RESERVOIR ENGINEERING STUDY OF BAKHRABAD GAS FIELD

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ABSTRACT

Bakhrabad Gas Field is located in the district of Comilla, about 35 km east of Dhaka city. Production from this field started in May 1984. A total of 8 wells were drilled in the five developed sands of this field Two workover wells were put into production experiencing shortened producing life. However, only five wells are still producing from three sands

In the recent years the production of gas from this field declined sharply. Fourteen years of production data have been analyzed using conventional material balance, flowing material balance and reservoir simulation to verify initial gas in place and reserve estimates for the Bakhrabad Gas Field. Four different approaches of the material balance study have led to consistent initial gas in place and reserve estimates for this field. The prediction of future field performances involves the determination of reservoir pressure depletion and offtake rate of gas Efforts have been made to understand the water production behaviour while analyzing the production data of Bakhrabad Gas Field.

This study estimates initial gas in place, recoverable reserves and remaining reserves of Bakhrabad Gas Field

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INTRODUCTION

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Bakhrabad structure was delineated by Pakistan Petroleum Limited (PPL) in 1953 as a gravity anomaly in the predominantly sub-alluvial area. Later in 1966, Pakistan Shell Oil Company Limited (PSOC) confirmed the gravity anomaly as an anticlinal structure using single fold seismic survey. Consequently in 1969 Bakhrabad exploratory well, BK 1 was drilled by PSOC to a depth of 2827 m and proved the presence of reservoir succession as A, B, C, D, F, G, J, K and L Sands, resulting in the discovery of Bakhrabad Gas Field.

In 1971, Bakhrabad Gas Systems Limited (BGSL) was formed to develop, produce and distribute gas from the gas field. In the First Stage Development, work-over and testing of Well BK 1 and the directional drilling and testing of four development wells, BK 2, BK 3, BK 4 and BK 5, were carried out by BGSL during 1980-1982.

In accordance with the commercial viability of the sands the wells, BK 1, BK 2, BK 3, BK 4 and BK 5, were developed and produced from J, D-Lower, G, D-Upper and B Sands, respectively

From June 1987, the Second Stage Development drilling of three directional wells, BK 6, BK 7, and BK 8, was implemented by BGSL to optimise gas production from the J Sand across the field. These wells were drilled from a second surface location, 485 m, N59°30'E from BK 1. All three wells were successfully completed in the J reservoir sands by October 1989 Thus in two stages of development a total of eight wells were drilled in five sands of Bakhrabad Gas Field (Figure 1).

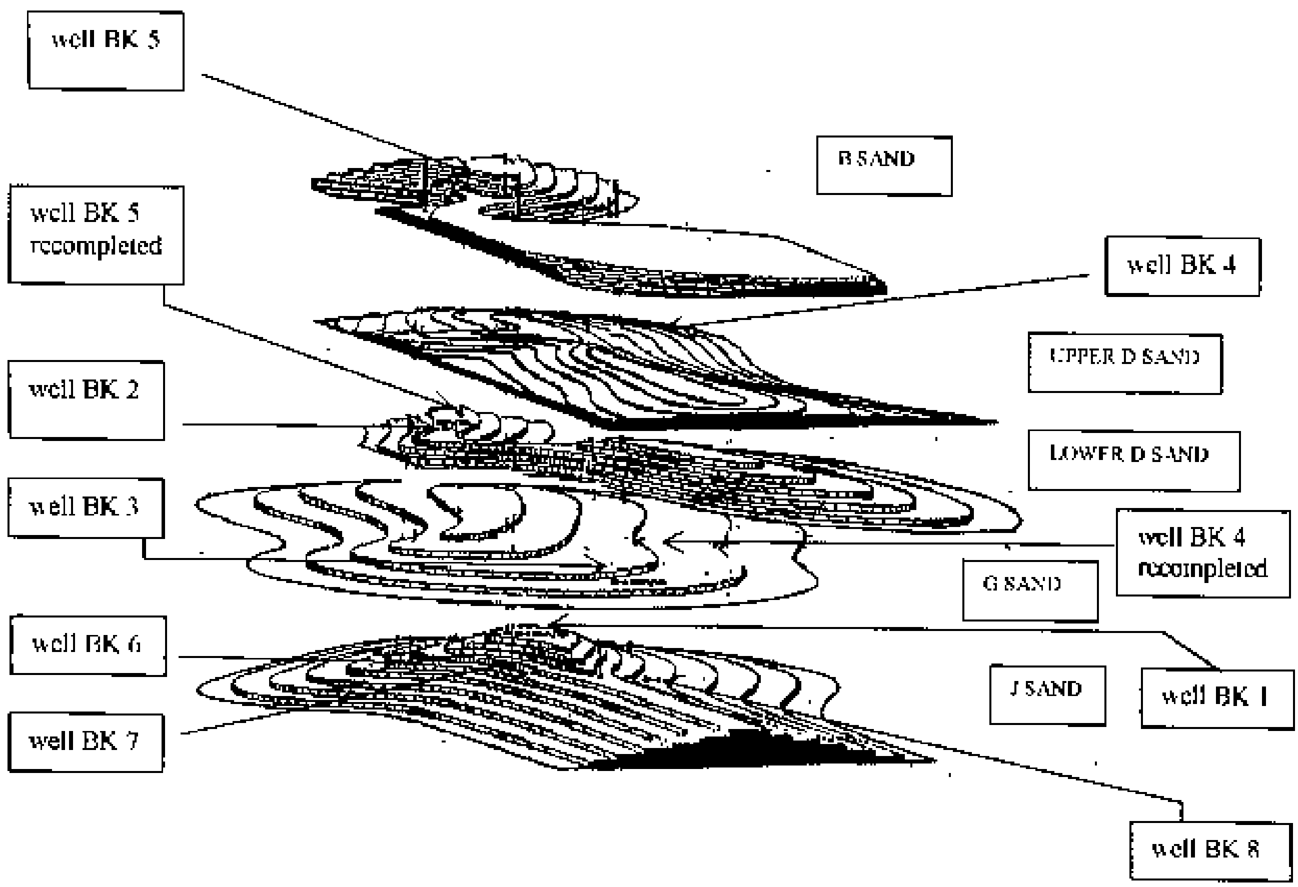
On the 1st June 1989, all drilling and production operations of BGSL at Bakhrabad were taken over by Bangladesh Gas Fields Company Limited (BGFCL).

The Bakhrabad Gas Field was first placed on production in May 1984 with Well BK 2 from D-Lower Sand, putting into stream The field has been supplying gas on a continual basis with total gas and condensate production of 553.7 BCF and 844 1 Mbbl to August 1998, respectively.

During the past few years Bakhrabad Gas Field has been experiencing rapid pressure decline and increased water cuts in the wells As a result, some wells have been shut off and some have been recompleted. In the year 1992 this field produced in its peak at an average 195 MMscfd. Wells, BK 4 of DU Sand, BK 5 of B Sand and BK 6 of J Sand, were shut off due to reservoir pressure decline and water production problems. Two workover wells, BK 4 of G Sand and BK 5 of DL Sand, were put into production experiencing shortened producing life. At present, only five wells are producing from three sands at the rate of 50 MMscfd This field experienced excessive sand production and water production problems due to overproduction or high rate of production without any prior study

The study has been undertaken to investigate the production problems and to find the remaining reserve of the field.

Figure 1 Different Developed Sands of Bakhrabad Gas Field



Chapter 2

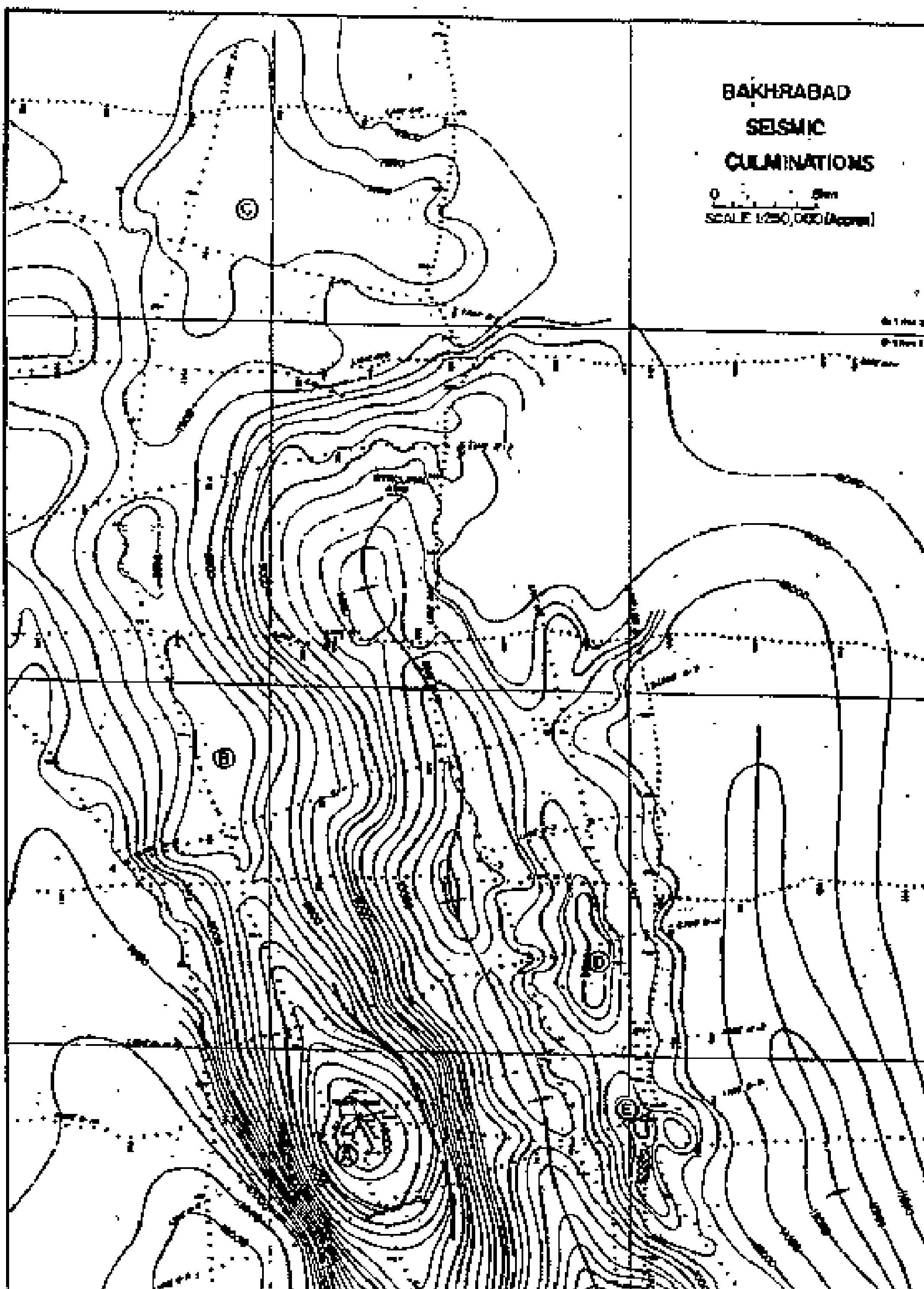
LITERATURE REVIEW

2.1 Introduction

Several studies have been conducted for different purposes at different development stages of Bakhrabad Gas field Bakhrabad Gas Field is located in the district of Comilla, about 35 km east of Dhaka city The presence of a potential gas bearing structure at Bakhrabad was first recognised from the results of the gravity survey made by Pakistan Petroleum Company in 1953 (Welldrill, 1989D) Pakistan Shell Oil Company (PSOC) took over the relinquished lease and conducted an extensive single fold seismic program during 1960-1966. The Bakhrabad Anticline, as defined by seismic, is a narrow, elongated almost symmetrical fold, about 69 km long and up to 10 km wide. At the top of the reservoir interval, seismic determines three culminations A, B and C along the axis of the Bakhrabad Structure (Figure 2.1). Bakhrabad seismic mapping was prepared by Hydrocarbon Habitat Study (HHS) in 1986 The central B and northern C culminations lie about 24 km and 48 km respectively just west of north from culmination A The culmination A is now termed as the Bakhrabad Structure The culmination B and the culmination C is termed as Narshindi Gas Field and Meghna Gas Field respectively.

The present Bakhrabad Structure is the southernmost crest, the culmination A, representing the Bakhrabad Gas Field This culmination, is the structurally highest

Figure 2.1 Bakhrabad Seismic Culminations A , B and C.



anticline, and was drilled by PSOC during 1968-1969. This vertical exploration well, BK 1 discovered commercial quantities of gas from a multilayered reservoir below 5870 feet, in the Bhuban Sand Formation in the Lower Miocene The discovery of Bakhrabad Gas Field proved the presence of reservoir succession as A, B, C, D, E, G, J, K and L Sands.

The sedimentary succession encountered in the Bakhrabad structure composed of thick repetitious sequences of fluvio-deltaic clastic deposits that rapidly accumulated in the subsiding Bengal Basin (Welldrill, 1989D)

The primary priority reservoirs in the Bakhrabad Gas Field are the B, D-Upper, D-Lower. G and J Sands The secondary priority reservoirs are A, C, E, K and L Sands. The criteria for primary reservoirs predominantly were

a) having a minimum AOF of 50 MMscfd, determined by testing,
b) sufficient acreage to be located in all wells, BK 1 to BK 8;
c) having a minimum net pay thickness of twenty feet vertically.

2.2 Previous Reserve Estimates

Significant previous determinations (Welldrill, 1983F) of gas in place in the Bakhrabad Field, include

a) Estimation of Gas Reserves in Bakhrabad Field, Bangladesh by J. R Carmichael (1974) Initial gas in place for the culmination in which the single well was drilled was calculated at 1200 BCF, based on volumetric estimations.

b) Appraisal study of the Bakhrabad Field, Bangladesh by Degolyer and MacNaughton (1975) Proved gas in place was given as 1525 BCF. This was also based on a single well. It was suggested that a further 2637 BCF could be classed as 'possible' reserves, to be proved by further drilling. The GIP estimations were based on volumetric calculations

c) Natural Gas Reserves and Deliverability Study, Bangladesh by JALECO (1980) Proved gas in place was calculated as 1578 BCF. Further 'probable' gas in place was given as 1291 BCF, based on volumetric estimations.

2.3 First Stage Development

The First Stage Development of Bakhrabad Gas Field included the wells, BK 1, BK 2, BK 3, BK 4 and BK 5 Reserve report along with the well completion reports was compiled by Welldrill in 1983 This report indicated a volumetric estimate of reserves in the 'A' Culmination of the Bakhrabad Anticline for the A, B, C, D, F, G, J, K and L Sands of between 1693 to 1842 BCF.

The lower figure was based on the indications that the D Sand is divided into two discrete sand sections, each having its own independent gas water contact. The higher figure was based on the assumption that the D Sand is considered to be one communicating-sand body with a common gas-water contact.

Utilising an abandonment wellhead pressure of 90 psia, recoverable reserves were estimated at 1354 to 1473 BCF.

2.4 Second Stage Development

The Second Stage Development of Bakhrabad Gas Field was successfully achieved by the drilling and completion of the three more gas wells, BK 6, BK 7 and BK 8. The drilling locations for the three gas wells were based on 1986 seismic mapping produced by the Hydrocarbon Habitat Study (HHS) group and the well data from the BK 1, BK 2, BK 3, BK 4 and BK 5 wells These infill wells were programmed to optimise the off-take from the J reservoir sands in the southernmost culmination A of the elongate Bakhrabad Anticline. Reserve report along with the well completion reports was compiled by Welldrill in 1990. In this period the revised volumetric estimate of gas-in-place amounts to 1844 BCF.

Gas in place was calculated on the assumption that the two D Sands (DU and DL) have their own gas-water contacts

The recoverable reserves, based on an abandonment wellhead pressure of 90 psia with compression were estimated at 1467 BCF

A comprehensive study report was submitted under Gas Field Appraisal Project by Intercomp-Kanata Management Ltd (IKM) in 1990.

The scope of the reservoir engineering study by IKM included a detailed, integrated approach using all available data to develop a description of the reservoir rock and fluid properties and predict future performance assuming alternate development and operating scenarios This report included the analysis and results of the first pressure survey conducted in Bakhrabad Gas Field in 1989

The main conclusions of IKM report were the following :

- The reservoir fluids of all produced Bakhrabad Sands are non-retrograde at reservoir temperature.
- The Bakhrabad Gas Sands contain a dry gas of relatively uniform composition
- The proved in-place reserves were 1369.7 BCF based on material balance reserve estimates of the producing horizons
- The in-place reserves of the C and F Sands were considered to be probable reserves of 24.1 and 37 8 BCF, respectively
- The reserves of the A, K, and L Sands were classified as possible reserves

Varying different operating parameters IKM made some additional performance prediction. They are as follows:

- Based on an abandonment pressure of 1200 psia, ultimate gas recovery from the Bakhrabad Gas Field would range from 55 to 63 percent of the initial gas in place for the B to J Sands.
- Based on an abandonment pressure of 600 psia achieved through the installation of inlet compression facilities, ultimate gas recovery from the Bakhrabad Gas field would range from 78 5 to 82 0 percent of the initial gas in place for the B to J Sands

- No further drilling of wells in the Bakhrabad Gas field is required to achieve optimal gas recovery.

A report on production problem of Bakhrabad Gas Field by Huq et al (1993), made an elaborate coverage on the production history of the field. In this report it was pointed out that in Bakhrabad, produced gas and liquid from all the wells are separated centrally and through a common header, the separated liquid flows further downstream for separation of water and condensate. The report opined that it was inconclusive to determine the optimum production rate for the individual wells by attempting to find a relationship between combined water production rate with gas production of the individual wells.

Reservoir Engineering Report Based on 1992 and 1993 Pressure Surveys (Reservoir Study Unit, 1993), was compiled by Reservoir Study Unit of Petrobangla. This report presented the results of analysis and interpretation of the second and third annual pressure surveys. The pressure transient test data of Bakhrabad were analyzed and interpreted with the assistance of an IKM engineer using a well test interpretation software 'Interpret/2' This report also included production forecasts for Bakhrabad Gas Field which were generated using Intercomp's Petroleum Workbench software. It should be mentioned that the second and third annual pressure surveys could not include J Sand owing to high gas demand for which the wells of the sand could not be shut down. Otherwise inter-well interference would have been observed as was in the case of first annual pressure survey

Recently, Mobil (BGFCL/Mobil, 1997A) has conducted a study on Bakhrabad Gas Field In that study, the proved in-place reserves were shown as 1439 BCF based on material balance reserve estimates of the producing horizons.

Schlumberger conducted Sand Free Production Test (BGFCL/Mobil, 1997B) under the supervision of Mobil in September and November of 1997 and some of the test results from that report are presented in Table 2 1.

Table 2 1 Sand Free Production Test Results conducted by Schlumberger in September and November 1997.

Well	Perf. Depth (MD)	Choke Size	W.H.P	Gas Prod. Rate	Cond. Prod. Rate	Sand Prod. Rate	Water Rate
	feet	/64"	psia	MMscfd	bbls/day	gm/day	bbls/MMscf
BK 1(J)	7035 -7360	47	1040.0	14.0	0 6	6 3	1 6
BK 2(DL)	7390 - 7360	74	920.0	16	0 0	13.7	0 9
BK 3(G)	8720 - 8910	45	1265 0	15.7	0.3	9.6	0 2
BK 4(G)	7694 - 7838	36	790.0	6.0	0 1	Trace	57 0
BK 5(DL)	7592 - 7704	32	870 0	5.5	0 0	264.0	69.2
BK 6(J)	8194 - 8450	96	825 0	16 0	1.8	Trace	17 5
BK 7(J)	8143 - 8450	50	1080.0	16.0	0 9	14 4	0 3
BK 8(J)	8209 - 8559	56	960.0	14 8	1 8	57.0	9.8

Note: Based on Sand Test Report, BGFCL/Mobil, 1997.

After analyzing the test results, Mobil recommended (BGFCL, 1998B) the following

- To set bridgeplug over the top of D-Lower Sand of Well BK 5 and perforate at D-Upper zone
- To reperforate wells, BK 1, BK 2, BK 3, BK 6, BK 7 and BK 8.
- To modify the surface facilities.

Accordingly Well BK 5 was perforated at D-Upper zone but production test resulted in excessive water production and ultimately ceased production. The reperforation jobs of the other wells did not produce any good results as well

Chapter 3

SCOPE OF THE STUDY

Objectives of the Study

The objective of this study is to perform an extensive reservoir engineering study to understand the reservoir behaviour and predict its future performance utilizing the available information. Reservoir performance predicted by simulation or analytical models can be verified by actual reservoir performance. Bakhrabad Gas Field has been chosen because it is a matured and depleted field. To achieve this objective, this study has been subdivided as follows:

1. To study the production performance of the producing wells.
2. To conduct material balance study and estimate remaining gas in place of the reservoirs.
3. To simulate the producing sands and predict their future performances

Methodology

To achieve the above objectives the following methods are adopted :

1. To collect all the available production and field data and analyze the data
2. To conduct flowing well approach, in addition to the traditional MBE methods to estimate the remaining gas reserves.

3 To simulate the producing sands of Bakhrabad Gas Field using a commercial simulator (Exodus 2 2), match the previous well and field production history and predict the future performance of the field and the wells.

Chapter 4

PRODUCTION DATA ANALYSIS

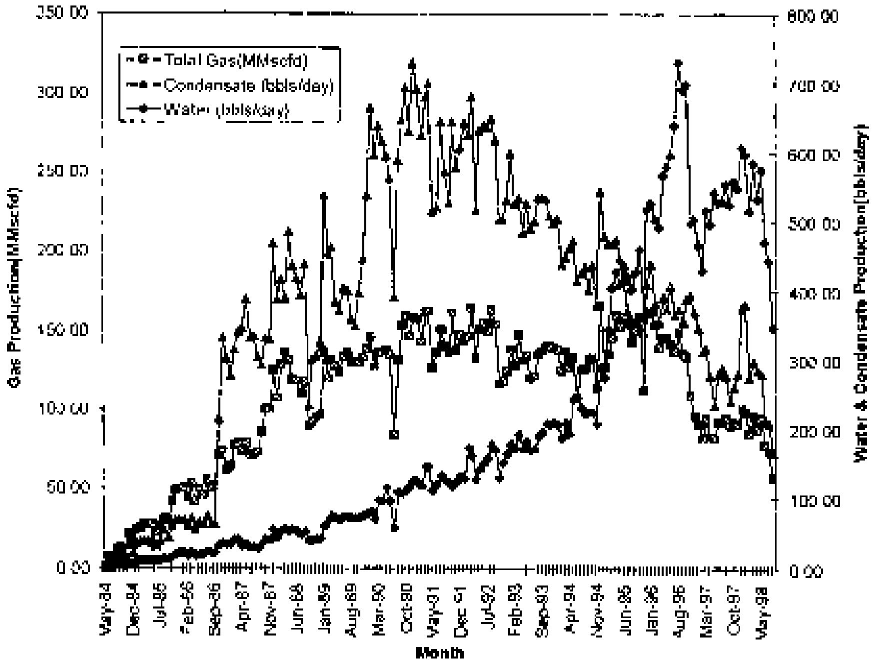
This chapter deals with the production history of Bakhrabad Gas Field along with the analysis of the water production behaviour of the different sands.

4.1 Production from the Bakhrabad Gas Field

Bakhrabad Gas Field went into production in May 1984 with BK 2 from D-Lower Sand putting into stream. Well BK 5 in B Sand, went into production in October 1984. Later in August 1985, BK 1 in J Sand, was put on production These three wells produced a total of 29.4 MMscfd on monthly average Wells, BK 3 in G Sand and BK 4 in D-Upper Sand, were put into production in October 1986 Thus by December 1987, the monthly average production was increased to 120 MMscfd. In December 1989, wells, BK 6, BK 7 and BK 8, all in J Sand, were put on streamline In January 1990, the monthly average of the field production came up to 140 MMscfd. There was not much change in production although production from wells, BK 2, BK 3 and BK 5, dropped

Figure 4.1, presents the monthly average production of gas, condensate and water, produced from Bakhrabad Gas Field from May 1984. till August 1998. With the introduction of workover wells, BK 4 and BK 5, a significant rise in production was observed in December 1994 from 135 MMscfd to 160 MMscfd whereas a substantial

Figure 4.1 Total Gas, Condensate and Water Production of Bakhrabad Field



wellhead-pressure drops at all the wells were observed Thus, continuously high-production rate from the wells in spite of the wellhead pressure drop led to an increase in water production. In 1990, the water production of the total field was at 0 72 bbls/MMscf, whereas in 1994 it rose to 1.72 bbls/MMscf Table 4.1 shows the yearly production of gas, condensate and water from the Bakhrabad Gas Field During 1984 water production was 0 36 bbls/MMscf. During 1988-1989 with the introduction of wells, BK 6, BK 7 and BK 8, the water production was 0.55 bbls/MMscf. During 1994, it increased to 1.72 bbls/MMscf and recently, as of August 1998, the water production was recorded as 6 10 bbls/MMscf. The average condensate production was 0.7 bbls/MMscf, 1 42 bbls/MMscf, 1 5 bbls/MMscf and 1 38 bbls/MMscf during the years 1984, 1989, 1994 and 1998 (till August), respectively.

Table 4.1 Yearly Production of Bakhrabad Gas Field

Year	Gas Production (MMscf)	Condensate Production (bbls)	Water Production (bbls)	Condensate (bbls/MMscf)	Water (bbls/MMscf)
1984	2343.39	1634 59	836 24	0.70	0.36
1985	11,342.96	7,190.91	4,726.73	0.63	0.42
1986	19,390.23	18,781.30	8,601.90	0.97	0.44
1987	29,889.34	53,261.69	13,207.00	1.78	0.44
1988	40,159.84	59,405.63	17,282.69	1.48	0.43
1989	47,054 92	66,959 89	25,778.27	1.42	0.55
1990	49,486 73	96,555 35	35,649.38	1.95	0.72
1991	52779 25	95888.80	45624.68	1.82	0.86
1992	51,509 60	94,257.08	55,176.90	1.83	1.07
1993	48,325.19	82,266.40	67,437.07	1.70	1.40
1994	46,854.56	70,355.41	80,636.67	1.50	1.72
1995	52,770.39	63,687.46	146,663.60	1.21	2.78
1996	49,404.94	60,345.22	210,904.70	1.22	4.27
1997	32,379.35	45,865.75	189,284.20	1.42	5.85
1998	20,015 62	27,648.40	122,120 80	1.38	6.10
Total	553,706 31	844,103 87	1,023,930.82	1 52	1.85

The production-test results of different wells of different sands representing the gas production, condensate production and water production are shown in Table 4 2

In the month of March 1992, a peak production of 210 MMscfd was recorded prior to the closure of Well BK 4 of DU Sand. In June 1992, Well BK 4 of DU Sand, was shut off due to excessive water production In October 1994, production from Well BK 5 of B Sand, was suspended due to excessive amounts of sand and water production Subsequently workover was performed on Well BK 4 and reopened for production from G Sand in October 1994 and continued till June 1998 In June 1998, Well BK 4 of G Sand was out of production due to pressure decline of the well, equalizing to the manifold pressure (800 psig). After workover, Well BK 5 started production from DL Sand in December 1994 and continued till May 1997. In May 1997, Well BK 5 was

Table 4.2 Production Test Results of Different Wells of Bakhrabad Gas Field.

Well	Date	Midpoint Perf's(feet)		Well Dia. (ft.)	AOF (MMscfd)	Gas Prod. Rate (MMscfd)	Cond. Prod. Rate (bbls/MMscf)	Sand Prod. Rate (gm/day)	Water Prod. Rate (bbls/MMscf)
BK 1(J)	Aug.'85	7197.5(DD)	7197.5(TVD)	0.3	400	54.5	0.4	nil	negligible
BK 6(J)	Dec.'89	8315(DD)	7231(TVD)	0.3	244	19.79	1	nil	0.67
BK 7(J)	Dec.'89	8297(DD)	7140(TVD)	0.3	345	35.99	0.89	nil	0.72
BK 8(J)	Dec '89	8384(DD)	7351.5(TVD)	0.3	221	30.8	< 1	nil	< 1
BK 3(G)	Oct.'86	8815(DD)	6907(TVD)	0.3	148	33	negligible	nil	nil
BK 4(G)	Oct.'94	7776(DD)	7088(TVD)	0.3		15.76			
BK 2(DL)	May'84	7445(DD)	6344(TVD)	0.3	231	30	0.5	nil	0.2
BK 5(DL)	Dec '94	7648(DD)	6679(TVD)	0.3		17.6			
BK 4(DU)	Oct.'86	7155(DD)	6546(TVD)	0.3	230	30	0.05	nil	negligible
BK 5(B)	Oct.'84	6809(DD)	5967(TVD)	0.3	260	20.7	1.1	nil	negligible

Note: Based on Welldrill Completion Reports shut down in the same manner, that is, declining wellhead pressure to the manifold pressure. In the year 1994 with the introduction of two workover wells, BK 4 in G Sand and BK 5 in DL Sand, the total production of the field from the 8 wells increased from 135 MMscfd to 170 MMscfd with condensate production of 1.85 bbls/MMscf and water 1.49 bbls/MMscf. In the year 1995, with the same set of wells in production, the gas production was 170 MMscfd and the condensate production increased to 2.16 bbls/MMscf and the water production to 2.72 bbls/MMscf

In the year 1996, BGFCL decided to reduce the gas production rate of the field at 5 MMscfd on a monthly basis, due to considerable reduction of shut-in wellhead pressure of the wells of Bakhrabad Gas Field (Reference Table 4.3) In October 1996, there were severe damages of the choke valves and control valves of Well BK 3, due to sand production Increased sand production was recorded in other wells as well at that time In November 1996, the production of the field was decreased from 130 MMscfd to 110 MMscfd due to excessive sand production In December 1996, it was further reduced to 100 MMscfd. With the end of production of Well BK 5 from DL Sand in May 1997, the daily production of the field was limited to 95 MMscfd At the end of 1997, condensate production was 1.3 bbls/MMscf and water production increased to 6 bbls/MMscf

In July 1998, the production of Bakhrabad Gas Field declined to 71 MMscfd on a monthly average with the water production of 6 bbls/MMscf and condensate production 1 3 bbls/MMscf At this time, production from Well BK 6 was suspended due to decline of pressure to 820 psig, which was almost equal to the manifold pressure (800 psig)

Table 4 3 Shut-in Wellhead Pressure at Different Wells of Bakhrabad Gas Field.

Well	Shut-in Wellhead Pressure (psig)								
	1984-1989	1990	1992	1993	1994	1995	1996	1997	1998
BK 1(J)	2800 (August.85)	2410 (18.7 90)	2150 (20 9.92)	1801 (18.10.93)	1630 (12.11.94)	1491 (14 9.95)	1300 (19 11.96)	1150 (19 9 97)	1154 (13.8 98)
BK 2(DL)	2520 (May,84)	1915 (28.2.90)	1800 (22.9 92)	1781 (18 10 93)	1700 (12.11.94)	1486 (14.9 95)	1215 (19 11 96)	1135 (21.9.97)	1096 (13 8 98)
BK 3(G)	2840 (October,86)	2410 (29.5.90)	2250 (13.9.92)	2020 (23 9.93)	1883 (12 11.94)	1700 (14.9.95)	1510 (19 11 96)	1470 (21 9 97)	1399 (17.8.98)
BK 4(DU)	2450 (October,86)	2015 (16 7.90)	1900 (7.9 92)	1700 (18.10.93)	1462 (27 3 94)				
BK 4(G)					1897 (12.11.94)	1710 (14.9.95)	1445 (19 11 96)	1300 (4.11 97)	
BK 5(B)	2330 (October,86)	2030 (29 5 90)	1850 (14.10.92)	1774 (25.9.93)	1712 (19.4 94)				
BK 5(DL)					1717 (20.12.94)	1465 (14.9 95)	1160 (19.11 96)	1230 (31.12.97)	
BK 6(J)	2561 (4 3 89)	2385 (20.6.90)	2040 (13 10 92)	1774 (19.10 93)	1604 (12.11.94)	1460 (16.9.95)	1235 (19 11.96)	1160 (6 11.97)	
BK 7(J)	2548 (9.7.89)	2420 (18.7.90)	1972 (14.10.92)	1800 (19 10 93)	1634 (12 11 94)	1501 (16.9.95)	1305 (19.11 96)	1175 (6.11 97)	1177 (21.8.98)
BK 8(J)	2544 (22 9 89)	2385 (18.8.90)	1943 (15.10.92)	1779 (20.10.93)	1661 (12 11.94)	1471 (16.9.95)	1285 (19 11.96)	1200 (7 11.97)	1141 (23.8.98)

Monthly average production rates and wellhead pressure of the wells of Bakhrabad Gas Field at different times are presented in Table 4 4 Production rate and wellhead pressure of the wells between January 1998 and July 1998 at specific dates are presented in the table to ascertain the recent condition.

Since the inception in May 1984, total production of eight wells from B, DU, DL, G and J Sands of Bakhrabad Gas Field till August 1998 are 553 BCF gas, 844103 bbls condensate and 1023930 bbls water

4.2 Sandwise Production Analysis

Analyzing the water production is difficult due to the unavailability of wellwise condensate and water production data The monthly report of the producing wells provided an excellent compilation of wellwise gas production data, but the condensate and water production data were only the field totals.

In Bakhrabad Gas Field, produced gas from different wells are gathered through manifolds. Gas and liquid from all the wells are separated centrally and through a common header, the separated liquid flows further downstream for separation of water and condensate. The partial schematic of the field gathering system is presented in Figure 4.2.

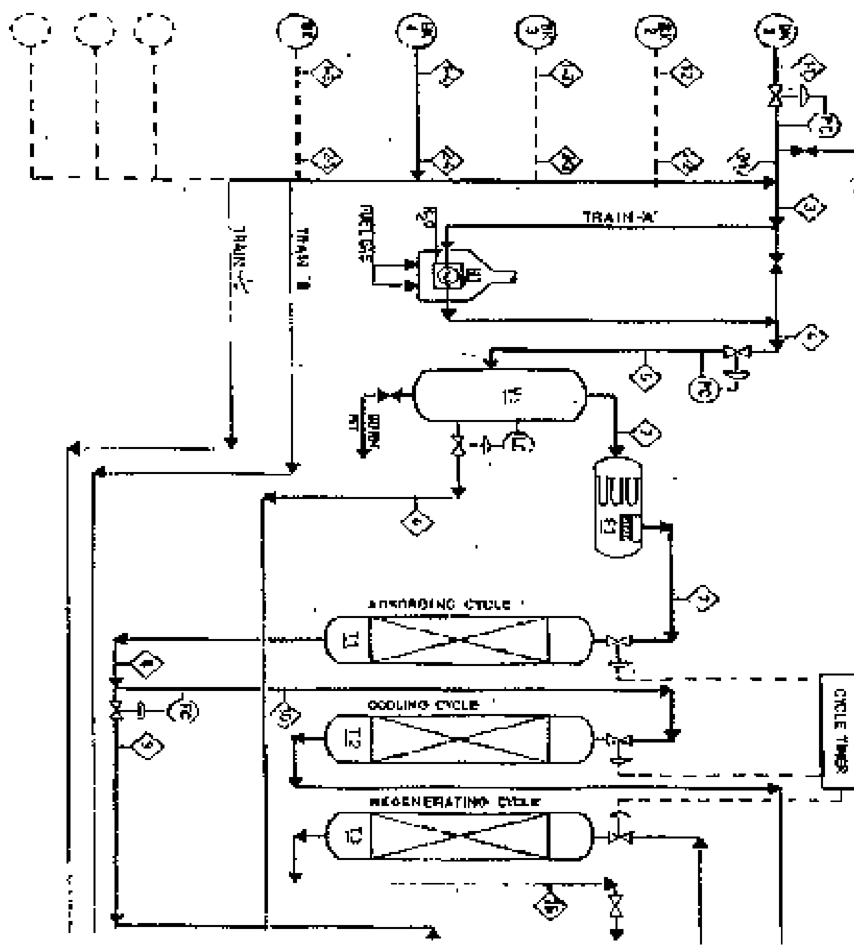
As the gas is processed centrally, water and condensate production from individual wells and sands can not be monitored Thus it is extremely difficult to identify the excessive water producing wells/sands without disrupting the production The recent Sand Free Production Test (BGFCL/Mobil, 1997B) will give some light on the present water

Table 4 4 Gas Production Status of Bakhrabad Gas Field.

Well	June 90		July 93		Dec.95		July 96		July 97		Jan.20.98		July.15.98	
	Avg. Gas Prod.	Avg. W.H.P	Avg. Gas Prod.	Avg. W.H.P	Avg. Gas Prod.	Avg. W.H.P	Avg. Gas Prod.	Avg. W.H.P	Avg. Gas Prod.	Avg. W.H.P	Gas Prod.	W.H.P	Gas Prod.	W.H.P
BK 1(J)	27.05	2400	17.92	1701	21.16	1217	18.68	1154	14.68	1063	16	972	13	965
BK 2(DL)	17.96	1825	7.79	1628	19.9	1239	17	1141	14.24	993	16	885	13	875
BK 3(G)	25.62	2400	24 21	1844	27 97	1330	25.68	1262	14 86	1297	15	1239	13	1215
BK 4(DU)	20 33	1800												
BK 4(G)					13.35	1051	10 49	1054	6.27	1023	6	861		
BK 5(B)			15 53	1640										
BK 5(DL)					14.16	1110	7.97	1058						
BK 6(J)	5 69	2231	18.54	1698	19 55	1209	17.38	1146	12.68	1015	11	863	6	820
BK 7(J)	18 71	2317	19.24	1735	24.61	1217	22 34	1159	15.00	1115	15	1058	14	1020
BK 8(J)	19.37	2208	18.01	1704	19.68	1221	17.32	1155	13 85	1098	16	983	12	915
Total	134.73		121 24		160.38		136 86		91 58		95		71	

Note: Gas production values are in MMscfd.
Wellhead pressure (W H.P) are in psig.

Figure 4 2 Partial Diagram of Field Gathering System



production behaviour of the Bakhrabad field; some of the test figures are presented in Table 2 1 of chapter 2.

4.2.1 J Sand

J Sand is one of the major reservoirs of Bakhrabad Gas Field This sand was penetrated by all eight wells and was tested in wells, BK 1, BK 2, BK 6, BK 7 and BK 8 At Well BK 2, lower part of J Sand was found to be tight, another test in the middle part of J Sand flowed 6.4 MMscfd gas on a 20/64" choke (Welldrill. 1983A) Water production rate was negligible. Production test of BK 1 at 7360 feet (TVD) showed initial reservoir pressure and absolute open flow potential (AOF) of the J sand as 3203 psia and 400 MMscfd respectively (Welldrill, 1983A) Production log indicated that at 54.5 MMscfd flowrate, 83% of the production was from interval 7035-7100 feet and there was no contribution from interval 7205-7270 feet.

Well BK 6 was perforated at interval 8194-8436 feet (DD) and on 50/64" choke a flow of 35.7 MMscfd was obtained. Production log indicated that at 28.8 MMscfd flowrate, 75% of the production originated from the perforated interval 8199-8290 feet (DD) with approximately 17% from the interval below 8380 feet (DD) (Welldrill, 1989A) Condensate and water production rates were 1 bbl/MMscf and 0 67 bbl/MMscf respectively. The absolute open flow potential (AOF) of Well BK 6 was 244 MMscfd Well BK 7 was perforated at interval 8143-8450 feet (DD) and 35 MMscfd flowrate was obtained on 52/64" choke Production log indicated that at 25 MMscfd flowrate about 55% production rate was from below 8380 feet (DD). Condensate and water production rate were found to be 0.89 bbl/MMscf and 0.72 bbl/MMscf respectively (Welldrill, 1989B).

