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Suitability Analysis of the Potential Gas Fields of Bangladesh for Carbon Dioxide Sequestration and A Simulation Approach for Titas Gas Field

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Abstract

Global warming has become one of the major environmental issues all over the world. The temperature of the world is increasing day by day, and fortunately, everybody wants to mitigate this fearful condition from own perspective. Carbon dioxide sequestration is a worldwide recognized project for making huge amount of carbon inactive, which is the main component of greenhouse gases, by sequestrating it beneath the Earth. The paper aims to dictate the probable success of CO_2 sequestration in Bangladesh. As abandoned gas fields are the best options for sequestration, characteristics of the potential gas fields of Bangladesh have been analyzed according to Stefan Bachu's method of classification for CO_2 sequestration. Titas gas field shows the best suitability, and accordingly, an Eclipse simulation software basis approach has been taken for this field to determine possible outcomes from probable sequestration project. Simulation result predicts an amount of 2.92 Tcf carbon dioxide gas to be sequestrated after 50 years of simulation. Other criteria such as field pressure, gas saturation are also evaluated.

Keywords: Bangladesh; CO_2 Sequestration; Eclipse simulation; Gas fields ranking; Stefan Bachu classification.

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1. Introduction

Vast majority of scientists agree that global climate change is occurring and that to prevent it’s most serious effects we must begin immediately to significantly reduce our greenhouse gas (GHG) emissions. One major contributor to climate change is the release of the greenhouse gas carbon dioxide (CO_2). As a developing country, carbon dioxide emission rate is explicitly escalating at a very high rate in Bangladesh. The GDP growth rate of Bangladesh increases from 6.5% to 7.1% from the year of 2012 to 2016 (World

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Bank, 2016) and according to Alam [1], for the growing GDP of Bangladesh, industry and service sectors play a vital role which are also responsible for increasing CO_2 emissions. Also, Bangladesh's remarkable economic growth is due to high cost of natural resources and health of the environment [2].

Gunter and Rahman [2] have worked together with a vision to provide an alternative projection for Bangladesh's future CO_2 emissions to assess if Bangladesh is likely to achieve 'simple per capita income limit' that would be consistent with the Copenhagen accord by using data for the period of 1972–2005, and their findings are quite important. They have reached to a decision that CO_2 emissions in Bangladesh will be 15 times larger in 2050 than 2005 if there is no improvement in country's energy efficiency. They finally concluded that as poverty reduction is imperative, some increases of CO_2 emissions are unavoidable in Bangladesh and therefore, it is important to minimize this increase as far as possible by providing appropriate technologies [3].

CO_2 emission as a whole and emission rate (metric tons per capita) of Bangladesh from the year of 1994 to 2014 are shown in Fig. 1. Both graphs showing an increase of CO_2 emission.

Bangladesh produces a very small amount of global CO_2 emission. But, the country's emission scenario has marked a rapid increase of CO_2 emission over a long time. The overall CO_2 emission has been increased to approximately 286% from the year 1994 to 2014 as shown in Fig. 1.

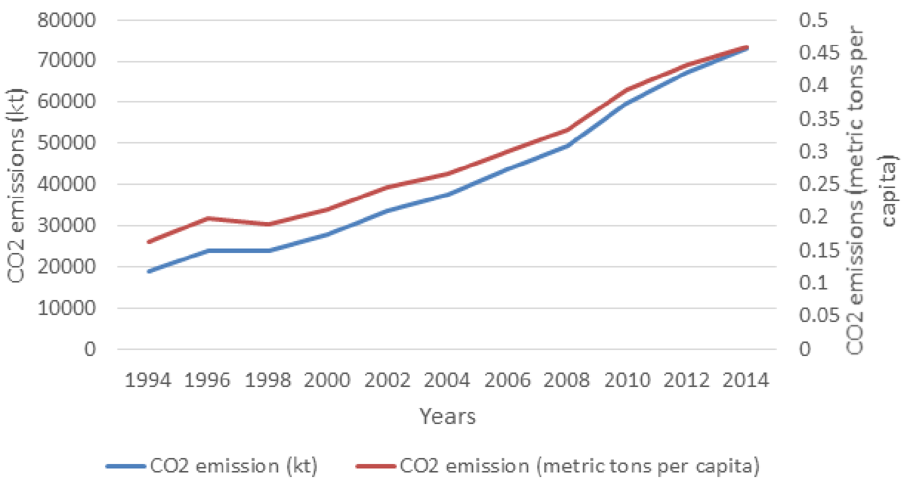

Fig. 1. Overall CO_2 emission and CO_2 emission rate (per capita) of Bangladesh (World Bank, 2015).

Evidently, Bangladesh is trying to implement a lot of initiatives and certain projects to decrease the emission rate and tackling climate changing impacts. Bangladesh has developed climate change strategy and action plan towards mitigation and low carbon development along with other strategic areas [4]. Eventually, with feasible economic planning, Bangladesh has a chance to develop a long term plan for CO_2 sequestration in suitable place. Carbon or CO_2 sequestration means putting carbon into long-term storage. It denotes the removal of CO_2, either directly from anthropogenic sources, or from the atmosphere, and disposing of it either permanently or for geologically-significant time periods [5]. CO_2 can be sequestered in deep underground formations of porous rock at least 2,500 feet below ground surface, but diligent geological site characterization is essential. To be suitable for CCS (Carbon Capture & Storage), porous formations must lie under layers of impermeable rock that will provide a "cap" or seal to prevent upward migration of the CO_2. Carbon dioxide can be sequestered in geological media by geological (stratigraphic and structural) trapping in depleted oil and gas reservoirs, solubility trapping in reservoir oil and formation water, adsorption trapping in uneconomic coal beds, cavern trapping in salt structures, and by mineral immobilization [6]. These media have both the space (porosity) and injectivity (permeability) necessary for CO_2 injection, and, by and large, have the ability to either prevent or delay for geologically significant periods of time the CO_2 return to the atmosphere. Crystalline and metamorphic rocks, such as granite, on continental shields are not suitable for CO_2 storage and sequestration because they lack the porosity and permeability needed for CO_2 injection, and because of their fractured nature. Volcanic areas and orogenic belts (mountains) are also unsuitable mainly because they lack capacity and are unsafe. Carbon dioxide sequestration in gas or oil field is far more attractive than other processes. The possibility of geological sequestration of carbon dioxide in Bangladesh is analyzed in this study. A series of suitability criteria for geological sequestration of CO_2 were previously developed [6], they are:

- Basin characteristics, such as tectonism, geology and geothermal and hydrodynamic regimes (these are ‘‘hard’’ criteria because they do not change).
- Basin resources (hydrocarbons, coal, salt), maturity and infrastructure (these ‘‘semi-hard’’ or ‘‘semi-soft’’ criteria because they may change with new discoveries, technological advances and/or economic development).
- Societal, such as level of development, economy, political structure and stability, public education and attitude (this is "soft" criteria because they are rapidly change or vary from one region to another).

