EFFECT OF OIL VISCOSITY CHANGE ON OIL PRODUCTION: CO_2 ENHANCED OIL RECOVERY IN THE PERMIAN BASIN AND POTENTIAL IN THE GABON BASIN

by

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Abstract

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With most oil fields around the world reaching maturation it is not uncommon for oil companies to investigate the possibility of implementing CO_2 Enhanced Oil Recovery. The injection of CO_2 in a reservoir reduces the oil viscosity within the reservoir, which can later be more easily pushed towards a producing well. Computer simulators such as BOAST NFR are key tools in order to simulate the response of a reservoir to CO_2 EOR and predict oil production. This thesis investigates an example of CO_2 EOR in the Gabon Basin where such technique has yet to be implemented. Oil production has been on the decline since the late 90s and the implementation of CO_2 EOR should not be overlooked. Estimates of a possible non neglectable oil production in the Rabi-Kounga oil field can be predicted using actual physical characteristics of both oil and reservoirs. CO_2 EOR has proven to be very successful in the Permian Basin where CO_2 yet has to be brought from distant sources using an elaborate network of pipelines. In

the Gabon Basin however, natural gas is readily available in great quantities which reduces the scale of infrastructures needed.

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Chapter 1

Introduction

Primary oil recovery, which is based solely on the formation pressure, allows the production of only about 10% of the oil in place (OOIP). Secondary recovery by injecting water vapor in the formation to wash out oil can increase the production by 20 to 40%. It is believed that all the "easy to produce" reservoir have been discovered around the world: as a result production is declining as most reservoirs have reached (or passed) their production peak. Given that the cost for drilling deeper and more remote areas is very high, companies look at CO_2-EOR as a solution to reboost and extend the life of hydrocarbon reservoirs. CO_2-EOR is a technique that can stimulate tertiary recovery in a reservoir to achieve an additional production of 20% with current technology.

It is evident today that the reservoirs in the Gabon Basin have passed their peak production and that production will continue to decline with the technology used today. Considering that the Gabon Basin is still believed hold 3.684 billion barrels of oil (Mbendi Information Services, 2012), CO_2-EOR is an option not to be overlooked, especially with the price of oil is so constantly high.

In this research I will address possible effects of applying CO_2 Enhanced Oil Recovery in the Gabon Basin. Without doing a complete economic analysis, I will try to conclude whether or not it is feasible, and if so, what could be the benefits. More specifically, in my project I will attempt to demonstrate that by reducing oil viscosity in Gabon through CO_2 EOR, the country's oil production could be considerably be boosted. Using the Permian Basin's production data as a comparison and BOAST NFR software for prediction in the Gabon basin, I will attempt to prove that CO_2 EOR has a bright future in Gabon and should therefore be implemented; especially considering the country's natural gas resources available as CO_2 sources.

Chapter 2

The CO_2 EOR Technique

2.1 How EOR works

The injected CO_2 mixes with the in-place oil and the mixture swells and becomes less viscous than the original crude oil (immiscible EOR is also possible. but is less productive than miscible EOR). In many situations, after a period of CO_2 injection (days to several months), water is injected. This cycle is repeated in what is termed “water alternating gas” (WAG) floods. Figure 1.1 presents a characterization of this process, on every cycle, some of the CO_2 stays behind in the reservoir, and some returns to the surface with the produced oil. The returned CO_2 is recaptured due to its value, and reinjected so that ultimately essentially all of the purchased CO_2 is permanently stored underground. The “net” (originally purchased) CO_2 needed varies by field, but typical estimates range from 0.254-0.40 tones CO_2 per barrel of oil produced (Carter L.D. 2011). Most current EOR operations use natural CO_2 produced from underground reservoirs in a manner similar to natural gas production. However, natural CO_2 resources are limited so some existing EOR operations use CO_2 captured from industrial processes.