Well BK 8 was perforated at interval 8209-8515 and 8531-8559 feet (DD). Production test obtained a flowrate of 43 MMscfd on a 64/64" choke. According to production log at 20.5 MMscfd flowrate, 83.2% of the production was from intervals above 8352 feet (DD). Both condensate and water production were found to be 1 bbl/MMscf (Welldrill, 1989C).

Wells, BK 1, BK 6, BK 7 and BK 8 have been producing from this sand. Well BK 1 started production in August 1985. Wells, BK 6, BK 7 and BK 8 were put on stream in December 1989. As of August 1998, cumulative production stood at 271.8 BCF which accounted for 49% of the total production (553.7 BCF) from the field. Sand Free Production Test (Table 2.1 of chapter 2) conducted by Schlumberger during September and November, 1997 showed that Well BK 6 was producing water at 17.5 bbls/MMscf and negligible sand, at the flowrate of 16 MMscfd. Well BK 7 was producing water at 0.3 bbl/MMscf and sand at 14.4 gm/day, at the flowrate of 16 MMscfd. Well BK 8 was producing water at 9.8 bbls/MMscf and sand at 57 gm/day, at the flowrate of 14.8 MMscfd. Thus it can be assumed in referring to the sand test result that as of July 1998, wells, BK 1, BK 7 and BK 8 were producing water at 20.8 bbls/day, 4.2 bbls/day and 177.6 bbls/day, for the production rate of 13 MMscfd, 14 MMscfd and 12 MMscfd, respectively (Reference, water production rates of the Sand Free Production Test, Table 2.1 of chapter 2 and gas production status, Table 4.4). The wellhead pressure of BK 1, BK 7 and BK 8 for the above stated gas production rates were 965 psig, 1020 psig and 915 psig, respectively (Table 4.4). From the end of July 1998, Well BK 6 was out of production due to fall of pressure to 820 psig Thus it can be observed that Well BK 8 will soon be out of production due to excessive water production and due to pressure decline in the reservoir. Well BK 8 also showed significant sand production in accordance with the Sand Free Production Test

Figure 4 3 represents the monthly average gas production rates of J sand along with the total water production of the field In December 1989, a sharp increase in production is due to the introduction of wells, BK 6, BK 7 and BK 8 A drop in production during the year 1996 was due to the depletion policy adopted by the management

Monthly average gas production of the wells, BK 1, BK 6, BK 7 and BK 8 along with the total water production of the field are shown in Figures 4.4 through Figure 4.7,

Figure 4 3 Gas Production of J Sand and Total Water Production of Bakhrabad Field

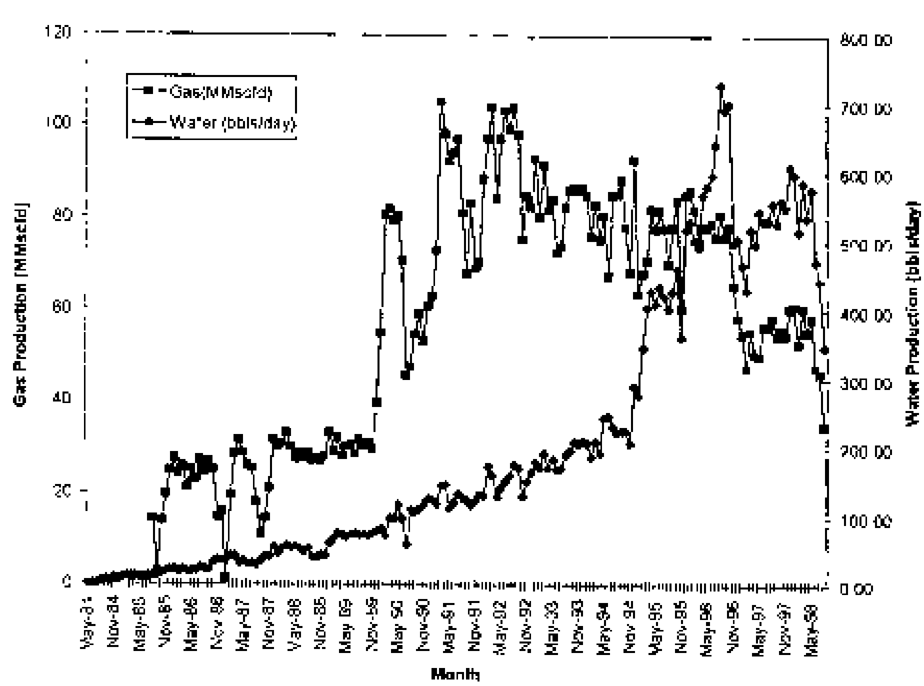


Figure 4.4 Gas Production at BK 1 of J Sand and Total Water Production of Bakhrabad Field

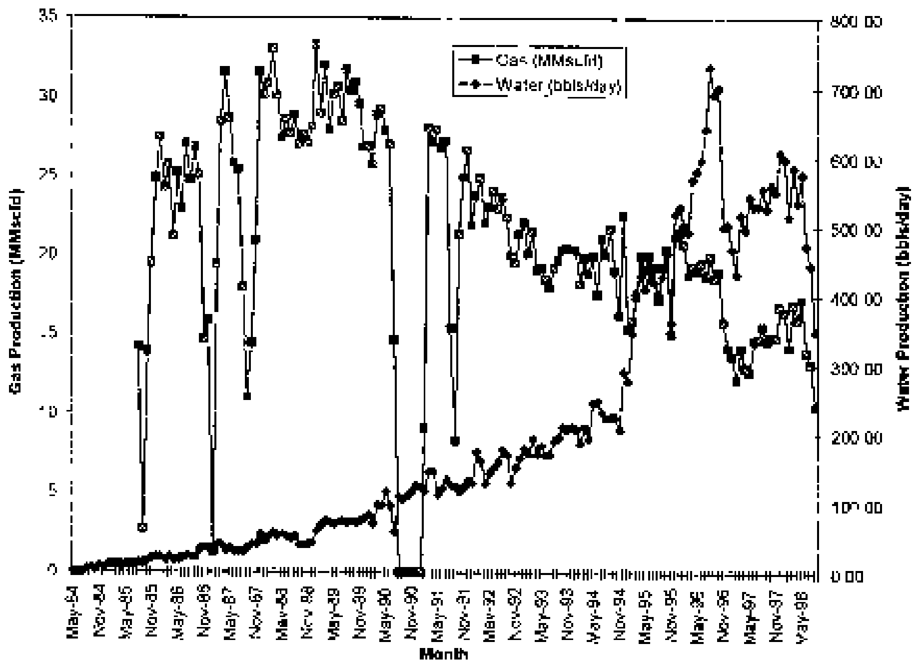


Figure 4.5 Gas Production at BK 8 of J Sand and Total Water Production of Bakhrabad Field

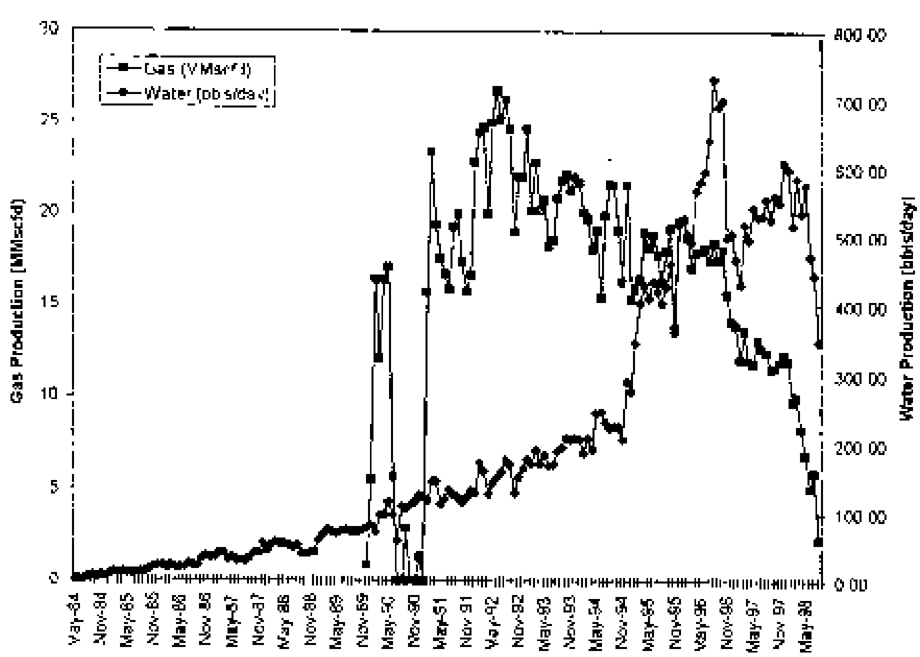


Figure 4.6 Gas Production at BK 7 of J Sand and Total Water Production of Bakhrabad Field

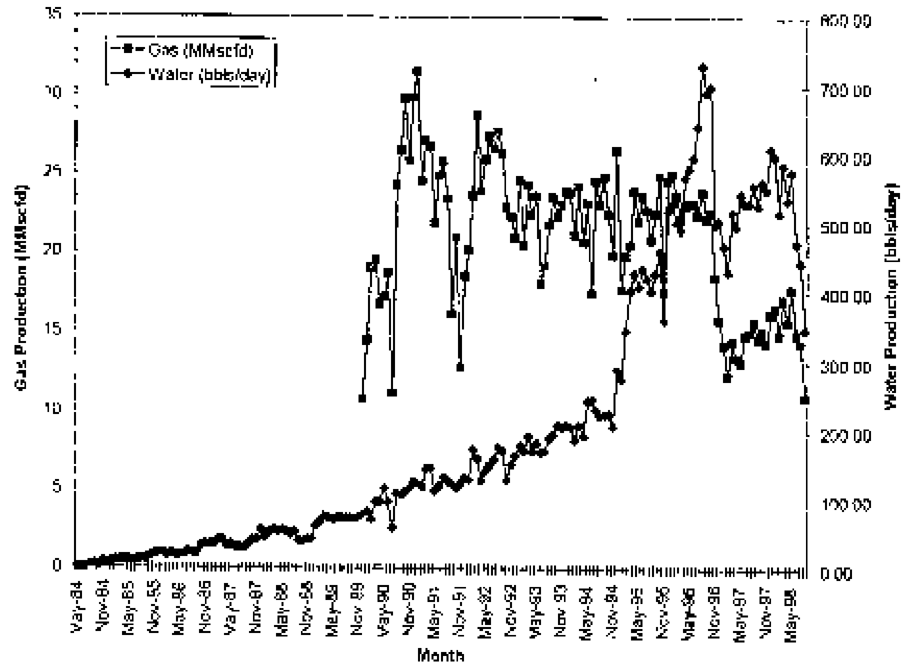
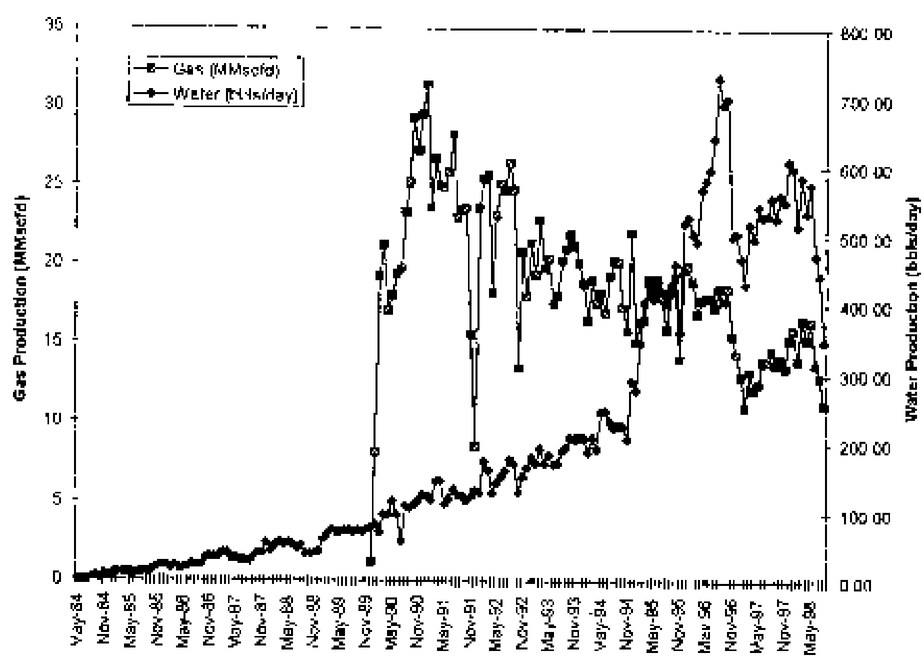


Figure 4.7 Gas Production at BK 8 of J Sand and Total Water Production of Bakhrabad Field



respectively The figures depict that high production rates, in lieu of sharp pressure drops (Table 4 3), during the year 1994-1995, contributed to the increase in water production of the field. It is observed from the figures that from the middle of 1996, production rates were dropped. During this period, a revised depletion policy was set out, due to pressure decline of the wells and due to excessive amount of water production and sand production in the field

4.2.2 G Sand

G Sand is the second largest reservoir of the field. Initially this sand was tested at wells, BK 2 and BK 5. This sand comprises of the wells, BK 3 and BK 4. Well BK 4 was recompleted in this sand later, after its production was suspended from DU Sand

Production test at Well BK 5 in this sand showed a gas rate of 26 MMscfd on a 40/64" choke Both condensate and water production rate were negligible Well BK 3 was tested on a 64/64" choke, producing at a flowrate of 40 MMscfd (Welldrill, 1983C). Condensate production rate was negligible and there was no indication of water production Production log indicated that at 33 MMscfd flowrate over 50% production was from interval 8820-8840 feet (DD) and out of 150 feet of perforation only 35 feet contributed Well BK 3 started its production from October, 1986

Well BK 4, was suspended producing of DU Sand, in June 1992 due to excessive amounts of water production. After workover, BK 4 was recompleted in G Sand and started production in October 1994 The initial reservoir pressure recorded at this well was 2194 psia and the well produced at a rate of 15.76 MMscfd and continued till June 1998

Well BK 4 is now out of production due to excessive water production and pressure decline

As of August 1998, cumulative production of this sand was 42.4 BCF. Figure 4.8 presents the total gas production from G Sand, along with the total water production of Bakhrabad Gas Field In October 1994, Well BK 4 was recompleted in G Sand It is observed from the figure that with an increase in gas production, there is an increase in water production in the field as well. During the year 1996, sand production and excessive water production was observed along with the pressure decline. Because of this production rate was decreased from October 1996.

Figure 4 9 presents the gas production at Well BK 3 of G Sand along with the total water production of the field Figure shows almost a steady production from this well till 1996 While the water production of the field increased during the early 1995, it can be observed that gas production is not in step with the water production. In October 1996, sand production was observed at Well BK 3 damaging the valves and the flanges (BGFCL, 1998B). A decrease in production was scheduled due to a trend of pressure decline of the wells and due to excessive amounts of water and sand production in the field Well BK 3 was producing water at 2.6 bbls/day at the production rate of 13 MMscfd (Sand Free Production Test, Table 2 1 of chapter 2 and gas production status, Table 4 4). From the above it can be concluded that Well BK 3 does not have an acute water production problem.

Figure 4.8 Gas Production of G Sand and Total Water Production of Bakhrabad Field

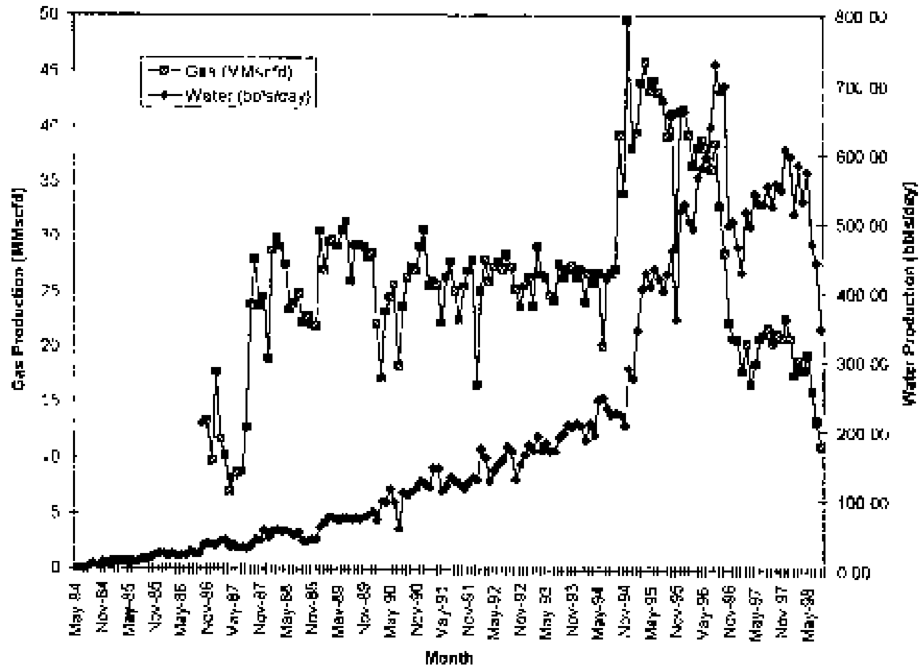
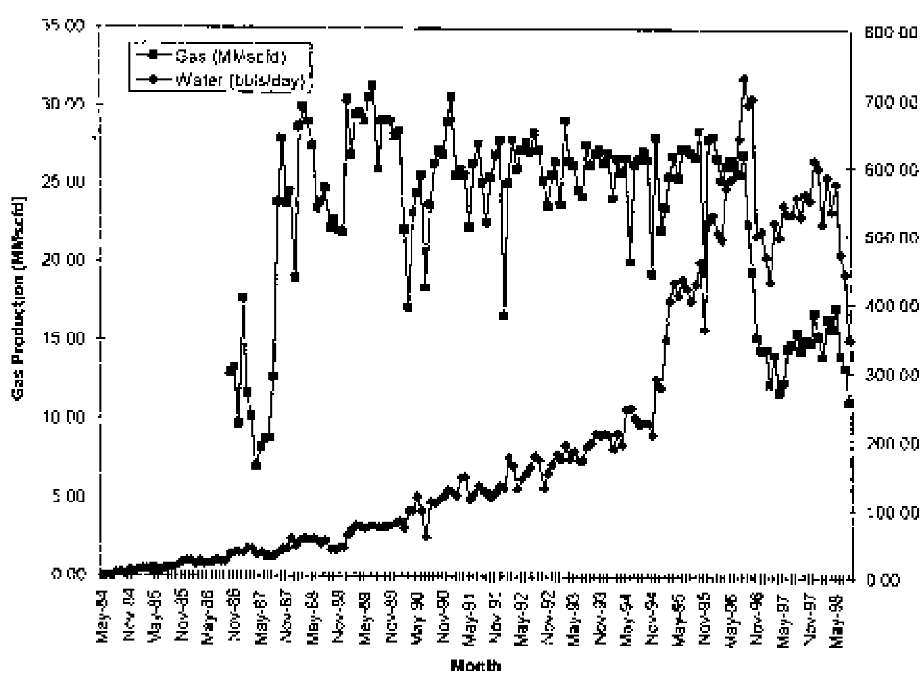


Figure 4.9 Gas Production at BK 3 of G Sand and Total Water Production of Bakhrabad Field

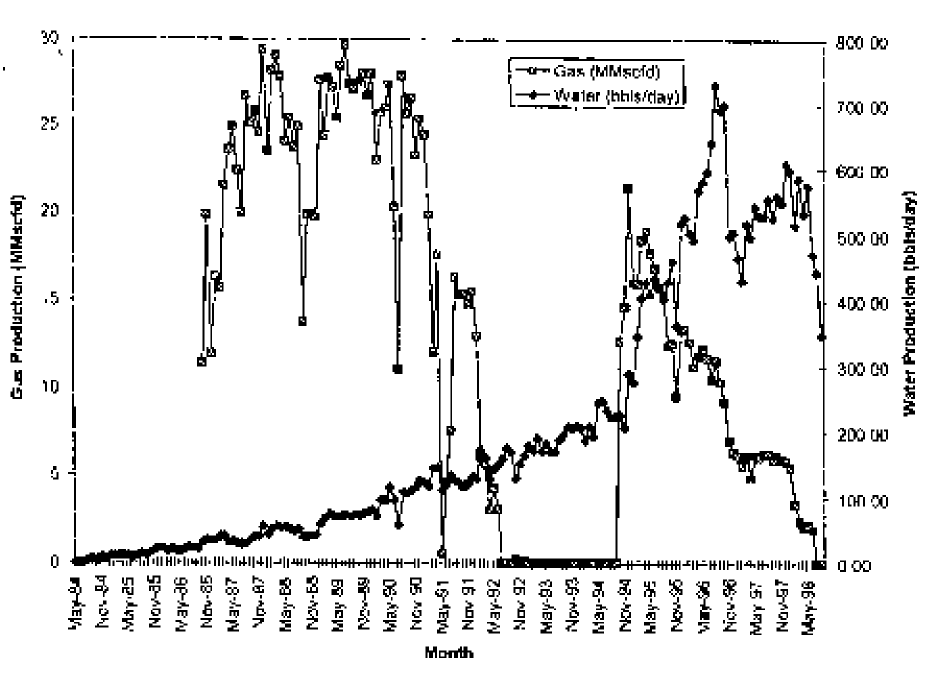


Gas production status of Well BK 4 along with the total water production of the field is set out in Figure 4.10 Increased production from October 1994 occurred because Well BK 4 was recompleted in G Sand. Figure 4 10 shows that the gas production of the well is in step with water production of the field. Well BK 4 in G Sand might have an acute water production problem Since July 1998, Well BK 4 of G Sand was out of production due to excessive amounts of water production and pressure decline (BGFCL. 1998B)

4.2.3 DL Sand

Bakhrabad Gas Field started its production with Well BK 2 in May 1984 from D-Lower Sand. D Sand is divided into two units DL (D-Lower) Sand and DU (D-Upper) Sand. Wells, BK 2 and BK 5 were completed in DL Sand. DL Sand was initially tested at

Figure 4 10 Gas Production at BK 4 of DU Sand and G Sand and Total Water Production of Bakhrabad Field

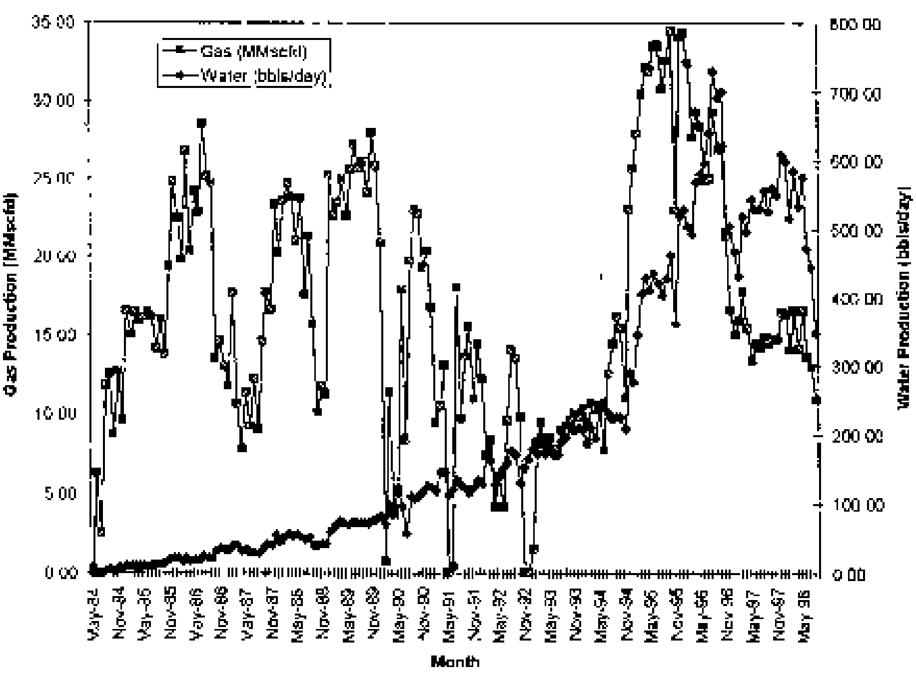


Well BK 2 only. Production test showed a flowrate of 65 MMscfd on a 96/64" choke Condensate and water production was found to be 1 9 bbls/MMscf and 0.2 bbl/MMscf, respectively (Welldrill, 1983B)

In October 1994, Well BK 5, which was producing from B Sand, was suspended due to excessive amounts of sand and water production. After workover, BK 5 was recompleted in DL Sand in December 1994 and started producing at a rate of 17.6 MMscfd with an initial pressure of 1930 psia. Well BK 5 continued production till May 1997, when it was shut off due to excessive water production.

As of August 1998, cumulative production from DL Sand was 85.4 BCF. Gas production status of DL Sand along with total water production of the field appears in Figure 4 11

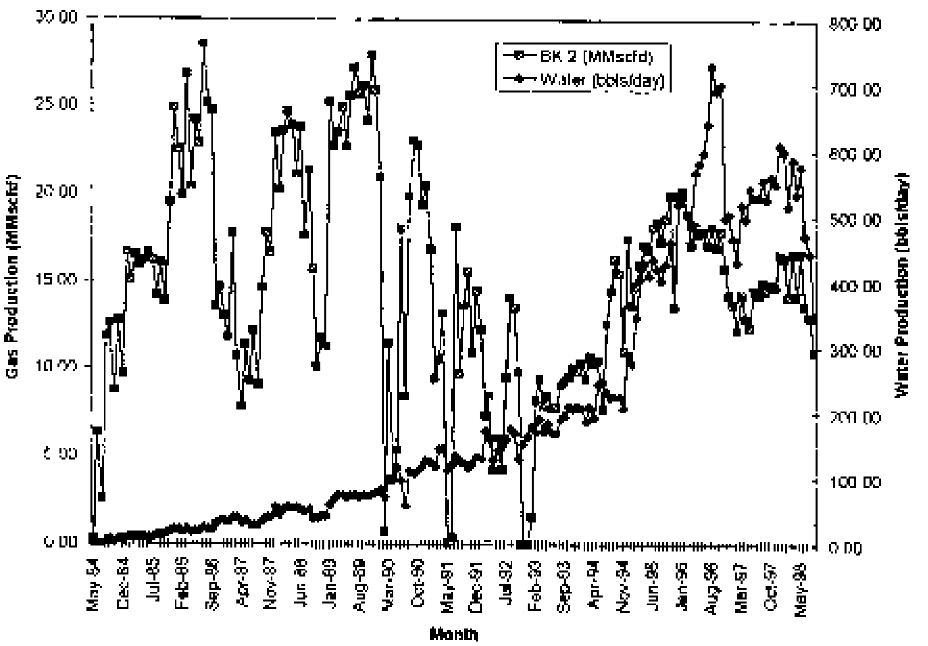
Figure 4 11 Gas Production of DL Sand and Total Water Production of Bakhrabad Field



The figure shows that production from DL Sand has not been steady. There were shut-down occurrences at different times A sharp increase in production in December 1994 was due to the introduction of recompleted Well BK 5 It can be observed that with the start of production from BK 5, the combined production of the wells, BK 2 and BK 5 is in step with the water production of the field. This might be due to excessive amounts of water production from Well BK 5

Figure 4 12 shows the gas production status of Well BK 2 in DL Sand along with the total water production of the field. During 1989 this well produced at an average rate of 23-28 MMscfd It is evident from the figure that there have been several shut-down periods. In the year 1993-1994 this well was producing below 10 MMscfd on an average A sharp increase in production in 1995-1996 is in step with the water production of the field Since 1996, production limiting measures were adopted due to sharp pressure decline.

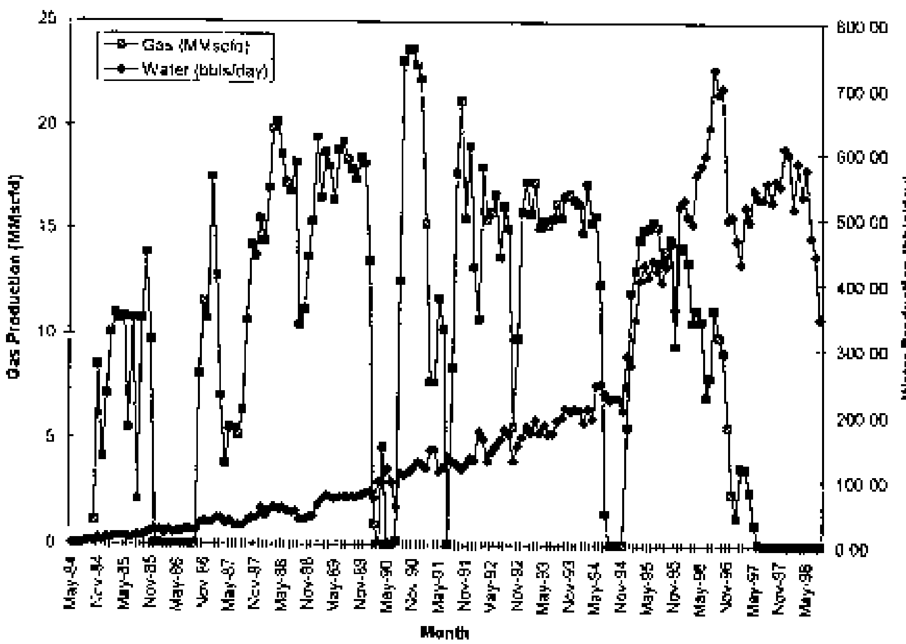
Figure 4 12 Gas Production at BK 2 of DL Sand and Total Water Production of Bakhrabad Field



During the Sand Free Production Test conducted by Schlumberger, this well was found to be producing water at 0.9 bbl/MMscf for a gas production rate of 16 MMscfd (BGFCL/Mobil, 1997B). In July 1998. Well BK 2 produced 13 MMscfd with the wellhead pressure of 875 psig. Assuming the Sand Free Production Test result (Table 2 1) this well was producing water at the rate of 11.7 bbls/day. Thus, it can be observed that Well BK 2 will soon be out of production due to pressure decline.

Gas production status of the recompleted well, BK 5 along with the total water production of the field appears in Figure 4.13. An increased production in the later part of the figure, which is, starting from December 1994, is due to the recompletion of Well BK 5 in DL Sand.

Figure 4.13 Gas Production at BK 5 of B Sand and DL Sand and Total Water Production of Bakhrabad Field



The figure shows it clearly that the gas production of Well BK 5 and the water production of the field are in step with each other During the Sand Free Production Test conducted by Schlumberger this well was producing sand and water at an alarming rate of 264 gm/day and 69.2 bbls/MMscf respectively, at a gas production rate of 5.5 MMscfd (Table 2.1). Thus it seems that Well BK 5 had an acute water production problem during its production tenure In May 1997, Well BK 5 of DL Sand was shut down due to an excessive amount of water production (BGFCL, 1998B)

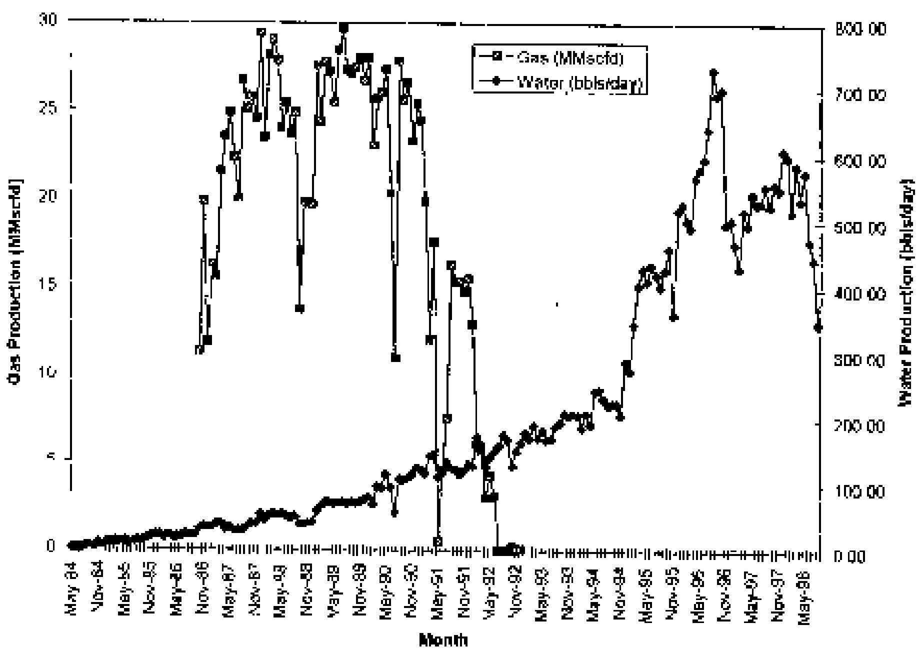
4.2.4 DU Sand

Well BK 4 was completed in D-Upper (DU) Sand DU Sand was tested at wells, BK 2 and BK 4 During the production test Well BK 2 produced at a rate of 35 MMscfd on a 52/64" choke Condensate production rate was 0 5 bbl/MMscf and water production was negligible. Production test at Well BK 4 showed a flowrate of 40 MMscfd on a 60/64" choke The absolute open flow potential (AOF) was 230 MMscfd Condensate production was 0.05 bbl/MMscf and water production was negligible (Welldrill, 1983D) Production log of BK 4 indicated that at 30 MMscfd, the entire production was from interval 7110-7170 feet (DD) and there was no contribution from the interval 7180-7200 feet (DD) At 10 MMscfd flowrate entire production at Well BK 4 was from interval 7110-7145 feet (DD)

Well BK 4 started its production in October 1986 with an initial reservoir pressure of 2883 psia at 6585 feet (TVD) Figure 4.14 presents monthly average production rates of Well BK 4 of DU Sand along with the total water production of the field. In April 1987.

it produced at a rate of 23 MMscfd. During 1989 it produced at a rate of 27 MMscfd. In April 1990. production rate was 17-18 MMscfd. In February 1991, flowrate was 20 MMscfd. In June 1992 prior to the shut down of the well, it produced at 4 to 5 MMscfd. This sand was out of production due to excessive water production and pressure decline (BGFCL, 1998B). The cumulative production from this well was 42.4 BCF.

Figure 4 14 Gas Production of DU Sand (BK 4) and Total Water Production of Bakhrabad Field

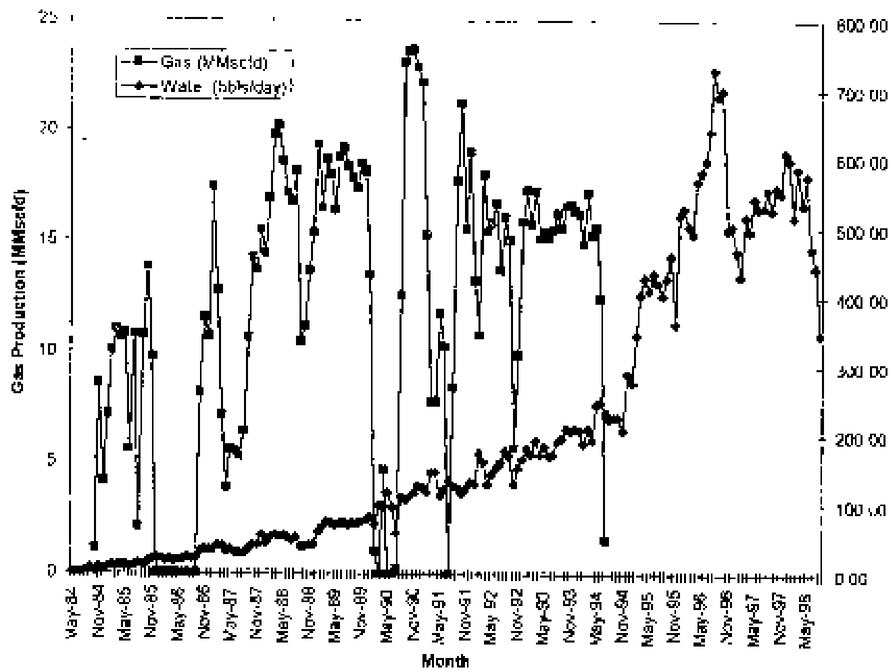


4.2.5 B Sand

Well BK 5 was completed in B Sand. This sand was tested at wells, BK 1, BK 2 and BK 5. At Well BK 1 lower part of B Sand was tested and it produced 1200 bbls/day of water along with 22 MMscfd of gas Well BK 2 produced 27 MMscfd gas on a 96/64" choke. Condensate production was 0.5 bbl/MMscf with negligible water production. Wells. BK 1 and BK 2 were sealed off in B Sand Production test at Well BK 5 showed a flowrate of 29 MMscfd on a 44/64" choke with the initial reservoir pressure of 2640 psia at 6868 feet (DD) (6017 feet TVD). Condensate production was 1.1 bbls/MMscf and water production was negligible. The absolute open flow (AOF) potential was 260 MMscfd (Welldrill, 1983E)

Well BK 5 started production in October 1984 Gas production status of B Sand along with the total water production of the field appears in Figure 4.15. Production rate fluctuated throughout the production period at BK 5 of B Sand During 1990, production rate was 20 MMscfd with a maximum of 27 MMscfd In October 1994, production from

Figure 4.15 Gas Production of B Sand (BK 5) and Total Water Production of Bakhrabad Field



Well BK 5 of B Sand was suspended due to excessive amounts of sand and water production (BGFCL, 1998B) The cumulative production from this well was 42.3 BCF.

Chapter 5

MATERIAL BALANCE STUDY

Material balance analysis has been performed using the conventional method and flowing well method to estimate both reserves and initial gas in place for Bakhrabad Gas Field The second method is specially suitable for Bangladesh situation where regular pressure tests are not conducted due to critical demand-supply situation Results of conventional method and the flowing well method have been compared with those of previous studies

5.1 Conventional Material Balance Analysis

Conventional material balance analysis for a gas reservoir relies on obtaining a straight line on p/z vs cumulative production (G_p) graph to estimate reserves and initial gas in place (GIP) This method requires fully built-up reservoir pressures, obtained by shutting in the wells for few days

The accuracy of reserve calculations by the volumetric method is dependent upon the accuracy of data available, mainly on the quality of seismic and log data In a fluvio-deltaic sequence, as in Bakhrabad, the probability for large errors in estimating rock volumes is much high and, thus, there may be substantial errors in estimating the original gas in place, using volumetric method On the other hand, the accuracy of reserves calculated from the material balance studies is dependent upon the accuracy of the well's production and pressure data. Unlike the volumetric method, the material balance accounts for reservoir heterogeneity and continuity variations, which occur within the reservoir The accuracy of the material balance approach for estimating reserves increases with production and pressure decline

Difficulty arises in evaluating the sands due to non-volumetric type behaviour because of regional water influx or layered reservoir characteristics, heterogeneous reservoir effects such as reservoir compartmentalization, non-uniform regional or zonal depletion levels, and production from wells drilled in different portions of reservoir at different times.