These criteria are developed & applied by Stefan Bachu [5]. It can also be applied for small regions like oil & gas reservoirs. Site selection for CO_2 sequestration among four potential gas fields of Bangladesh [7] is analyzed here carefully according to Bachu's method where 15 important criteria are considered. The criteria are, tectonic setting, size, depth, geology, hydrogeology, geothermal, hydrocarbon potential, maturity, coal & CBM, salts, on/offshore, climate, accessibility, infrastructure, CO_2 sources. S. Bachu [6] assigned weight for all characteristics according to their importance. Thus geology, hydrogeology, geothermal, maturity, on/offshore, climate and CO_2 sources are considered as most important criteria. It can also be easily proved that initial capacity of a gas field, its maturity and nearby CO_2 sources would be the most valuable criteria in case of CO_2 sequestration in a gas field.

The suitability analysis of the gas fields is far more reliable after simulation takes place. The ECLIPSE simulator has been the benchmark for commercial reservoir simulation for more than 25 years, covering the entire spectrum of reservoir models, including black oil, gas field operations, compositional, thermal finite-volume, and streamline simulation. In this research, Schlumberger Eclipse (version 2010.1)-E300 portion has been used to carry whole simulation process. The grid portion is prepared by Petrel software. Simulation result analyses are the most important part that should be done carefully to interpret reservoir conditions after simulation.

2. Materials and Methods

Stefan Bachu's criteria for suitability analysis of CO_2 sequestration can be divided into two parts, i) variable criteria which are different for the gas fields with respect to their respective existing conditions and ii) constant criteria that are dictated by geological conditions of Bangladesh.

2.1. *Analyzation of Bachu's variable criteria for potential gas fields of Bangladesh*

Criteria under this category are, size, depth, geology, hydrogeology, hydrocarbon potential, maturity, infrastructure and CO_2 sources.

i) Size: Titas gas field is one of the major contributors in the supply of gas in Bangladesh. It has a size of 16 km by 8 km. It can be considered as large size reservoir along with Rashidpur gas field, which has an area of 35 km by 7 km. Habiganj gas field has a small area of 11.5 km by 4.5 km whereas Kailashtila gas field has a medium area of 17 km by 5 km [8]. The classes are mainly assigned with respect to each other of the gas fields.

ii) Depth, Geological and Hydrogeological condition: Titas gas reservoir includes multiple sandstone layers in the Bhuban and Bokabil formations of Miocene-Pliocene age. The depths of the gas reservoirs [8] range from about 2616 m to 3124 m below the surface. Recently BAPEX (Bangladesh Petroleum Exploration and Production Company Limited) has discovered country's deepest gas reserve at Titas around 7000 m under the ground. Data analysis suggests that there is no major fault but seismic study indicates relatively small faulting having down throw to the east in the crestal region adjoining the eastern flank [9]. The fault affects older section at depth of about 2800 to 3000 m [10]. Also, Clayton [11] identified few small faults within depths of around 2650 to 2750 m. Other analysis also suggests the same. Water injection with reservoir depth analysis reveals that aquifer presents in a shallow depth and compaction water flow exists in the reservoir [12]. The Habiganj gas field sandstones belonging to the Surma group (Bhuban and Bokabil formations) of Miocene-Pliocene age. There are two gas zones known as upper gas sand (UGS) and lower gas sand (LGS). The upper gas sand lies at a depth of 1320 m where the lower gas sand has a depth of 3000 m. Though no significant fault is yet discovered, but some analysis results indicate that there may be some big features like faults mainly in the upper gas sand of Habiganj gas field [13]. As the formation also contains mostly sandstones, it may be considered as 'extensively faulted and fractured'. Habiganj gas field has already been identified as a strong bottom water drive. Without considering water influx, the conventional material balance (p/z vs. Gp method) for OGIP of upper sand can be determined as 16 Tcf that appears to be overestimation of real volume, and cannot match with the present flow and pressure data. Considering bottom water drive, the Havlena-Odeh method for materials balance analysis has been applied, as the total underground withdrawal is equal to summations of water influx and gas-water expansion. The calculation of water influx by Allard-Chen and Carter-Tracy methods for Havlena-Odeh plot indicate that the average OGIP of that sand is 4.52 Tcf which is acceptable and seems more reliable with respect to the present production data [14]. So shallow distance short flow system exists here. The Rashidpur gas field has a depth of 1380-2787 m. The volumes of shale values were low within the hydrocarbon-bearing zones of Rashidpur gas field [15] and also the major fault is of narrower width but there are numerous other small faults running N-S trend on the eastern flank of the structure [16]. So the field is classified as 'extensively faulted and fractured'.It contains significant water bearing zones show in the table 1 for well-4 analysis.

Table 1. Permeable zones of the Rashidpur well-4 in the Rashidpur Gas Field [15].

Zone No.	Fluid Type	Depth Range (m)	Thickness (m)
1	Water-bearing	1374-1402	28
2	Hydrocarbon-bearing	1447-1523	76
3	Water-bearing	1534-1550	16
4	Water-bearing	1555-1565	10
5	Water-bearing	1575-1595	20
6	Water-bearing	1635-1670	35
7	Water-bearing	1718-1740	22
8	Water-bearing	1760-1780	20
9	Water-bearing	1795-1805	10
10	Water-bearing	1855-1885	30
11	Water-bearing	1930-1960	30
12	Water-bearing	1962-1985	23
13	Water-bearing	2060-2090	30
14	Water-bearing	2180-2190	10
15	Water-bearing	2215-2225	10
16	Water-bearing	2314-2335	21
17	Hydrocarbon-bearing	2337-2350	13
18	Water-bearing	2405-2440	35
19	Hydrocarbon-bearing	2466-2483	17
20	Hydrocarbon-bearing	2668-2732	64

In Kailashtila gas field, there are three main gas zone (upper, middle and lower) ranging from 2280 m to 3045 m. It is visible that Kailashtila gas field's lithology comprises mostly of sandstone with less shale which belongs to the Bhuban & Bokabil formation of Surma group. According to the analysis of the four wells (KTL-2, KTL-3, KTL-4, KTL-5) and considering small amount of shale presence, the gas field may be classified as 'moderately faulted and fractured' [17]. Fig. 2 shows a great difference between the Analytical method with Aquifer Influx and without Aquifer Influx which indicates an active Aquifer model for the Kailashtila upper gas sand [18].

