SUMMARY AND CONCLUSIONS

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In the year 1984, an oil field has been discovered at Gandhar in the Cambay basin of Gujarat state. This was considered to be a major discovery in the last decade. Studies carried out in this field revealed that the reservoir is a multilayered one having thirteen sands of interest out of which seven are proved to be major oil/gas producers.

To exploit the hydrocarbon reserves from this field, various completion techniques were tried. In the process it was observed that the existing correlations showed a large deviation in predicting the performance of the choke that is one of the critical components of a well completion system. Most of the literature reported on the performance of chokes mainly deal with critical flow through surface chokes and some investigations have also been reported on subcritical flow through chokes. But very little work has been done on the performance of bottomhole choke. Further, in view of the multilayered nature of the reservoir, it is thought possible to produce more than one zone through a single tubing-string using bottomhole chokes.

The present investigation was undertaken with the following objectives :

- **To suggest a suitable empirical correlations for the performance of surface choke by conducting field trial tests.**
- **To develop a theoretical model for multiphase flow through chokes and test the same with the data obtained from the field trial tests.**
- **To test the applicability of the theoretical and empirical models developed for predicting the performance of bottomhole chokes.**
- **To suggest a bottomhole choke size selection procedure with the help of employing system analysis.**
- **To study the performance of commingling production using bottomhole chokes and**
- **To develop a procedure for choke size selection for commingling flow.**

The thesis is presented in six chapters.

Chapter I is devoted to the introduction and description of Gandhar reservoir.

In Chapter II, a comprehensive review of various correlations available for predicting the performance of chokes in oil and gas production is presented. It was observed that most of the correlations deal with critical flow through surface chokes. Only some information is available for sizing the choke in the subsurface safety valves and little information is available on the performance of bottomhole chokes. A few investigations have also been reported on subcritical flow through chokes. Many of the correlations are based on data obtained using air-water, air-water-kerosene as fluids. Further, it was observed that the existing models have been developed for a very low gas liquid ratio.

Chapter III deals with the development of a theoretical model for multiphase flow through a choke. The assumptions made in developing the theoretical model are :

- **Isentropic frictionless flow**
- **The liquid is dispersed in the continuous gas phase**
- **One dimensional flow**
- **Liquid phase is incompressible**

The model is developed equating the expression relating fluid specific volume and velocity to the mass flow rate and an equation relating the specific volume of the fluid with pressure and temperature.

The theoretical model developed is given by the following equation:--

$$Q = (184648.26)\frac{C_d\, A_c \left[k\left(\frac{2}{k+1}\right)^{\left(\frac{k+1}{k-1}\right)} g_c\, P_{tf}\, A\, B(1+C)\right]^{0.5}}{A(B+C)} \qquad \text{.............(1)}$$

Where

$$A = \rho_o + \frac{\rho_g R_s}{5.615} + F_{wo}\rho_w$$

$$B = B_o + F_{wo}$$

$$C = \frac{(R_p - R_s)}{5.615} + \frac{P_{sc}}{144T_{sc}}\frac{T_1 Z_1}{P_{tf}}$$

Chapter IV is devoted to studies on the performance of surface choke system. Techniques and procedures adopted for the field trial tests are described. The theoretical correlations developed in the present work as given by equation (1) has been tested using the surface choke data obtained from field trial tests. A discharge coefficient of 0.758 has been found to best predict the field trial test data. The statistical accuracy in predicting the flow rate through surface choke by various theoretical correlations along with the present model given by equation (1) are as follows:

Correlations	Average Relative Percent error	Standard deviation	Correlations coefficient
Omana	-76.69	203.64	0.9120
Ashford	-16.98	36.01	0.9973
Sachdeva	39.56	46.18	0.9908
Poettmann & Beck	-5.09	61.54	0.9927
Ashford and Pierce	14.76	90.71	0.9717
Perkins	-30.48	193.28	0.9670
Present	19.90	25.20	0.9983

It can be seen that the present theoretical model predicts the field trial test data better than other existing theoretical models. Further, equation (1) has also been tested with the experimental data reported by Omana and field data reported by Ashford and Pierce and the standard deviations obtained are 27.66 and 33.47 respectively.

Apart from these theoretical models, many empirical models are available for predicting the performance of surface chokes. These empirical equations are basically the modifications of the equation suggested by Gilbert. The empirical correlation obtained through regression analysis to fit the field trial test data is given by the following equation :

$$P_{tf} = \frac{17.125\, q_L'\, R^{0.5}}{d_c^{\,2}} \qquad \text{.......................(2)}$$

where, P_{tf} = **Tubinghead pressure, psi.**

q_L' = **Liquid flow rate, Bbls/day.**

R = **Gas Liquid Ratio, Scf/bbl.**

d_c = **Choke diameter,** $\frac{1}{64}$ **inch.**

The statistical accuracy in predicting the Tubinghead pressure by various empirical correlations along with the model given by equation (2) are as follows :-

Correlation	Average Relative percent error	Standard deviation	Correlation coefficients
Pilvehari	-54.07	55.22	0.9636
Gilbert	14.33	16.28	0.9966
Mach	-7.49	9.50	0.9990
Achong	3.04	14.32	0.9975
Baxendell	-2.10	7.45	0.9993
Ros	1.82	5.75	0.9995
Present	0.89	5.52	0.99998

It can be seen that the present empirical model best predicts the field trial test data.