The general form of the material balance equation was first presented by Schilthuis in 1941. The equation is derived as a volume balance, which equates the cumulative observed production, expressed as an underground withdrawal, to the expansion of the fluids in the reservoir resulting from a finite pressure drop. The volume balance can be evaluated in reservoir barrels as:

Underground withdrawal (rb) = Expansion of oil and originally dissolved gas (rb)

+ Expansion of gas cap gas (rb)

+ Reduction in HCPV due to connate water expansion and decrease in the pore volume (rb)

The general form of the material balance equation (Dake, 1978):

$$N_p B_o + (G_p - N_p R_s) B_g = NB_{oi} \left(\frac{(B_o - B_{oi}) + (R_{si} - R_s)B_g}{B_{oi}}\right) + G (B_g - B_{gi}) + (NB_{oi} + GB_{gi}) \left(\frac{c_w S_{wc} + c_f}{1 - S_{wc}}\right) \Delta p + (W_e - W_p) \qquad (5.1)$$

When working with gas reservoirs, there is no initial oil; therefore, N and N_p are equal to zero The general material balance for a gas reservoir can then be obtained ·

$$G(B_g - B_{gi}) + GB_{gi}\left(\frac{c_w S_{wc} + c_f}{1 - S_{wc}}\right)\Delta p = G_p B_g - (W_e - W_p) B_w \tag{5.2}$$

For most gas reservoirs, the gas compressibility term is much greater than the formation and water compressibility, and the second term on the left hand side of equation (5 2) becomes negligible,

$$G(B_g - B_{gi}) = G_p B_g - (W_e - W_p) B_w \tag{5.3}$$

When there is neither water encroachment into nor water production from a reservoir of interest, the reservoir is said to be volumetric. For a volumetric gas reservoir, equation (5.3) reduces to

$$G(B_g - B_{gi}) = G_p B_g \tag{5.4}$$

Substituting expressions for B_g and B_{gi} into equation.(5 4) yields ·

$$G\left(\frac{p_{sc} z T}{T_{sc} p}\right) - G\left(\frac{p_{sc} z_i T_i}{T_{sc} p_i}\right) = G_p\left(\frac{p_{sc} z T}{T_{sc} p}\right) \tag{5 5}$$

Noting that production is essentially an isothermal process (i e., the reservoir temperature remains constant), then equation (5.5) is further simplified to

$$G\left(\frac{z}{p}\right) - G\left(\frac{z_i}{p_i}\right) = G_p\left(\frac{z}{p}\right) \tag{5 6}$$

Rearranging :

$$\frac{p}{z} = -\frac{p_i}{z_i G} G_p + \frac{p_i}{z_i} \tag{5.7}$$

Since p_i, z_i, and G are constants for a given reservoir, plotting p/z vs G_p would yield a straight line. If p/z is set equal to zero, which would represent the production of all the gas from a reservoir, than the corresponding G_p equal to G, the initial gas in place. Deviations from this straight line can be caused by external recharge or offset drainage. In water drive reservoirs, the relation between G_p and p/z is not linear, because of the water influx, the pressure drops less rapidly than under volumetric control.

5.2 Different Approaches Used in the Study of Material Balance

Because of critical demand-supply situation, pressure tests are not conducted on a regular interval in Bakhrabad Gas Field, the same prevails elsewhere in the country. In the material balance study, due to non-availability of needed pressure surveys, four approaches have been taken using (a) static bottom hole pressure (SBHP) estimated from shut-in wellhead pressure (b) shut-in wellhead pressure (SWHP) (c) flowing bottomhole pressure (FBHP) of the wells (d) flowing wellhead pressure (FWHP). Data for approach (a) and (b) were recorded during occasional shut-ins due to some production problems or any other reason.

5.2.1 Static Bottomhole Pressure, Estimated from Shut-in Wellhead Pressure:

To record the static bottom-hole pressure or the reservoir pressure by downhole gauge measurement, the well is required to shut-in for a few days for pressure build up. This is not feasible due to critical demand-supply situation. But different wells of the field were shut-in from time to time because of production problems or any other reason and pressure build up data were recorded in these situations. The recorded shut-in wellhead pressure data was taken from monthly records of Bakhrabad Gas Field, BGFCL and corresponding bottomhole pressure were calculated. The calculated static bottomhole pressure is, however, not a substitute for the data recorded from a properly designed well test program, particularly due to the uncertainty of the degree of pressure stabilization achieved during shut-in wellhead pressure measurements. In the absence of any well-test program, this approach can be a good alternative. The following approach is used for estimating shut-in bottomhole pressure from shut-in wellhead pressure.

General equation for vertical flow calculations (Kumar, 1987) is written as follows

$$\int_2^1 \frac{(zT/p)dp}{1+(6.7393\times10^{-4} fLq_{sc}^2 z^2T^2)/(zp^2d^5)} = 0.01875\gamma_g Z \qquad (5.8)$$

where the units are, p = psia; q_{sc} = Mscfd; d = in.; T = ^{0}R; and L, Z = feet (Z is the vertical elevation difference between the bottomhole, inlet point 1 and surface, outlet point 2)

The left integral of equation (5.8) cannot be evaluated easily because z is a complex function of p and T, and the temperature variation with depth is not easily defined.

Various simplifying assumptions made in the evaluation of this integral form the basis for the different methods that give results of varying degrees of accuracy

Some methods for vertical flow assume an average temperature, in which case equation (5.8) becomes :

$$\int_{2}^{1} \frac{(z/p)dp}{1+(6.7393\times10^{-4} fLq_{sc}^{2}z^{2}T^{2})/(zp^{2}d^{5})} = \frac{0.01875\gamma_g Z}{T_{av}} \qquad (5.9)$$

For a shut-in well, the flow rate (q or q_{sc}) is equal to zero, and equation (5 9) simplifies to:

$$\int_{p_{wh}}^{p_{ws}} (zT/p)dp = 0.01875\gamma_g Z \qquad (5\ 10)$$

Equation (5.10) describes the relationship between the pressure measured at the surface (or wellhead), p_{wh}, and the pressure at the bottom, p_{ws}.

In calculating the static bottom hole pressure of the wells, Average Temperature and z-factor Method (Kumar, 1987), is used This method is used to simplify the left-hand side integral in equation (5.10) as :

$$z_{av} T_{av} \int_{p_{wh}}^{p_{ws}} (dp/p) = 0\ 01875\gamma_g Z \qquad (5\ 11)$$

Upon integration :

$$\ln \frac{p_{ws}}{p_{wh}} = \frac{0\ 01875\gamma_g Z}{z_{av} T_{av}} \qquad (5\ 12)$$

or,

$$p_{ws} = p_{wh} \exp[\frac{0.01875\gamma_g Z}{z_{av} T_{av}}] \tag{5.13}$$

Generally this is written as

$$p_{ws} = p_{wh}\, e^{s/2} \tag{5.14}$$

where $s = (0.0375\gamma_g Z)/(z_{av} T_{av})$ (5.15)

To determine the average temperature, the bottom-hole temperature and the surface temperature should be known. For static column of gas, an arithmetic average temperature is satisfactory to use. For calculating z_{av}, the average pressure is required (in addition to average temperature). Thus a trial and error type solution is necessary. A good initial estimate of p_{ws} can be made using equation (Kumar, 1987):

$$p_{ws} = p_{wh} + 0.25\,(\frac{p_{wh}}{100})(\frac{Z}{100}) \tag{5.16}$$

The FORTRAN program calculating the p/z values of SBHP from the recorded SWHP is shown in Appendix-I

5.2.2 Shut-in Wellhead Pressure :

In this approach field recorded shut-in wellhead pressure are used to make a p/z vs cumulative production plot. The approach is based on the assumption that there is no liquid in the wellbore. For the material balance study, p/z term has been calculated by the means of calculating the z-factor using Hall and Yarborough (1973) correlation.

FORTRAN program for calculating the z-factors for the given pressure is presented in Appendix-I.

Since static gas gradient is very small, the plots set out for p/z using the shut-in wellhead pressure vs cumulative production for various sands of Bakhrabad Gas Field, should provide quite acceptable results. This method will yield erroneous results if there is a liquid build up in the tubing.

5.2.3 Flowing Bottomhole Pressure of the Wells :

Theoretically it has been understood for many years that original gas in place can be estimated using measured gas volumes and flowing pressures. This method is based on the pseudosteady state pressure behaviour, which requires that the rate of change of pressure at every location of the reservoir is constant. It can also be assumed that after the attainment of the pseudosteady state the rate of change of the average reservoir pressure is also constant as production continues. Mattar and McNeil (1998) illustrated that original gas in place can be determined from the flowing data (pressure and production). These authors have opined that it is possible to determine original gas in place with reasonable certainty when shut-in pressure are not available. This procedure requires the flowing sand face pressure at the wellbore to be measured for plotting p_{wf}/z vs cumulative production. A straight line drawn through the flowing sand face pressure data and then a parallel line from the initial reservoir pressure gives the original gas in place. The method of calculating the reserves of medium and high permeability reservoirs, from flowing pressure data have the potential of preventing loss of valuable production, without having to shut-in the well.

The method is specially suitable for Bakhrabad Gas Field as well as for other gas fields of Bangladesh where routine pressure testing can not be conducted due to critical demand-supply situation

The flowing bottomhole pressure is calculated from the monthly representative flowing wellhead pressure and the monthly average gas flow rate of different wells, using the software Pipesim 3.08 (1998). The recorded flowing wellhead pressure data was taken from monthly records of Bakhrabad Gas Field, BGFCL. For the material balance study, z-factor for the p/z term is calculated using the same FORTRAN program as in the shut-in wellhead pressure case

5.2.4 Flowing Wellhead Pressure:

In this approach monthly average flowing wellhead pressure data are used. The z-factor for the p/z term is calculated using the same FORTRAN program as in the shut-in wellhead pressure The flowing wellhead pressure data was taken from monthly records of Bakhrabad Gas Field. BGFCL.

Mattar and McNeil demonstrated in the "flowing" material balance method that the wellhead pressure also has a similar trend of decline as the sand-face pressure This is true when single phase gas flows through the well and there is no liquid build up in the tubing While studying the plots for p/z of FWHP vs cumulative production, it has been observed that the apparent gas in place figures of the various sands of Bakhrabad Gas Field are lower than those obtained from static bottomhole pressure and shut-in wellhead pressure methods This makes sense because flowing wellhead pressure decreases from the shut-in wellhead pressure because of frictional losses. The straight line drawn from the initial wellhead pressure in parallel to the flowing wellhead pressure data gives the original gas in place

In this study interference in pressure data due to production of other wells of the sand, will affect the accuracy of the results.

5.3 Discussion on Sand-wise Material Balance Results

In this section the results of the material balance study using the different approaches have been presented. In the sand-wise discussion gas in place value of all the wells of the sands are evaluated using the four different methods of material balance study, i.e., (1) SBHP (2) SWHP (3) FBHP, and (4) FWHP For all the wells of the different sands and finally for the sand itself gas in place values are estimated from the plot of p/z vs cumulative production. Remaining reserve is calculated from the graphs assuming the abandonment p/z to be 1000 psia. based on SBHP approach.

In recent years, Bakhrabad Gas Field is producing significant amount of water. However, separator is located downstream of the common header, which only gives the total amount of water produced from the field. With this total water production data, it is not possible to find the amount of water produced from the sands and the wells individually. Therefore, water production of the individual wells can not be incorporated in the material balance study.

5.3.1 J Sand

There are four wells in J Sand, i.e., BK 1, BK 6, BK 7 and BK 8. Material balance studies have been conducted at each of these wells using the respective well data All four approaches of material balance study have been applied at each well.

Well BK 1

The p/z vs cumulative production graphs of Well BK 1 for static bottom-hole pressure, shut-in wellhead pressure, flowing bottomhole pressure and flowing wellhead pressure appears in Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5 4 respectively. The initial uptrend of the pressure points of the plots is because of the fact that only BK 1 produced from J Sand during the years 1984 to 1989 Thus pressure declined at a much slower rate initially. But when wells, BK 6, BK 7 and BK 8 came into production in late 1989, the pressure started to fall at a much faster rate.

Gas in place values estimated from the plots of p/z vs cumulative production using the static bottomhole pressure, shut-in wellhead pressure, flowing bottomhole pressure and flowing wellhead pressure approaches are 155.46 BCF, 153 56 BCF, 155 00 BCF and 155.00 BCF respectively.

As of August 1998, the cumulative production from Well BK 1 was 96.7 BCF. Assuming the gas in place value for Well BK 1 as 155.46 BCF, reserve at the abandonment p/z of 1000 psia is 115 BCF. Remaining reserve for this location is 18.3 BCF The recovery of this well till August 1998 is 62.38%.

Figure 5.1 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK1 of J Sand

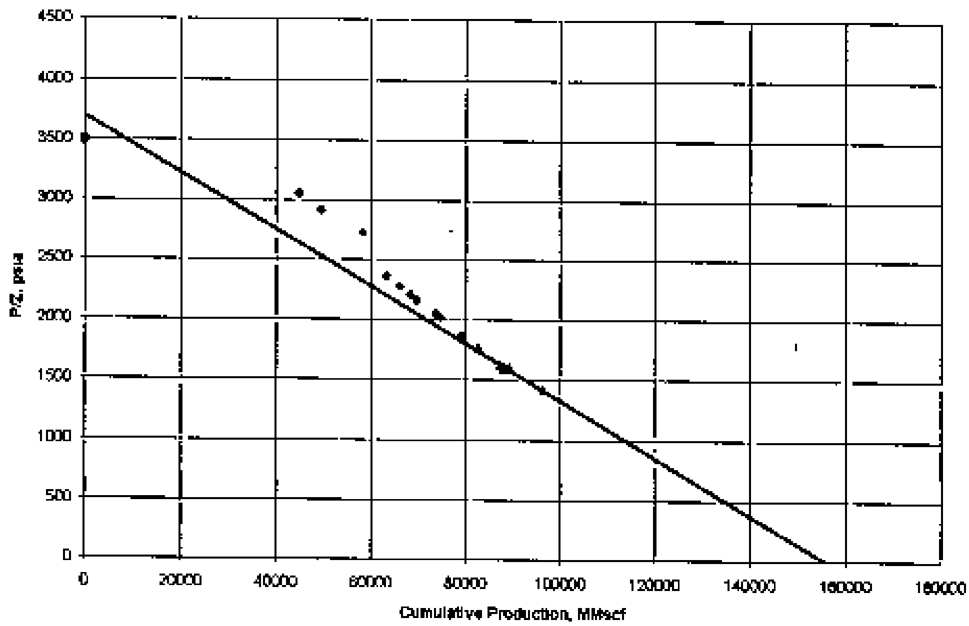


Figure 5.2 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 1 of J Sand

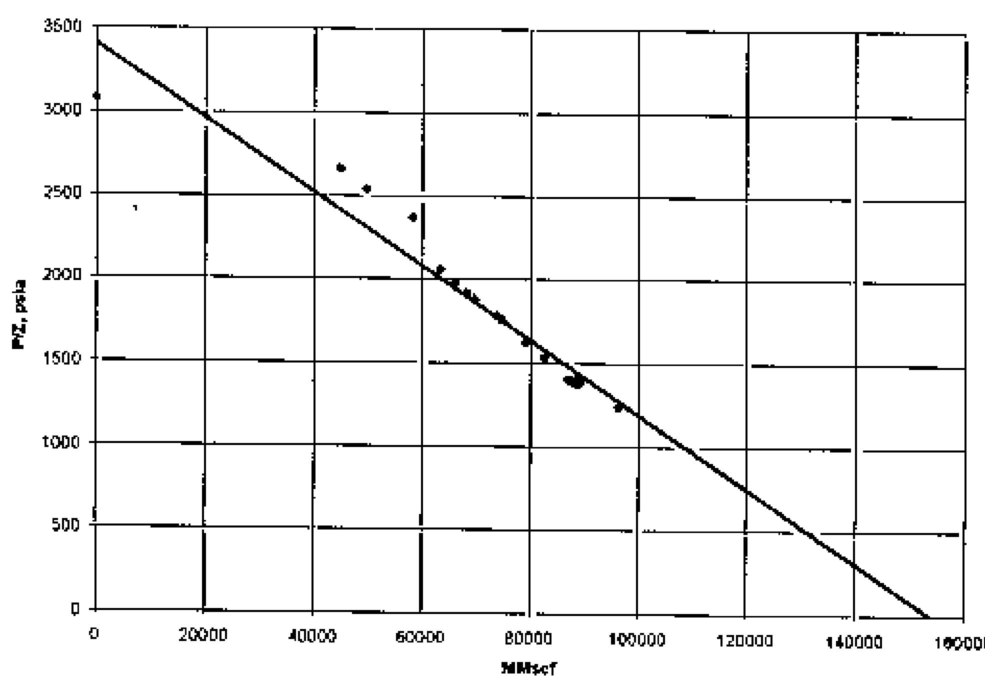


Figure 5.3 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 1 of J Sand

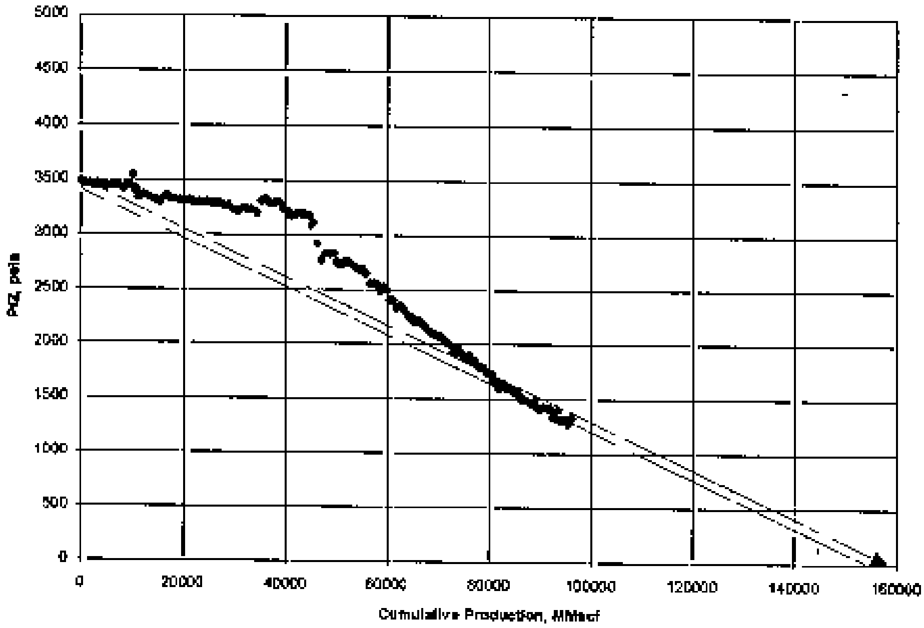
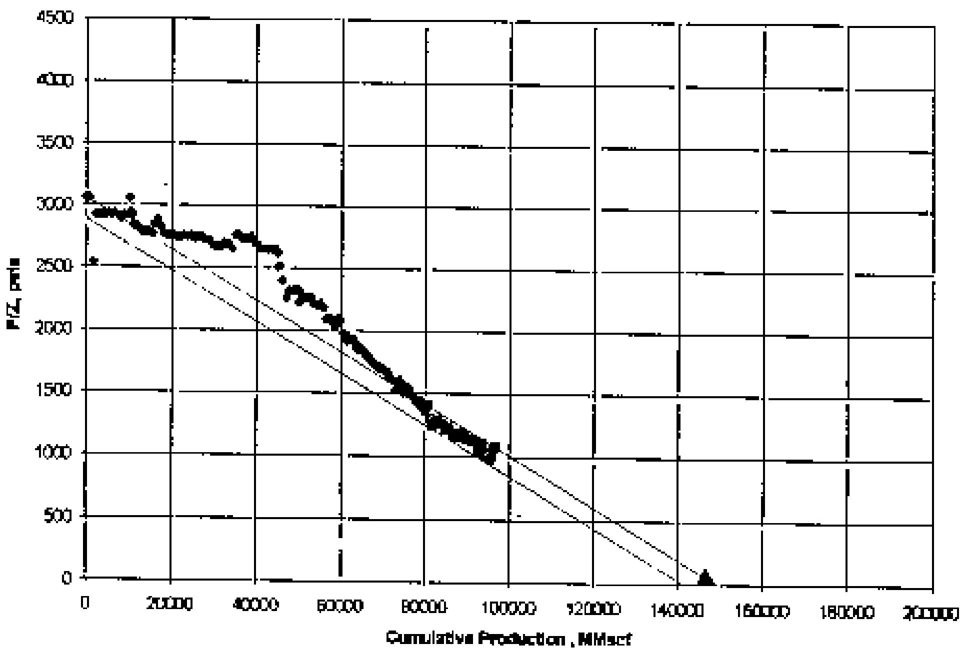


Figure 5.4 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 1 of J Sand



Well BK 6

Figures 5 5 through Figure 5.8 present p/z vs cumulative production graphs of the Well BK 6 for the methods of static bottomhole pressure, shut-in wellhead pressure, flowing bottomhole pressure and flowing wellhead pressure respectively. From the figures it can be estimated that the gas in place values of SBHP, SWHP, FBHP and FWHP are 85.14 BCF, 84.62 BCF, 85.00 BCF and 89.00 BCF, respectively.

As of July 1998, the cumulative production from Well BK 6 was 50 2 BCF. Assuming the gas in place value for the J Sand, Well BK 6 location as 85 14 BCF, reserve at the abandonment *p/z* of 1000 psia is 58 BCF. Remaining reserve for this location is 7.8 BCF. The recovery of this well till July 1998 is 59%. Well BK 6 was watered out in July 1998.

Well BK 7

Figures 5.9 through Figure 5 12 show the material balance plots of the four different approaches of Well BK 7. Gas in place values using methods SBHP, SWHP, FBHP and FWHP are 115.22 BCF, 115 42 BCF, 118 50 BCF and 121.5.00 BCF, respectively.

As of August 1998, the cumulative production from Well BK 7 was 65.8 BCF. Assuming gas in place value for J Sand, Well BK 7 as 115.22 BCF, reserve at the abandonment *p/z* of 1000 psia is 79 BCF Thus the remaining reserve for this location is 13.2 BCF. The recovery of this well till August 1998 is 55.52%.

Figure 5.5 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 6 of J Sand

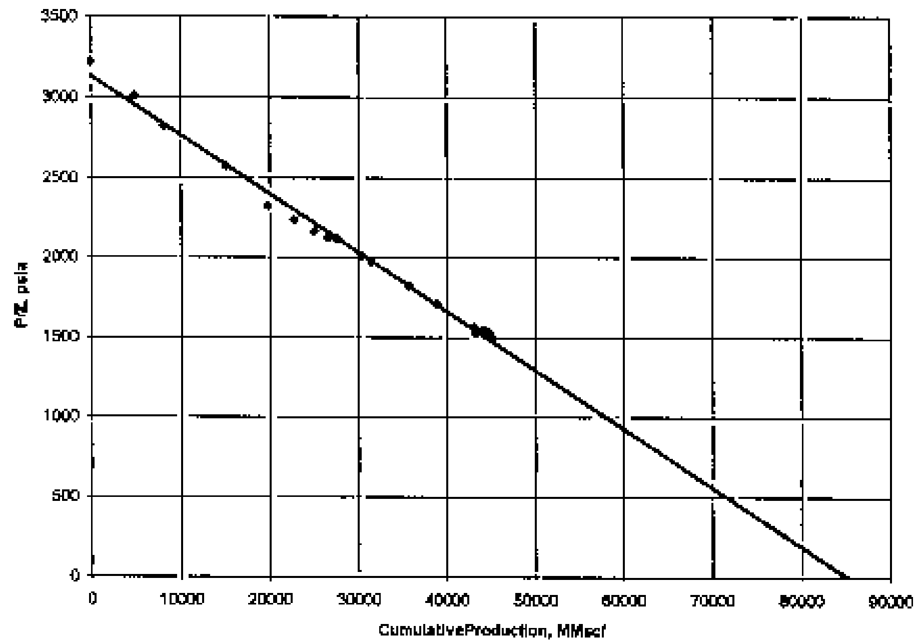


Figure 5.6 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 6 of J Sand

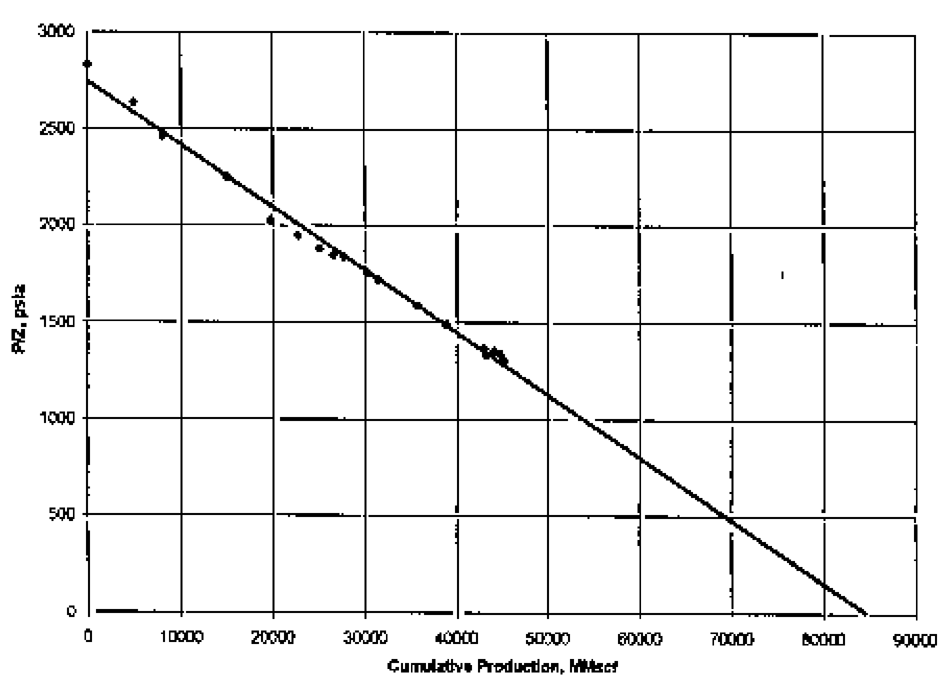


Figure 5.7 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 6 of J Sand

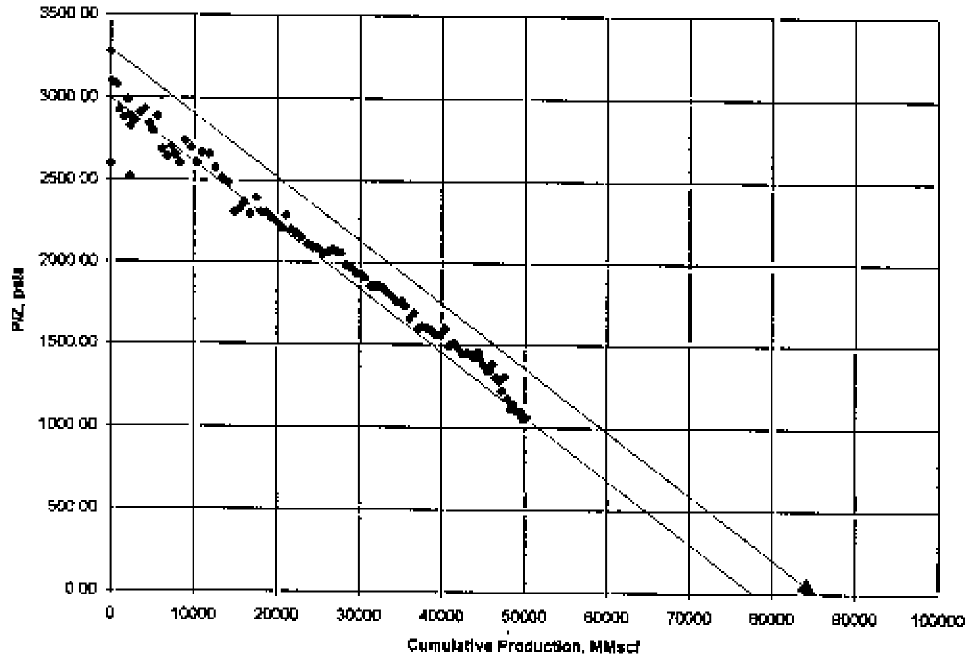


Figure 5.8 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 6 of J Sand

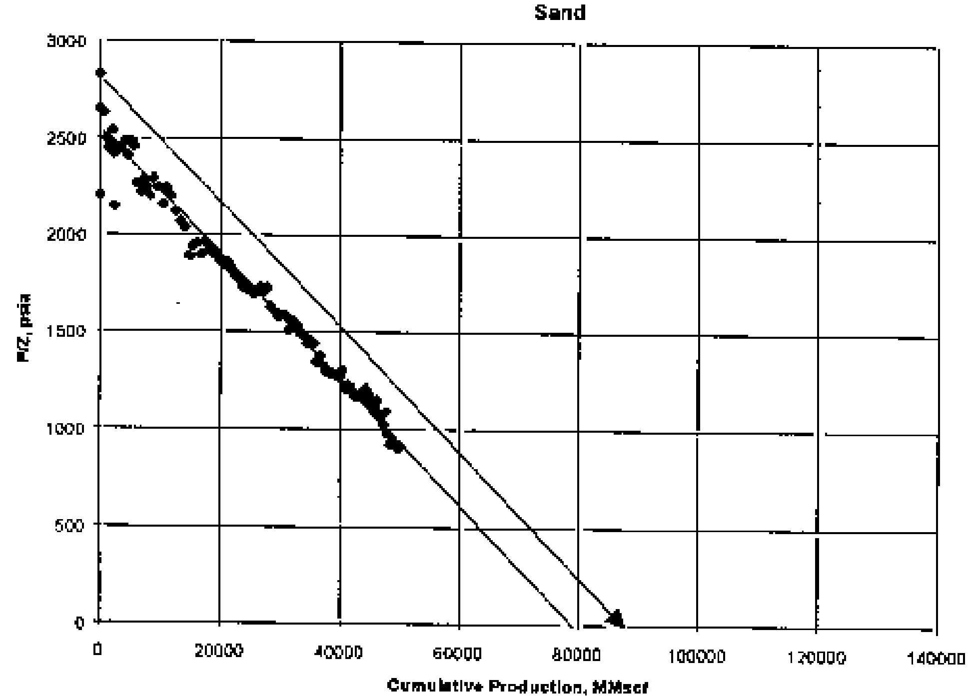


Figure 5.9 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 7 of J Sand

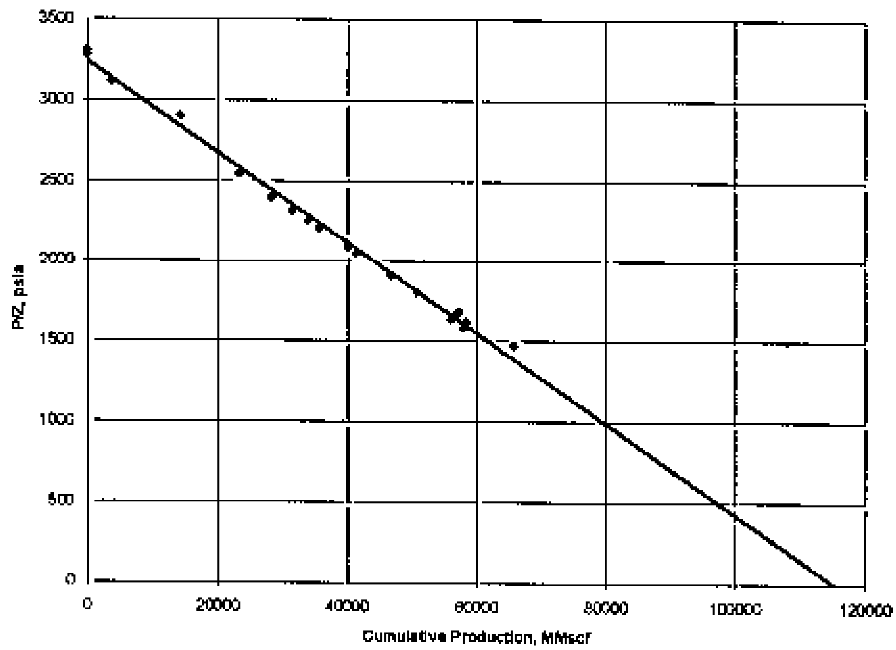


Figure 5.10 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 7 of J Sand

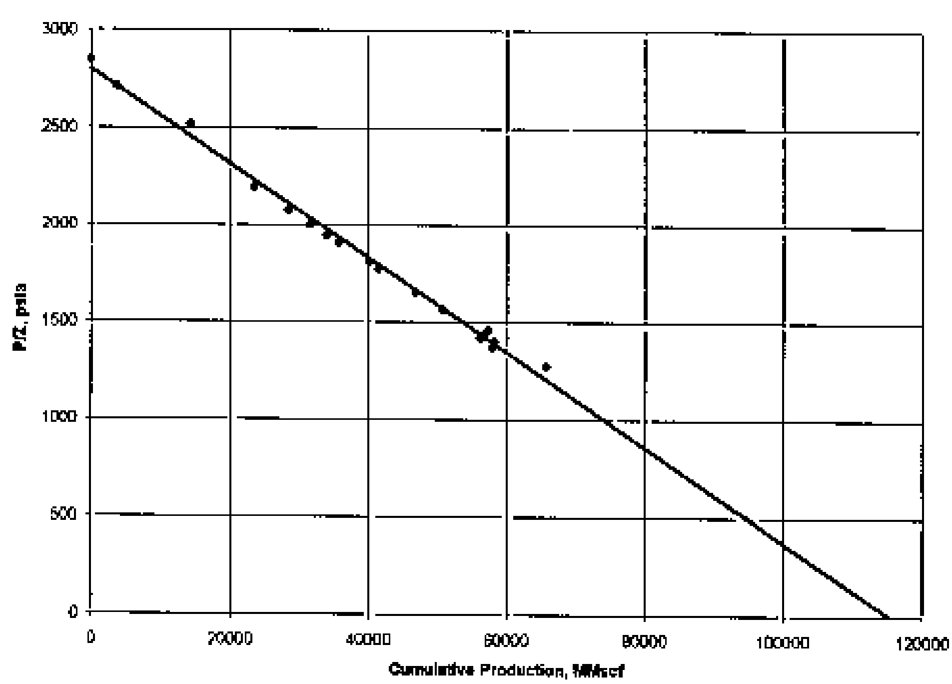


Figure 5.11 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 7 of J Sand

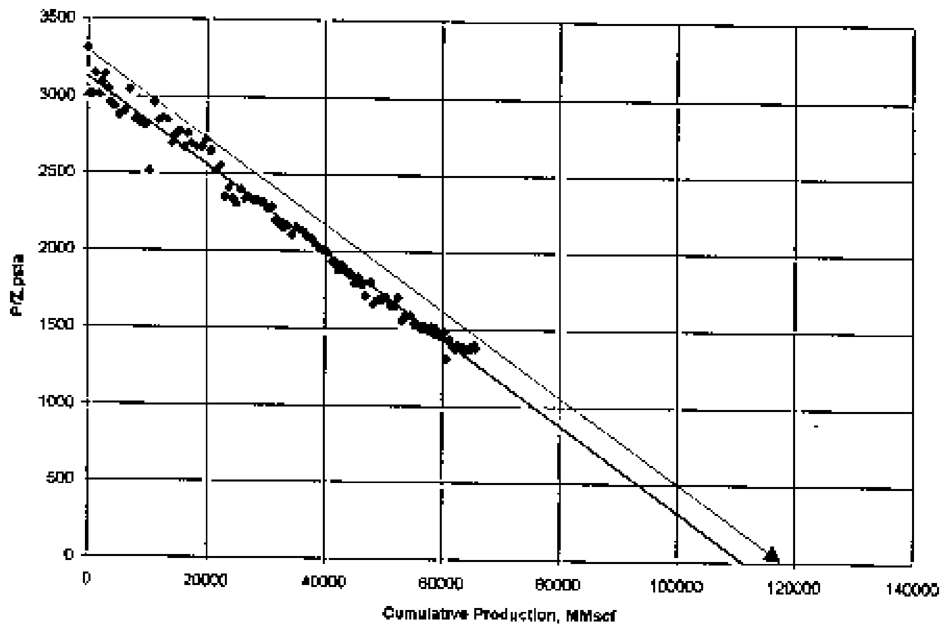
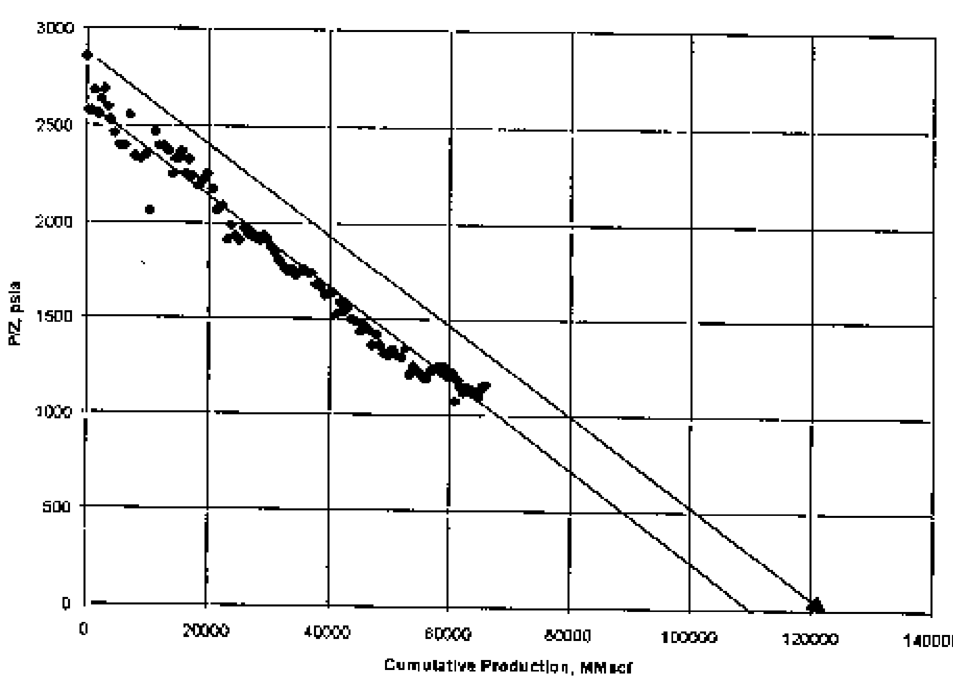


Figure 5.12 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 7 of J Sand



Well BK 8

The *p/z* vs cumulative production plots using the approaches static bottomhole pressure, shut-in wellhead pressure, flowing bottomhole pressure and flowing wellhead pressure of Well BK 8 of J Sand are set out in Figure 5 13, Figure 5.14, Figure 5 15 and Figure 5.16, respectively. Gas in place values of the four approaches are very close and are found to be 99.54 BCF, 100 BCF, 102.00 BCF and 104.00 BCF for the approaches of SBHP, SWHP, FBHP and FWHP, respectively.

As of August 1998, the cumulative production from Well BK 8 was 59.1 BCF. Assuming the gas in place value of Well BK 8 as 99.54 BCF, reserve at the abandonment *p/z* of 1000 psia is 70 BCF Thus the remaining reserve for this location is 10.9 BCF. The recovery of this well till August 1998 is 57.94%.