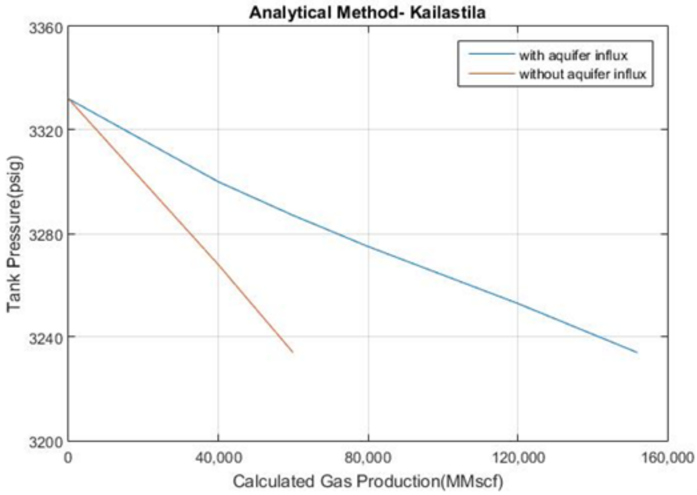

Fig. 2.Analytical Method Comparison with and without Aquifer Model for UGS [18].

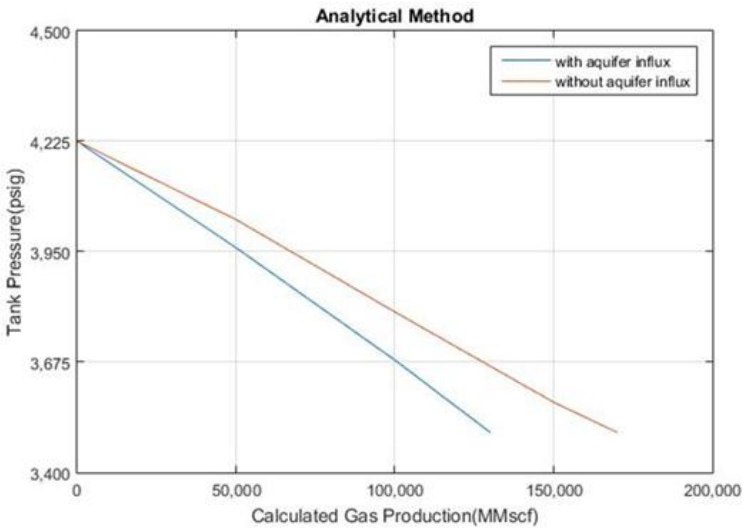

Fig. 3. Analytical Method Comparison with and without Aquifer Model for MGS [18].

Fig. 3 shows difference between the Analytical method with Aquifer Influx and without Aquifer Influx which indicates an active aquifer model for the Kailashtila middle gas sand. Fig. 4 shows difference between the Analytical method with Aquifer Influx and without Aquifer Influx which indicates an active Aquifer model for the Kailashtila lower gas sand. Although significant water flux occurs for upper gas sand, water flux is relatively low for middle and lower gas sand in Kailashtila gas field. So, Kailashtila gas field's hydrogeology can be classified as 'intermediate flow systems'.

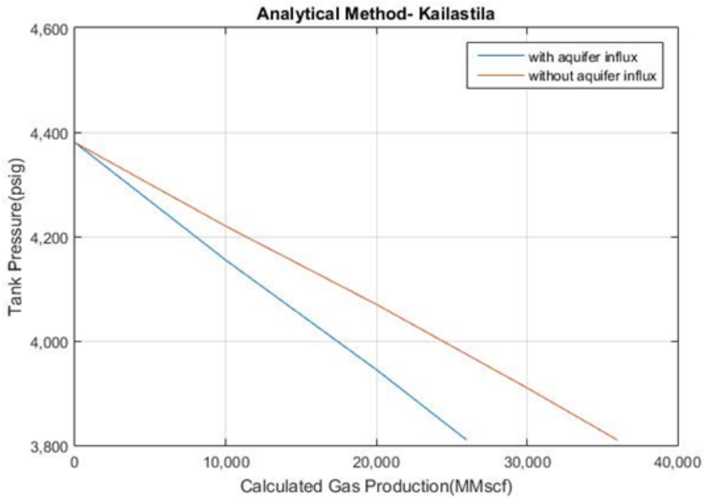

Fig. 4. Analytical method comparison with and without Aquifer model for LGS [18].

iii) Hydrocarbon potential: According to hydrocarbon reserve the gas fields can be classified as giant, large, medium or small size showing in Table 2 [8].

Table 2. Classification of hydrocarbon potential by reserve size.

Reserve size	Field category
>3 Tcf	giant
>1 Tcf – 3 Tcf	large
>300 Bcf – 1 Tcf	medium
<300 Bcf	small

Titas gas field has been an example in which significant reserve growth has been demonstrated. Recently 1 Tcf of natural gas has been found in the gas field. Now overall Gas Initially In Place (GIIP) of the field is 8.05 Tcf gas. It is one of the giant gas reserves for Bangladesh. Petrobangla published a revised estimate of Habiganj gas field in 2011 which shows estimated GIIP of 3.68 Tcf and an initial reserve of 2.63 Tcf [8]. Based on the reserve size, it can be considered as 'large' hydrocarbon potential gas field. Also, Kailashtila is a large hydrocarbon potential reservoir with 2.76 Tcf initial reserve of gas and 109 million barrels of oil [17]. The gas field is in production since 1983 and almost 2 Tcf reserve remaining according to SGFL (Sylhet Gas Fields Limited). Rashidpur gas field is also regarded as large hydrocarbon potential reservoir as it has a huge hydrocarbon reserve of 1.481 Tcf.

iv) Maturity: Although Titas gas field started production in 1968, the field is however yet to enter into a mature state of development and most of the 16 production/appraisal wells drilled are concentrated at the crestal part of structure [8]. Production data analysis from Table 3 also suggests that it is still producing at a significant rate and it is the second largest supplier of gas field (after Bibiyana) to the national grid. Approximately 4383 billion cubic feet gas or 57.8 % of reserves has been recovered. So the gas field can classify as ‘developing’ in the criteria of ‘maturity’.

Table 3. Daily production of Titas gas field (1st April, 2009) [19]

Wells	Formation	Production Period	Average Daily Production			Average Wellhead Pressure (psig)
			Gas (mmscfd)	Cond. (bpd)	Water (bpd)	
Titas 1	A Sand	April 68 - Mar 09	31.27	32.62	26.59	1885
Titas 2	A Sand	May 68 - Mar 09	33.06	34.49	28.12	1900
Titas 3	A Sand	July 85 - Jan 08	0.0	0.0	0.0	0
Titas 4	A Sand	Oct. 69 - Jan 08	32.33	33.73	27.50	1860
Titas 5	A Sand	Jan 81 - Mar 09	33.38	34.82	28.39	1850
Titas 6	A Sand	Feb 84 - Mar 09	35.00	36.48	29.77	1830
Titas 7	A Sand	Jul 85 - Mar 09	32.99	34.43	28.07	1910
Titas 8	B and C Sand	April 68 - Mar 09	22.13	23.09	18.81	1550
Titas 9	B and C Sand	March 89 - Mar 09	31.37	33.16	26.68	1600
Titas 10	B and C Sand	Sept 90 - Mar 09	14.84	15.49	12.58	1460
Titas 11	A Sand	Jun 91 - Mar 09	25.93	27.06	22.06	2015
Titas 12	A Sand	Jul 02 - Mar 09	21.37	31.79	1286.44	1725
Titas 13	A Sand	Jun 00 - Mar 09	21.36	32.22	215.70	2100
Titas 14	A Sand	Jun 00 - Nov 06	0.0	0.0	0.0	0
Titas 15	A Sand	May 06 - Mar 09	29.99	31.30	25.51	1966
Titas 16	A Sand	Dec 05 - Mar 09	29.96	31.26	25.48	1968
Total			**394.98**	**431.94**	**1801.7**	