Chapter V deals with the performance of bottomhole choke. Static bottomhole pressure surveys have been made for calculating the pressure drop per unit mass of oil for both surface and bottomhole choke systems. It has been observed that when the surface choke system is changed to bottomhole choke system, the well requires a minimum of 8 days for stabilization. During this transition period, the gas production is higher than that obtained under stabilized flow conditions. However, under stabilized conditions the gas production through the bottomhole choke was less than that obtained with surface choke. The data obtained from the experiments show that the use of bottomhole chokes in this field resulted in:

- **Increase in oil production**
- **Decrease in gas production**
- **Reduction in surface handling pressures.**

On analysis of the static bottomhole pressure data, it is observed that the pressure declines per ton of oil production with bottomhole choke system is much less when compared to that of surface choke system. In a typical case, the drop in static bottomhole pressure per ton of oil production through 10/64" bottomhole choke is 29.69 x 10^{-5} kg/cm^2 whereas with a 6 mm surface choke, it is 1699 x 10^{-5} kg/cm^2 per ton. While calculating the energy spent in lifting unit mass of oil from the reservoir to the stock tank, it has been observed that the use of bottomhole choke system consumes only 27 to 60 percent of the energy consumed by the surface choke system depending on the reservoir conditions.

The data collected from the experiments have been fitted in the model presented by equation (1). A discharge coefficient of 1.574 best predicts the flow rate through bottomhole choke.

The average percentage errors and standard deviations shown by various existing theoretical models along with the present model are as follows:

Model	**Average Relative percent error**	**Standard deviation**	**Correlations coefficient**
Omana	**-34.79**	**42.34**	**0.9871**
Ashford	**53.34**	**54.01**	**0.9768**
Sachdeva	**-69.90**	**68.87**	**0.9595**
Poettmann & Beck	**69.90**	**68.93**	**0.9596**
Ashford and Pierce	**-77.76**	**79.93**	**0.9457**
Perkins	**-36.52**	**34.69**	**0.9259**
Present	**-4.17**	**14.04**	**0.9984**

It can be seen that the present model best predicts the performance of bottomhole chokes with an average relative percentage error of -4.17, standard deviation of 14.04 and correlations coefficient of 0.9984. The other theoretical models reveal their over or under estimation.

It has already been brought out by Perkins that the empirical correlations generally are valid over range where experimental data were available but may give poor results when extrapolated to new conditions. Hence, equation (2) has been modified to fit the experimental data by adjusting the value of C'. A value of 10.82 has been found to best fit the data. Introducing the value of C' , equation becomes :

$$P_{tf} = \frac{10.82\ q_L^{'}\ R_p^{0.500}}{d_c^{2.000}} \qquad \text{.......................(3)}$$

The data collected from the bottomhole choke experiments have also been fitted in the empirical correlations. The statistical accuracy in predicting the choke upstream pressure (Tubinghead pressure) are as follows:

Correlation	Average Relative percent error	Standard deviation	Correlation coefficient
Pilehvari	-36.49	40.25	0.867
Gilbert	63.01	69.18	0.976
Mach	34.82	40.88	0.939
Achong	53.68	59.11	0.969
Baxendal	41.82	47.31	0.953
Ros	48.38	54.71	0.964
Present	-7.73	14.77	0.9998

It can be seen that all the empirical correlations predict the bottomhole choke data with high relative percent error and standard deviation. This is because these correlations do not consider the physical properties of the fluid.

A method of selecting choke size for a given tubing head pressure is presented adopting system analysis approach. The well starting from the reservoir to the tubing head is considered as a system. Mist flow is assumed in the downstream of the choke because the pressure drop across the bottomhole choke is too high , therefore, the fluid is flashed liberating almost all the solution gas, making the whole stream as liquid dispersed in continuous gas phase. Tests carried out using chokes selected as above showed that the flow rates measured match with the flow rates predicted.

In Chapter VI, a method of commingling flow, that is, flow of more than one zone through a single string obtained by regulating the flow from each zone through a bottomhole choke, is presented. A method of commingling choke size selection for a given well head pressure is also presented. The flow rate predicted by the optimum choke size selection procedure closely matches with the field trial test data.

CONCLUSIONS

1. **The empirical model developed enables the prediction of the performance of the surface choke in oil production from Gandhar field with minimum deviation.**

2. **The theoretical model developed in the present investigation for the prediction of performance of surface choke best predicts the production data with a discharge coefficient of 0.758**

3. **The theoretical model with a discharge coefficient of 1.574 is also able to predict the performance of bottomhole choke with an average percentage error of -4.17 and a standard deviation of 14.04. The difference in the value of discharge coefficient is attributed to the higher pressure, higher solution gas liquid ratio and change in flow pattern in the upstream side of the bottomhole choke.**

4. **The use of bottomhole in Gandhar field resulted in:**
   - **Increase in oil production due to lower gas liquid ratio**
   - **Reduction in surface handling pressures.**
   - **Minimum use of reservoir energy**
   - **a decreased rate of change of static bottomhole pressure**

5. **The model developed for the bottomhole choke size selection enables the prediction of Tubing head pressure for a given well with a reasonable accuracy.**

6. **The use of bottomhole choke enables the production of more than one zone through a single tubing string from a well where only a single well single zone completion is recommended due to the reservoir characteristics.**

7. **It is possible to control the flow rate from each zone in the commingling system of production by choosing proper size of bottomhole chokes.**

8. **The model developed for commingling choke size selection performs well in predicting the Tubing head pressure for a given well.**

9. **The models developed in the present investigation are based on field trial test data, while most of the models available in the literature are based on laboratory experiments with fluids having properties different from reservoir fluids. Therefore, these models are expected to be more dependable.**