Table 5.1 presents the gas in place values of J Sand using the four approaches of this study. Based on the results of SBHP approach, gas in place of J Sand would be 455 36 BCF, which is below the gas in place estimates of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997) as shown in Table 5.2. The cumulative production of J Sand till August 1998 is 271.8 BCF. The remaining gas of this sand is 183 56 BCF. Assuming the abandonment *p/z* of J Sand as 1000 psia, the recoverable reserve is 322 BCF and the remaining reserve is 50.2 BCF. Thus, the recovery of J Sand as of August 1998, is 59%

While studying the J Sand differences have been observed in gas in place values estimated at different well locations. This happened because different wells have different

Figure 5.13 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 8 of J Sand

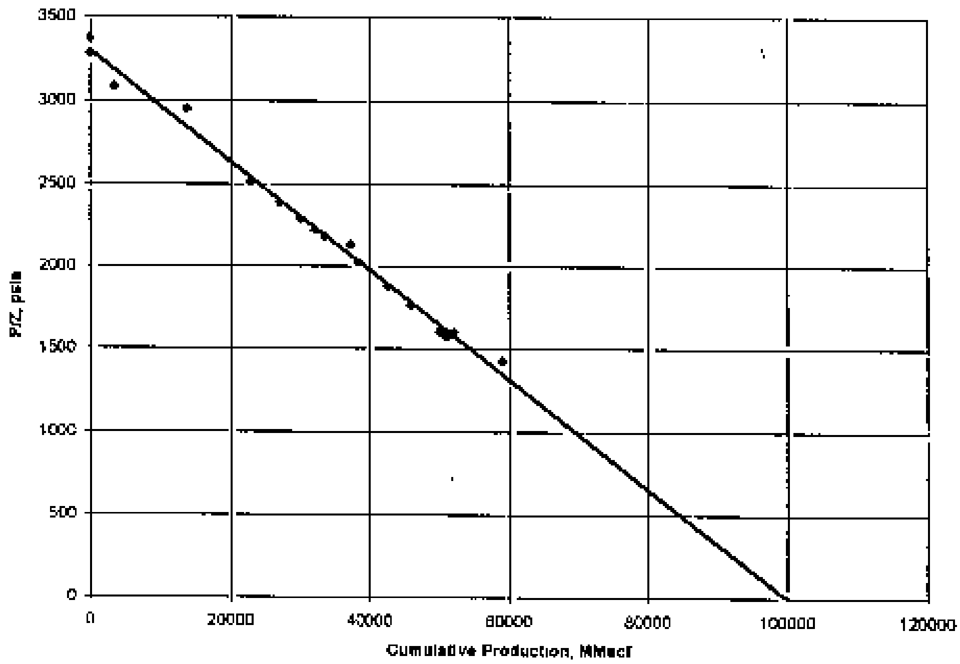


Figure 5.14 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 8 of J Sand

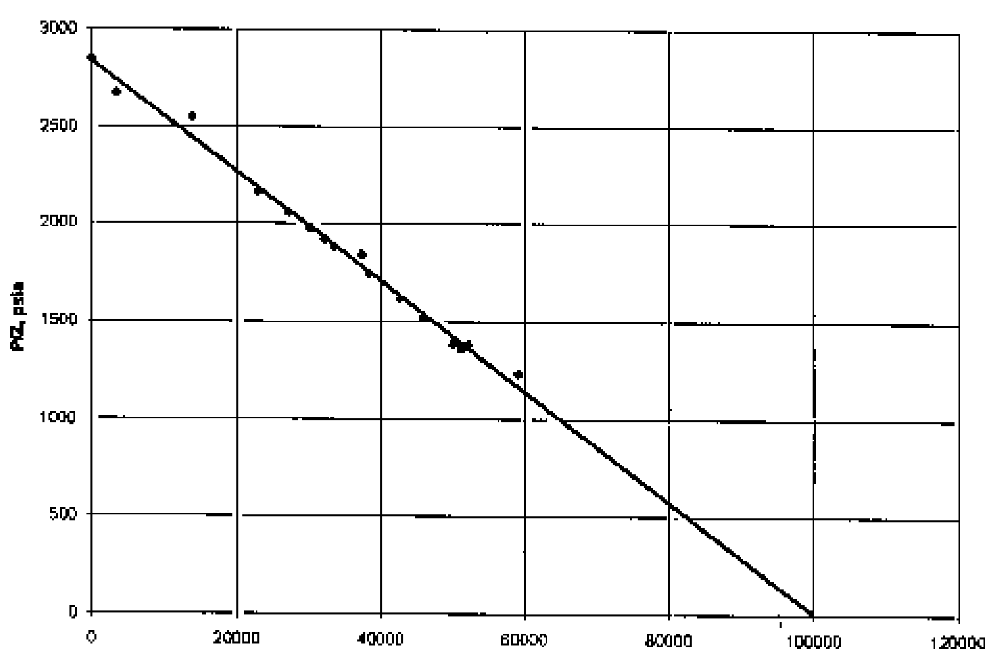


Figure 5.15 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 8 of J Sand

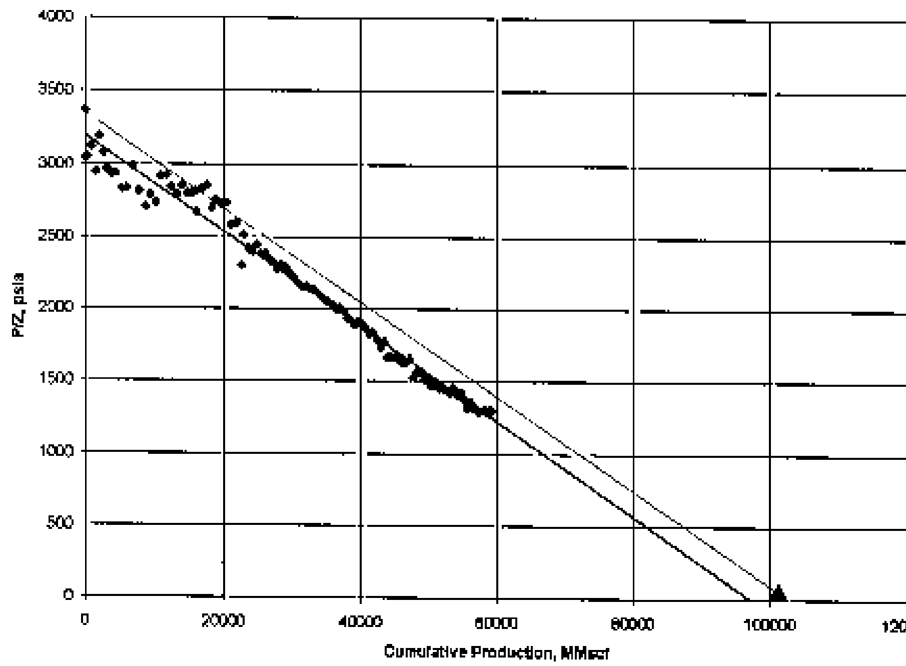


Figure 5.16 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 8 of J Sand

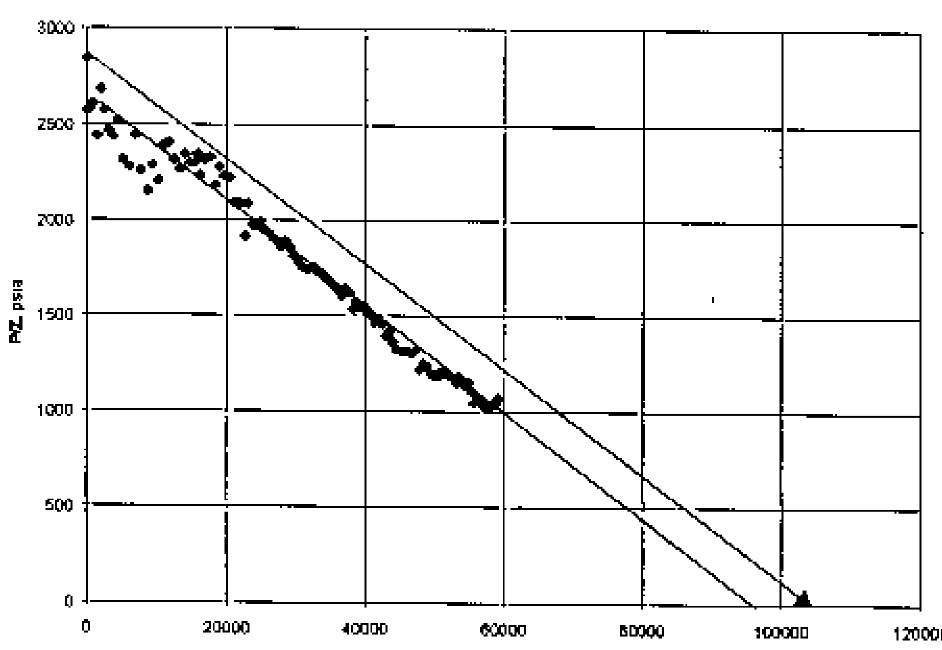


Table 5.1 Present Status of J Sand:

J Sand	OGIP, BCF				Reserve (BCF) (SBHP)	Cum. Prod. (BCF)	Remaining Reserve (BCF)	Recov %
	SBHP	SWHP	FBHP	FWHP				
BK 1	155 46	153.56	155.00	155.00	116	96.7	19 3	62.38%
BK 6	85.14	84.62	85 00	89.00	60	50.2	9.8	59.00%
BK 7	115.22	115.42	118 50	121 50	84	65 8	18.2	55 52%
BK 8	99.54	100 00	102 00	104.00	72	59.1	12.9	57.94%
Total (J)	455.36	453.60	460.50	469.50	332	271 8	60.2	59.00%

Table 5.2 Comparison of gas in place (BCF) estimates of J Sand by different studies using material balance method

Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study (SBHP)
585	597	665	666	455 36

5.3.2 G Sand

G Sand comprises of the wells, BK 3 and BK 4. Well BK 4 was watered out in June 1998 The material balance analysis has been conducted well-wise using the four approaches. The following sections present the results of the analysis.

Well BK 3

The p/z vs cumulative production graphs of SBHP, SWHP, FBHP and FWHP of Well BK 3 are shown in Figures 5.17 through Figure 5.20.

Figure 5.17 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 3 of G Sand

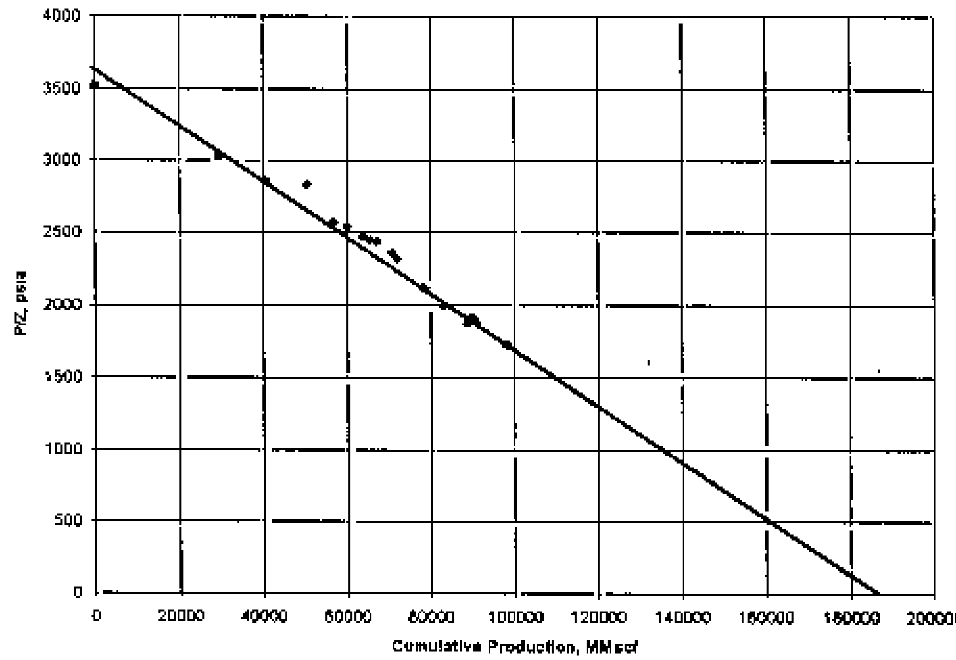


Figure 5.18 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 3 of G Sand

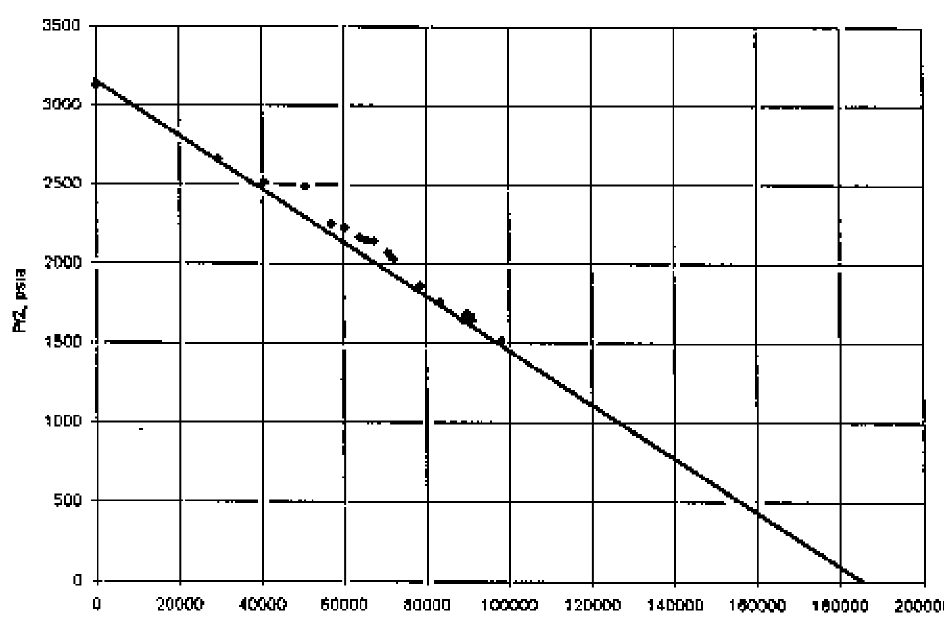


Figure 5.19 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 3 of G Sand

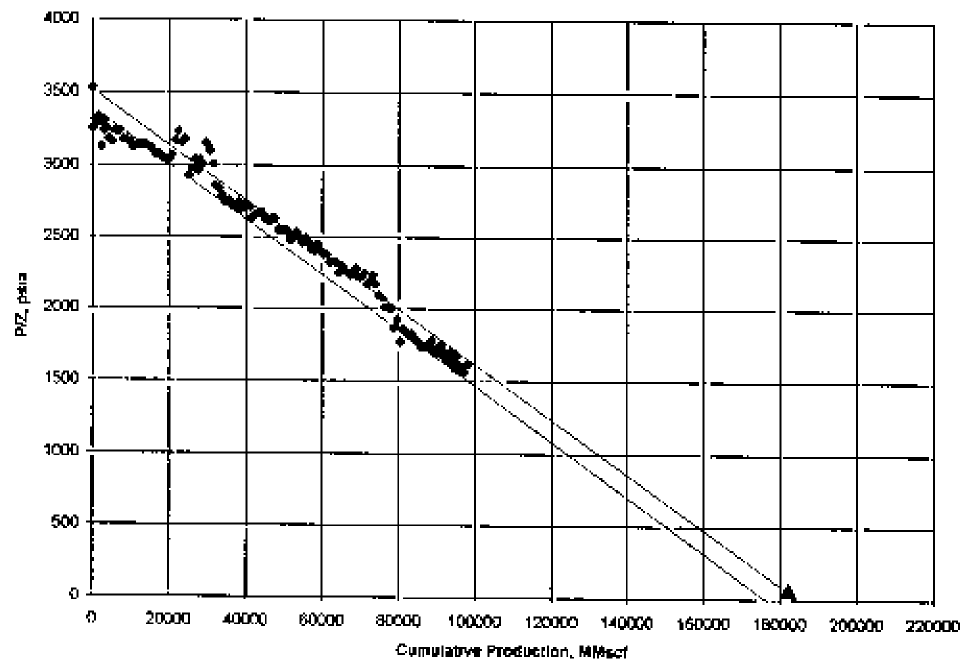
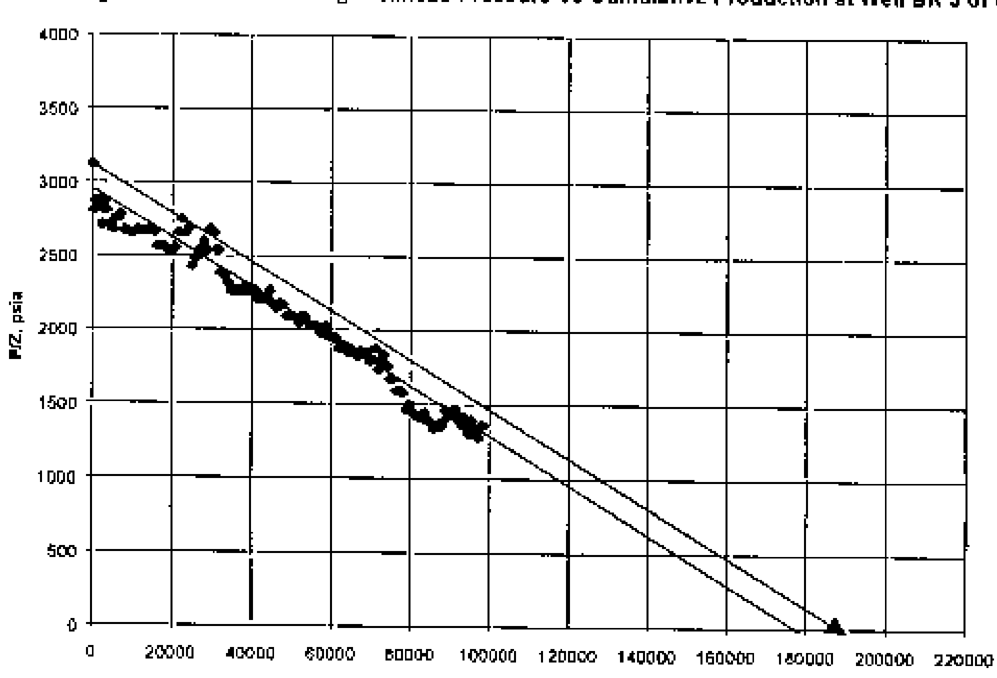


Figure 5.20 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 3 of G Sand



Gas in place values of different methods are very much similar. The approaches of SBHP, SWHP, FBHP and FWHP have yielded a gas in place value of 185.00 BCF, 186.00 BCF, 184.00 BCF and 190.00 BCF, respectively

As of August 1998, the cumulative production from Well BK 3 was 98.3 BCF. Assuming the gas in place value for the G Sand, Well BK 3 location as 185 BCF, reserve at the abandonment p/z of 1000 psia is estimated as 135 BCF. Thus, the remaining reserve for this location is 36.7 BCF. The recovery of this well till August 1998 is 53.14%.

Well BK 4

93700

The p/z graphs of the different approaches of material balance study for Well BK 4 of G Sand appears in Figures 5.21 through Figure 5.24. Well BK 4 of G Sand was watered out in June 1998. Gas in place values of the SBHP, SWHP, FBHP and FWHP approaches are estimated to be 38.50 BCF, 37.50 BCF, 32.00 BCF and 31.00 BCF, respectively

The p/z graph of static bottom-hole pressure of Well BK 4 shows the gas in place to be 38.50 BCF. As on June 1998, the cumulative production from Well BK 4 is 13.5 BCF. Reserve at the abandonment p/z of 1000 psia is 23 BCF. Thus the remaining reserve for this location is 9.5 BCF The recovery of this region of the reservoir till June 1998 is 35%.

Gas in place value of G Sand assuming SBHP approach is estimated to be 223.50 BCF, which is below the gas in place estimates of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997). Table 5.3 shows the GIP estimated by the four approaches

Figure 5.21 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 4 of G Sand

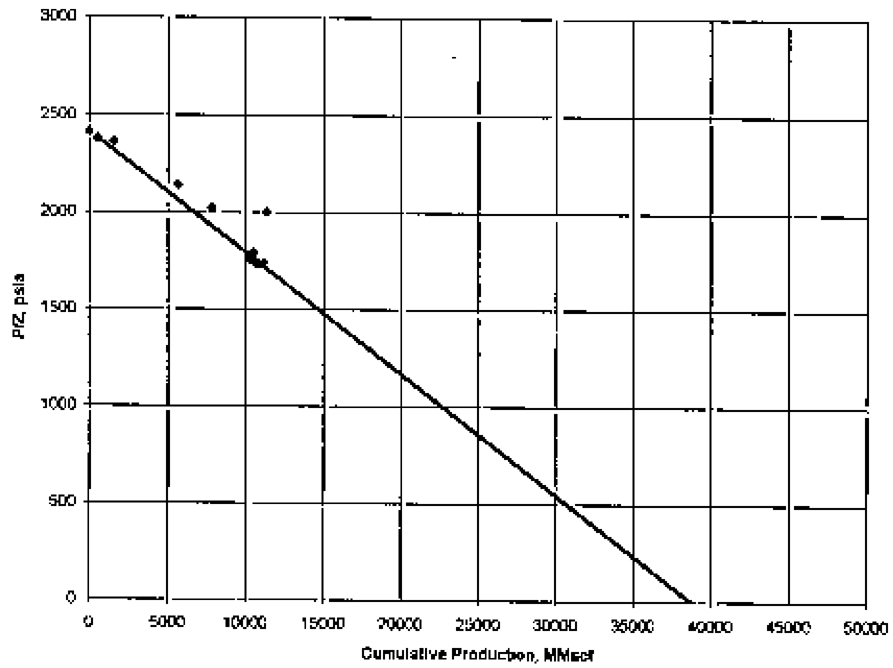


Figure 5.22 P/Z of Shutin Wellhead Pressure Vs Cumulative Production at Well BK 4 of G Sand

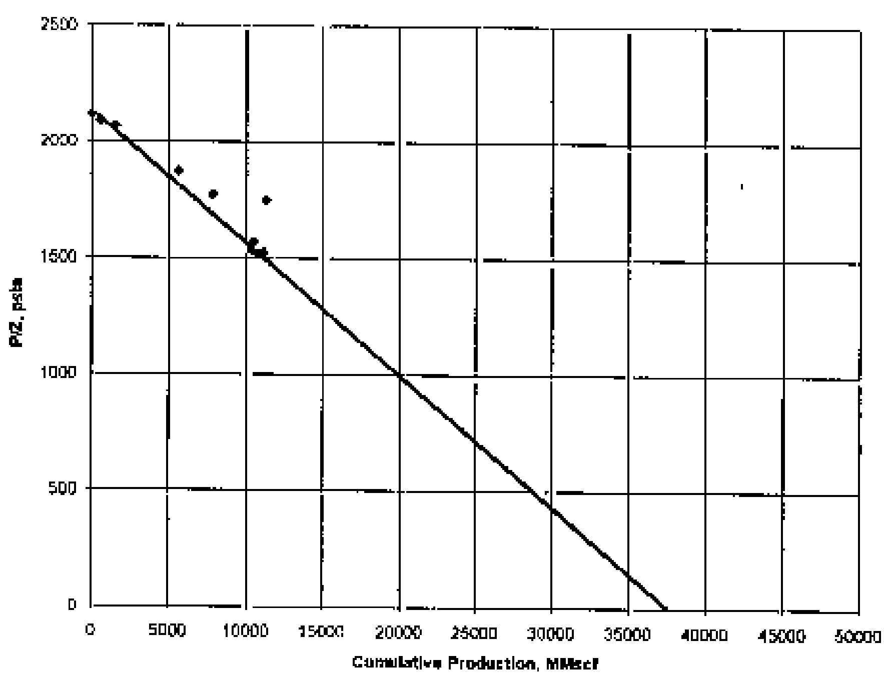


Figure 5.23 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 4 of G Sand

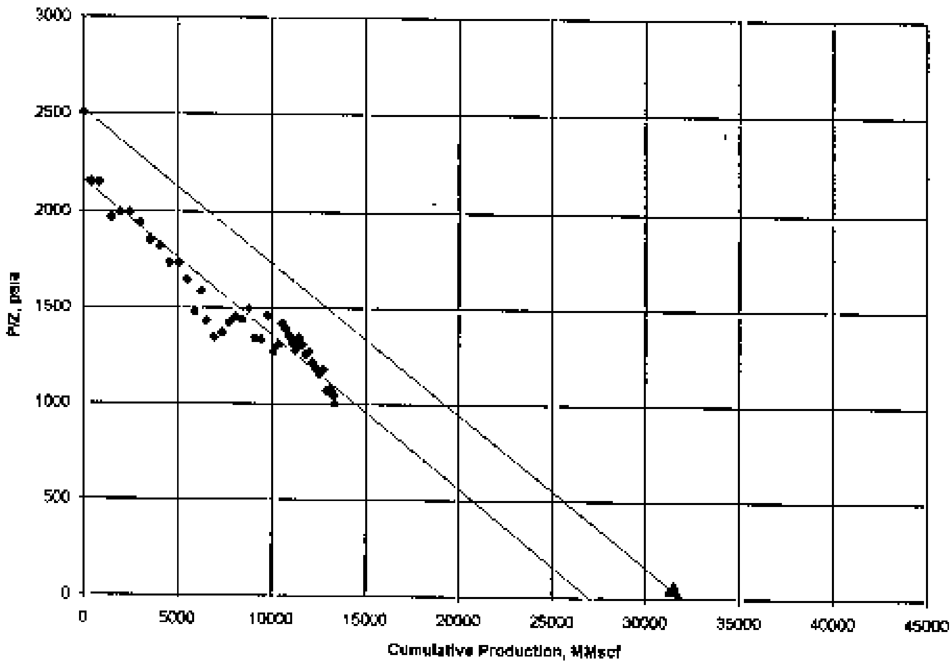
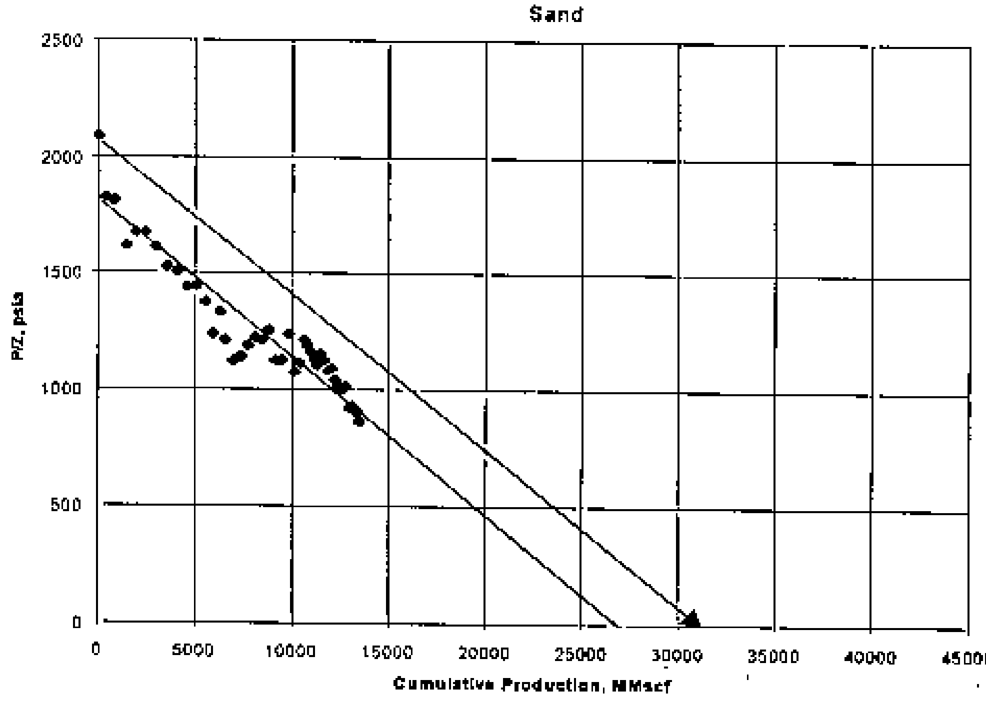


Figure 5.24 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 4 of G Sand



along with remaining reserve and recovery. The cumulative production of this sand till August 1998 was 111.8 BCF The remaining gas in place of this sand is 111 80 BCF. Assuming the abandonment p/z of G Sand as 1000 psia, the recoverable reserve is 158 BCF and the remaining reserve is 46.2 BCF. Thus, the recovery of G Sand is 50%. Table 5.4 compares the GIP estimated by this study with that of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997). GIP estimates of Welldrill and IKM are considerably higher than this study, but GIP estimates of Petrobangla (1993), Mobil (1997) and this study are very close

Table 5.3 Present Status of G Sand:

G Sand	OGIP, BCF				Reserve (BCF) (SBHP)	Cum. Prod. (BCF)	Remaining Reserve (BCF)	Recov %
	SBHP	SWHP	FBHP	FWHP				
BK 3	185.00	186 00	184.00	190.00	135	98.3	36.7	53 14%
BK 4	38 50	37.50	32.00	31 00	23	13.5	9.5	35%
Total (G)	223 50	223.50	216.00	221.00	158	111.8	46.2	50%

Table 5 4 Comparison of gas in place (BCF) of different studies conducted on G Sand·

Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study (SBHP)
370	318	245.5	244	223.50

5.3.3 DL Sand

DL Sand is produced by wells, BK 2 and BK 5. Well BK 5 was watered out in May 1997. Material balance study has been conducted on both these wells using the four approaches.

Well BK 2

The *p/z* vs cumulative production graphs of the four different approaches for Well BK 2 of DL Sand is presented in Figures 5.25 through Figure 5.28 Gas in place values of SBHP, SWHP, FBHP and FWHP approaches are 118.0 BCF, 118 0 BCF, 120 BCF and 120 BCF, respectively .

As of August 1998, the cumulative production from Well BK 2 is 76.5 BCF. Assuming the abandonment *p/z* to be 1000 psia, the recoverable reserve is 84 BCF and the remaining reserve is 7.5 BCF. Thus, the recovery from this region of this well is 64.83%.

Well BK 5

The *p/z* vs cumulative production of four different approaches for this well are presented in Figures 5.29 through Figure 5.32. Gas in place values of the different methods are very close. The gas in place values of SBHP, SWHP, FBHP and FWHP are estimated to be 27.54 BCF, 27 54 BCF, 25.00 BCF and 27.50 BCF, respectively.

As of August 1998, the cumulative production of Well BK 5 is 8.9 BCF. As obtained from SBHP approach gas in place value of Well BK 5 is assumed to be 27.54 BCF. Assuming the abandonment *p/z* to be 1000 psia, the recoverable reserve is 14 BCF and the remaining reserve is 5 1 BCF. Thus, the recovery from this region of this well is 32.32%.

Table 5.5 shows the GIP estimates of the four approaches of wells, BK 2 and BK 5, along with their remaining reserve and recovery. The gas in place estimate of the two wells

Figure 5.25 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 2 of DL Sand

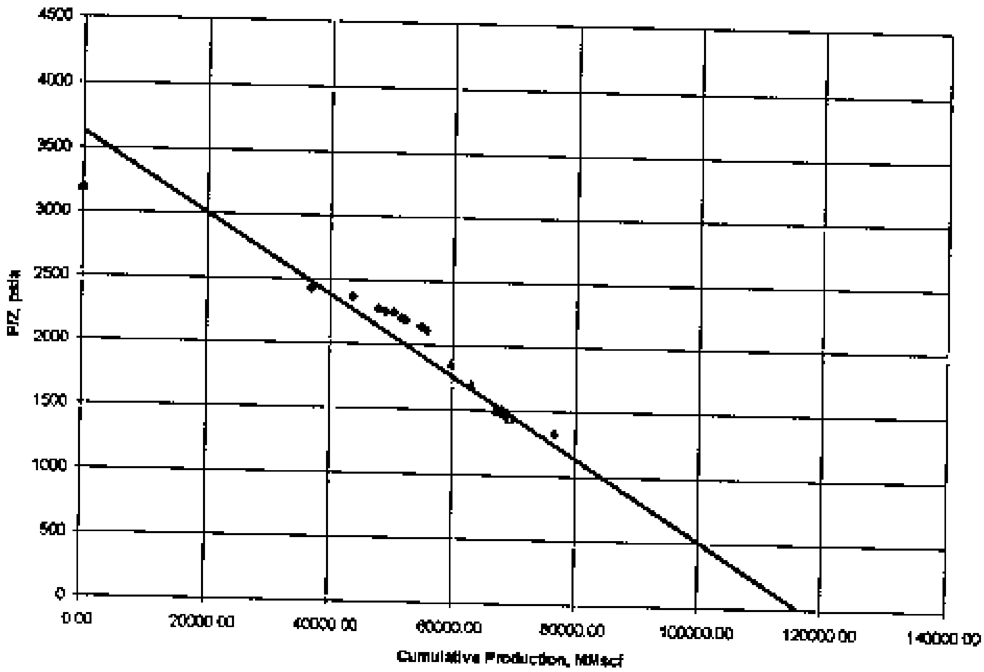


Figure 5.26 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 2 of DL Sand

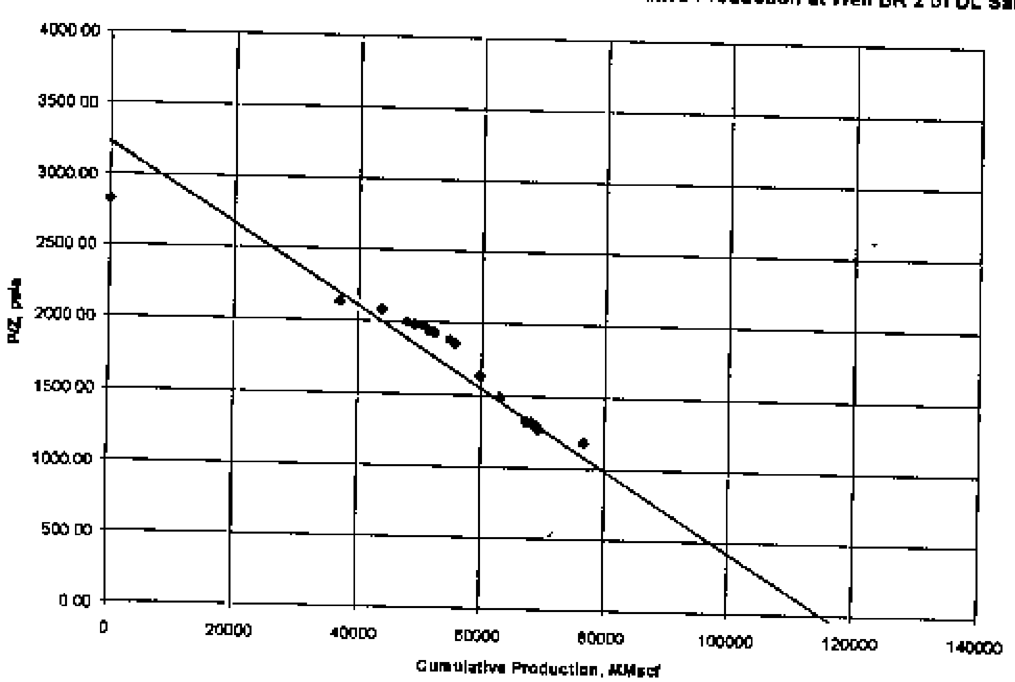


Figure 5.27 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 2 of DL Sand

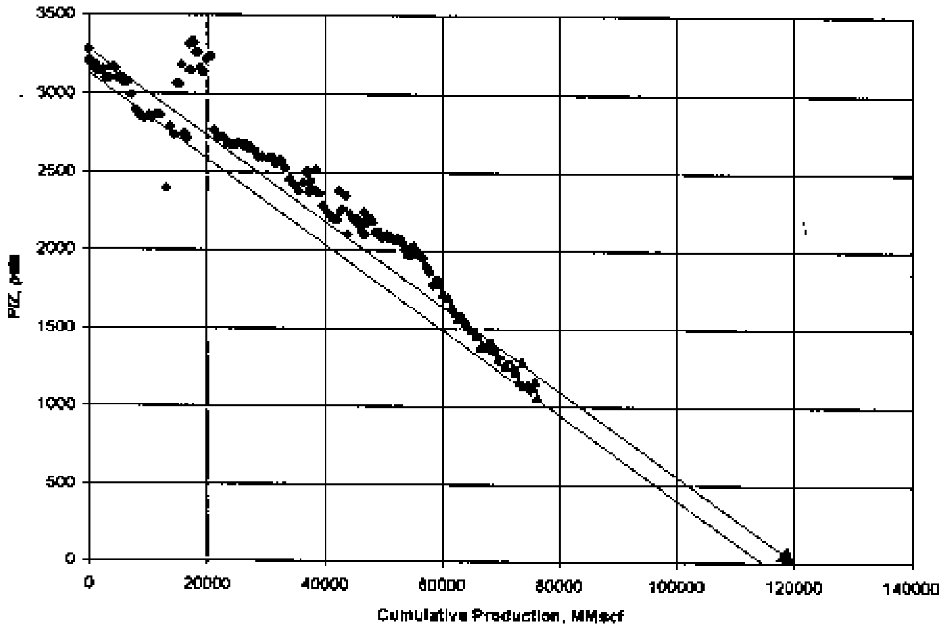


Figure 5.28 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 2 of DL Sand

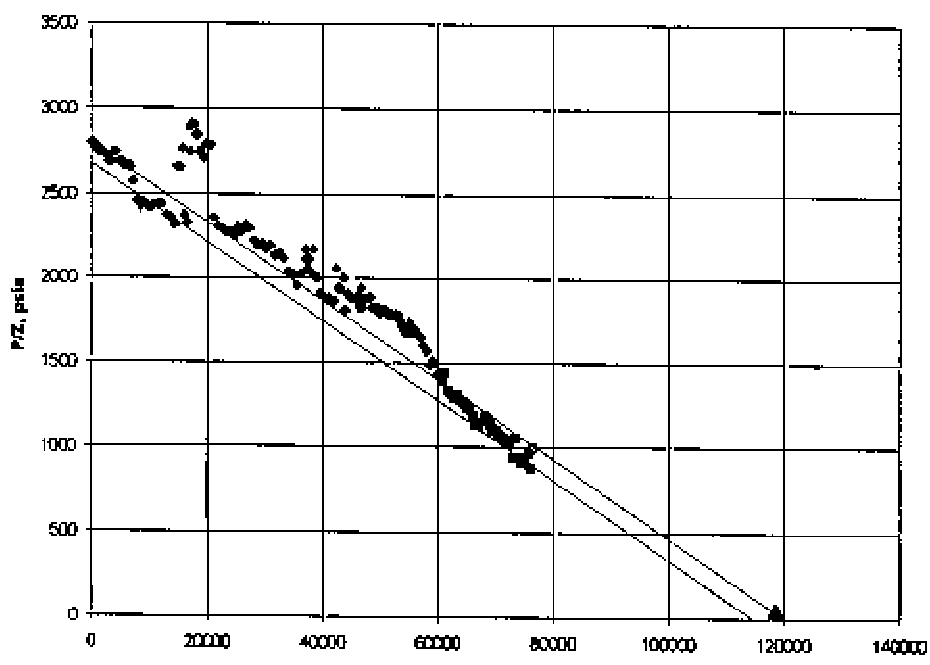


Figure 5.29 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 5 of DL Sand

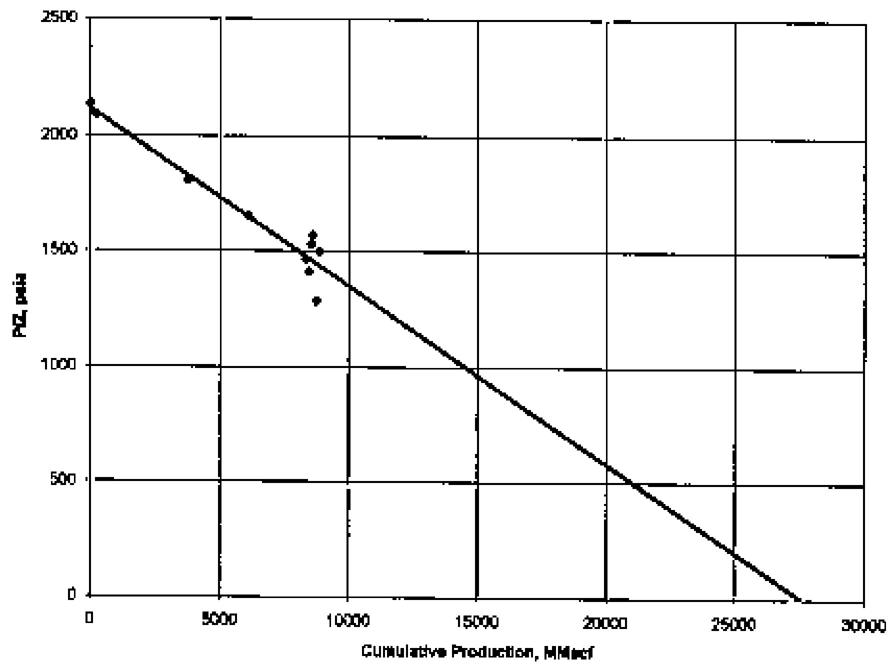


Figure 5.30 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 5 of DL Sand

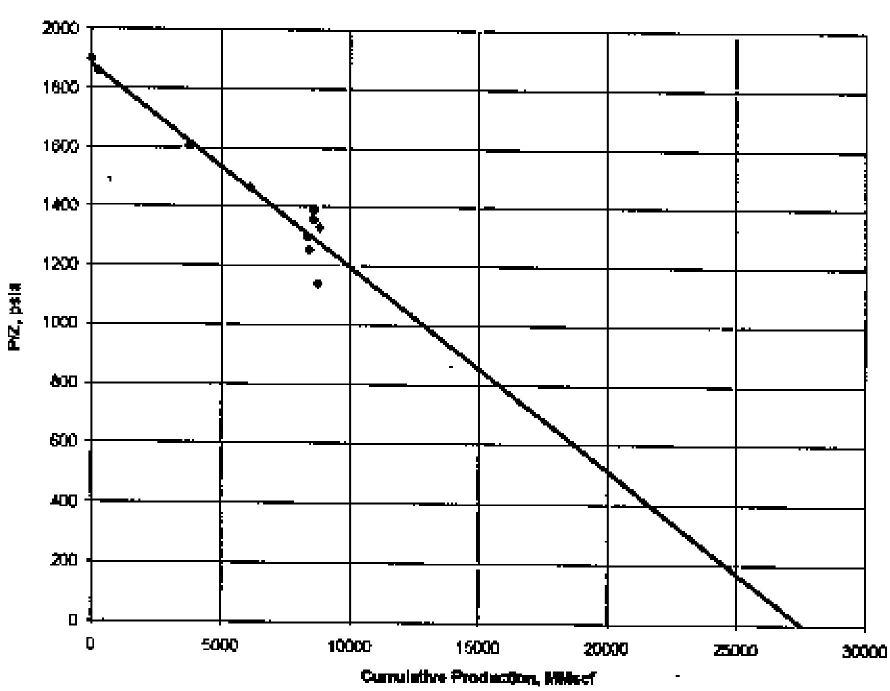


Figure 6.31 P/Z of Flowing Bottomhole Pressure Vs Cumualtive Production at Well BK 5 of DL Sand