Daily production rate analysis of Habiganj gas field for the year of 2007 (Table 4) and 2017 (Table 5) shows a significant decrease in producing gas. Production of water also increases at a high rate in this time period. Also near 85 % of the reserves of this field has been recovered already. So the field is in its way to mature stage.

Table 4. Production data of well-07 and well-10 of Habiganj gas field for the year of 2007 [20].

Date (M/D/Y)	Well-07			Well-10		
	Gas (MMScf)	FWHP (Psig)	Water (bbl)	Gas (MMScf)	FWHP (Psig)	Water (bbl)
1/1/2007	23.268	1600	4.101	23.004	1575	4.038
1/2/2007	25.693	1555	4.296	25.402	1540	4.265
1/3/2007	31.196	1545	4.516	30.842	1495	4.472
1/4/2007	35.323	1542	4.164	34.922	1491	4.12
1/5/2007	41.327	1525	4.755	40.858	1488	4.693
1/6/2007	42.097	1486	4.875	41.619	1484	4.80
1/7/2007	42.953	1468	4.894	42.466	1468	4.837
1/8/2007	43.245	1437	5.573	42.754	1445	5.523
1/9/2007	43.837	1412	5.548	43.349	1435	5.46
1/10/2007	43.633	1414	5.12	43.147	1432	5.095

Table 5. Daily production data of BGFCL [21]

BANGLADESH GAS FIELDS COMPANY LIMITED

(A Company of Petrobangla)

To : General Manager (Production & Marketing), Petrobangla
From : General Manager (Operation), BGFCL
CC : 1. Managing Director, BGFCL
2. Director (Operation), GTCL
3. Deputy General Manager (Co-ordination) to Chairman, Petrobangla
4. Assistant Manager to Director (Operation & Mines), Petrobangla
5. Deputy General Manager (Dhaka Liaison Office), BGFCL

Sub : Daily Production & Sales Report **Date : 11 October 2017**

Well No.	TITAS FIELD			HABIGANJ FIELD			BAKHRABAD FIELD			NARSINGDI FIELD			MEGHNA FIELD			
	Avg.Prod. (MMSCFD)	Avg.WHP (Psig)	Total Cond. Prod.(BBL)	Avg.Prod. (MMSCFD)	Avg.WHP (Psig)	Total Cond. Prod.(BBL)	Avg.Prod. (MMSCFD)	Avg.WHP (Psig)	Total Cond. Prod.(BBL)	Avg.Prod. (MMSCFD)	Avg.WHP (Psig)	Total Cond. Prod.(BBL)	Avg.Prod. (MMSCFD)		Avg WHP (Psig)	Total Cond. Prod.(BBL)
1	24.492	915		0.000	0		0.000	0		16.897	1165		Short String	12.676	1440	
2	32.855	1100		0.000	0		1.378	262		10.620	1050					
3	0.000	0		36.075	1482		6.367	373								
4	32.855	1040	395.0	36.075	1463	11.7	0.000	0	15.0			45.586				21.5
5	33.500	1030		26.051	1443		5.052	1630								
6	33.550	1210		15.064	1377		0.000	0								
7	30.850	1150		40.687	1330		0.000	0								
8	18.255	1020	Total Water Prod.(BBL)	0.000	--	Total Water Prod.(BBL)	8.473	504	Total Water Prod.(BBL)			Total Water Prod.(BBL)				Total Water Prod.(BBL)
9	22.656	1050		0.000	--		9.462	1013								
10	21.500	1160		39.166	1320		3.833	1031								
11	29.450	1285		27.475	1417											
12	14.050	1495														
13	20.200	1095														
14	23.150	1210														
15	0.000	0														
16	26.655	1220														
17	18.729	1155														
18	19.500	1170														
19	16.750	1415	1334.0			56.1			91.0			29.288				5.9
20	9.751	1420														
21	7.655	1280														
22	12.150	1000														
23	16.493	2320														
24	7.555	1235														
25	16.971	1315														
26	26.753	1865														
27	16.653	1260														
TOTAL	532.978			220.593			34.565			27.517				12.676		

For Rashidpur gas field, an analysis shows that if wells produce at a constant flow rate, then Rashidpur-1, 3, 4, 7 wells will run for next 58.90, 16.90, 32.72 and 32.67 year respectively [22]. Thus it may consider as developing reservoir.

v) Infrastructure and CO_2 sources: The overall infrastructure is in moderate condition for Titas gas field. Significant number of wells are producing in this giant gas field. The gas field also surrounded by major carbon dioxide sources as it is near Dhaka. Big Ashuganj power plant is situated at a near distance approximately 22 km and other small sources also available. Moderate infrastructure with good well condition is assumed for Hobiganj gas field. It places at a near distance of Titas gas field and surrounds with major CO_2 sources like Shahjibazar power plant & rental, Habiganj power plant and other small sources. However, Kailashtila gas field has only one big (fenchuganj) power plant around and also has little build-in infrastructure. For Rashidpur gas field, minor infrastructure presents due to only 8 wells for this large gas field and also as a result of developing reservoir, all facilities will not be yet included. Moderate classification for CO_2 sources (i.e. Shahjibazar power & rental, Habiganj power plant, Ashuganj power plant) as they situated at a distance not too close.

2.2. *Analyzation of Bachu's constant criteria for potential gas fields of Bangladesh*

Geological condition of Bangladesh dictates constant criteria; tectonic setting, geothermal condition, coal & CBM, salts, on/off shore, climate, accessibility.

The tectonic framework of Bangladesh may be broadly divided into two main units: 1) stable platform in the northwest and 2) deep (geosynclinal) basin to the east and southeast. A narrow northeast-southeast trending 'Hinge zone' separate the above two units diagonally. The geosynclinal basin is subdivided into two parts: 1) fold belt in the east, and 2) foredeep in the west (Fig. 5).