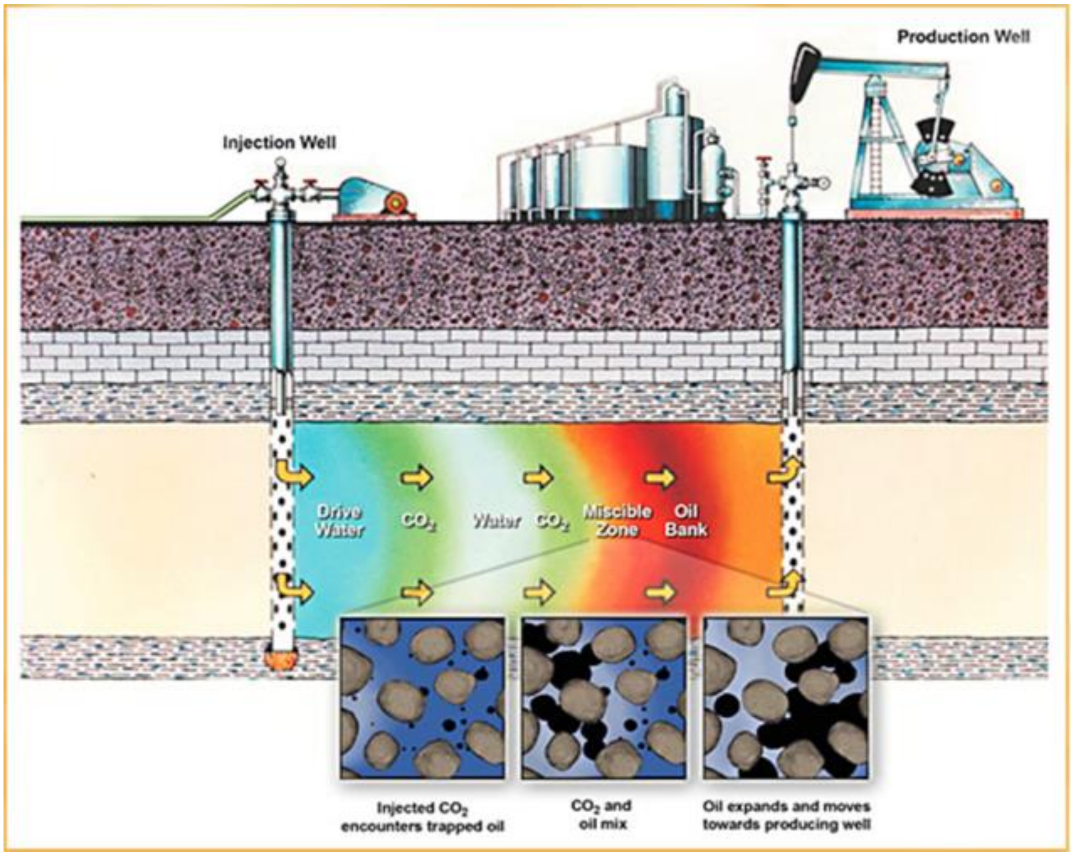

Figure 1-1 WAG illustration (US Department of Energy, CO2 Enhanced Oil Recovery 2004)

Even though it might sound simple, CO_2 EOR requires a lot of infrastructures for its successful implementation. Some of these infrastructures include oil/gas separators, CO_2 capture systems, injection wells, and miles of pipeline in the case that CO_2 must be brought in from distant areas. A detailed overview of the complexity of the process flow is shown on figure 1.2 below.