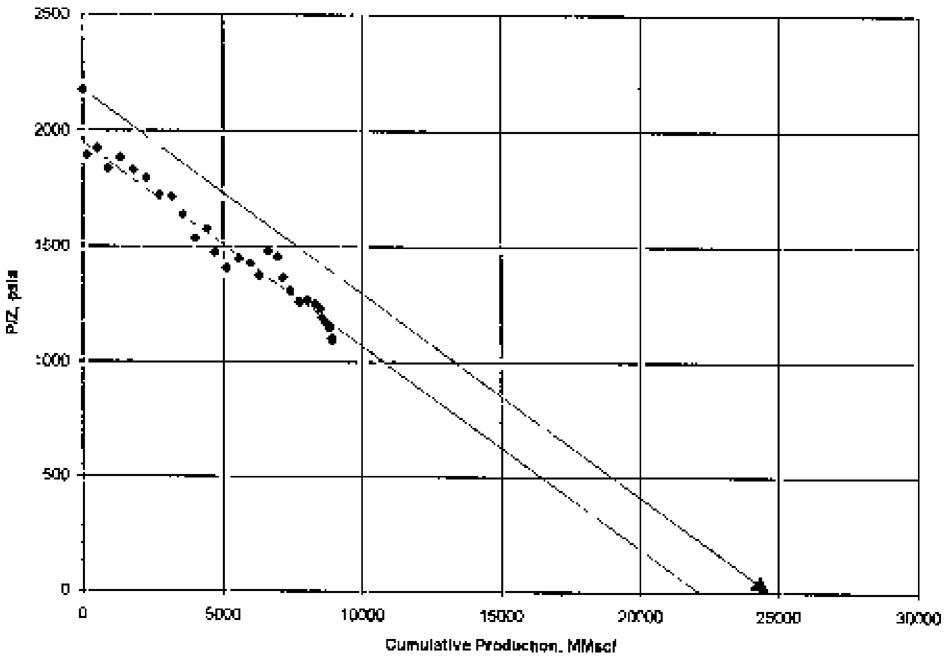
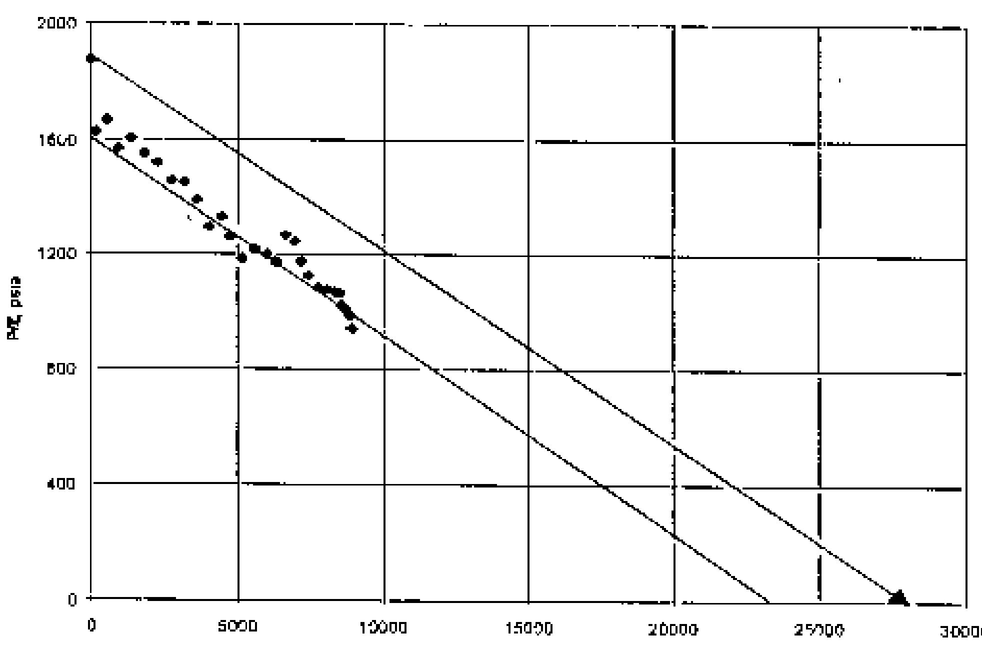


Figure 6.32 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 5 of DL Sand



considering the static bottom-hole pressure approach is 145.54 BCF The cumulative production of the sand till August 1998 was 85.4 BCF The remaining gas in place of this sand is 60.14 BCF Assuming the abandonment p/z of DL Sand as 1000 psia, the recoverable reserve is 98 BCF and the remaining reserve is 12.6 BCF Thus, the recovery of DL Sand is 58.68%. Table 5 6 compares the GIP estimate of this study with that of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997). Estimate of this study is very close with that of IKM, although estimates of Welldrill, Petrobangla and Mobil are a bit higher

Table 5 5 Present Status of DL Sand

DL Sand	OGIP, BCF				Reserve (BCF) (SBHP)	Cum Prod (BCF)	Remain. Reserve (BCF)	Recov. %
	SBHP	SWHP	FBHP	FWHP				
BK 2	118.00	118 00	120.00	120 00	84	76 5	7.5	64.83%
BK 5	27 54	27 54	24.50	27.50	14	8.9	5.1	32.32%
Total (DL)	145 54	145.54	144.50	147 50	98	85 4	12.6	58 68%

Table 5 6 Comparison of gas in place (BCF) estimates of different studies conducted on DL Sand

Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study (SBHP)
200	148	176	175	145.54

5.3.4 DU Sand

DU Sand was produced by Well BK 4. This well was watered out in October 1992. The p/z vs cumulative production graphs of four different methods are set out in Figures 5.33 through Figure 5.36 Gas in place values of the four different approaches show the same value and is 150 BCF

Till October 1992, this sand produced a total of 42.4 MMscf of gas. Assuming the abandonment p/z as 1000 psia the recoverable reserve is 106 BCF Thus, the remaining reserve is 63.6 BCF The percentage of recovery of DU Sand is 28.26%. Table 5.7 shows the GIP estimates of the four approaches of DU Sand, along with the remaining reserve and recovery. Table 5.7 compares the gas in place values of other studies with that of this study.

Table 5.7 Present Status of DU Sand:

DU Sand	OGIP, BCF				Reserve (BCF) (SBHP)	Cum. Prod. (BCF)	Remain. Reserve (BCF)	Recov. %
	SBHP	SWHP	FBHP	FWHP				
BK 4	150.00	150.00	150 00	150.00	106	42.4	63.6	28 26%

Table 5 8 Comparison of gas in place (BCF) estimates of different studies conducted on DU Sand.

Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study (SBHP)
167	180	222.4	187	150

Figure 5.33 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 4 of DU Sand

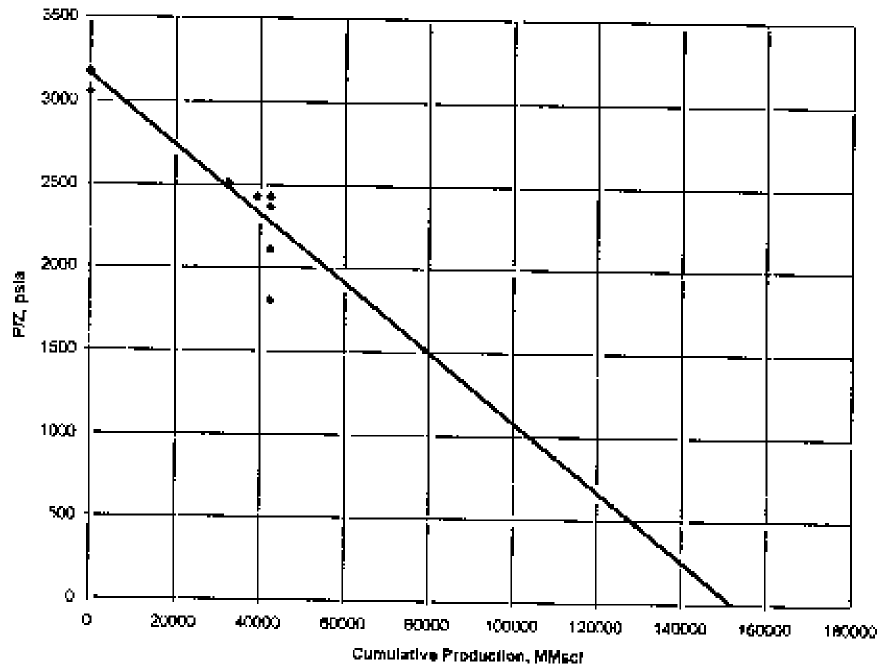


Figure 5.34 P/Z of Shut-In Wellhead Pressure Vs Cumulative Production at Well BK 4 of DU Sand

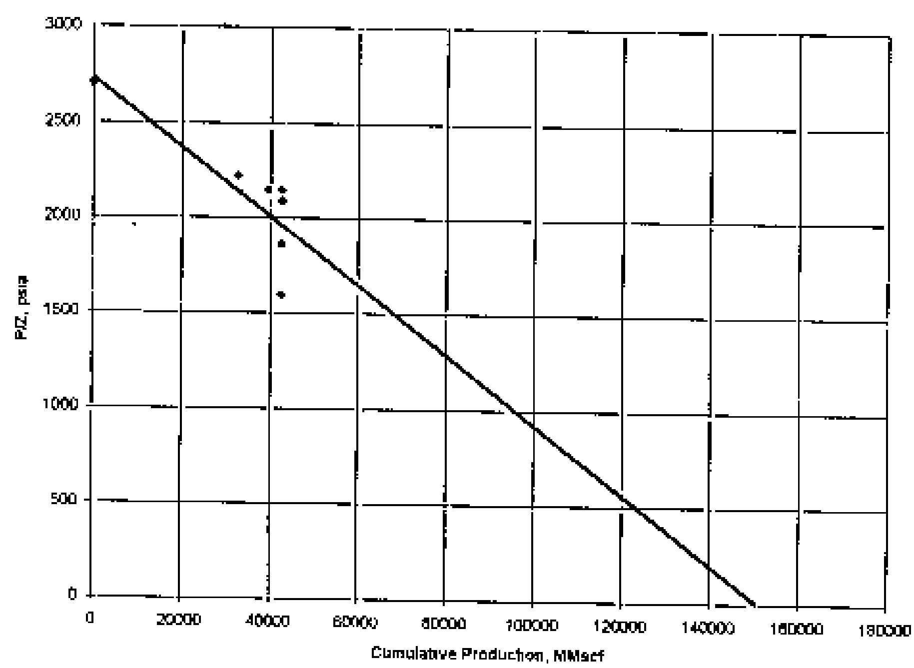


Figure 5.35 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 4 of DU Sand

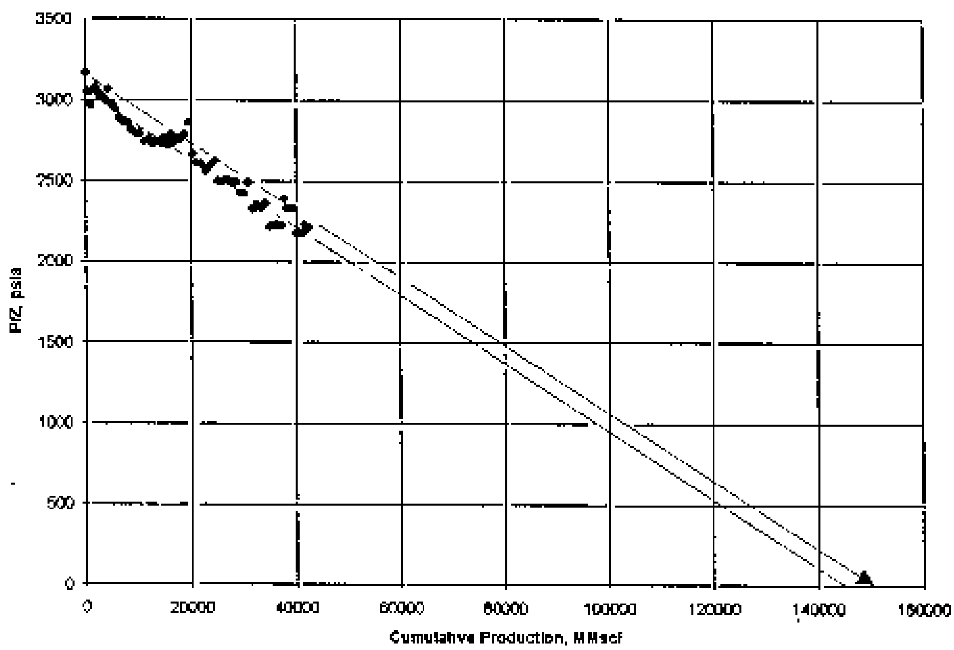
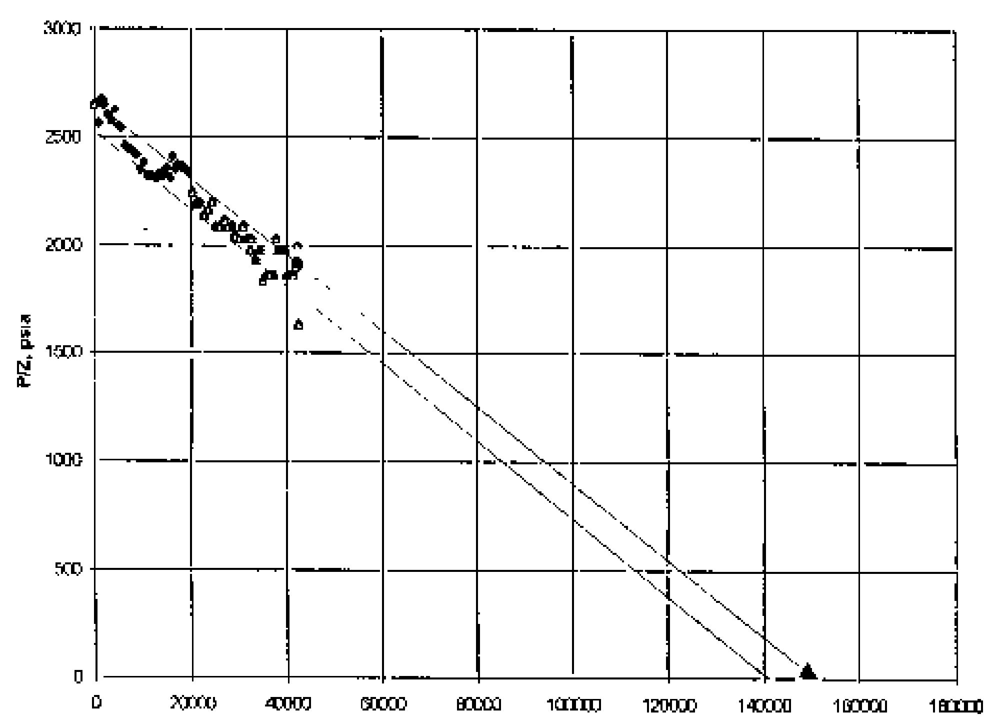


Figure 5.36 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 4 of DU Sand



5.3.5 B Sand

B Sand was produced by Well BK 5. This well was watered out in July 1994 The p/z vs cumulative production plots of Well BK 5 are presented in Figures 5.37 through Figure 5.40. Gas in place values of the four approaches are very close and are found to be 153 00 BCF, 153 00 BCF, 151.00 BCF and 154.00 BCF for the approaches of SBHP, SWHP, FBHP and FWHP, respectively

Till July 1994, this sand produced a total of 42.3 BCF Gas in place value of B Sand is assumed to be 153 BCF. Assuming the abandonment p/z to be 1000 psia, the recoverable reserve is 103 BCF. The remaining reserve is 60 7 BCF. Thus, the percentage of recovery is 27.65% Table 5.9 presents the gas in place values of B Sand using the four approaches of this study Table 5.10 compares the GIP values of this study with that of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997).

Table 5.9 Present Status of B Sand.

DU Sand	OGIP, BCF				Reserve (BCF) (SBHP)	Cum. Prod. (BCF)	Remain Reserve (BCF)	Recov. %
	SBHP	SWHP	FBHP	FWHP				
BK 5	153.00	153.00	151 00	154.00	103	42.3	60 7	27.65%

Table 5.10 Comparison of gas in place (BCF) estimates of different studies conducted on B Sand:

Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study (SBHP)
231	145	166.6	167	153

Figure 5.37 P/Z of Static Bottomhole Pressure Vs Cumulative Production at Well BK 5 of B Sand

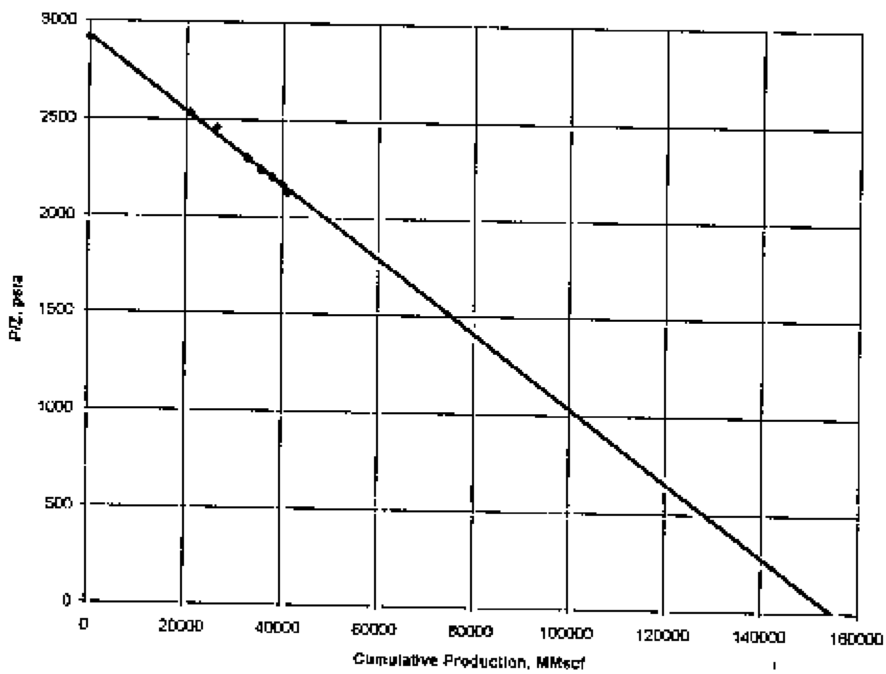


Figure 5.38 P/Z of Shut-in Wellhead Pressure Vs Cumulative Production at Well BK 5 of

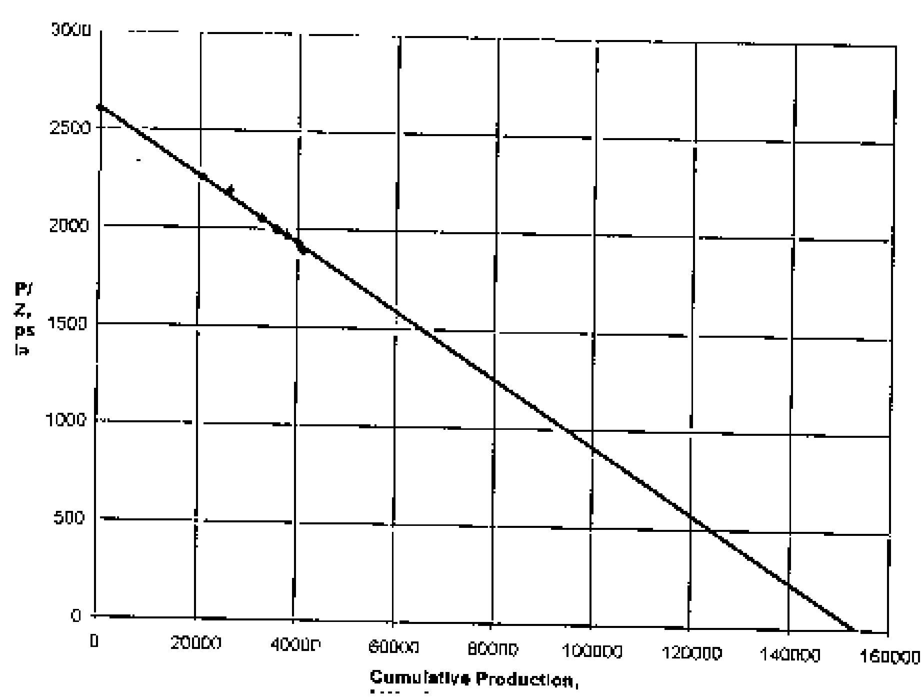


Figure 5.39 P/Z of Flowing Bottomhole Pressure Vs Cumulative Production at Well BK 5 of B Sand

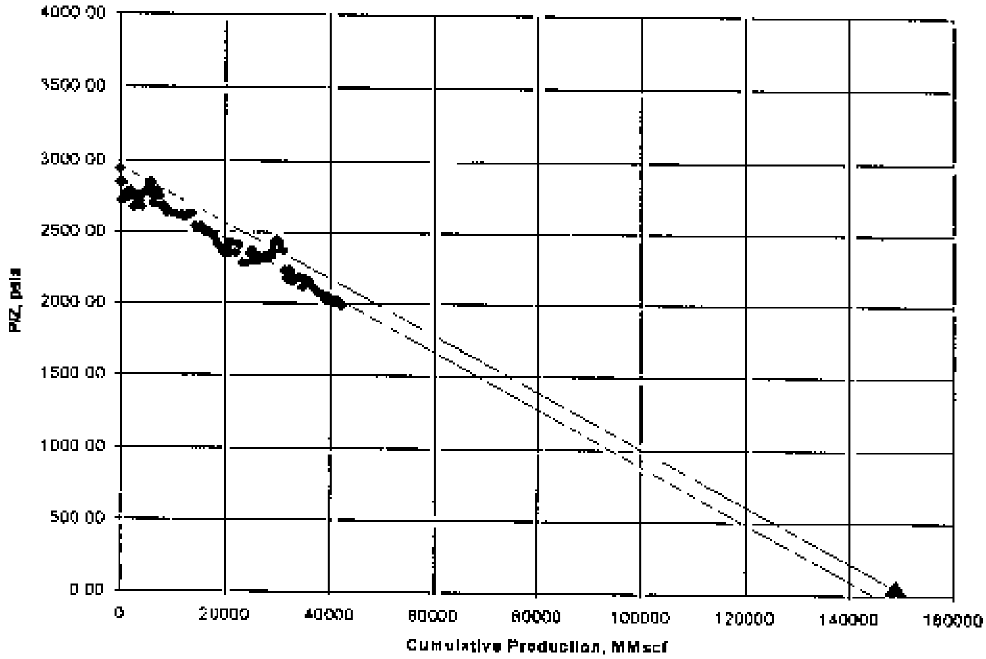
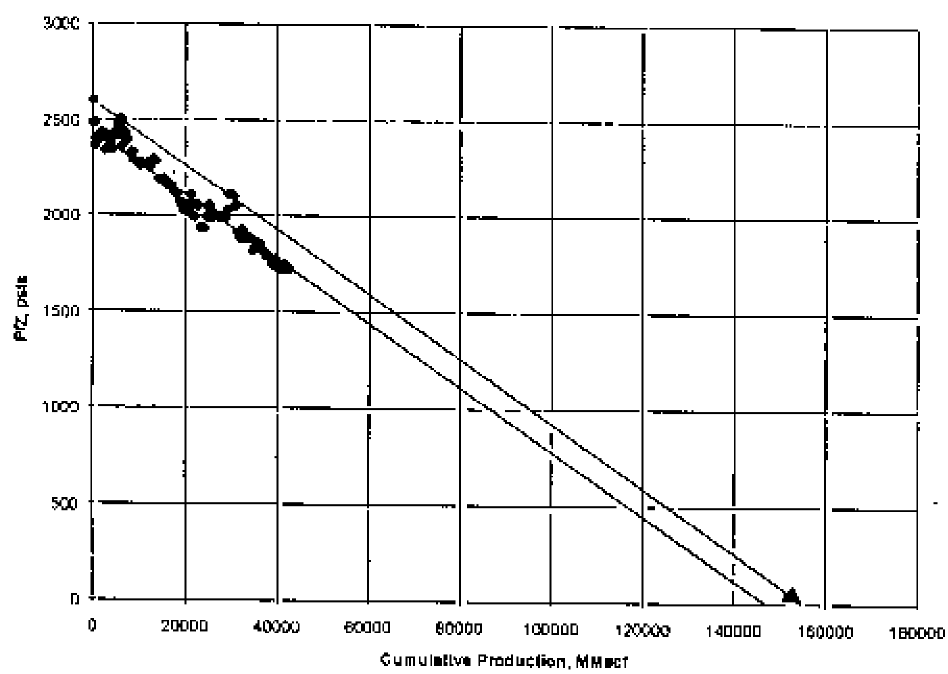


Figure 5.40 P/Z of Flowing Wellhead Pressure Vs Cumulative Production at Well BK 5 of B Sand



The above results show that all the sands of the Bakhrabad Gas Field are volumetric There is no significant aquifer support for any of the sands This is evident from the straight line nature of the p/z vs G_P plots for various methods Initial water saturation (S_{wi}) of Sands B, DU, DL, G and J are 0.4, 0.24, 0.31, 0.3 and 0.26, respectively (Welldrill, 1983F). Whereas the irreducible water saturation (S_{wir}) of all the sands has been assumed as 0.22 (Laboratory, 1989). Therefore, water production is due to the mobile water present in the sands.

Gas in place estimate of the producing sands of the Bakhrabad Gas Field is assumed to be 1127.4 BCF, as obtained from SBHP approach. As of August 1998, cumulative production of Bakhrabad Gas Field was 553.7 BCF Therefore, the recovery of the gas in place is 49%. Material balance estimates in sands having multiple wells have a higher degree of uncertainty due to the interference effects when all the wells are not shut in simultaneously. Table 5.11 summarises the present status of the wells of Bakhrabad Gas Field. Table 5 12 shows the summary of the comparison of gas in place (BCF) values of different studies conducted on different sands of Bakhrabad Gas Field.

Table 5.11 shows the gas in place estimates of the wells based on SBHP method It also shows the recoverable reserves of the wells of the various sands, assuming an abandonment p/z of 1000 psia, remaining reserve and the recovery are also set out in this table This table shows that with abandonment p/z of 1000 psia, the recoverable reserve of all the sands is 797 BCF In reference to the amount of gas produced till August 1998, an additional 243.3 BCF gas should be produced from the field under the present production system. The rate at which the production and wellhead pressure are falling, it is very

Table 5 11 Summary of gas in place (P/Z plot, SBHP method) of Bakhrabad Sands.

Well	Sand	Datum Depth(ft) (TVD)	P*(Initial) psia	Operation Suspended	P(Static) B.H.P(Shut-in-Pressure) psia	GIP (BCF) (SBHP)	Recover. Reserve at P/Z of 1000 psia	G_p (BCF) (Aug'98)	Remain. Reserve (BCF)	Recovery %
BK-1	J	7360	3203(Aug.'85)		1326(Aug.'98)	155.46	116	96.7	19 3	62%
BK-6		7230	2988(Dec.'89)	July'98	1385(Apr '98)	85.14	60	50.2	9 8	59%
BK-7		7140	2973(Dec '89)		1320(Aug.'98)	115.22	84	65 8	18.2	56%
BK-8		7260	3035(Dec.'89)		1320(Aug.'98)	99.54	72	59 1	12 9	58%
Total (J)						455.36	332	271.8	60 2	59%
BK-3	G	6910	3190(Oct '86)		1595(Aug.'98)	185	135	98 3	36 7	53%
BK-4		7000	2194(Oct.'94)	Jun.'98	1829(Apr.'97)	38.50	23	13.5	9 5	35%
Total (G)						223.50	158	111.8	46.2	50%
BK-2	DL	6630	2952(May'84)		1245(Aug.'98)	118	84	76.5	7 5	65%
BK-5		6676	1930(Dec.'94)	May'97	1382(Apr.'97)	27.54	14	8.9	5.1	32%
Total (DL)						145 54	98	85.4	12.6	59%
BK-4	DU	6546	2883(Oct.'86)	Oct.'92	1655(Mar '94)	150	106	42 4	63.6	28%
BK-5	B	5967	2693(Oct.'84)	Jul '94	1924(Apr.'94)	153	103	42.3	60.7	28%
Total (BK)						1127.40	797	553.7	243.3	49%

Table 5 12 Comparison of the GIP (BCF) estimates of different studies, conducted on Bakhrabad Gas Field, using material balance method

Sand	WellDrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study SBHP	Present study SWHP	Present study FBHP	Present study FWHP
J	585	597	665.0	666	455.36	453.60	460.50	469.50
G	370	318	245 5	244	223.50	223.50	216.00	221.00
DL	200	148	176.0	175	145.54	145.54	144.50	147.50
DU	167	180	180.3	187	150.00	150.00	150.00	150 00
B	231	145	166.6	167	153 00	153 00	151 00	154 00
Total (BK)	1553	1388	1433.4	1439	1127 40	1125 64	1122 00	1142.00

unlikely that remaining 243.3 BCF gas can be produced by the existing system which is a strong indication that the reservoir has been damaged by overproduction.

GIP comparison of Table 5.12 shows that the gas in place estimates of Welldrill (1990), IKM (1990), Petrobangla (1993) and Mobil (1997) are close but higher than this study. GIP obtained by Welldrill is about 37% higher whereas that obtained by IKM is 23% higher compared to this study.

Chapter 6

RESERVOIR SIMULATION

The producing reservoir sands of Bakhrabad Gas Field have been simulated by history matching and thereafter production forecasts have been made using a commercial reservoir simulator Implicit compositional model has been used to simulate the reservoir. Compositional simulators can model performance of volatile-oil and gas condensate reservoirs in which phase compositions vary widely with pressure. The confidence level of the forecasts depends heavily on the accuracy of the geological data as well as the fluids and reservoir properties.

6.1 Reservoir Simulator

Numerical reservoir simulator Exodus 2.2 (1995) is a general purpose compositional model for simulating black oil, gas or gas condensate, and volatile oil reservoirs. The compositional formulation of the model accurately represents phase behaviour for treatment of variable points, mixing of different PVT regions, tracer tracking and differentiation of injected and in-place fluids. The transfer of any component between the oil, gas and water phases is calculated using equilibrium ratios. In this model black oil data are internally converted to compositional models

The program can simulate problems in one, two or three dimensions using either rectangular (x-y-z) or cylindrical (r-Ø-z) coordinates, with any combination of oil, gas or water phases, and characterizing the reservoir fluid into one or more components. Interblock mass transfer is represented by Darcy's law with relative permeability, capillary pressure and gravity effects. The reservoir description capability includes naturally fractured and communicating faulted reservoirs Dual porosity/dual permeability reservoirs may be simulated. The model also allows special connection of non-neighbouring grid cells for unconventional problems. Wells can be vertical, deviated or horizontal. Multiphase correlations are fully coupled to provide pressure losses in the tubing.

EXODUS has non-linear regression parameters built into it whereby the program user may find the best values of porosity, permeability, relative permeability that will match observed field history. This is commonly known as automatic history matching. This feature is of great value in reducing the time required to obtain a history match.

6.2 Mathematical Basis for Implicit Compositional Model

The simulation model is a fully implicit, three dimensional, multi-component model for simulating isothermal processes The finite difference formulation is a block centered approximation to the partial differential equations. In addition to five and nine point finite difference approximations, the model allows the linking of any pair of grid cells for mass transfer.

In finite difference formulation a partial differential equation is converted to a finite difference equation using the Taylor series expansion. The reservoir is discretized to a number of blocks and each block is represented by a finite difference equation. The boundary conditions are also converted to a corresponding finite difference equations These result in a set of algebraic equations which is then solved using a suitable scheme

Mathematical formulation used in the model is briefly discussed below ·

Any component can exist in any phase and we assume there are N phases and N_C components

Component balance, i = 1, 2 .... N_C

$$\sum_{n=1}^{N}\nabla\left[T\frac{k_{rn}\rho_n X_{in}}{\mu_n}(\Delta P+\Delta P_{cn}-\gamma_n\Delta z)\right]=\frac{V}{\Delta t}\delta\left(\phi\sum_{n=1}^{N}\rho_n S_n X_{in}\right)+q_i \qquad (6\ 1)$$

where the terms are · T = transmissibility; k_r = relative permeability, ΔP = pressure drop; ΔP_c = capillary pressure drop; γ = specific gravity; V = volume; Δt = length of timestep; ρ = density, q_i = production rate

The interface mass transfer is handled by means of K values. Thus for each pair of phases e.g. , oil and gas ·

$$y_i = K_{go}X_i \qquad (6.2)$$

where y_i is the mole fraction of component, i, in the gas phase, K_{go} is the interface mass transfer coefficient for the component i, X_i is the mole fraction of component, i, in the oil phase.

Phase constraint equations, one for each phase, ensure that the mole fractions sum to 1.

$$\sum_{i=1}^{N_c} X_{in} = 1.0 \qquad (6.3)$$

A saturation constraint equation:

$$\sum_{n=1}^{N} S_n = 1.0 \qquad (6.4)$$

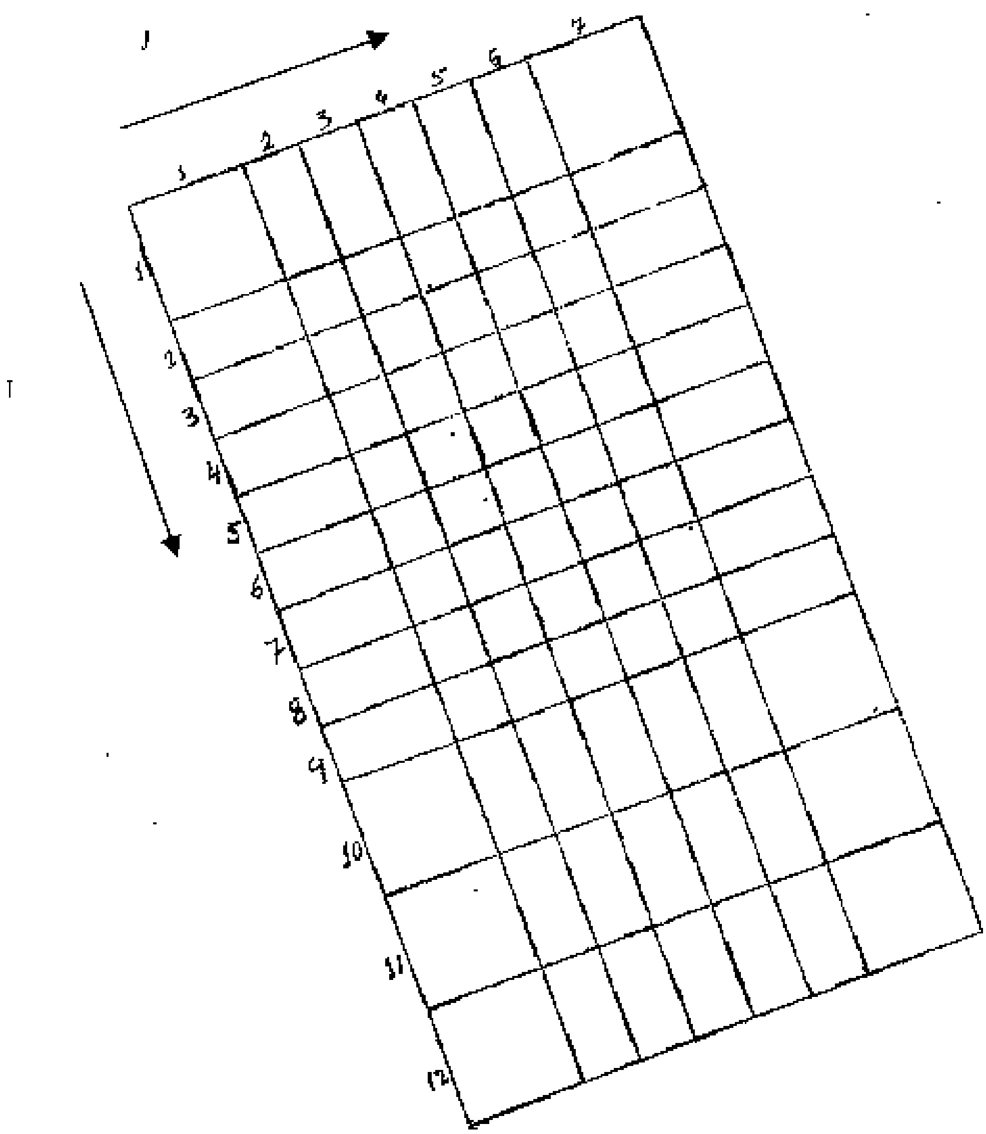
completes the equation set

6.3 Reservoir Grid Description

Partial differential equations that describe fluid flow in reservoirs are solved numerically, by discretising the differential equations with difference equations. To use difference equations, reservoir is treated as if it is composed of discrete volume elements and changes in conditions within each volume element are computed over each of many discrete time intervals. Reservoir volume elements are termed as gridblocks.

A three-dimensional grid model for each of the developed sands of Bakhrabad Gas Field was used for the simulation purpose to predict the future performance of the reservoir. The individual sands were modeled and simulated individually. Figure 6.1 shows the grid system used in this study The reservoir sand to be simulated is divided into 12 grid blocks in I direction and 7 grid blocks in J direction. The number of grid blocks in the vertical direction varies with the thickness of the sand The different sand layers of Bakhrabad Gas Field used in the simulation is shown in Figure 1.