The Bengal Basin is located at a junction point of the three lithospheric plates viz. the Indian Plate, the Eurasian Plate and the Burma Plate posing high seismic susceptibility in the region according to West Bengal Disaster Management Department. The earthquakes in the Tripura fold belt are much more frequent than in the Eocene Hinge zone because of the plate boundary activity. In addition, adjacent Indo-Burma subduction zone helps identifying the fold belt region as 'Convergent Oceanic'. The fold structures favoring gas accumulation occur in the eastern fold belt part and thus most of the gas fields are located in the eastern part of the country which are mainly onshore gas reservoirs. No salt beds or dome is present in the gas reservoirs of Bangladesh. Also, a huge amount of CO_2 sources present in this region. Total CO_2 emissions from large point sources in Bangladesh in the IEAGHG R&D program database amount to some 17 Mt CO_2. The coal fields occupy in the northwest stable platform. Average temperature of this region is said to be 25 °C. The geothermal gradient [5] of the fold belt region of Bangladesh ranges from 20 °C /km to 30 °C /km. This results to an overall P-T diagram like Fig. 6. It relates to warm basin behavior according to phase behavior of CO_2 [6].

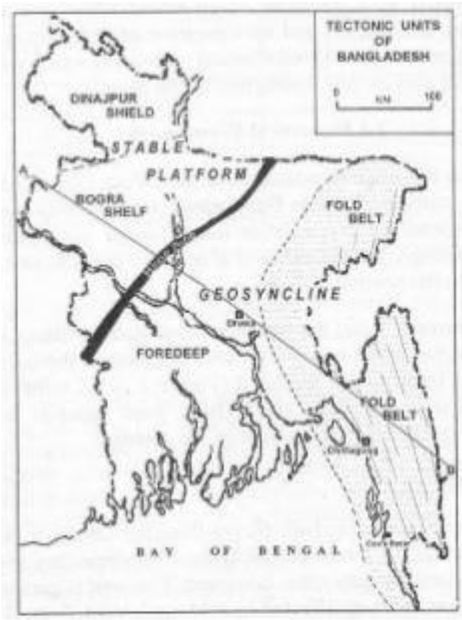

Fig. 5**.** Tectonics units of Bangladesh [8].

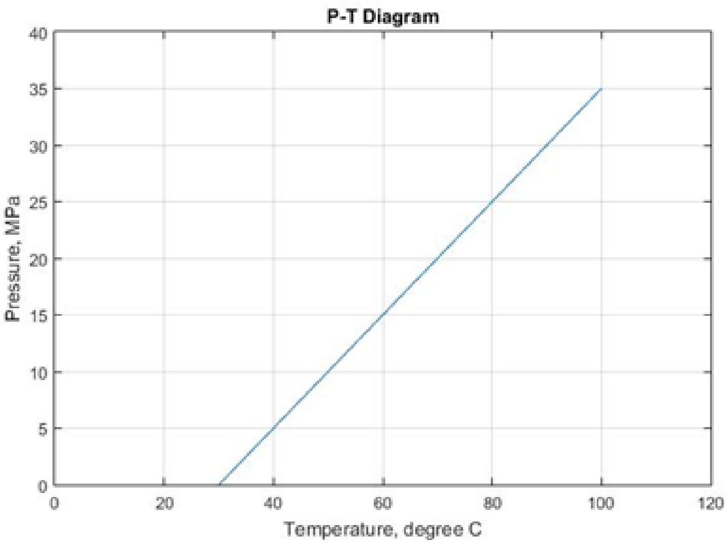

Fig. 6. Overall P-T diagram for fold belt region of Bangladesh.

2.3. *Simulation process*

A simulation model is one which shows the main features of a real system, or resembles it in its behavior, but is simple enough to make calculations on [23]. To establish a tangential real system, huge amount of data is required to provide in data file. Our data file is generated by using RUNSPEC, GRID, PROPS, SOLUTION, SUMMARY and SCHEDULE section in GASWAT (i.e., modeling gas phase/aqueous phase) option within "Eclipse 300" portion [24].

The simulation is done for Titas gas field. Analysis of Haq [25] indicates a complete ending of Titas gas field's life approximately in the year of 2060. The planning for carbon sequestration in this study is as such planned to start from 2060. Six injection wells (well no. 2, 5, 6, 7, 11 & 13) are used in this model to inject carbon dioxide gas in 'A' sand for 50 years. Injection rates of the wells are determined according to their respective production rates. Injection locations are distributed into five layers (A1, A2, A3, A4U, A4L) of 'A' sand such that no well will face shut-in situation in future. Table 6 contains information about injections wells.

Table 6**.** Injection well conditions.

Well no.	Injection rate (MMSCFD)	Injection layer	
		from	to
2	25	A3	A4L
5	30	A1	A3
6	30	A1	A3
7	30	A4U	A4L
11	25	A4U	A4L
13	20	A1	A3

Fracture pressure is determined to set injection well shut-in pressure value. According to Haq [25], initial pressure at an average depth of 8800 ft of Titas gas field is 4005.9 psia. This value is added by minimum matrix stress to find overall fracture pressure of 'A' sand. Matrix stress ratio (0.775) and vertical overburden stress (0.96 for 100 µs/ft at 8900 ft [26]) are calculated from Pennebaker correlation [27]. Then the value of minimum matrix stress will be 3442 psia and fracture pressure will be 7448 psia. For safety, injection well shut-in pressure is set to the limit of 6000 psia.

The entire cartesian grid of 'A' sand is prepared using Petrel software. The simulation model is a non-orthogonal corner-point model. 'A' sand contains 50 grid blocks in X direction with average dimension 252 m and 100 grid blocks in Y direction with average dimension 264 m in each of the five layers. Average thickness of layers A1, A2, A3, A4U and A4L are 24, 178, 112, 79, and 50 ft, respectively. The permeability distribution ranges from 12 to 30 mD in section A that is determined by a hydraulic flow element study [28].

Four components, C1(CH_4), C2(C_2H_6), CO_2, H_2O have to be considered with their critical properties, acentric factor, Molecular Weight (MW) for PROPS section. All the properties are recorded in field units with essential command within simulator. Table 7 contains the information.

Table 7. Properties of the components [29].

Component	Critical temperature (TCRIT)	Critical pressure (PCRIT)	Critical compressibility factor (ZCRIT)	Acentric factor (ACF)	Molecular weight (MW)
C1(CH_4)	343.1	667.8	0.289	0.0115	16
C2(C_2H_6)	549.8	707.8	0.285	0.0908	30
CO_2	547.6	1070.9	0.274	0.2250	44
H_2O	1165.1	3203.6	0.230	0.3210	18

The ZMFVD function of PROPS section is assembled with approximate values assumed with respect to abandonment condition of the gas field. Abandoned reservoir temperature is considered similar to present condition (188°F). GSF (gas saturation factor) and WSF (water saturation factor) values are prepared by SCAL.

Initial equilibration conditions, which are the characteristics of abandonment condition in this case, are specified in solution section. Summary file of the simulation process is generated in summary section.

