kh ratio between layers for a single well in the center of a circular two layer commingled reservoir. The method

requires relatively long production time and buildup data be taken through final pressure rise. Cobb [66] , and Earlougher [67] reported methods to estimate average reservoir pressure from buildup tests in commingled systems. Woods [68] has studied the pulse test behavior in a two layer system. His studies include commingled case, the full communication case and intermediate situations. He showed how a combination of a single well tests, pulse tests and flow meter survey may be used to estimate individual zone properties for two layer reservoirs with communication only at the well bore. He derived the following conclusions from the pulse test :

a) Apparent kh/μ is always equal or greater than actual total kh/μ for the reservoir.

b) Apparent kh/μ is always equal or less than total kh/μ for the reservoir.

c) The deviation of apparent values from the actual total values depends on the pulse duration.

d) When wells are undamaged or have uniform damage, the ratio of flow rates into the zones is a good estimation of kh/μ of the zones for non-communicating systems. The estimate is actually valid within +15% when the zones are partially communicating.

The transmitivity, diffusivity and skin factor for each layer can be different. The models used to estimate the pressure behavior of the system usually assume that the properties of each layer are constant, gravity effects are ignored and thereby identical well bore pressure for all zones.

It has been reported by the authors Dolan [69] , Ramey [70] and Hornor [71] that although the model is simple one, it predicts the results within 0.01% error.

2.5 CRITICAL REVIEW

2.5.1 PERFORMANCE OF SURFACE CHOKE

The literature survey reveals that though many theoretical correlation are available in this literature for the prediction of flow rate through chokes, only a few of them are strictly for the critical flow. They are

1. **Poetmann and Beck**
2. **Ashford**
3. **Omana**
4. **Ashford and Pierce**
5. **Sachdeva**
6. **Perkins**

The correlation developed by Poetmann and Beck[4] considers the physical properties of fluids but it is mainly based on the slip velocities. Also it gives a mean error of +6.5% and a standard deviation of 26.4 %. But Watson proved that there will be no slippage when the mixture velocity is greater than 32.78 ft/sec and the Froude number is greater than 600. However, at critical flow the velocity will be more than 32.78 ft/sec. Ashford[6] assumed in developing his model that the critical pressure ratio of 0.547 and he found that the discharge coefficient varies from 0.765 to 1.218 for choke sizes ranging from 16/64 inch to 40/64 inch.

The model developed by Omana[13] is based on dimensional analysis. It also assumes that the critical pressure ratio is 0.546 and covers the choke sizes from 4/64 inch to 14/64 inch and flow rate upto 800 bbls/day.

Ashford and Pierce[8] developed the model based on the experiments conducted in flowing oil wells through OTIS 22 J037 subsurface safety valve covering only 14/64 inch, 16/64 inch and 20/64 inch choke sizes, upstream pressure of 1161 to 1226 psi, and flow rate 334 to 559 bbls/day.

The model developed by Sachdeva[14] was tested with the experiments conducted on air-water-kerosene covering choke sizes of 16/64 inch to 32/64 inch, flow rate upto 1340 bbls/day and maximum pressure of 105.5 psi. Whereas Perkins[15] model is based on thermodynamic principles. He tried to calculate the k value using heat capacities of components which is complicated.

The critical review of literature shows that the existing models do not cover all the range of data and show large deviation while predicting the experimental data. There is a need for developing a theoretical model which can give better prediction over a wide range of production parameters.

The literature survey further reveals that all the empirical correlation are of the form suggested by Gilbert[2] but the coefficient and exponents are modified to fit individual field data. Hence, there is also a possibility of deriving an empirical correlation to fit the field production data from Gandhar field.

2.5.2 PERFORMANCE OF BOTTOMHOLE CHOKE

No systematic study has been reported on performance of bottomhole choke and the applicability of the existing models for predicting the performance of bottomhole choke has not been established.

2.5.3 COMMINGLING FLOW

The latest model for commingling system developed by Woods[69] in 1970 deals with the well test analysis of the two layered commingling system. The method employed by him does not deal with the performance of production but only deals with the interpretation of well test analysis of commingled system. It also does not permit the optimized oil production from each zone and there is no control of flow from individual zones. Further, this type of commingling can not be applied when the distance between the zones is high and the zones have different reservoir characteristics.