Figure 6.1 Model Grid System Used in the Simulation Study



Note $\Delta I = 2628$ ft for I_1, I_{10} to I_{12}
$\Delta I = 1314$ ft for I_2, to I_9
$\Delta J = 2628$ ft for J_1 and J_7
$\Delta J = 1314$ ft for J_2 to J_6

The five developed sands of Bakhrabad Gas Field correspond to B, D Upper, D Lower, G and J Sand. The net isopach maps for the developed gas sands are presented in Figures 6.2 through Figure 6.6. Three dimensional model has been used for simulating the reservoir, based on the net isopach maps of different sands The net isopach maps used in the model were prepared by IKM (1990) from information provided by Petrobangla.

A 12×7×5 grid model for J Sand distributes the vertical layers as 13 ft, 3×50 ft and 75 ft with a net thickness of 238 ft A 12×7×2 grid model for G Sand includes the vertical layers as 2×50 ft with a net thickness of 100 ft A 12×7×2 grid model for DL Sand comprises of vertical layers as 2×50 ft with a net thickness of 100 ft. A 12×7×4 grid model for DU Sand distributes the vertical layers as 4×20 ft with a net thickness of 80 ft. A 12×7×3 grid model for B Sand comprises of vertical layers as 3×40 ft with a net thickness of 120 ft. The above features have been used as the grid model for simulating the five developed sands of Bakhrabad Gas Field.

6.4 Simulation Input Parameters

Most of the input parameters used in this study are taken from the previous studies conducted by Welldrill (1983, 1990) and IKM (1990). The rock and fluid properties have been assumed uniform throughout the model. The necessary data for the simulation study have been derived from geological and geophysical study, core-analysis, well-log analysis, well-test results compiled by Welldrill (1983, 1990) and IKM (1990) BGFCL provided the production data of different wells and sands.

Figure 6.2 Net Pay Isopach Map of Bakhrabad J Sand

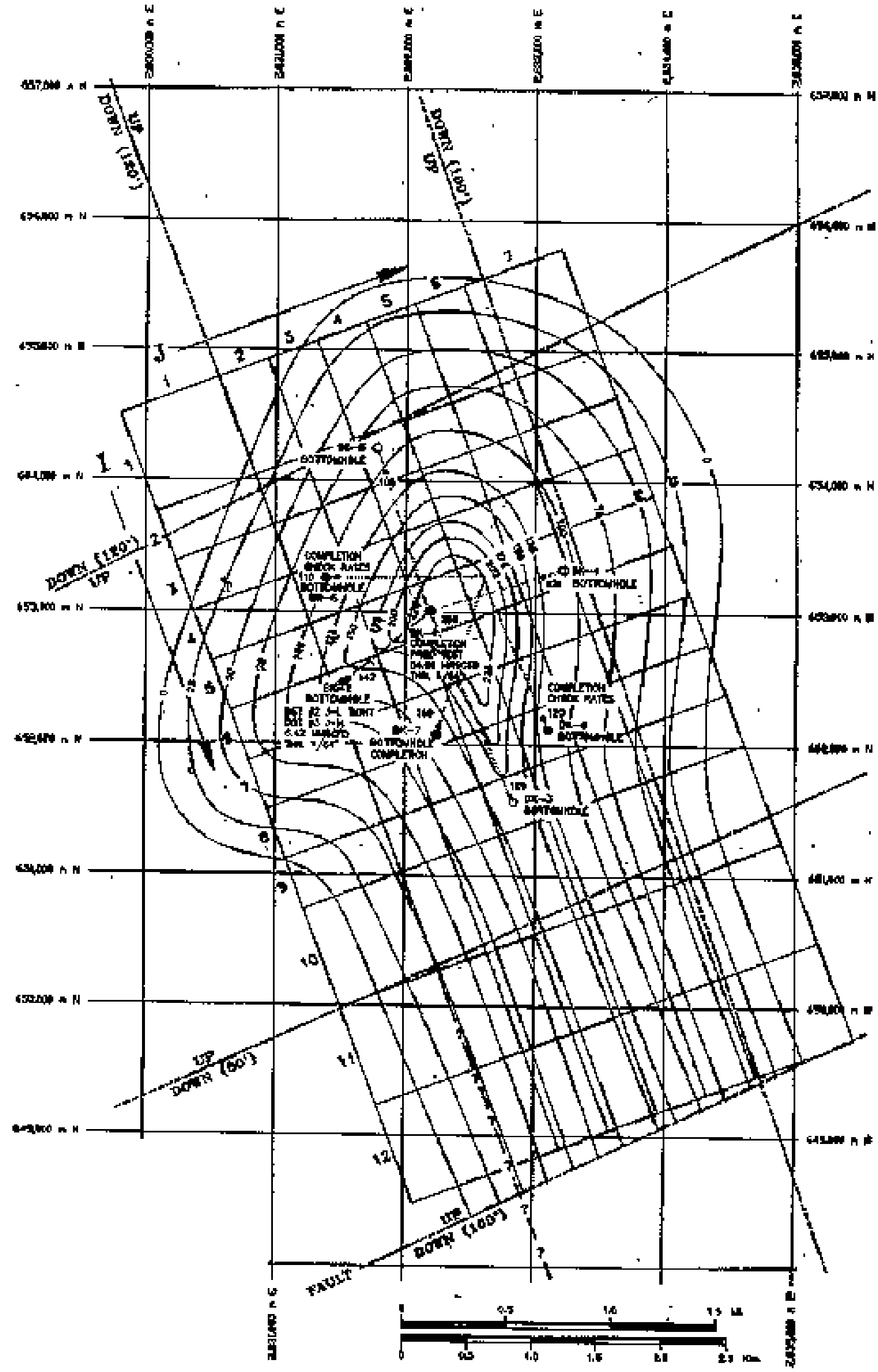


Figure 6.3 Net Pay Isopach Map of Bakhrabad G Sand

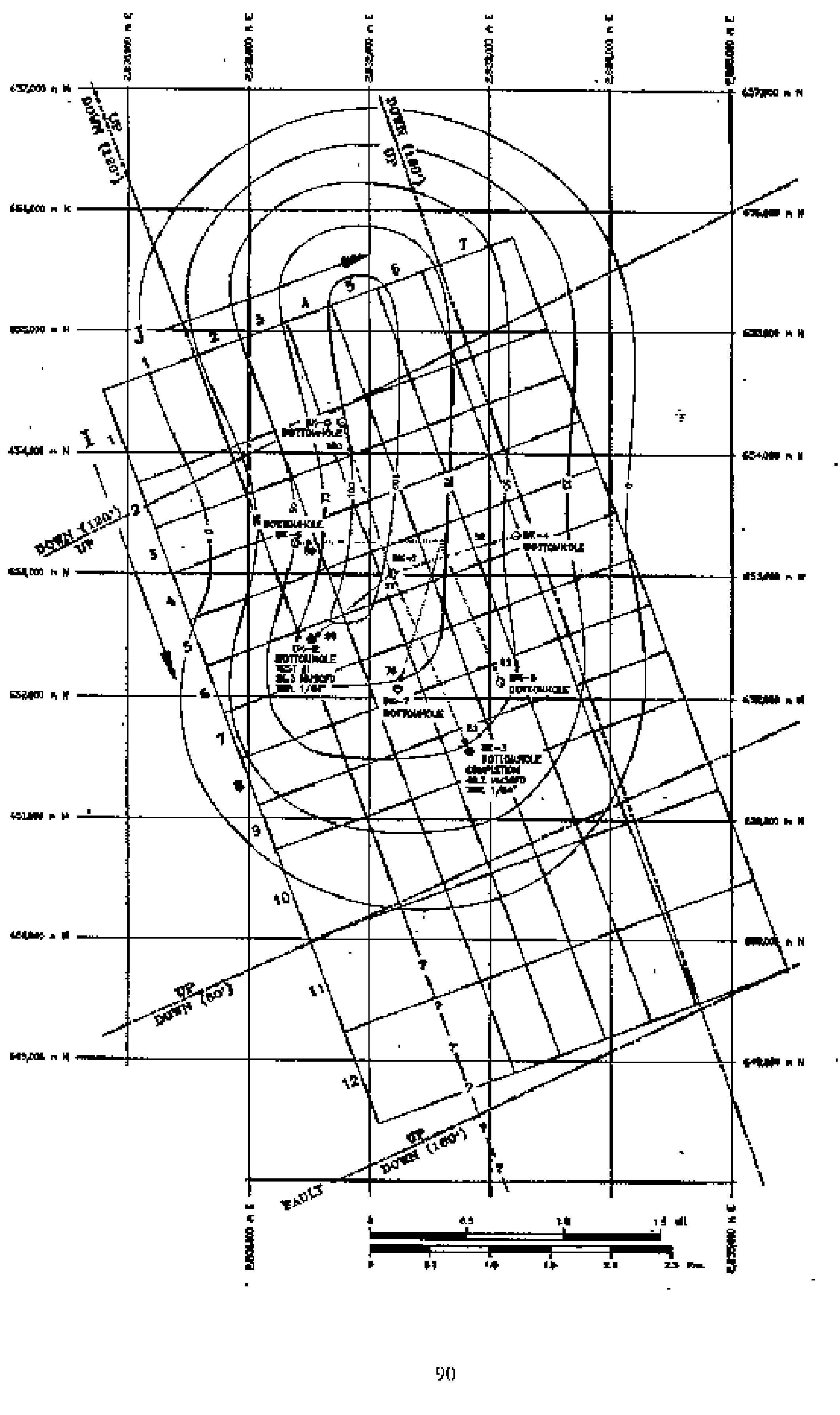


Figure 6 4 Net Pay Isopach Map of Bakhrabad Lower D Sand

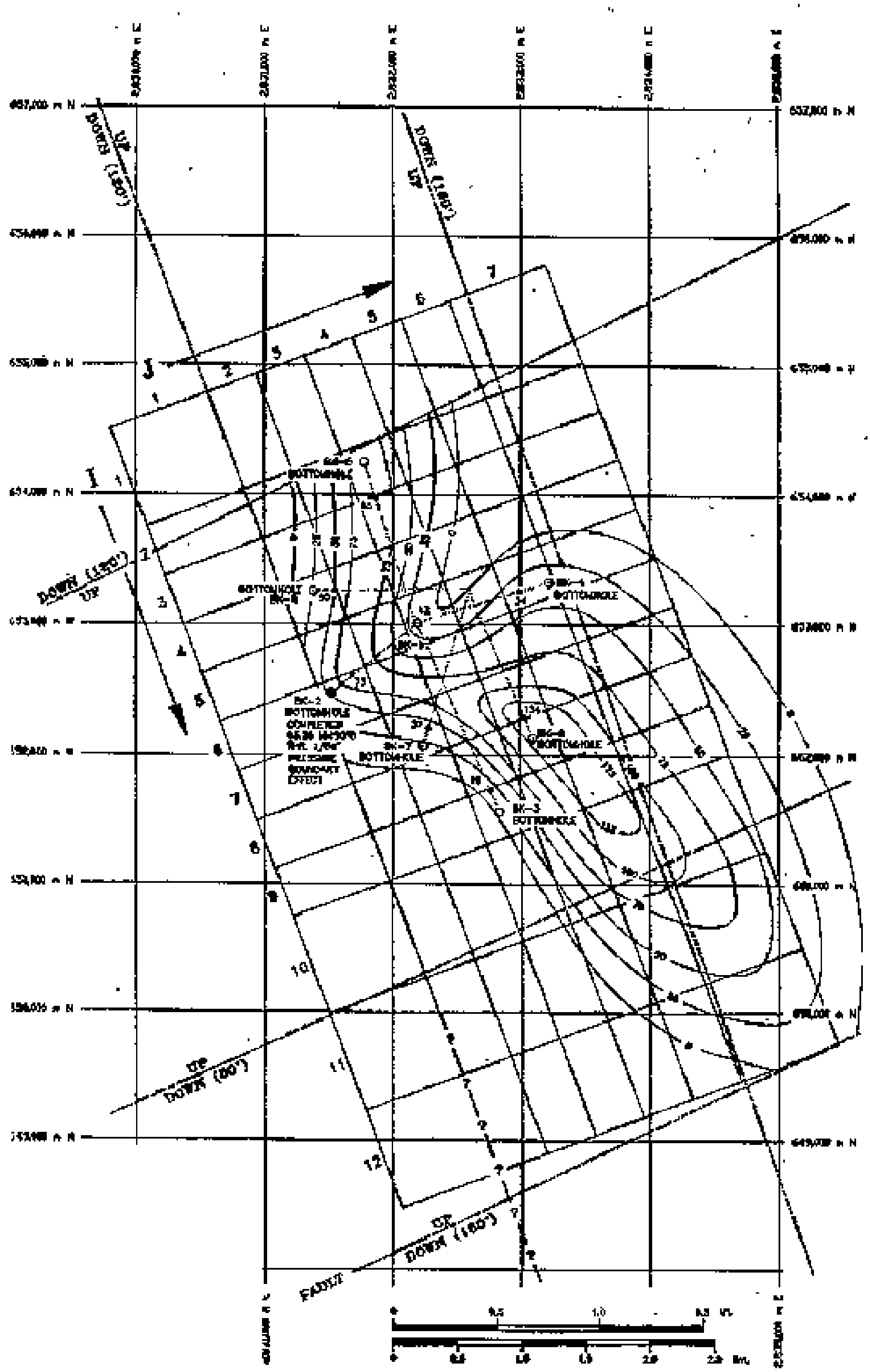


Figure 6.5 Net Pay Isopach Map of Bakhrabad Upper D Sand

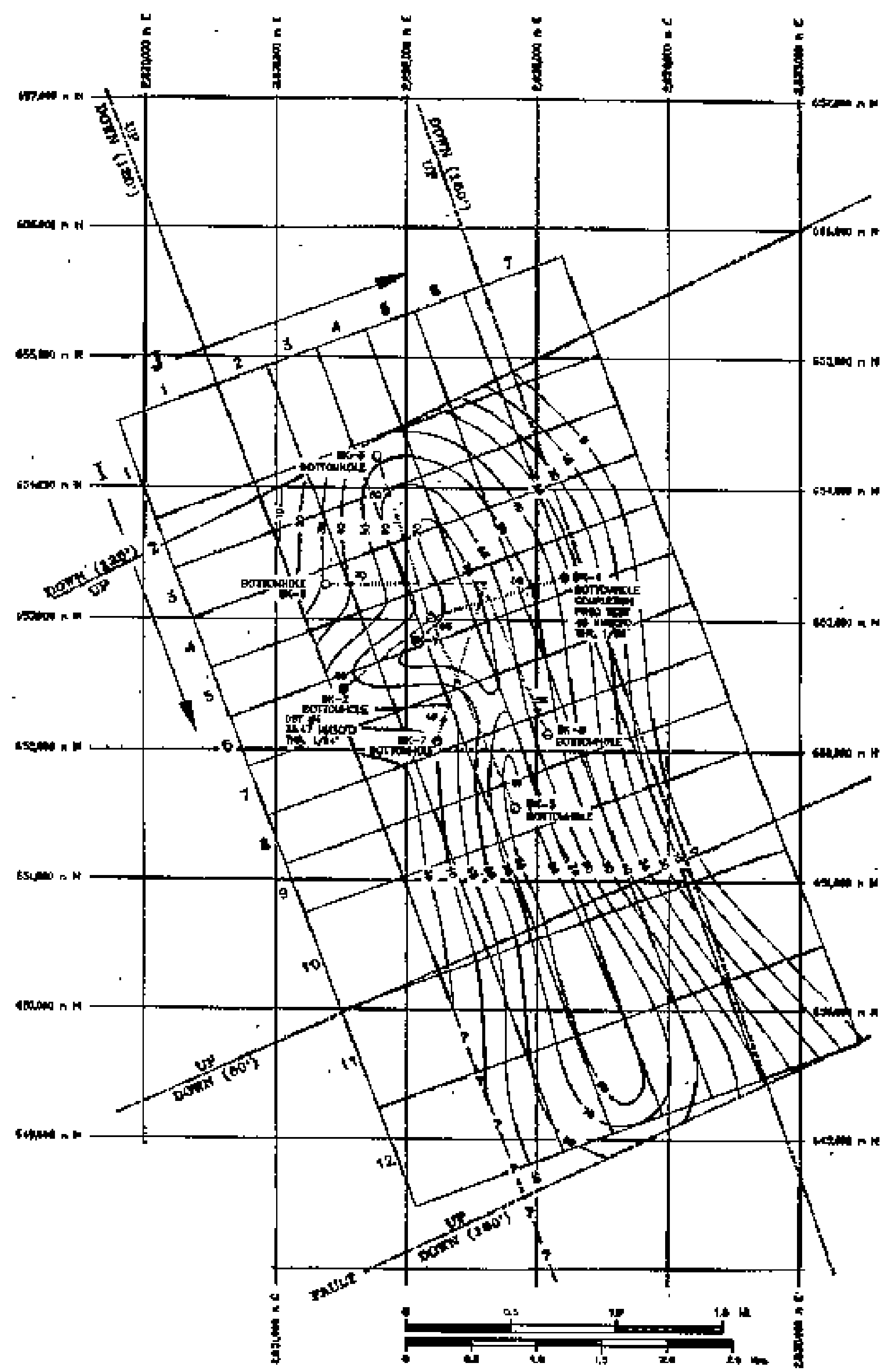
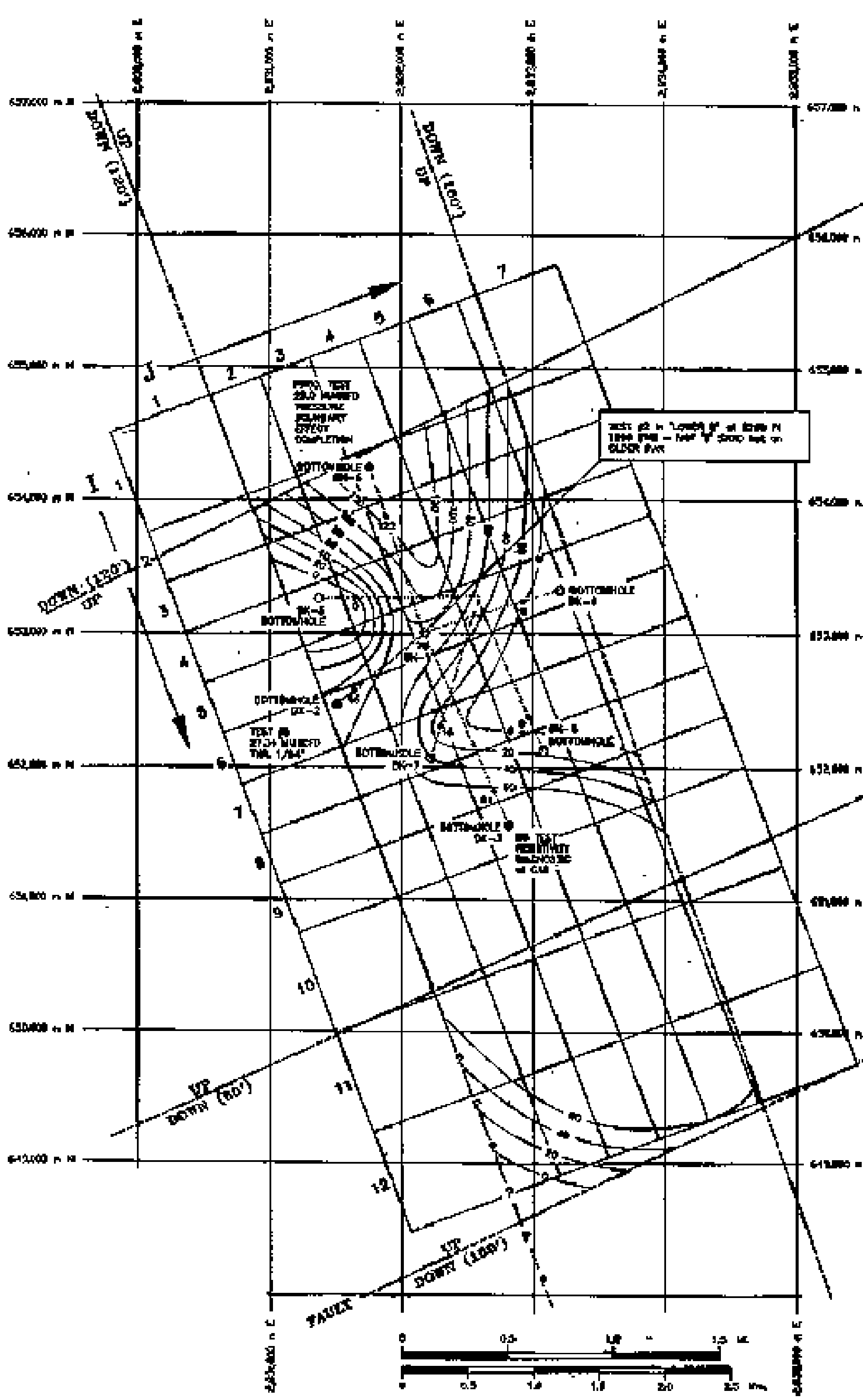


Figure 6.6 Net Pay Isopach Map of Bakhrabad B Sand



Irreducible water saturation and residual gas saturation are taken to be 0.22 and 0.3 respectively (Laboratory, 1989) Capillary pressure and Relative permeability data are not available and these values have been calculated using Honarpour correlations of Exodus. The values are presented in Table 6.1

Table 6.1 Water saturation, relative permeability and capillary pressure values used in this study.

S_w	K_{Rw}	P_{Cw} (psia)	K_{Rg}	P_{Cg} (psia)
0.2	0	7	0.77992	3.9
0.24231	0.00287	4	0.36416	3.5
0.28462	0.00596	3	0.32191	3
0.32692	0.00941	2.5	0.28184	2.5
0.36923	0.01341	2	0.24392	2
0 41154	0.01819	1.5	0.20817	1.5
0.45385	0.02408	1	0.17458	1
0.49615	0.03143	0.5	0.14315	0.5
0 53846	0.04072	0.25	0.11389	0.2
0.58077	0.05246	0	0.08679	0
0.62308	0.06727	0	0.06185	0
0 66538	0 08585	0	0.03907	0
0.70769	0.10899	0	0.01845	0
0.75	0.13756	0	0	0
1	0.47719	0	0	0

PVT Properties

Formation volume factors and viscosity of gas and water used in this study are tabulated in Table 6 2 Formation volume factor, B_g and gas viscosity, μ_g values used in the simulation are correlated values of Belabo Gas Field (IKM, 1990D). Formation volume factor, B_w and water viscosity μ_w values are not known from the available literature and therefore have been assumed. Summary of gas formation volume factors of different sands are shown in Table 6 3 (Welldrill, 1983F).

Table 6 2 Gas formation volume factor, gas viscosity, and water formation volume factor and water viscosity values used in this study.

Pressure (psia)	B_g (rcf/scf)	μ_g (cp)	B_w (rb/stb)	μ_w (cp)
74.3	0.250665	0.0133	0.9606	0.31
324 3	0.05627	0 0135	0 95988	0.31
574 3	0.031192	0 0138	0.95916	0.31
824 3	0.02138	0.0142	0.95772	0.31
1074.3	0.016176	0.0146	0.95484	0.31
1324 3	0.012972	0 015	0 9534	0.31
1574.3	0.0108159	0.0156	0.95196	0.31
1824.3	0.0092762	0.0161	0.94908	0.31
2074.3	0.0081224	0.0167	0.93467	0 31
2324 3	7 25E-03	0.0174	0.93365	0.31
2574.3	0.0065496	0.0181	0.93124	0.31
2824 3	5.99E-03	0.0188	0.92914	0 31
3074.4	0.0055301	0.0195	0.92841	0.31
3324.3	5.15E-03	0.0203	0.92744	0.31
3574.3	0.0048289	0.0211	0.92625	0.31
3824.3	0.0045558	0.0219	0.92458	0.31
4074.3	0.0043214	0.0227	0.92322	0.31
4324.3	0.0041179	0.0235	0.92247	0.31
4574.3	3.94E-03	0.0243	0.92133	0.31
4824.3	0 0037832	0.0252	0.91811	0.31

Table 6 3 Summary of the gas formation volume factors of different sands.

Sand	S_g=(1-S_w)	Gas Gravity	Temp (^{0}F)	Z	FVF (B_g)
J	0 74	0.593	189	0 928	0.00526
G	0 7	0 577	185	0.931	0.00522
DL	0 69	0 585	178	0.916	0.00555
DU	0.76	0.58	176	0 915	0.00565
B	0 6	0 577	171	0.91	0 00607

Porosity, and Rock Compressibility

Porosity and rock compressibility values of different sands are shown in Table 6 4. These parameters are taken from reports of Welldrill (1983, 1990).

Well Parameters

Thickness of the different layers of the sands are obtained from the net isopach maps (IKM, 1990B) Average thickness, well diameter, permeability and initial pressure values of the different sands have been obtained from the well completion reports compiled by Welldrill (1983, 1990) These values are shown in Table 6.4.

Table 6.4 Porosity, permeability and rock compressibility values of different sands.

Sand	Well	Pay Sand Subsea Comp. Zone (TVD) (ft)	Avg. Reservoir Thickness (ft)	Porosity	Permeability (md)	Rock Compressibility (1/psi)
J	BK-1	7001-7331	87 4	0.17	691	0.0000039
	BK-6	7071-7399		0.17	114	0.0000039
	BK-7	6963-7278		0.17	174	0.0000039
	BK-8	7045-7383		0.17	309	0 0000039
G	BK-3	6806-6938	51.2	0.19	98 84	0 0000037
	BK-4	6983-7108				
DL	BK-2	6551-6642	49 4	0.21	53 9	0 0000037
	BK-5	6601-6707				
DU	BK-4	6470-6546	37.6	0 2	204	0.0000036
B	BK-5	5883-6050	63 5	0.26	454.1	0 0000032

6.5 Discussion on Simulation Results

Simulation results including the history matching of various sands of Bakhrabad Gas Field is discussed in this section. Bakhrabad Gas Field has been simulated till 2010. The prediction of future field performances involves prediction of the reservoir pressure depletion along with the offlake rate of reservoir fluids It is important that for a model to behave like the actual reservoir it must mathematically incorporate all the physical aspects of the actual reservoir The only available way to test the model is to simulate past performance of the reservoir and compare the simulation results with actual, historical performance.

6.5.1 History Matching

The process of history matching is very useful and powerful reservoir description technique although it has inherent non-uniqueness problem associated with it. The key factors such as. gas rate and reservoir pressure depletion with time of the model are compared with the actual reservoir performance Daily wellhead pressure data and gas rates were assimilated on a monthly average basis for history matching. A good match validates the reservoir model used The gas rate and reservoir pressure depletion along with the model output for all the wells and the sands of Bakhrabad Gas Field are displayed graphically using Exodus

6.5.1.1 J Sand

J Sand consists of wells, BK 1, BK 6, BK 7 and BK 8. History matching and production forecasting have been conducted for each well, as well as for the sand as a whole. The permeability of the sand is 691 md, the best among the five developed sands. The top most depth of the sand at Well BK 1 is 7001 ft and base at 7331 ft. The net thickness of this sand is 238 ft with an average thickness of 87.4 ft. The porosity and rock compressibility of this sand is 0.17 and 0.0000039 psi^{-1} respectively.

Well BK 1

The simulated results along with the history matching of gas rate and pressure depletion for Well BK 1 are set out in Figure 6.7 and Figure 6.8. Figure 6.7 shows production rate vs time whereas Figure 6.8 shows the pressure decline with time at Well BK 1. These figures show a good match between the historical data and the simulated results for both the production rate and pressure decline Both simulated and the actual data show a drastic production and pressure decline at this well and the figures show a gas rate of 6 MMscfd will be prevailing with the pressure declining to 1283 psia during the year 1999.

Well BK 6

Figure 6.9 and Figure 6 10 presents the simulated result and the actual historical gas rate and pressure depletion of Well BK 6. These figures also show a good match of the historical data with the simulated results Well BK 6 was watered out in July 1998.

Figure 6.7 Simulated and Actual Production History of Well BK 1 of J Sand

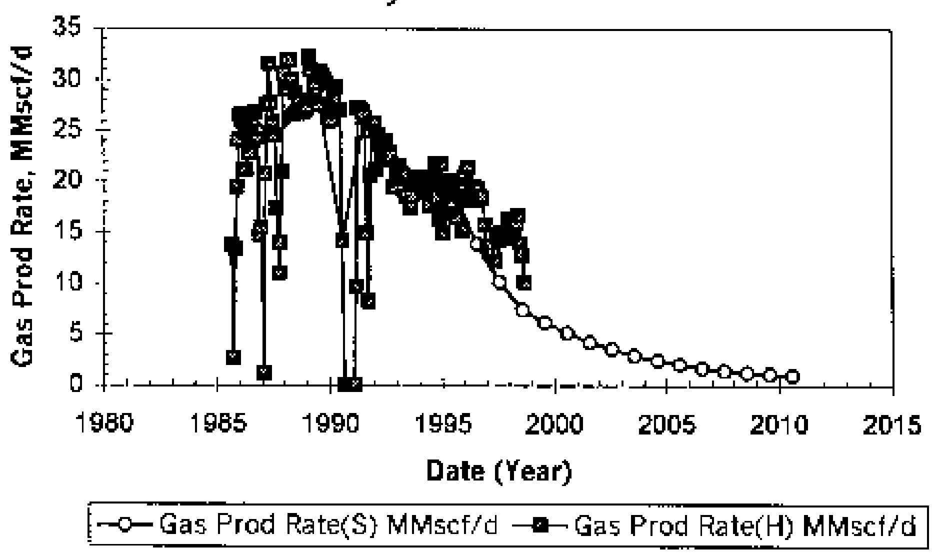
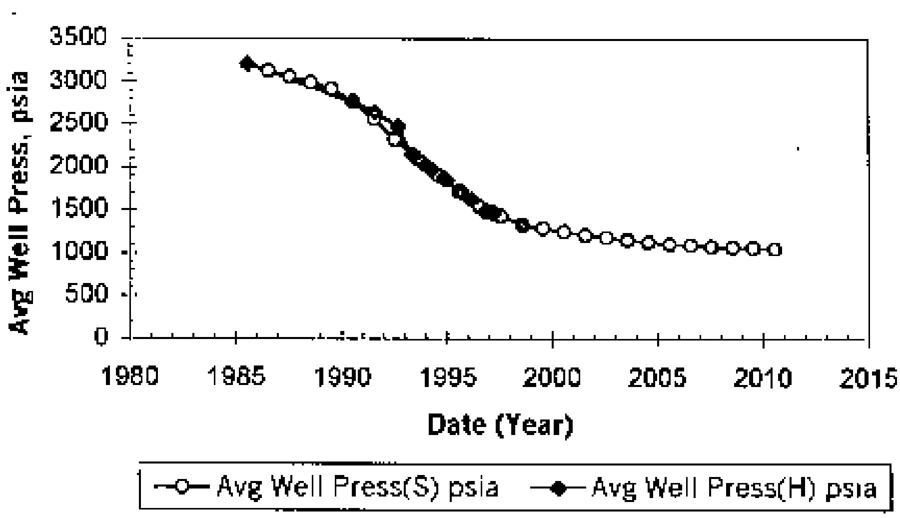


Figure 6.8 Simulated and Pressure History of Well BK 1 of J Sand



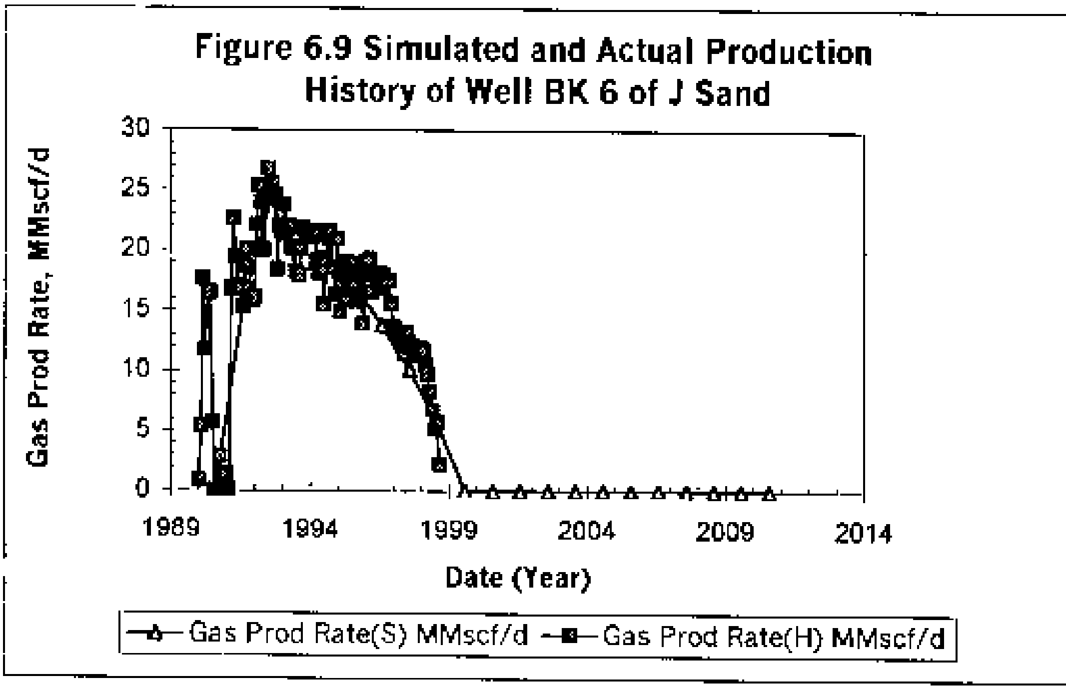


Figure 6.9 Simulated and Actual Production History of Well BK 6 of J Sand
Gas Prod Rate, MMscf/d
30
25
20
15
10
5
0
1989
1994
1999
2004
2009
2014
Date (Year)
Gas Prod Rate(S) MMscf/d
Gas Prod Rate(H) MMscf/d

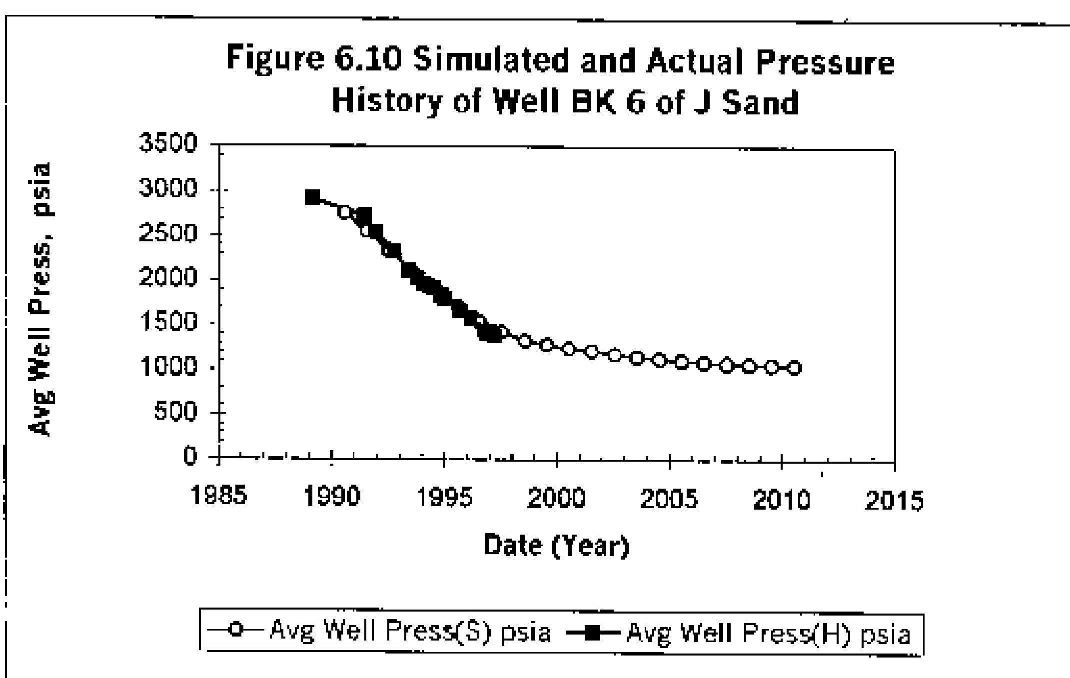


Figure 6.10 Simulated and Actual Pressure History of Well BK 6 of J Sand
Avg Well Press, psia
3500
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Avg Well Press(S) psia
Avg Well Press(H) psia

Well BK 7

The simulated result along with the actual historical gas rate and pressure depletion for Well BK 7 appears in Figure 6.11 and Figure 6 12 These figures show that the simulated results compare well with the historical data From the figures it can be seen that the flow rate and pressure will decline to 5 MMscfd and 1243 psia, respectively after the year 2000.

Well BK 8

Figure 6.13 and Figure 6 14 show the simulated result along with the historical gas rate and pressure depletion of Well BK 8. These figures also show that the simulated results compare well with the historical data. These figures show that the flow rate and pressure will decline to 6 MMscfd and 1243 psia, respectively after the year 2000.

The simulated gas rate and the reservoir pressure depletion vs time with the historical rate and pressure data of J Sand as a whole are shown in Figure 6 15 and Figure 6.16.