3. Results

3.1. *Suitability result*

As stated in the introduction chapter: geology, hydrogeology, geothermal, maturity, on/off shore, climate, CO_2 sources are the most important criteria in selecting suitable location for carbon dioxide sequestration. Only hydrogeological condition of Kailashtila gas field and maturity of Habiganj gas field are better than Titas gas field. For all other criteria, Titas gas field provides the best condition. Also from scoring and ranking of Hoque et al. [30], Titas gas field has been proved to be geologically better gas field for carbon sequestration among the gas fields of Bangladesh.

3.2. *Eclipse simulation result*

Gas saturation of the field (SGAS), field gas injection total (FGIT), field gas in place (FGIP) and field pressure(FPR) have been analyzed after 50 years of carbon dioxide simulation process. Carbon dioxide accumulates in the lower part of the reservoir as expected. It sweeps existing hydrocarbon gases upwards. As a result, saturation of gas in the bottom portion of the reservoir is relatively small than upper part of the reservoir (Fig. 7).

A total of 2.92 Tcf carbon dioxide gas has been sequestrated after 50 years of time period (Fig. 8). This huge amount of gas has been injected without any break of continuation. 2.58 Tcf of existing (abandon) hydrocarbon gas and 2.92 Tcf of carbon dioxide gas sums up a total of 5.5 Tcf gas in the reservoir (Fig. 9). It is lower than the capacity of Titas gas field. FGIT vs time, FGIP vs time graphs are showed here which are prepared by using office option within eclipse.

Field pressure of the gas field has been escalated to an amount of 2410 psia after the ending of carbon dioxide injection (Fig. 10). The value is much lower than the fracture pressure (7530 psia) and as such, reservoir shouldn't face any fracture problem within this time.

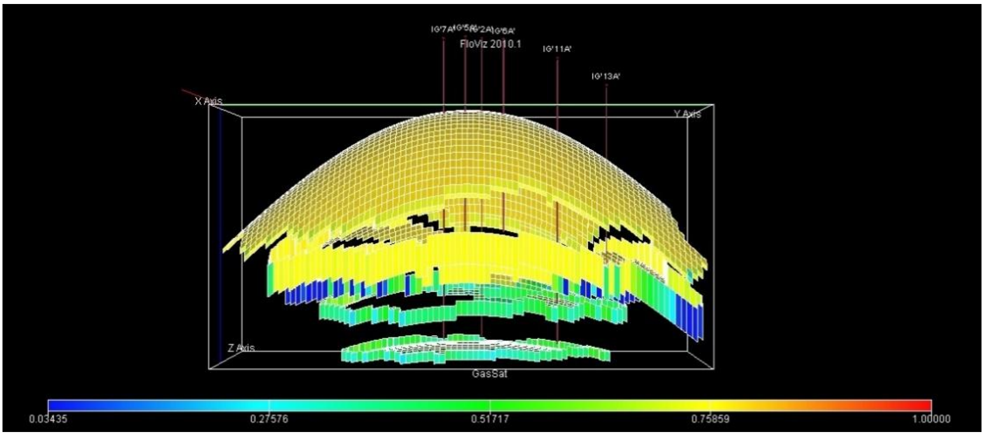

Fig. 7**.** Gas saturation 3D model of Titas gas field after carbon dioxide simulation (using FloViz option-front view).

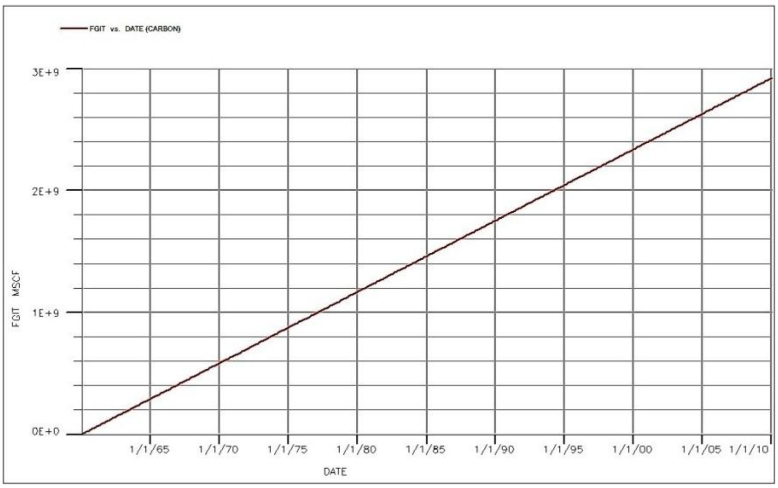

Fig. 8**.** Field Gas Injection Total (FGIT) vs time graph.

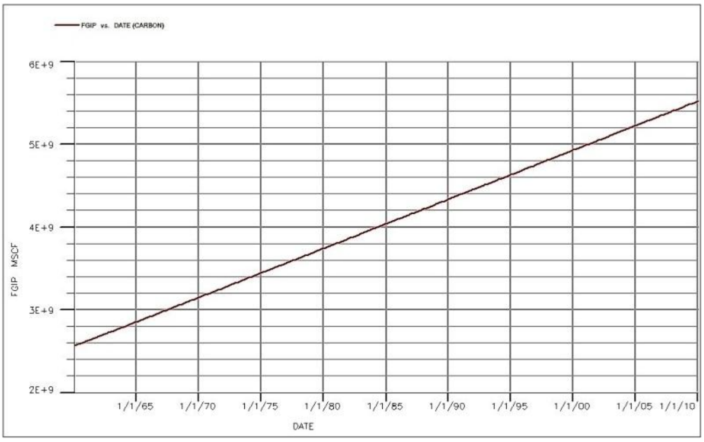

Fig. 9**.** Field Gas In Place (FGIP) vs time graph.

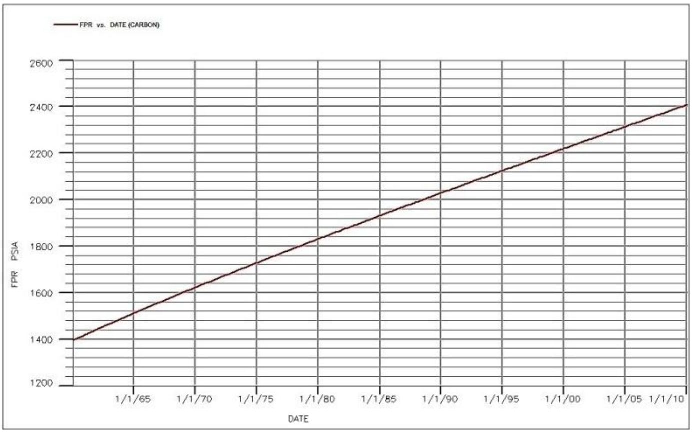

Fig. 10. Field Pressure (FPR) vs time graph.