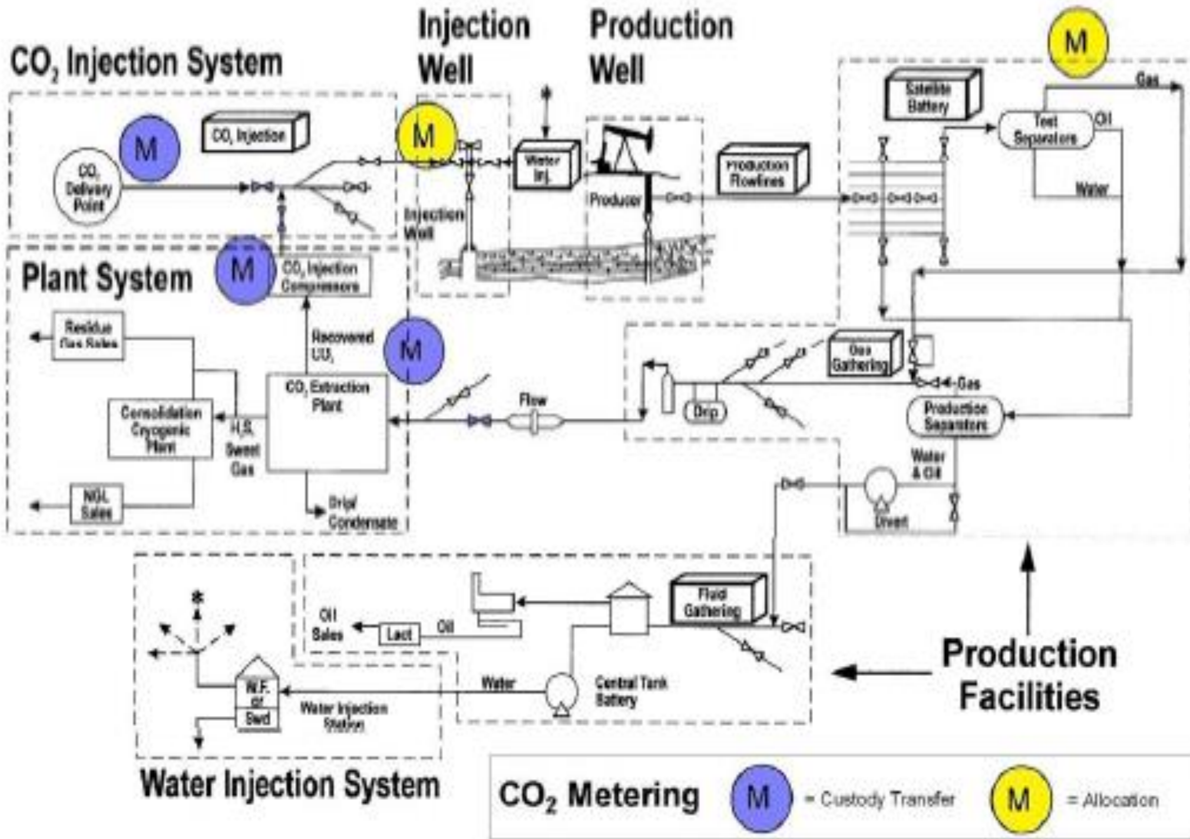

Figure 1-2 CO2 EOR Process Flow (Stephen L. Melzer, 2012)

2.2 Future of the EOR technique

In September 2010 the Department of Energy (DOE) decided to select seven projects for the preparation of CO_2 EOR research improvement (Advanced Resources International Inc, Melzer Consulting, 2010):

Four projects are developing techniques to control the mobility of the injected CO_2. New foams and gels have the potential to prevent highly mobile CO_2 to be directed through areas of high permeability in the reservoir, leaving unswept areas within the reservoir. By filling potential fractures and zones of higher porosity, the foams allow for a more homogeneous diffusion of the CO_2 injected in the reservoir.

One project aims to investigate the potential of oil production by CO_2 injection in the residual oil zones or ROZs. These zones are not well understood and are subject to very intensive research in the Permian Basin particularly by the University of Texas of the Permian Basin. ROZs are believed to hold just as much oil (if not more) as the main pay zones; therefore, expanding CO_2 injections appropriately into these zones could boost production and wells' life even more.

Two projects are focused on developing tools for modeling and simulation for CO_2 EOR. These projects will help determining 1) the most efficient CO_2 injection wells distribution in order to optimize oil production and 2) how to increase the amount of CO2 injected so that it mixes with even more oil within the reservoir.

The technology used today is known as "State-of-the-Art CO_2-EOR Technology" and includes all the actual techniques and knowledge. Any EOR made after farther study of maximum CO_2 volumes to be injected and injection wells distribution is called "Next Generation EOR Technology". Finally, if oil is produced from both the main pay zone and the ROZ with injection of 100% CO_2 to be stored in the reservoir, then one refers to it as "Second Generation EOR Technology" (Advanced Resources International Inc, 2012).

Chapter 3

Overview of the Basins

3.1. The Permian Basin

3.1.1. Geology of the basin

The Permian Basin is located in West Texas and the neighboring area of southeastern New Mexico (figure 3.1). It comprises several components such as the Midland Basin, the Central Basin Platform and the Delaware Basin.

It underlies an area approximately 402 km wide and 482 km long, or about 194.166 sq. km (Abiodun and Shameem, 2009). The thickest of sediment in the Basin was deposited in the Paleozoic era. The deposits in the Basin are the thickest deposits of Permian rocks found anywhere in the world. Most Permian Basin oil reservoirs have been depleted through primary and secondary phases and most are at the tertiary stage of their productive life.