History matching of gas rate of J Sand has been conducted by adding the actual monthly average gas rate values of all the wells i e , BK 1, BK 6, BK 7 and BK 8 Since the required pressure survey data is not available, history matching of pressure depletion of J Sand has been performed using calculated static bottomhole pressure corresponding to the recorded shut-in wellhead pressure of Well BK 1 Figure 6.15 and Figure 6.16 show a good match between the simulated results and the historical data. Both production rate and reservoir pressure compare well with corresponding historical data

Figure 6.11 Simulated and Actual Production History of Well BK 7 of J Sand

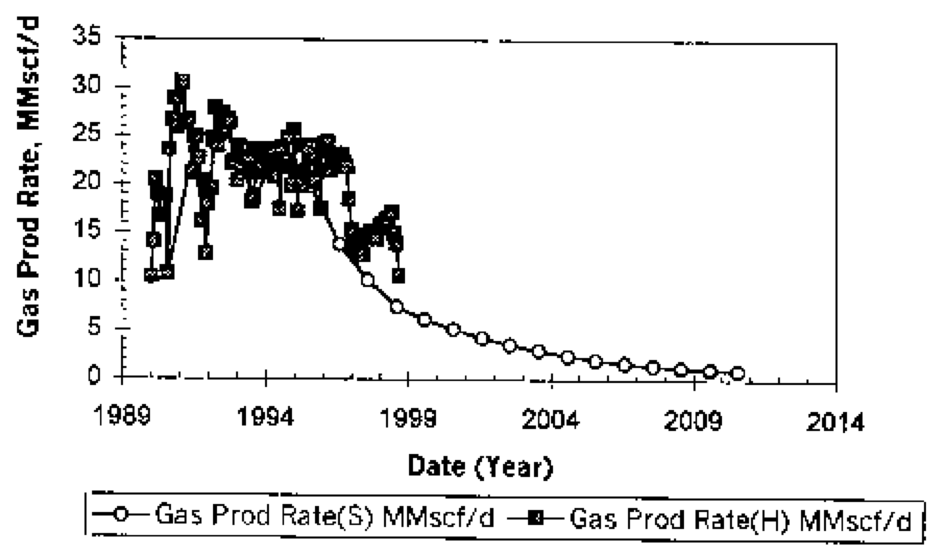
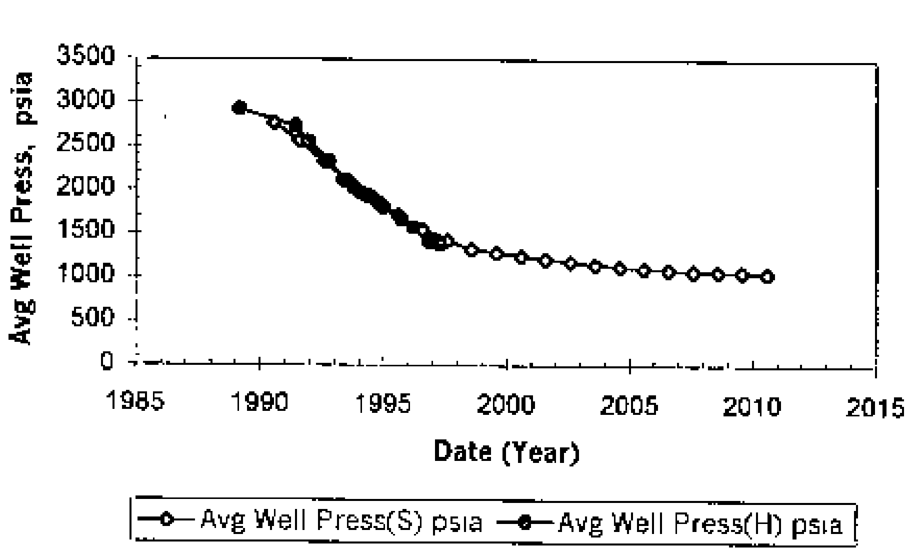


Figure 6.12 Simulated and Actual Pressure History of Well BK 7 of J Sand



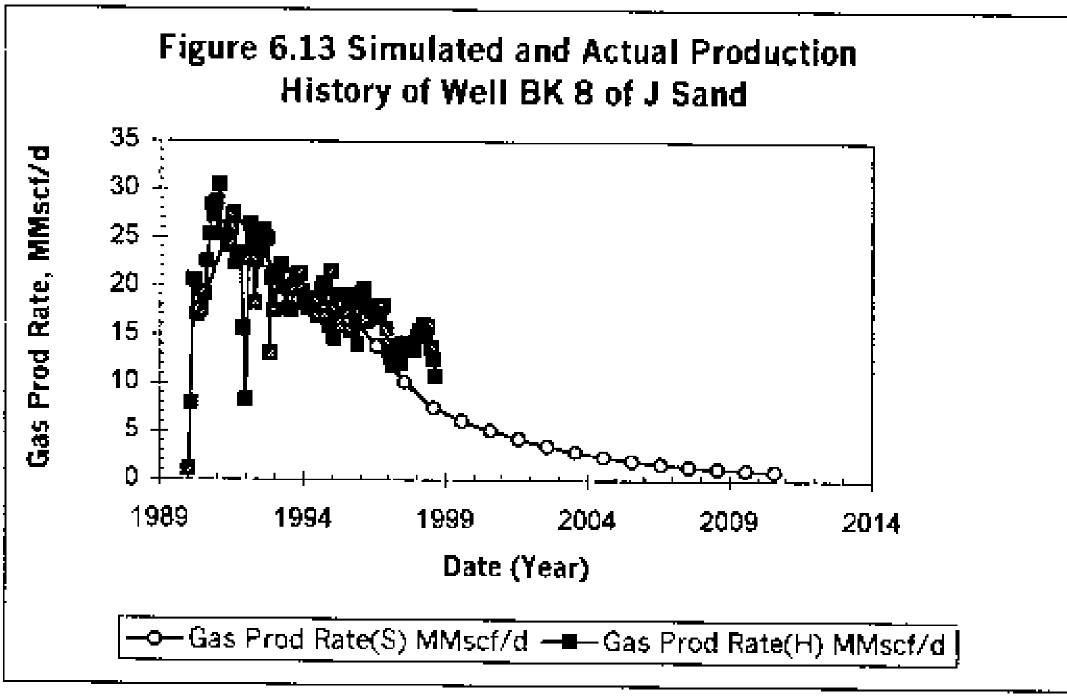


Figure 6.13 Simulated and Actual Production History of Well BK 8 of J Sand
Gas Prod Rate, MMscf/d
35
30
25
20
15
10
5
0
1989
1994
1999
2004
2009
2014
Date (Year)
Gas Prod Rate(S) MMscf/d
Gas Prod Rate(H) MMscf/d

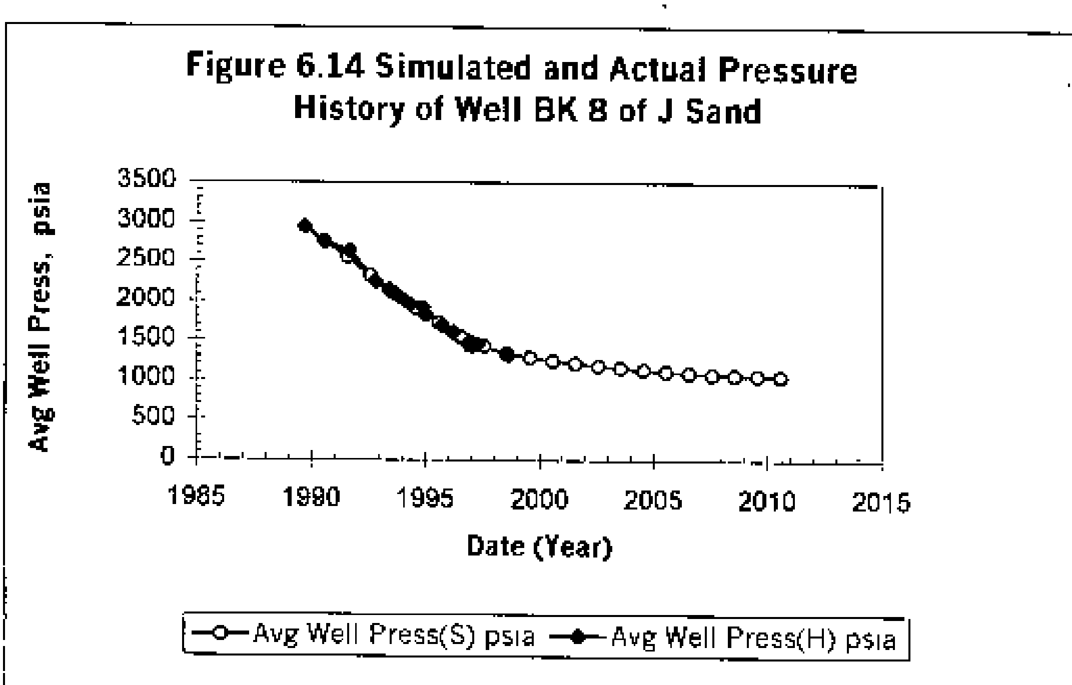


Figure 6.14 Simulated and Actual Pressure History of Well BK 8 of J Sand
Avg Well Press, psia
3500
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Avg Well Press(S) psia
Avg Well Press(H) psia

Figure 6.15 Simulated and Actual Production History of J Sand

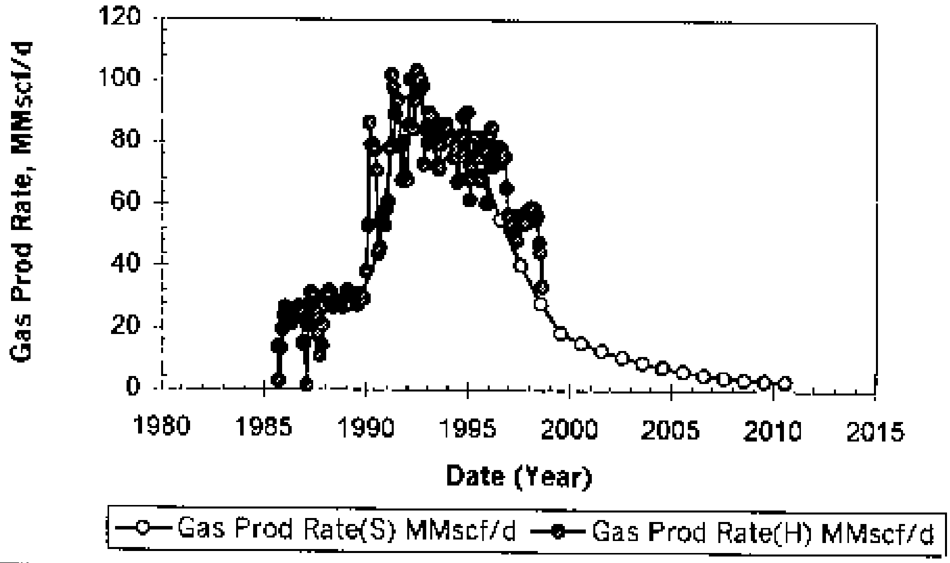
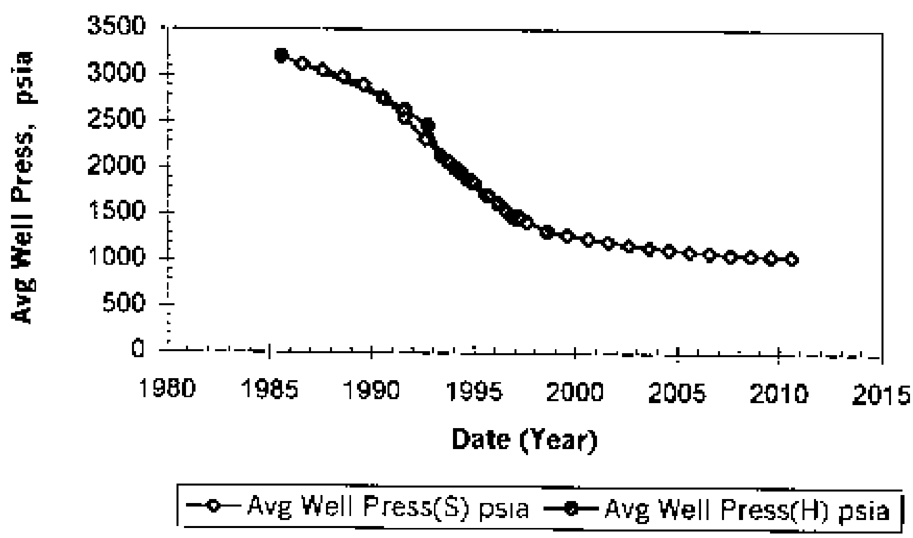


Figure 6.16 Simulated and Actual Pressure History of J Sand



The simulation results show that at the gas rate of 8 MMscfd, the reservoir pressure will decline to 1153 psia during the year 2003 with a recovery of 65 %. The gas in place value of J Sand according to the simulated result is 427 BCF.

6.5.1.2 G Sand

G Sand comprises of wells, BK 3 and BK 4. The top most depth of this sand at Well BK 3 is 6806 ft and base at 6938 ft The net thickness of the sand is 100 ft with an average thickness of 51.2 ft The permeability of the sand is 98.84 md. The porosity and rock compressibility of the sand is 0.19 and 0 0000037 psi^{-1} respectively The simulated results have been compared with the historical data for the whole sand as well as for individual wells.

Well BK 3

Simulated gas rate and pressure depletion scenario along with the historical data of Well BK 3 of G Sand are set out in Figure 6 17 and Figure 6.18. Figure 6.17 shows gas production rate vs time whereas Figure 6.18 shows average well pressure vs time. Both these figures show a good match between the simulated results and the actual historical data. Simulation of Well BK 3 forecasts a gas rate of 7 MMscfd with pressure declining to 1534 psia in the year 2003.

Figure 6.17 Simulated and Actual Production History of Well BK 3 of G Sand

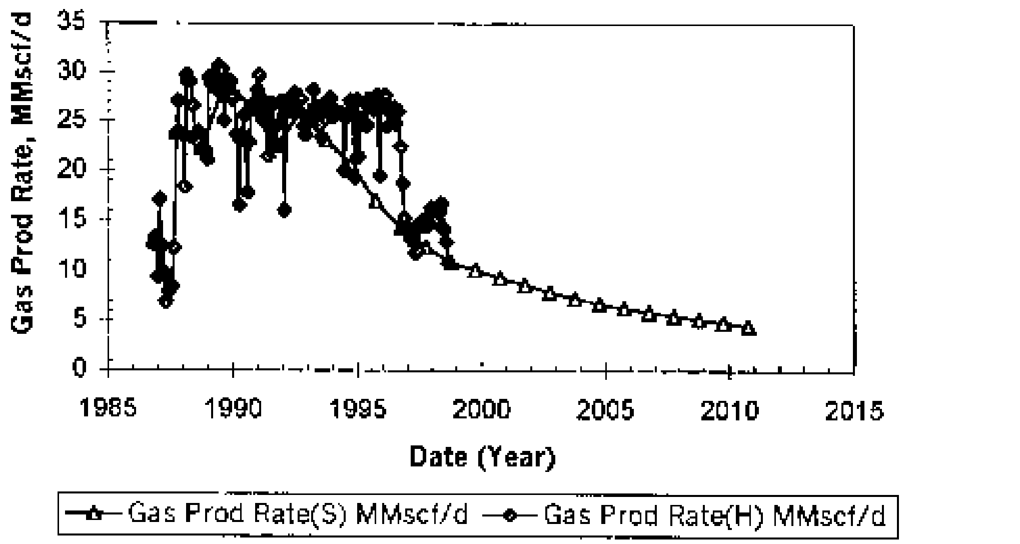
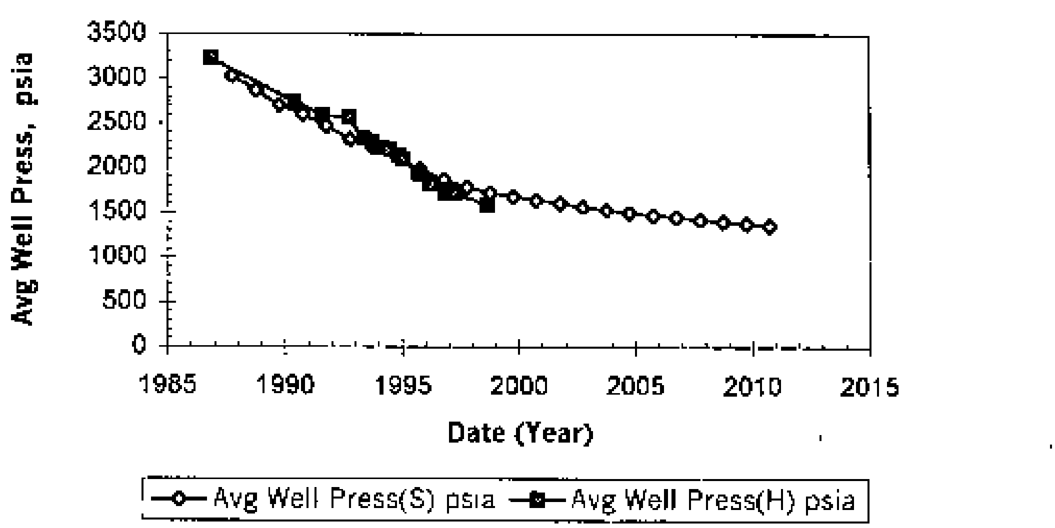


Figure 6.18 Simulated and Actual Pressure History of Well BK 3 of G Sand



Well BK 4

Figure 6.19 and Figure 6.20 show the simulated results along with the historical data of gas rate and pressure depletion of Well BK 4 of G Sand. Both figures show a good match between the simulated results and the historical data. Well BK 4 was out of production with depleted wellhead pressure of 800 psia (same as manifold pressure) in June 1998.

The simulated results, of G Sand along with historical data are graphically presented in Figure 6 21 and Figure 6 22 Gas rate simulation of G Sand is the combined production of Well BK 3 and Well BK 4. Static bottom hole pressure at Well BK 3 is used as the historical data for comparing the pressure depletion scenario of G Sand Both these figures show a good match between the simulated results and the historical data. Simulation of G Sand shows a gas rate of 8 MMscfd corresponds to the year 2001 with a reservoir pressure declining to 1678 psia and a gas recovery of 48%. The gas in place value of G Sand according to the simulated result is 233 BCF.

6.5.1.3 DL Sand

DL Sand consists of wells, BK 2 and BK 5. The top of the sand at Well BK 2 is 6551 ft and base at 6642 ft. The net thickness of the sand is 100 ft with an average thickness of 49 4 ft. The permeability of the sand is 53.9 md The porosity and rock compressibility of the sand is 0 21 and 0.0000037 psi^{-1} respectively The simulated results have been compared with the historical data of the sand and the wells.

Figure 6.19 Simulated and Actual Production History of Well BK 4 of G Sand

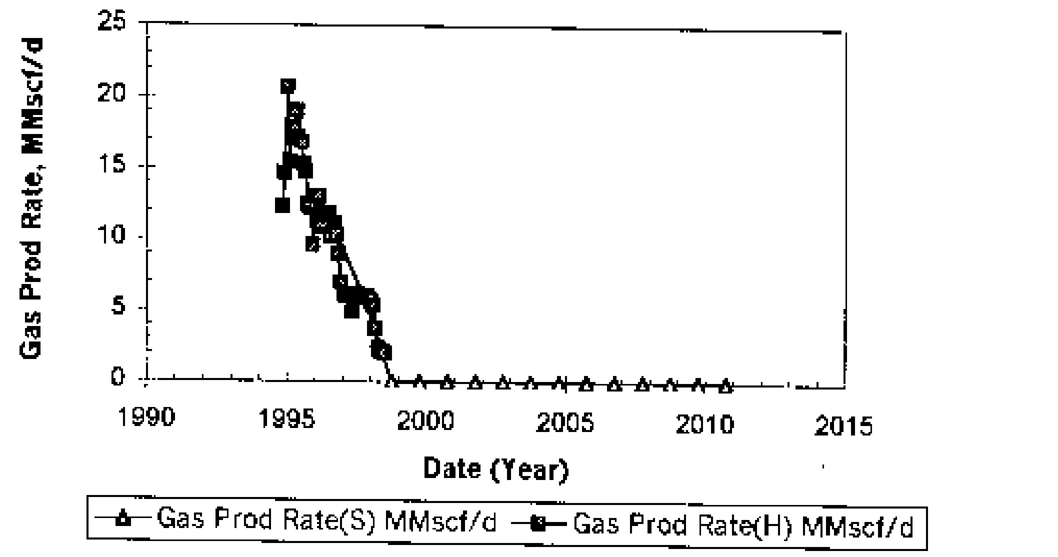


Figure 6.20 Simulated and Actual Pressure History of Well BK 4 of G Sand

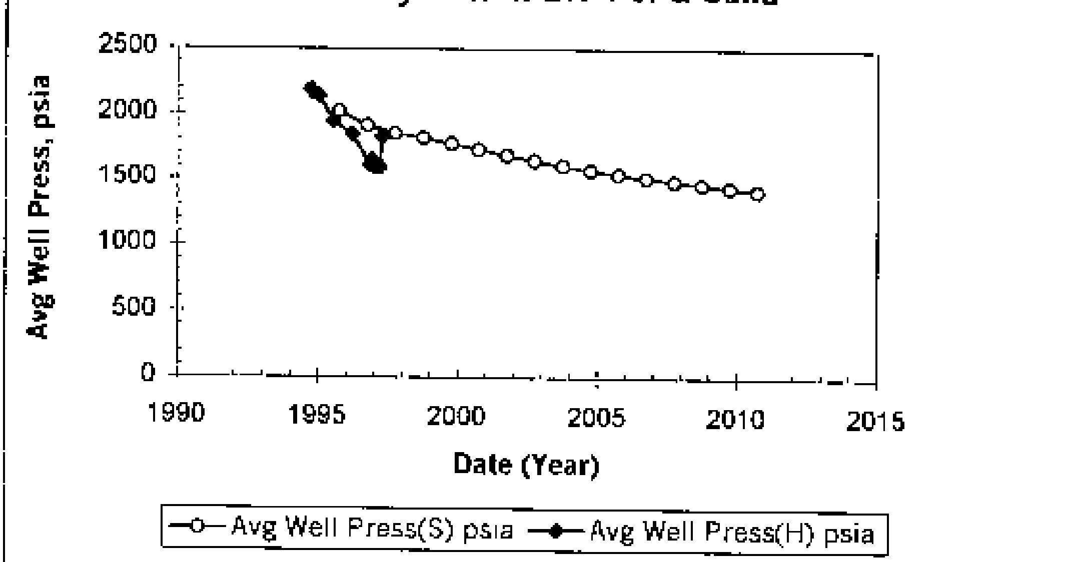


Figure 6.21 Simulated and Actual Production History of G Sand

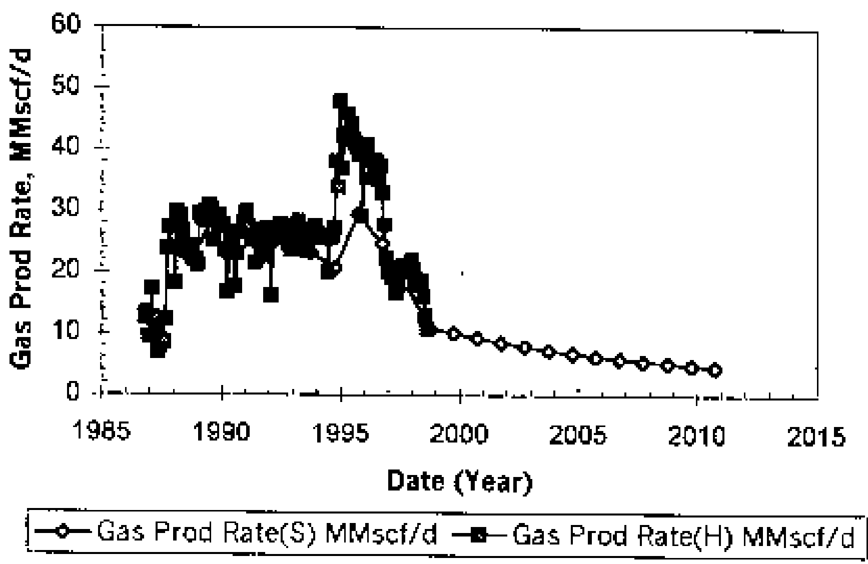
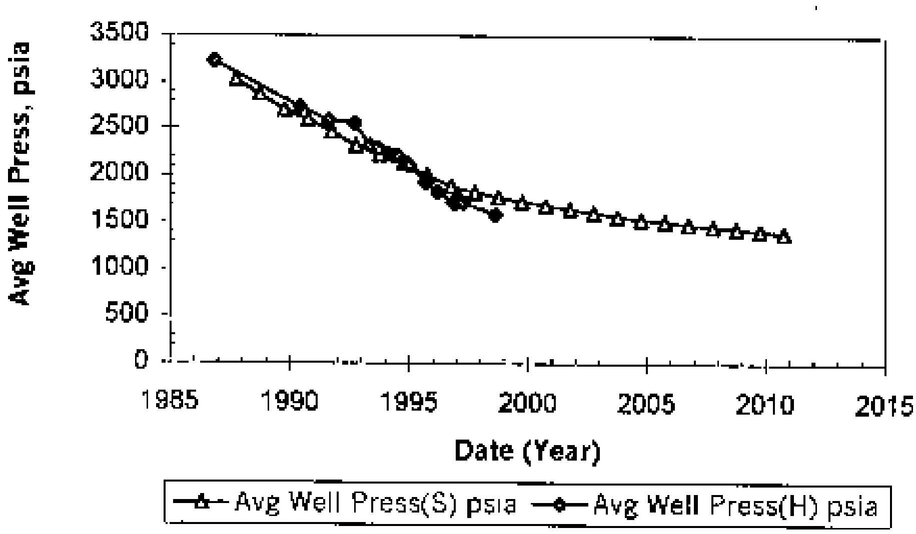


Fig 6.22 Simulated and Actual Pressure History of G Sand



Well BK 2

The simulated results along with the historical gas rate and pressure depletion data of Well BK 2 are set out in Figure 6.23 and Figure 6.24. These figures show that the simulation results and the historical data compare well with each other. Well BK 2 simulation shows the gas rate will decline to 6 MMscfd with the pressure declining to 1298 psia in the year 2002

Well BK 5

Figure 6.25 and Figure 6.26 show the simulated result along with the historical gas rate and pressure depletion of Well BK 5. This well was depleted in May 1997

The simulation results of DL Sand have been compared with the historical gas rate and pressure depletion in Figure 6.27 and Figure 6.28 The simulated result of DL Sand predicts the gas rate to decline to 6 MMscfd with pressure declining to 1310 psia in the year 2002, with a gas recovery of 54% The gas in place value of DL Sand according to the simulated result is 168 BCF

6.5.1.4 DU Sand

Well BK 4 was the only producing well of DU Sand. This well was watered out in October 1992 The top of this sand at Well BK 4 is 6470 ft and base at 6546 ft. The net thickness of this sand is 80 ft with an average thickness of 37.6 ft. The permeability of this sand is 204 md. The porosity and rock compressibility of this sand is 0.2 and 0.0000036 psi^{-1} respectively.

Figure 6.23 Simulated and Actual Production History of Well BK 2 of DL Sand

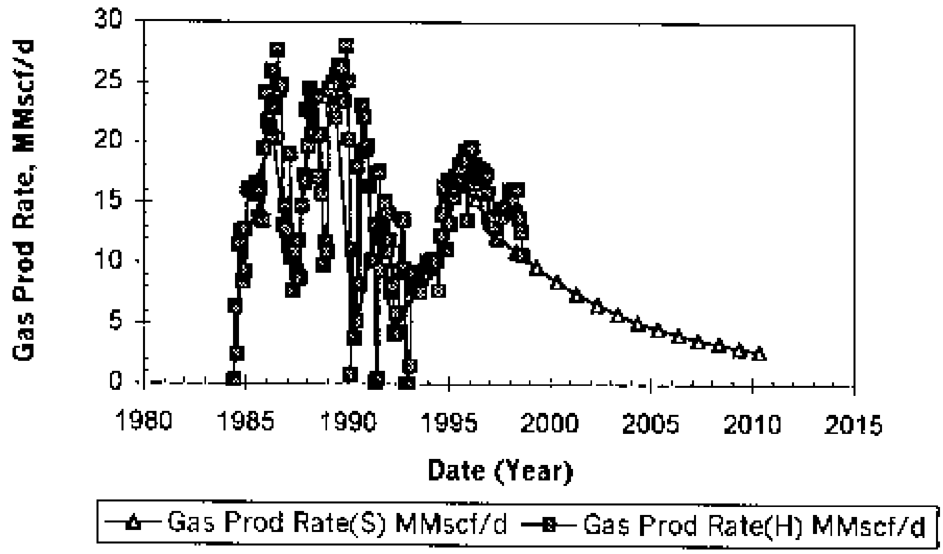


Figure 6.24 Simualted and Actual Pressure History of Well BK 2 of DL Sand

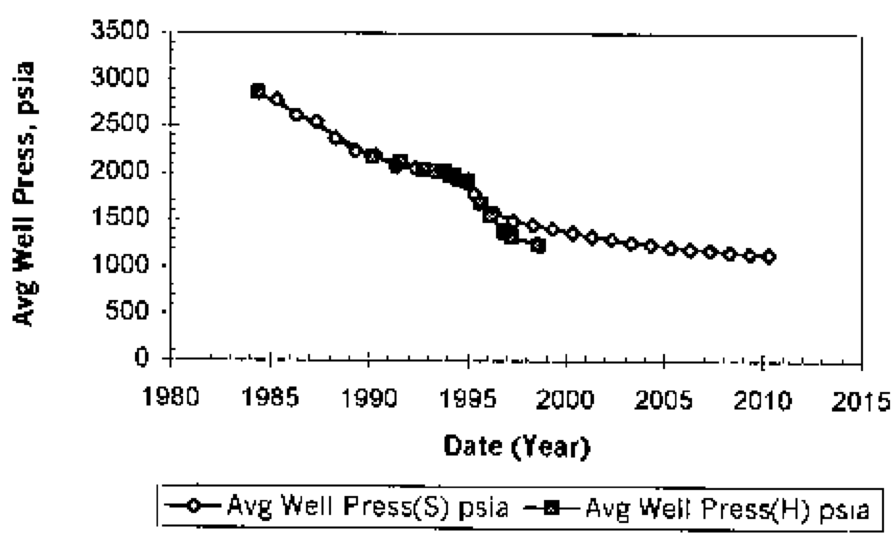


Figure 6.25 Simulated and Actual Production History of Well BK 5 of DL Sand

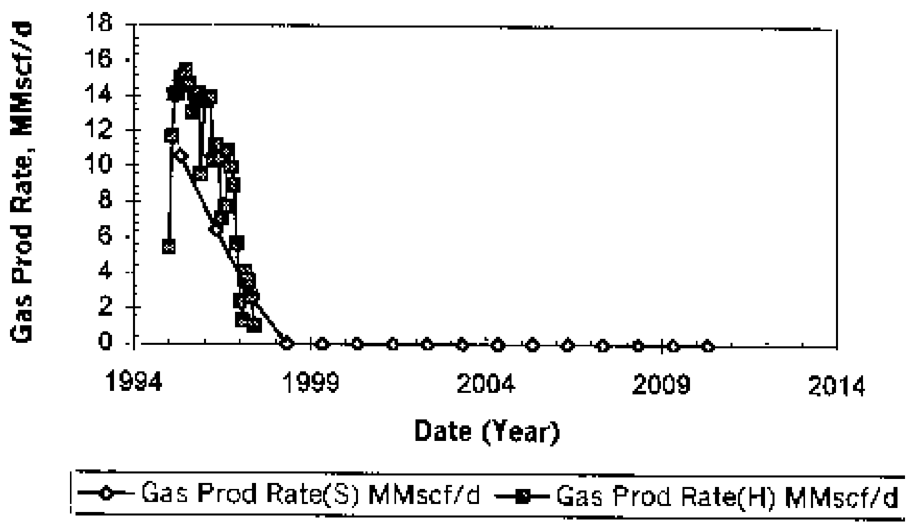
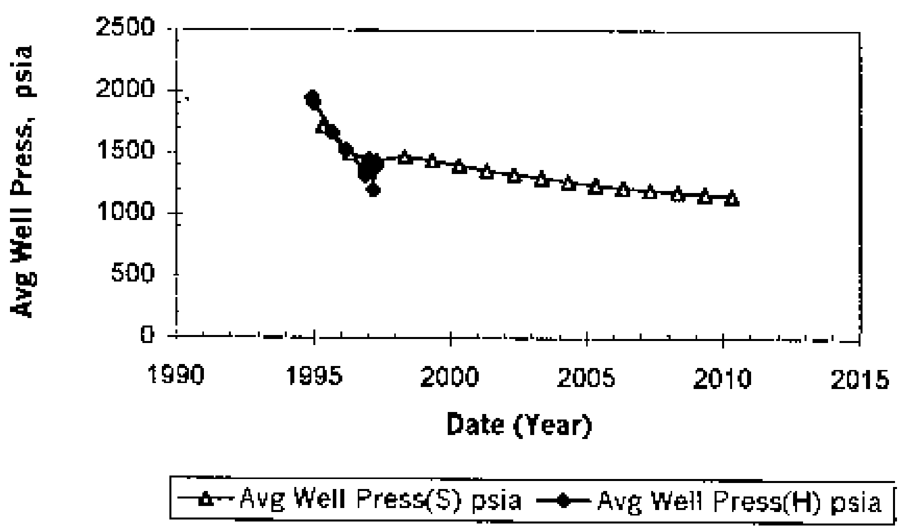


Figure 6.26 Simulated and Actual Pressure History of Well BK 5 of DL Sand



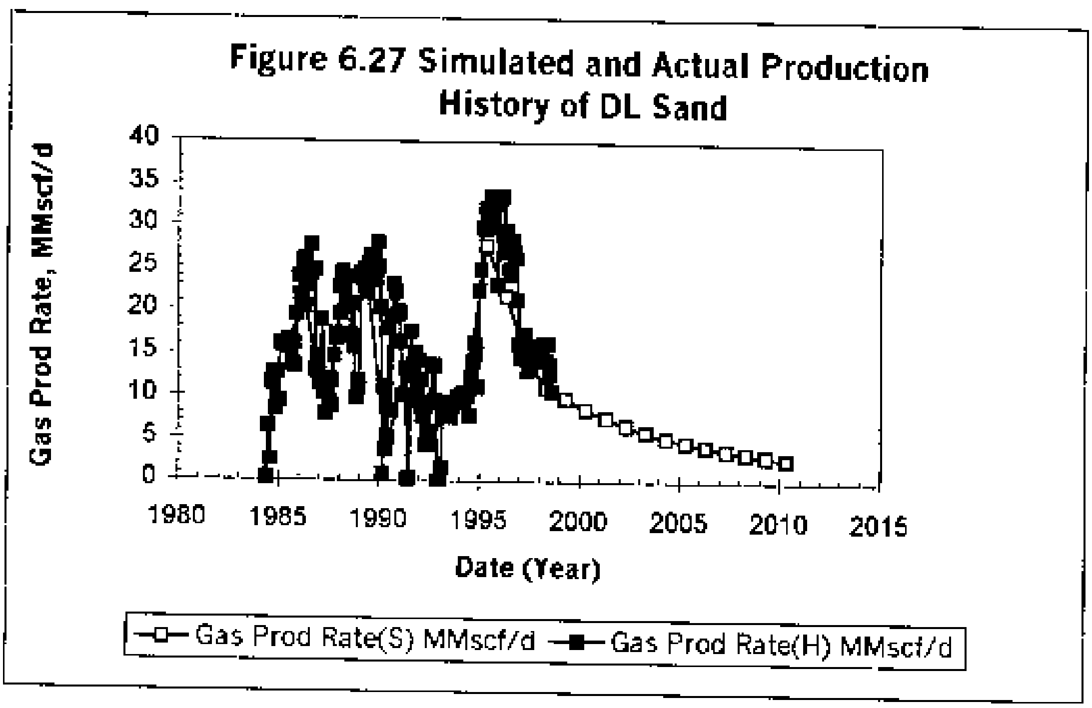


Figure 6.27 Simulated and Actual Production
History of DL Sand
Gas Prod Rate, MMscf/d
40
35
30
25
20
15
10
5
0
1980
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Gas Prod Rate(S) MMscf/d
Gas Prod Rate(H) MMscf/d

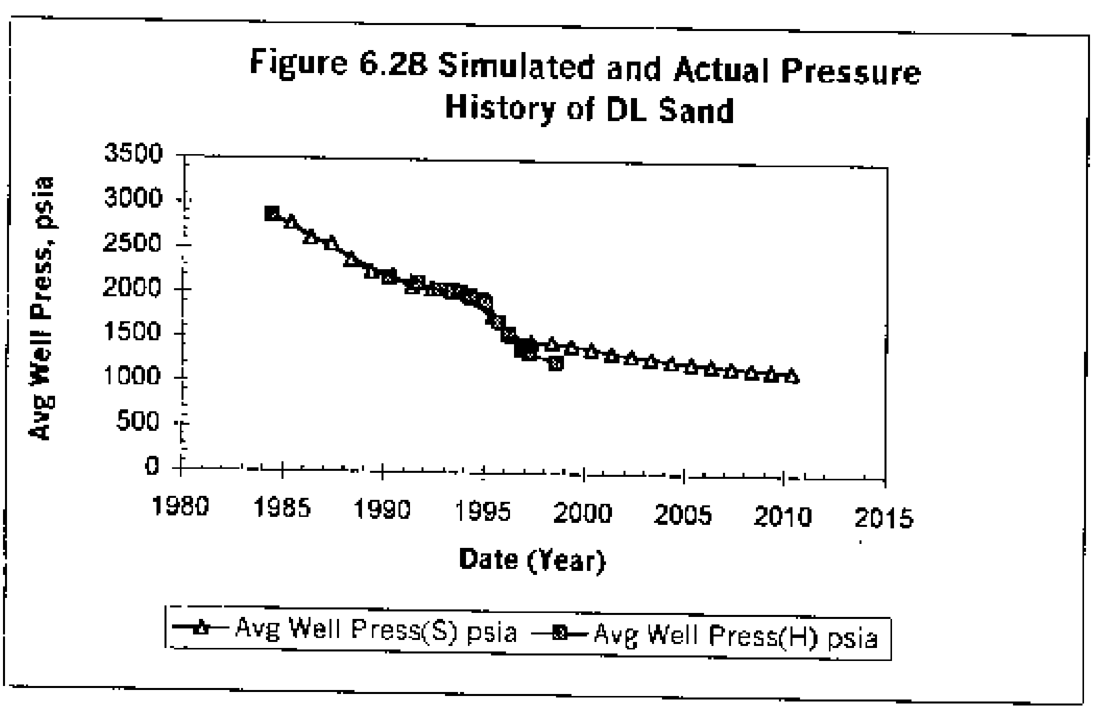


Figure 6.28 Simulated and Actual Pressure
History of DL Sand
Avg Well Press, psia
3500
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Avg Well Press(S) psia
Avg Well Press(H) psia

The simulated results of the sand are compared with the actual historical performance in Figure 6 29 and Figure 6.30 The gas in place value of DU Sand according to the simulated result is 174 BCF. The sharp decline in pressure in Figure 6.30 needs some more investigation. The recovery was only 24 52% at shut in.

6.5.1.5 B Sand

Well BK 5 was the only producing well of B sand. This well was watered out in May 1997. The top of this sand at Well BK 5 is 5883 ft and base at 6050 ft. The net thickness of this sand is 120 ft with an average reservoir thickness of 63 5 ft. The permeability of this sand is 454 1 md. The porosity and rock compressibility of this sand is 0 26 and 0 0000032 psi^{-1} respectively The simulated results along with the historical performance are graphically presented in Figure 6.31 and Figure 6.32. The gas in place value of B Sand according to the simulated result is 202 BCF and the recovery at shut-in is 21%.