4. Discussion

Titas gas field is one of the main gas fields of Bangladesh which serves to the energy sector of this country at large in present time. The geological criteria for carbon dioxide sequestration are fit to this field more perfectly than other gas fields. Huge storage capacity of this gas field should be used for environmental purpose. The field will be abandoned approximately around the year of 2060 and immediately after that period, carbon dioxide sequestration project can be undertaken using the existing wells.

As Titas gas field is one of the giant gas fields of Bangladesh which has GIIP of 8.05 Tcf, simulation result is completely in accordance with real condition. 2.92 Tcf CO_2 gas sequestration with increased field pressure of 2410 psia can be considered as safe implementation of CO_2 sequestration project. The results of this study is extensively dependent on the data used from different sources. However, it is to be noted that the integrity of the caprocks and lateral seals of gas fields should be investigated for better understanding on the potentiality of gas fields. The feasibility of the project would be more reliable if economic analysis can be made. Different simulation approaches can also be undertaken for determining the accuracy of the result.

Acknowledgment

We express deep respect to our respectable teachers Tareq Uz Zaman and Md. Nahin Mahmood for helping us through the entire process. We are also thankful to Shafaet Jamil for helping and instructing us about the use of software and data base.

Appendices

Appendix A: Eclipse raw DATA file

```
RUNSPEC
FIELD
GASWAT
AIM
COMPS
4/
EOS
PR/
--       Number of cells
--      NX     NY     NZ
--      --     --     --
DIMENS
         50    100          5            /
NUMRES
  5 /
 CART
TABDIMS
        1 1 40 40 /
EQLDIMS
1 100 /
UNIFOUT
-- Simulation start date
START
        1 'JAN' 2060     /
--===============================================================
GRID
INCLUDE
 './GRID/map.INC'  /
--5 reservoir in z dorection
COORDSYS
--z1 z2
  1  1 INCOMP SEPARATE /
  2  2 INCOMP SEPARATE /
  3  3 INCOMP SEPARATE /
  4  4 INCOMP SEPARATE /
  5  5 INCOMP SEPARATE /
 --reservoir number   A
RESVNUM
 1 /
```

```
BOX
1 50 1 100 1 1 /
INCLUDE
 './GRID/A/A1/coord.INC'  /
INCLUDE
 './GRID/A/A1/zcorn.INC'  /
INCLUDE
 './GRID/A/A1/actnum.INC'  /
ENDBOX

RESVNUM
 2 /
BOX
1 50 1 100 2 2 /
INCLUDE
 './GRID/A/A2/coord.INC'  /
INCLUDE
 './GRID/A/A2/zcorn.INC'  /
INCLUDE
 './GRID/A/A2/actnum.INC'  /
ENDBOX

RESVNUM
 3 /
BOX
1 50 1 100 3 3 /
INCLUDE
 './GRID/A/A3/coord.INC'  /
INCLUDE
 './GRID/A/A3/zcorn.INC'  /
INCLUDE
 './GRID/A/A3/actnum.INC'  /
ENDBOX

RESVNUM
 4 /
BOX
1 50 1 100 4 4 /
INCLUDE
 './GRID/A/A4U/coord.INC'  /
INCLUDE
 './GRID/A/A4U/zcorn.INC'  /
INCLUDE
 './GRID/A/A4U/actnum.INC'  /
ENDBOX

RESVNUM
 5 /
BOX
1 50 1 100 5 5 /
INCLUDE
 './GRID/A/A4L/coord.INC'  /
INCLUDE
 './GRID/A/A4L/zcorn.INC'  /
INCLUDE
 './GRID/A/A4L/actnum.INC'  /
ENDBOX
--------------------------------A
BOX
 1 50 1 100 1 5 /
```

```
INCLUDE
 './GRID/A/permx.INC'  /
INCLUDE
 './GRID/A/permy.INC'  /
INCLUDE
 './GRID/A/permz.INC'  /
INCLUDE
 './GRID/A/poro.INC'  /
INCLUDE
 './GRID/A/ntg.INC'  /
ENDBOX

GRIDFILE
2 1 /
INIT
NEWTRAN
--=================================================================
EDIT
PROPS
ROCK
8500 0.0000032
/
EOS
PR   /

CNAMES
C1 C2 CO2 H2O /
TCRIT
343.1 549.8 547.6 1165.1 /
PCRIT
667.8 707.8 1070.9 3203.6 /
ZCRIT
0.289 0.285 0.274 0.230 /
ZMFVD
        8287 0.18 0.006 0.001 0.813
        8290 0.05 0.00003 0.000006 0.949964
        8400 0.10 0.000001 0.0000003 0.8999987
        8600 0.08 0.00002 0.000002 0.919978
/
ACF
0.0115 0.0908 0.2250 0.3210 /
MW
16 30 44 18 /
DENAQA
/
VISCAQA
/
RTEMP
188 /
BIC
0.1
0.1    0.0360
0.4850 0.4920 0.1896 /
GSF
0.0000 0.0000 0
0.0500 0.0000 0
0.0900 0.0320 0
0.1800 0.0890 0
0.2700 0.1640 0
0.3600 0.2530 0
```

```
0.4500 0.3540 0
0.5400 0.4650 0
0.6300 0.5860 0
0.7200 0.7160 0
0.8100 0.8540 0
0.9000 1.0000 0
/
WSF
0.1000 0.0000
0.1600 0.0005
0.2200 0.0040
0.2800 0.0135
0.3400 0.0320
0.4000 0.0625
0.4600 0.1080
0.5200 0.1720
0.5800 0.2560
0.6400 0.3650
0.7000 0.5000
0.8000 0.6670
0.9000 0.8330
1.0000 1.0000 /
------------------------------ Solution Section --------------------------------
REGIONS
SOLUTION
-- Initial equilibration conditions
--      Datum   Pi@datum    GWC    Pc@WOC                          10        11
--      -----   --------   -----   ------
EQUIL
        8287    1440               8900          0            0        1*        1*
/
RPTRST
PRESSURE SWAT SGAS DENG DENW AMF XMF YMF/
--=================================================================
SUMMARY
ALL
RUNSUM
-- Create Excel readable Run Summary file (.RSM)
EXCEL
--=================================================================
SCHEDULE
RPTRST
PRESSURE SWAT SGAS DENG DENW AMF XMF YMF/
OUTSOL
SWAT SGAS XMF YMF AMF /
RPTSCHED
SWAT SGAS AMF /
WELSPECS
IG'2A'  FIELD   24  53  1* Gas /
IG'5A'  FIELD   28  50  1* Gas /
IG'6A'  FIELD   27  57  1* Gas /
IG'7A'  FIELD   28  46  1* Gas /
IG'11A' FIELD   25  67  1* Gas /
IG'13A' FIELD   26  76  1* Gas /
/
COMPDAT
IG'2A'   24  53  3  5 /
IG'5A'   28  50  1  3 /
IG'6A'   27  57  1  3 /
IG'7A'   28  46  4  5 /
```

```
IG'11A'  25  67  4  5 /
IG'13A'  26  76  1  3 /
/
WELLSTRE
--   C1   C2 CO2 H2O
InjG 0.0 0.0 1.0 0.0 /
/
--Set gas injection rates
WINJGAS
IG'2A'  STREAM InjG /
IG'5A'  STREAM InjG /
IG'6A'  STREAM InjG /
IG'7A'  STREAM InjG /
IG'11A' STREAM InjG /
IG'13A' STREAM InjG /
/
WCONINJE
IG'2A'  GAS OPEN RATE 25000 1* 6000 /
IG'5A'  GAS OPEN RATE 30000 1* 6000 /
IG'6A'  GAS OPEN RATE 30000 1* 6000 /
IG'7A'  GAS OPEN RATE 30000 1* 6000 /
IG'11A' GAS OPEN RATE 25000 1* 6000 /
IG'13A' GAS OPEN RATE 20000 1* 6000 /
/
DATES
1 'FEB' 2060     /1 'MAR' 2060    /1 'APR' 2060    /1 'MAY' 2060    /1 'JUN' 2060
/1 'JUL' 2060    /1 'AUG' 2060    /1 'SEP' 2060    /1 'OCT' 2060    /1 'NOV' 2060
/1 'DEC' 2060    /
/

DATES
1 'JAN' 2061     /1 'FEB' 2061    /1 'MAR' 2061    /1 'APR' 2061    /1 'MAY' 2061
/1 'JUN' 2061    /1 'JUL' 2061    /1 'AUG' 2061    /1 'SEP' 2061    /1 'OCT' 2061
/1 'NOV' 2061    /1 'DEC' 2061    /
/
DATES
1 'JAN' 2062     /1 'FEB' 2062    /1 'MAR' 2062    /1 'APR' 2062    /1 'MAY' 2062
/1 'JUN' 2062    /1 'JUL' 2062    /1 'AUG' 2062    /1 'SEP' 2062    /1 'OCT' 2062
/1 'NOV' 2062    /1 'DEC' 2062    /
/
DATES
1 'JAN' 2063     /1 'JUL' 2063    /1 'JAN' 2064    /1 'JUL' 2064    /1 'JAN' 2065
/1 'JUL' 2065    /1 'JAN' 2066    /1 'JUL' 2066    /1 'JAN' 2067    /1 'JUL' 2067
/1 'JAN' 2068    /1 'JUL' 2068    /1 'JAN' 2069    /1 'JUL' 2069    /1 'JAN' 2070
/1 'JUL' 2070    /1 'JAN' 2071    /1 'JUL' 2071    /1 'JAN' 2072    /1 'JUL' 2072
/1 'JAN' 2073    /1 'JUL' 2073    /1 'JAN' 2074    /1 'JUL' 2074    /1 'JAN' 2075
/1 'JUL' 2075    /1 'JAN' 2076    /1 'JUL' 2076    /1 'JAN' 2077    /1 'JUL' 2077
/1 'JAN' 2078    /1 'JUL' 2078    /1 'JAN' 2079    /1 'JUL' 2079    /1 'JAN' 2080
/1 'JUL' 2080    /
/
DATES
1 'JAN' 2081     /1 'JAN' 2082    /1 'JAN' 2083    /1 'JAN' 2084    /1 'JAN' 2085
/1 'JAN' 2086    /1 'JAN' 2087    /1 'JAN' 2088    /1 'JAN' 2089    /1 'JAN' 2090
/1 'JAN' 2091    /1 'JAN' 2092    /1 'JAN' 2093    /1 'JAN' 2094    /1 'JAN' 2095
/1 'JAN' 2096    /1 'JAN' 2097    /1 'JAN' 2098    /1 'JAN' 2099    /1 'JAN' 2100
/
DATES
1 'JAN' 2101     /
1 'JAN' 2102     /
1 'JAN' 2103     /
```

1 'JAN' 2104 /
1 'JAN' 2105 /
1 'JAN' 2106 /
1 'JAN' 2107 /
1 'JAN' 2108 /
1 'JAN' 2109 /
1 'JAN' 2110 /
/

Grid files are generated by Schlumberger Petrel 2013 software. All data files are uploaded in '4TU.Centre'. dataset: https://doi.org/10.4121/uuid:e8ae2444-84f0-4410-bc82-210376ef5e64

Appendix B: Fracture pressure determination of Titas gas field

For minimum matrix stress (σ_{min}) and formation pore pressure (P_f),
fracture pressure (P_{ff}) = $\sigma_{min} + P_f$ [26]
Again, $\sigma_{min} = F_\sigma(\sigma_{ob} - P_f)$; where, F_σ= Matrix stress ratio and σ_{ob} = Vertical overburden stress = Avg. overburden gradient * Depth
Now, at a depth of 8800ft in Titas gas field, formation pore pressure (P_f) = 4005.9 psia [25]
Matrix stress ratio (F_σ) = 0.775 (from fig. 11)
From sonic log data of Titas gas field[26], 100µs/ft interval transit time is found approximately at a depth of 8900ft. Then, from fig. 12, Avg. vertical overburden gradient = 0.96 psi/ft.
So, Vertical overburden stress (σ_{ob}) = 0.96 * 8800 = 8448 psi
Then, Minimum matrix stress (σ_{min}) = 0.775 (8448 – 4005.9) = 3442 psi
Now, Fracture pressure (P_{ff}) = 3442 + 4005.9 = 7448 psi

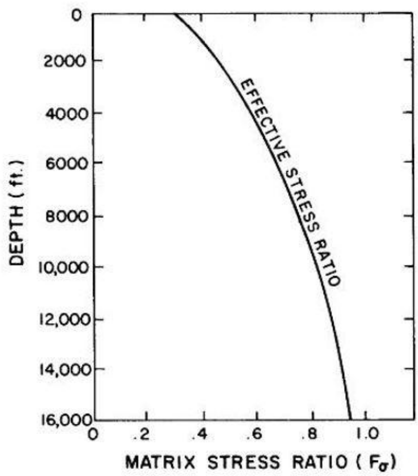

Fig. 11. Pennebaker Correlation for Effective Stress Ratio [27].

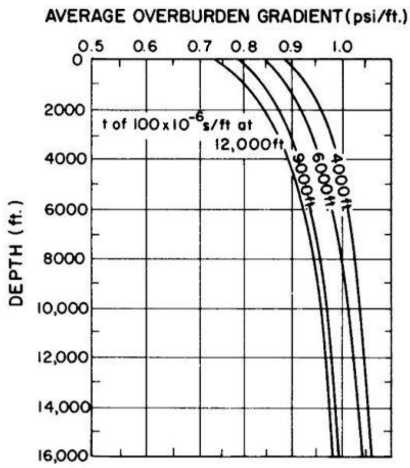

Fig.12. Pennebaker correlation for vertical overburden stress [27].

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