Tabulated reservoir simulation results of different sands are presented in Table 6.6 through Table 6 10 in Appendix II

6.6 Comparison of Results

Table 6 5 shows different gas in place values estimated by different studies including this study. Welldrill, IKM, Petrobangla and Mobil presented gas in place values evaluated from the material balance study representing the pressure survey results. The material balance study of these studies are based only on the initial reservoir pressure and the 1989 pressure survey points of the different sands. The material balance study of Petrobangla and

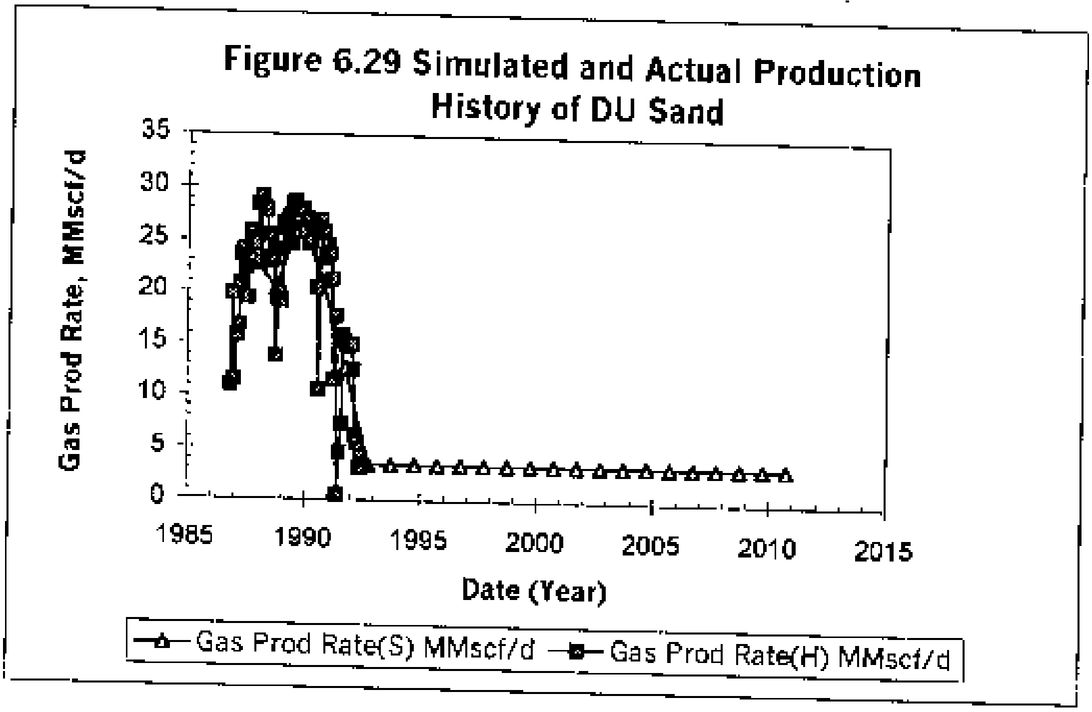


Figure 6.29 Simulated and Actual Production History of DU Sand
Gas Prod Rate, MMscf/d
35
30
25
20
15
10
5
0
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Gas Prod Rate(S) MMscf/d
Gas Prod Rate(H) MMscf/d

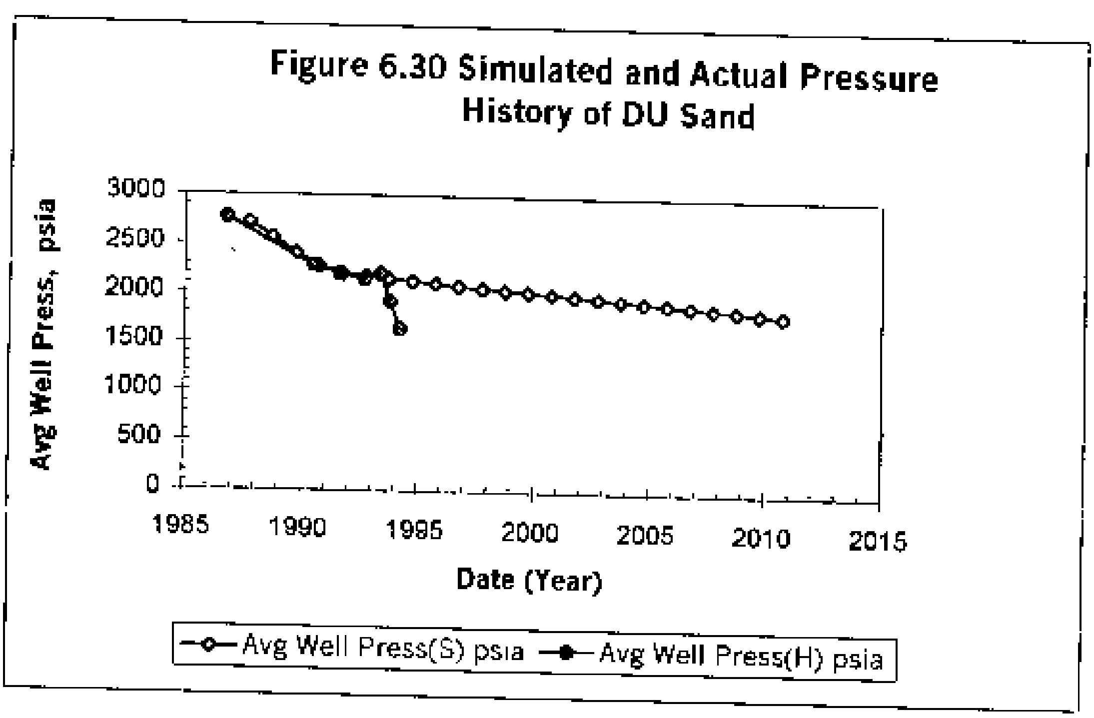


Figure 6.30 Simulated and Actual Pressure History of DU Sand
Avg Well Press, psia
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Avg Well Press(S) psia
Avg Well Press(H) psia

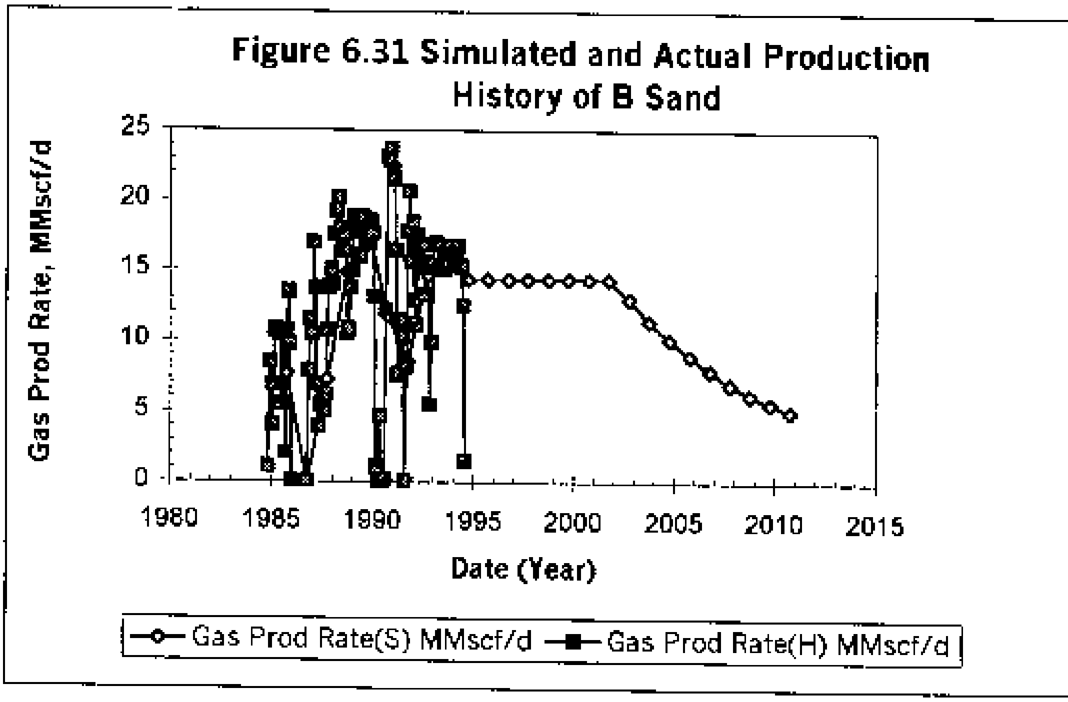


Figure 6.31 Simulated and Actual Production
History of B Sand
Gas Prod Rate, MMscf/d
25
20
15
10
5
0
1980
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Gas Prod Rate(S) MMscf/d
Gas Prod Rate(H) MMscf/d

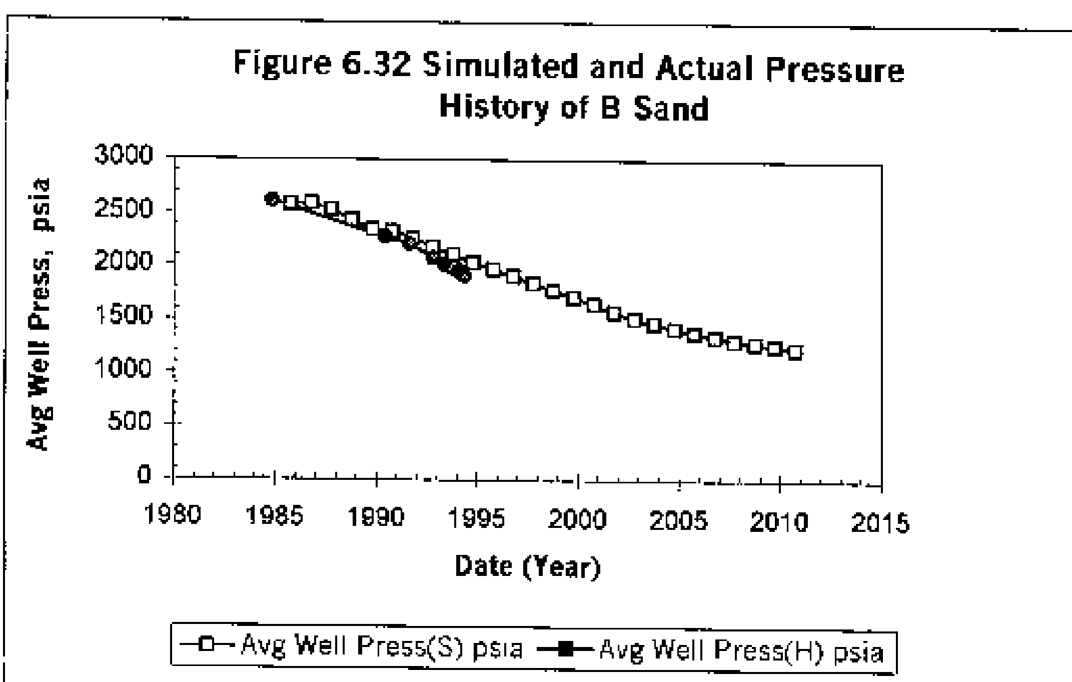


Figure 6.32 Simulated and Actual Pressure
History of B Sand
Avg Well Press, psia
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
Date (Year)
Avg Well Press(S) psia
Avg Well Press(H) psia

Table 6.5 Comparison of gas in place (BCF) figures of Bakhrabad Gas Field, estimated by different studies, using different methods.

Sand	Volumetric			Material Balance								Simulation
	Welldrill (1990)	IKM (1990)	Mobil (1997)	Welldrill (1990)	IKM (1990)	Petrobangla (1993)	Mobil (1997)	Present study				Present study
								SBHP	SWHP	FBHP	FWHP	
J	610	554	550	585	597	665.0	666	455 36	453.60	460 50	469 50	427
G	300	262	247	370	318	245.5	244	223.50	223.50	216.00	221.00	233
DL	150	151	132	200	148	176 0	175	145.54	145.54	144 50	147.50	168
DU	187	222	254	167	180	180.3	187	150 00	150.00	150 00	150 00	174
B	145	143	98	231	145	166.6	167	153.00	153 00	151.00	154.00	202
Total BK	1392	1332	1281	1553	1388	1433.4	1439	1127.40	1125.64	1122.00	1142.00	1204

Mobil includes the 1993 pressure survey results as well. Table also compares the volumetric estimate of Bakhrabad Gas Field presented by Welldrill, IKM and Mobil.

The present study evaluated gas in place values applying different approaches of material balance study, namely, static bottomhole pressure, shut-in wellhead pressure, flowing wellhead pressure and flowing bottomhole pressure, results are very similar Based on the SBHP approach the gas in place estimate of Bakhrabad Gas Field is 1127.4 BCF Assuming the abandonment p/z as 1000 psia, recoverable gas is 797 BCF (Table 5.9) As of August 1998, cumulative production of Bakhrabad Gas Field was 553.7 BCF Thus, the recovery of this field is 49%.

This study also accommodates the gas in place values of different sands through reservoir simulation study. Both the material balance study and simulation study is showing very close results in terms of gas in place estimate of Bakhrabad Gas Field. Gas in place estimate of the present simulation study of the field is 1204 BCF Thus, the recovery of the field is 46%

Chapter 7

Conclusion and Recommendation

7.1 Conclusion

Production Data Analysis

- Excessive production from different wells is the most likely reason for sand production problems and early water breakthrough in Bakhrabad Gas Field.
- Wells, BK 1 and BK7 of J Sand are not having acute water production problem and seems that these wells will be able to continue production for some time.
- In J Sand, Well BK 8 is producing significant amount of water. Pressure at this well is also declining fast This well may go out of production soon.
- Although Well BK 3 of G Sand has sand production problem, it may not have an acute water production problem.
- Pressure in DL Sand is declining sharply The only producing Well BK 2 will be out of production soon.

Material Balance Study

- Material balance study utilising the flowing well method can be used as an alternate to conventional material balance study. This method is specially useful for the reservoir where regular pressure survey can not be conducted due to high gas demand situation.

- Both flowing wellhead pressure and the calculated flowing bottom hole pressure can be used in the flowing well method Flowing well method is based on the assumption of no liquid buildup in the well.

- All the sands of the Bakhrabad Gas Field are volumetric. There is no acquifer support and the water production of the field is due to the presence of mobile water.

- The total gas in place value of Bakhrabad Gas Field obtained by flowing well method (FBHP) and conventional material balance (SBHP) are 1122.00 BCF and 1127 40 BCF.

- Assuming a cut off p/z of 1000 psia, the recoverable reserve of Bakhrabad Gas Field is 797 BCF. As of August 1998, the cumulative production of the field is 553 7 BCF. Thereafter, the remaining reserve of the field is 243.3 BCF. The overall gas in place recovery of Bakhrabad Gas Field is 49%.

Reservoir Simulation

- All the producing sands have been simulated using a commercial simulator. The simulated results compare well with the actual production and pressure history of the sands and individual wells.

- The total gas in place value of Bakhrabad Gas Field obtained by reservoir simulation is 1204 BCF. As of August 1998, the cumulative production of the field is 553.7 BCF Thus, the overall gas in place recovery of the field is 46%.

- The gas in place value estimated from simulation study compares well with that obtained from material balance study and other studies previously conducted on Bakhrabad Gas Field.

7.2 Recommendation

- Flowing well method can be applied to other gas fields of Bangladesh where regular pressure survey cannot be conducted due to critical demand-supply situation.
- Proper attention should be given in designing the gathering system so that flow from individual well/sand can be isolated to study its performance

NOMENCLATURE

B_g = Gas formation volume factor, rb free gas/scf gas

B_{gi} = Gas formation volume factor at initial reservoir pressure

B_o = Oil formation volume factor, rb(oil + dissolved gas)/stb oil

B_{oi} = Oil formation volume factor at initial reservoir pressure

c_w = Water isothermal compressibility, psi^{-1}

c_f = Formation isothermal compressibility, psi^{-1}

f = Moody friction factor

G = Initial reservoir gas volume

m = Ratio, initial hydrocarbon volume of the gascap/initial hydrocarbon volume of the oil

N = Initial reservoir oil, stb

N_p = Cumulative produced oil, stb

p_{sc} = Pressure at standard conditions

p = Reservoir pressure, psia

p_i = Initial reservoir pressure, psia

p_{ws} = Shut-in wellhead pressure, psia

p_{wh} = Static bottom-hole pressure, psia

Δp = Change in reservoir pressure, psia

q_{sc} = Gas flow rate at standard conditions

R_p = Cumulative produced gas-oil ratio, scf/stb

R_s = Solution gas oil ratio, scf gas/stb oil

R_{si} = Solution gas oil ratio at initial reservoir pressure, scf gas/stb oil

S_{wc} = Connate or irreducible water saturation

T = Temperature, °R

T_{av} = Average temperature, °R

T_{sc} = Temperature at standard conditions, °R

V_f = Total pore volume, rb

V_w = Connate water volume, rb

W_e = Cumulative water influx from the aquifer into the reservoir, stb

W_p = Cumulative amount of aquifer water produced, stb

z = Gas compressibility factor

z_{av} = Average gas compressibility factor

z_i = Gas compressibility factor at initial reservoir pressure

γ = Specific gravity

ϕ = Porosity

μ = Viscosity, cp

SBHP - static bottom hole pressure

SWHP - shut-in wellhead pressure

FBHP - flowing bottomhole pressure

FWHP - flowing wellhead pressure

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APPENDIX I

```
C   Fortran Program To Calculate Static Bottom-Hole Pressure From
C   Given Wellhead Pressure And Bottom Hole Temperature.

C   This program calculates the Static Bottom-Hole Pressure from
C   given Shut-in Wellhead Pressure and bottom-hole temperature for
C   well BK 1 of J sand.

      IMPLICIT REAL*8 (A-H, O-Z)
      DIMENSION PWH(19),PWSI(19),PWS(19),ZAV(19),PAV(19),S(19),PBYZ(19)

      OPEN(UNIT=51, FILE='B1(BP).IN', STATUS='OLD')
      OPEN(UNIT=61, FILE='B1(BP).OUT', STATUS='UNKNOWN')


C   Variables Used In Program:


C   GAMMAG  = GAS GRAVITY
C   H       = DEPTH OF WELL, FT.
C   PAV(I)  = AVERAGE PRESSURE, PSIA.
C   PSEUPC  = PSEUDO-CRITICAL PRESSURE, PSIA.
C   PWH(I)  = WELLHEAD PRESSURE, PSIA
C   PWS(I)  = STATIC BOTTOMHOLE PRESSURE, PSIA
C   PWSI    = INITIAL STATIC BOTTOMHOLE PRESSURE.
C   S(I)    = 0.0375*G*H/(TAV*ZAV(I))
C   T(I)    = TEMPERATURE, R.
C   TAV     = AVERAGE TEMPERATURE, R.
C   TBH     = BOTTOM HOLE TEMPERATURE, R.
C   TSEUTC  = PSEUDO-CRITICAL TEMPERATURE.
C   TWH     = WELLHEAD TEMPERATURE
C   ZAV(I)  = AVERAGE Z-FACTOR



      WRITE(61,*)
      WRITE(61,*)
      WRITE(61,*)'SHUT-IN WHP(PSIA) STATIC BHP(PSIA) Z-FACTOR P/Z(PSIA)'
      WRITE(61,*)
      WRITE(61,*)

      N=19
      T=655.0D0
      PSEUPC=675.70D0
      PSEUTC=354.80D0
      H=7360.0D0
      TWH=544.6D0
      TBH=T
      GAMMAG=0.593D0
```

```
      DO 10 I=1,N
      READ (51,*) PWH(I)
      PWSI(I)=PWH(I)+0.25D0*(PWH(I)/100.0D0)*(H/100.0D0)
      PAV(I)=(PWH(I)+PWSI(I))/2.0D0
      TAV=(TWH+TBH)/2.0D0

      CALL ZFAC(PAV(I), TAV, PSEUPC, PSEUTC, ZAV(I))

      S(I)=(0.0375*GAMMAG*H)/(TAV*ZAV(I))
      PWS(I)=PWH(I)*DEXP(S(I)/2.0D0)
      PBYZ(I)=PWS(I)/ZAV(I)


      WRITE(61,11) PWH(I), PWS(I), ZAV(I), PBYZ(I)
      WRITE(*,11) PWH(I), PWS(I), ZAV(I), PBYZ(I)
   11 FORMAT (2X,F10.4, 3X,F10.4, 3X,F10.6, 3X,F12.6)
   10 CONTINUE

      STOP
      END


C     SUBROUTINE ZFAC CALCULATES Z-FACTOR FOR GIVEN PRESSURE AND
TEMPERATURE

C     VARIABLES:

C     A,B,C,D  = TEMPERATURE-DEPENDENT FUNCTIONS
C     PR       = REDUCED PRESSURE.
C     RTR      = RECIPROCAL REDUCED TEMPARATURE.
C     Y        = REDUCED DENSITY
C     N        = NO. OF PESSURE DATA
C     T        = ABSOLUTE TEMPERATURE
C     PSEUPC   = PSEUDOCRITICAL PRESSURE
C     PSEUTC   = PSEUDOCRITICAL TEMPERATURE
C     P        = PRESSURE


      SUBROUTINE ZFAC(P,T,PSEUPC,PSEUTC,Z)

      IMPLICIT REAL*8 (A-H, O-Z)


      N=19
      T=655.0D0
      PSEUPC=675.70D0
      PSEUTC=354.80D0
      RTR = PSEUTC/T

C     DO 10 I=1,N
C     READ (51,*) P
```

```
      PR  = P/PSEUPC

      A = 0.06125D0*RTR*DEXP(-1.2D0*(1.0D0-RTR)*(1.0D0-RTR))
      B = RTR*(14.76D0-9.76D0*RTR+ 4.58D0*RTR*RTR)
      C = RTR*(90.7D0-242.2D0*RTR+42.4D0*RTR*RTR)
      D = 2.18D0+2.82D0*RTR
      Y = 0.001D0

        DO 100 J=1,N
        F=-A*PR+(Y+Y*Y+Y**3-Y**4)/((1.0D0-Y)**3)-B*Y*Y+C*(Y**D)
        IF(DABS(F)-1.0E-5) 2,2,1
    1   DFDY=+(1.0D0+4.0D0*Y+4.0D0*Y*Y-4.0D0*Y**3+Y**4)/((1.0D0-Y)**4)
     +   -2.0D0*B*Y+D*C*(Y**(D-1.0D0))
        Y=Y-(F/DFDY)
  100   CONTINUE

C 10 CONTINUE

    2 Z=A*PR/Y

      RETURN
      END
```

```
C    Fortran Program to Calculate Z-Factor For Given Pressure
C    And Temperature Using Yarborough & Hall Procedure
C
C    This program calculates the Z-factor for given pressure and
C    temperature using Yarborough & Hall Procedure for well BK 1
C    of J sand.

      IMPLICIT REAL*8 (A-H, O-Z)

      OPEN(UNIT=51, FILE='ZBK1(S).IN', STATUS='OLD')
      OPEN(UNIT=61, FILE='ZBK1(S).OUT', STATUS='UNKNOWN')

C    VARIABLES:

C    A,B,C,D  = TEMPERATURE-DEPENDENT FUNCTIONS
C    PR       = REDUCED PRESSURE
C    RTR      = RECIPROCAL REDUCED TEMPARATURE
C    Y        = REDUCED DENSITY
C    N        = NO. OF PESSURE DATA
C    T        = ABSOLUTE TEMPERATURE
C    PSEUPC   = PSEUDOCRITICAL PRESSURE
C    PSEUTC   = PSEUDOCRITICAL TEMPERATURE
C    P        = PRESSURE

      WRITE(61,*)
      WRITE(61,*)
      WRITE(61,*)'SHUT-IN PRESSURE (PSIA)        Z FACTOR'
      WRITE(61,*)
      WRITE(61,*)

      N=19
      T=655.0D0
      PSEUPC=675.70D0
      PSEUTC=354.80D0
      RTR = PSEUTC/T

      DO 10 I=1,N
      READ (51,*) P

      PR = P/PSEUPC

      A = 0.06125D0*RTR*DEXP(-1.2D0*(1.0D0-RTR)*(1.0D0-RTR))
      B = RTR*(14.76D0-9.76D0*RTR+ 4.58D0*RTR*RTR)
      C = RTR*(90.7D0-242.2D0*RTR+42.4D0*RTR*RTR)
      D = 2.18D0+2.82D0*RTR
      Y = 0.001D0
```

```
      DO 100 J=1,N
      F=-A*PR+(Y+Y*Y+Y**3-Y**4)/((1.0D0-Y)**3)-B*Y*Y+C*(Y**D)
      IF(DABS(F)-1.0E-5) 2,2,1
 1    DFDY=+(1.0D0+4.0D0*Y+4.0D0*Y*Y-4.0D0*Y**3+Y**4)/((1.0D0-Y)**4)
     + -2.0D0*B*Y+D*C*(Y**(D-1.0D0))
      Y=Y-(F/DFDY)
100   CONTINUE
 2    Z=A*PR/Y
      WRITE(61,*) P, Z
10    CONTINUE
      STOP
      END
```

APPENDIX II

Table 6 6 Important Simulation Results of Bakhrabad J Sand

BAKHRABAD "J Sand Simulation"							
Date	Avg Pressure psia	GIP Mcf	Water Rate bbls/d	Gas Rate Mcf/d	Cum Water Prod bbls	Cum Gas Prod Mcf	Gas Recovery %
(1985 AUG 1)	3193.394	4.27E+08	0.00E+00	0	0	0	0
(1986 AUG 1)	3134.512	4.19E+08	5.75E-04	25618.41	46.63223	7.27E+06	1.704635
(1987 AUG 1)	3069.438	4.12E+08	2.18E-04	17697.3	46.78517	1.51E+07	3.541062
(1988 AUG 1)	3000.915	4.02E+08	5.17E-04	27285.46	46.95449	2.44E+07	5.729851
(1989 AUG 1)	2919.506	3.92E+08	6.47E-04	29562.53	47.17538	3 50E+07	8.204049
(1990 AUG 1)	2789.83	3.72E+08	5 23E-03	48153.46	46.91579	5.45E+07	12.76841
(1991 AUG 1)	2568.92	3.46E+08	1.67E-02	80178.32	53.36244	8.09E+07	18.95141
(1992 AUG 1)	2335.601	3.14E+08	2.73E-02	96346.59	60.54893	1.13E+08	26.41515
(1993 AUG 1)	2113.74	2.83E+08	1.07E-02	78864.13	64.94534	1.43E+08	33.62801
(1994 AUG 1)	1916.079	2.54E+08	9 00E-02	84151.48	88.44781	1.73E+08	40.46759
(1995 AUG 1)	1724.229	2.28E+08	1.77E-02	71923 24	106.1654	2.00E+08	46.94967
(1996 AUG 1)	1550.568	2.03E+08	7.03E-03	55285.78	111.674	2.24E+08	52.47299
(1997 AUG 1)	1433.742	1.86E+08	4.24E-03	40640.28	113.555	2.41E+08	56.49483
(1998 AUG 1)	1335.766	1.73E+08	1.77E-03	25076.23	114.7349	2.53E+08	59.38286
(1999 AUG 1)	1287.267	1.66E+08	6 44E-04	18430.73	115 0545	2.61E+08	61.13807
(2000 AUG 1)	1247.422	1.60E+08	4.96E-04	15346.1	115.2603	2.67E+08	62.57192
(2001 AUG 1)	1211.96	1.55E+08	3.76E-04	12768.79	115 4169	2.72E+08	63 762
(2002 AUG 1)	1180.715	1.50E+08	2.80E-04	10608.27	115.5346	2.76E+08	64.7514
(2003 AUG 1)	1153.396	1.47E+08	2.07E-04	8804.46	115.6219	2.80E+08	65.57301
(2004 AUG 1)	1129.679	1.44E+08	1.50E-04	7296.559	115.6856	2.83E+08	66.25825
(2005 AUG 1)	1109.353	1.42E+08	1.08E-04	6044.677	115.732	2.85E+08	66.82082
(2006 AUG 1)	1091.998	1.40E+08	7.66E-05	5003.814	115.765	2.87E+08	67.28832
(2007 AUG 1)	1077.261	1.38E+08	5.46E-05	4139.491	115.7885	2.89E+08	67.67521
(2008 AUG 1)	1068.593	1.37E+08	4.29E-05	3623.821	115.8074	2.90E+08	68.00466
(2009 AUG 1)	1061.433	1.35E+08	3.45E-05	3205.541	115.8213	2.91E+08	68 29494
(2010 JUL 31)	1055.028	1.34E+08	2.73E-05	2837.291	115.8324	2.92E+08	68 55109

Table 6.6 Important Simulation Results of Bakhrabad G Sand

BAKHRABAD "G Sand Simulation"							
Date	Avg Pressure psia	GIP Mcf	Water Rate bbls/d	Gas Rate Mcf/d	Cum Water Prod bbls	Cum Gas Prod Mcf	Gas Recovery %
(1986 OCT 1)	3188.586	2.33E+08	0	0	0	0	0
(1987 OCT 1)	3124.028	2.29E+08	45.07669	23790.63	8103.278	4328474	1.855834
(1988 OCT 1)	2994.71	2.20E+08	43.30968	22198 1	25748.98	1.35E+07	5.772293
(1989 OCT 1)	2854.261	2.10E+08	59.19212	29124.07	45452	2.33E+07	10.00539
(1990 OCT 1)	2733 455	2.01E+08	54.94742	26323.81	63712.41	3.22E+07	13.80653
(1991 OCT 1)	2603 019	1.92E+08	48.74502	22479.56	83888.39	4.17E+07	17.85758
(1992 OCT 1)	2479.864	1.82E+08	58.66841	25999.31	104564.9	5.10E+07	21.84553
(1993 OCT 1)	2360.97	1.73E+08	54.33088	23086.71	124879	5.97E+07	25.61354
(1994 OCT 1)	2258.797	1.66E+08	50.29868	20680.11	143808.5	6.76E+07	29.00075
(1995 OCT 1)	2088.364	1.53E+08	78.24747	29371.25	175157.9	8.03E+07	34.43762
(1996 OCT 1)	1968.177	1.43E+08	69.38962	24584.19	201982.1	9.02E+07	38 66783
(1997 OCT 1)	1879.029	1.36E+08	54.56099	18329.64	222346.1	9.72E+07	41.67961
(1998 OCT 1)	1810.351	1.31E+08	33.20512	10792.26	238321.9	1.02E+08	43.93705
(1999 OCT 1)	1764.911	1.27E+08	31.91993	10093.49	250268.6	1.06E+08	45.57658
(2000 OCT 1)	1720.927	1.23E+08	30.16304	9308.768	261601	1.10E+08	47.09268
(2001 OCT 1)	1678.23	1.20E+08	28.45914	8584.15	272272.3	1.13E+08	48 48754
(2002 OCT 1)	1636.836	1.17E+08	26.80246	7904.459	282330.2	1.16E+08	49.77299
(2003 OCT 1)	1597.533	1.14E+08	25.25103	7261.673	291799	1.19E+08	50.95378
(2004 OCT 1)	1563.028	1.12E+08	23.87434	6717.84	300763	1.21E+08	52.04594
(2005 OCT 1)	1535.708	1.09E+08	22.69209	6268.118	309238.4	1.24E+08	53.05811
(2006 OCT 1)	1509.404	1.07E+08	21.603	5868.189	317304.3	1.26E+08	54.00472
(2007 OCT 1)	1483.79	1.05E+08	20.54709	5493.757	324979.7	1.28E+08	54.89103
(2008 OCT 1)	1458.83	1.03E+08	19.515	5139.834	332294.4	1.30E+08	55.72276
(2009 OCT 1)	1434.694	1.01E+08	18.5132	4807.066	339218.4	1.32E+08	56.49864
(2010 SEP 30)	1411.406	9.98E+07	17.54301	4494 36	345765	1.33E+08	57.22217

Table 6.8 Important Simulation Results of Bakhrabad DL Sand

BAKHRABAD "DL Sand Simulation"							
Date	Avg Pressure psia	GIP Mcf	Water Rate bbls/d	Gas Rate Mcf/d	Cum Water Prod bbls	Cum Gas Prod Mcf	Gas Recovery %
(1984 MAY 1)	2947.078	1.68E+08	0	0	0	0	0
(1985 MAY 1)	2874.886	1.64E+08	3.381483	15887.97	1178.49	3850835	2.297794
(1986 MAY 1)	2752.726	1.57E+08	1.922811	20352.03	2087.055	1.06E+07	6.353603
(1987 MAY 1)	2639.997	1.51E+08	0.3398784	7779.898	2530.698	1.71E+07	10.19464
(1988 MAY 1)	2530.31	1.44E+08	0.5657416	23854.93	2713.278	2.33E+07	13.89114
(1989 MAY 1)	2412.857	1.37E+08	0.323195	24818.33	2828.867	3.01E+07	17.98485
(1990 MAY 1)	2286.33	1.30E+08	2.32E-02	3880.386	2903.758	3.74E+07	22.31544
(1991 MAY 1)	2190.901	1.25E+08	5.56E-02	13150.12	2934.725	4.30E+07	25.68227
(1992 MAY 1)	2131.77	1.21E+08	9.61E-03	4199.828	2949.282	4.65E+07	27.72169
(1993 MAY 1)	2087.223	1.19E+08	2.90E-02	7929.556	2959.404	4.90E+07	29.23241
(1994 MAY 1)	2031.757	1.15E+08	7.12E-02	10335.23	2977.953	5.24E+07	31.24859
(1995 MAY 1)	1928.168	1.09E+08	34.18303	27603.6	7769.513	5.89E+07	35.14627
(1996 MAY 1)	1778.679	9.97E+07	23.55623	21690.21	17869.94	6.79E+07	40.50103
(1997 MAY 1)	1671.517	9.31E+07	9.876954	14860.64	24083.1	7.44E+07	44.4198
(1998 MAY 1)	1601.099	8.89E+07	4.02E-02	10938.71	24195.95	7.87E+07	46.93911
(1999 MAY 1)	1535.156	8.52E+07	2.28E-02	9877.132	24206.77	8.24E+07	49.17292
(2000 MAY 1)	1481.335	8.19E+07	1.44E-02	8504.457	24213.28	8.57E+07	51.14472
(2001 MAY 1)	1433.078	7.90E+07	1.00E-02	7482.936	24217.6	8.86E+07	52.87414
(2002 MAY 1)	1388.828	7.64E+07	7.25E-03	6578.167	24220.68	9.12E+07	54.39431
(2003 MAY 1)	1349.549	7.42E+07	5.47E-03	5819.483	24222.94	9.34E+07	55.73616
(2004 MAY 1)	1314.039	7.22E+07	4.32E-03	5139.855	24224.7	9.54E+07	56.92514
(2005 MAY 1)	1285.384	7.04E+07	3.43E-03	4566.614	24226.1	9.72E+07	57.97499
(2006 MAY 1)	1261.718	6.89E+07	2.71E-03	4091.027	24227.2	9.87E+07	58.912
(2007 MAY 1)	1239.567	6.74E+07	2.18E-03	3680.346	24228.08	1.00E+08	59.75362
(2008 MAY 1)	1218.82	6.62E+07	1.78E-03	3313.554	24228.8	1.01E+08	60.51326
(2009 MAY 1)	1199.481	6.50E+07	1.47E-03	2983.645	24229.38	1.03E+08	61.19541
(2010 APR 30)	1181.525	6.40E+07	1.22E-03	2685.435	24229.87	1.04E+08	61.80786

Table 6 9 Important Simulation Results of Bakhrabad DU Sand

BAKHRABAD "DU Sand Simulation"								
Date	Avg Pressure psia	GIP Mcf	Water Rate bbls/d	Gas Rate Mcf/d	Cum Water Prod bbls	Cum Gas Prod Mcf	Gas Recovery %
(1986 OCT 1)	2881.499	1.74E+08	0	0	0	0	0
(1987 OCT 1)	2760.688	1.67E+08	1.16E-02	23395.94	192.1143	7171133	4.114285
(1988 OCT 1)	2608.481	1.58E+08	3.84E-03	20331.73	194.5269	1.62E+07	9.278303
(1989 OCT 1)	2462.156	1.49E+08	6.15E-03	27413.15	197.0616	2.53E+07	14.51319
(1990 OCT 1)	2312.632	1.40E+08	2.57E-03	21015.11	199.1106	3.42E+07	19 62485
(1991 OCT 1)	2223.413	1.34E+08	9.93E-04	12773.56	199.7165	4.00E+07	22.95384
(1992 OCT 1)	2179.062	1.32E+08	3.15E-05	3434.872	199.8799	4.27E+07	24.52348
(1993 OCT 1)	2158.088	1.30E+08	7.78E-05	3434.876	199.9057	4.40E+07	25.24278
(1994 OCT 1)	2136.714	1.29E+08	7.98E-05	3434.67	199.9348	4.53E+07	25.96208
(1995 OCT 1)	2114.924	1.28E+08	8.21E-05	3434.858	199.9642	4.65E+07	26.68138
(1996 OCT 1)	2092.647	1.27E+08	8 40E-05	3434.861	199.9946	4.78E+07	27.40264
(1997 OCT 1)	2071.195	1.25E+08	5.78E-04	3434.865	200.1158	4.90E+07	28.12193
(1998 OCT 1)	2054.081	1.24E+08	5.38E-04	3434.869	200.3181	5.03E+07	28.84122
(1999 OCT 1)	2036.704	1.23E+08	5 49E-04	3434.868	200.5145	5.15E+07	29.56051
(2000 OCT 1)	2018.935	1.22E+08	5.63E-04	3434.867	200.7182	5.28E+07	30.28178
(2001 OCT 1)	2000.882	1.20E+08	5.78E-04	3434.866	200.9266	5 40E+07	31.00106
(2002 OCT 1)	1982.423	1.19E+08	5.92E-04	3434.869	201.1403	5.53E+07	31.72036
(2003 OCT 1)	1963.611	1.18E+08	6.08E-04	3434.868	201.3595	5 65E+07	32.43964
(2004 OCT 1)	1944.359	1.16E+08	6.23E-04	3434.864	201.585	5.78E+07	33.1609
(2005 OCT 1)	1924.761	1.15E+08	6.40E-04	3434.866	201.8158	5.91E+07	33.8802
(2006 OCT 1)	1904.753	1.14E+08	6.57E-04	3434.868	202.0528	6.03E+07	34.59949
(2007 OCT 1)	1884.322	1.13E+08	6.75E-04	3434.866	202.2961	6.16E+07	35.31877
(2008 OCT 1)	1863 393	1.11E+08	6.93E-04	3434.863	202.5467	6.28E+07	36.04004
(2009 OCT 1)	1842.071	1.10E+08	7.12E-04	3434.866	202.8035	6.41E+07	36.75933
(2010 SEP 30)	1821.335	1.09E+08	1.60E-04	3434 867	202.9624	6.53E+07	37.47665

Table 6.10 Important Simulation Results of Bakhrabad B Sand

BAKHRABAD "B Sand Simulation"							
Date	Avg Pressure psia	GIP Mcf	Water Rate bbls/d	Gas Rate Mcf/d	Cum Water Prod bbls	Cum Gas Prod Mcf	Gas Recovery %
(1984 OCT 1)	2836 237	2.02E+08	0	0	0	0	0
(1985 OCT 1)	2597.653	1 99E+08	8.75E-03	7673.103	167 7522	2765563	1.369408
(1986 OCT 1)	2587 615	1.98E+08	0	0	168.0812	3472306	1.719361
(1987 OCT 1)	2548.172	1 95E+08	4.35E-04	7241.575	168 4202	6613783	3.274908
(1988 OCT 1)	2475.751	1.89E+08	1 88E-03	14804.13	169.4933	1.25E+07	6.186328
(1989 OCT 1)	2395.91	1.83E+08	3 46E-03	18080.02	170.5533	1.86E+07	9.207477
(1990 OCT 1)	2351.19	1.80E+08	1.22E-03	11694.1	170 9019	2.19E+07	10.82586
(1991 OCT 1)	2286.623	1 75E+08	1.94E-04	8521.53	171 4902	2.70E+07	13.37014
(1992 OCT 1)	2216.405	1.69E+08	1 16E-03	14632.41	172.0359	3.27E+07	16.20221
(1993 OCT 1)	2147 855	1.64E+08	1.47E-03	15454.09	172 4994	3.80E+07	18.80036
(1994 OCT 1)	2073.887	1 58E+08	9.20E-03	14312.66	174.6263	4.35E+07	21.55337
(1995 OCT 1)	2014.465	1.53E+08	9.41E-03	14312.66	178 1299	4.88E+07	24.14017
(1996 OCT 1)	1953.623	1 48E+08	9.99E-03	14312.66	181.669	5.40E+07	26.73403
(1997 OCT 1)	1888.758	1 43E+08	1 09E-02	14312.66	185.4855	5.92E+07	29.32083
(1998 OCT 1)	1822 345	1.38E+08	2 64E-03	14312.66	187.6377	6.44E+07	31.90763
(1999 OCT 1)	1761.52	1 32E+08	2 57E-03	14312.66	188.588	6.97E+07	34.49442
(2000 OCT 1)	1697 862	1.27E+08	2.79E-03	14312.66	189.567	7.49E+07	37.08828
(2001 OCT 1)	1629 022	1.22E+08	3.12E-03	14312.66	190.6483	8.01E+07	39.67506
(2002 OCT 1)	1563 004	1.17E+08	1.39E-03	12953.69	191.3025	8.52E+07	42.16475
(2003 OCT 1)	1512 687	1.12E+08	9.96E-04	11383.05	191.7269	8.96E+07	44.3447
(2004 OCT 1)	1465.9	1.08E+08	8.35E-04	10087.36	192.0568	9.35E+07	46.27813
(2005 OCT 1)	1421.702	1 05E+08	0.0007104	8929.031	192.3363	9.69E+07	47.98602
(2006 OCT 1)	1380.146	1 02E+08	6.00E-04	7887.974	192.5734	1.00E+08	49.49619
(2007 OCT 1)	1342.16	9 93E+07	4.24E-04	6975.237	192.7652	1.03E+08	50.82941
(2008 OCT 1)	1311.228	9 69E+07	3.54E-04	6209.355	192.9063	1.05E+08	52.01714
(2009 OCT 1)	1288.222	9 48E+07	2.57E-04	5610.208	193.0135	1.07E+08	53.07849
(2010 SEP 30)	1266.513	9 28E+07	2.19E-04	5099.841	193.0992	1.09E+08	54.03905

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তাং 21.11.99
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