Figure 3.1: Location and components of the Permian Basin (Circle Star Energy, 2013)

3.1.2. Application of CO_2 EOR in the Permian Basin

The predominant secondary recovery mechanism is water flooding. The combined recovery from primary and water flooding operation basin-wise is about 20-40%. The high residual oil in place (ROIP) opens up a huge opportunity for implementation of CO2-EOR processes. CO_2 EOR was first tested at large scale in the 1970's in the Permian Basin of West Texas and southeastern New Mexico. The first two large scale projects consisted of the SACROC flood in Scurry County, TX implemented in January of 1972 and the North Crossett flood in Crane and Upton Counties, TX initiated in April, 1972 (Melzer, 2012).

As of February 2012, 111 floods are underway in the U.S. with 64 of those in the Permian Basin. The aggregate production from CO_2 EOR has grown to about 18% of the Permian Basin's total oil production, reaching 180.000 out of the 1.000.000 barrels of oil per day produced (Melzer, 2012). Table 3.1 shows a listing of CO_2 EOR floods in the Permian Basin (CCS Global Institute, 2013).

Table 3-1 Listing of CO2 EOR floods in the Permian Basin (CCS Global Institute, 2013)

	Operator	Field	State	County	Start Date	Area, Acres	No. Wells Prod.	No. Wells Inj.	Total Prod., b/d	Enh. Prod., b/d
CO_2 Miscible										
1	Apache	Adair	TX	Gaines	1997	5,338	90	61	2,350	
2	Apache	Adair	TX	Gaines	2004	2,550	11	11	420	
3	Apache	Slaughter	TX	Hockley/Terry	5/85	569	43	21	600	580
4	Apache	Slaughter	TX	Hockley/Cochran	6/89	8,559	259	164	5,800	4.000
5	Chevron	Mabee	TX	Andrews/Martin	1/92	3,600	220	85	3,100	2,000
6	Chevron	Slaughter Sundown	TX	Hockley	1/94	5,500	155	144	5,950	4,747
7	Chevron	Vacuum	NM	Lea	7/97	1,084	48	24	4,500	2,950
8	Chevron	Dollarhide (Devonian) Unit	TX	Andrews	5/85	6,183	83	66	2,420	1,970
9	Chevron	Dollarhide (Clear Fork "AB") Unit	TX	Andrews	11/95	160	21	4	230	124
10	Chevron	Reinecke	TX	Borden	1/98	700	32	8	977	830
11	ConocoPhillips	South Cowden	TX	Ector	2/81	4,900	43	22	450	250
12	ConocoPhillips	Vacuum	NM	Lea	2/81	4,900	192	103	6,200	5,200
13	Energen Resources	East Penwell (SA) Unit	TX	Ector	5/96	1,020	49	30	1,626	827
14	ExxonMobil	Means (San Andres)	TX	Andrews	11/83	8,500	484	284	10,000	8,700
15	Fasken	Abell (Devonian)	TX	Crane	4/09	809	21	19	180	85
16	Fasken	Hanford	TX	Gaines	7/86	1,120	23	26	400	400
17	Fasken	Hanford East	TX	Gaines	3/97	340	7	4	60	30
18	Fasken	Hanford (San Andres)	TX	Gaines	7/09	113	8	4	280	
19	Fasken	River Bend (Devonian)	TX	Crane	4/09	400	9	10	290	20
20	George R. Brown	Post-Montgomery Unit	TX	Garza	11/09	1,778				
21	Great Western Drilling	Twofreds	TX	Loving/Ward/Reeves	1/74	4,392	32	9	170	170
22	Hess	Seminole Unit – Main Pay Zone	TX	Gaines	7/83	15,699	408	160	16,500	16,500
23	Hess	Seminole Unit – ROZ Phase 1	TX	Gaines	7/96	500	15	10	1,200	1,200
24	Hess	Seminole Unit – ROZ Phase 2	TX	Gaines	4/04	480	16	9	1.700	1,700
25	Hess	Seminole Unit – ROZ State 1	TX	Gaines	12/07	2,380	47	29	1,000	1,000
26	Kinder Morgan	SACROC	TX	Scurry	1/72	49,900	391	444	29,580	26,530
27	Occidental	Alex Slaughter Estate	TX	Hockley	8/00	246	21	11	270	220
28	Occidental	Anton Irish	TX	Hale	4/97	4,437	151	90	5,800	2,800
29	Occidental	Cedar Lake	TX	Gaines	8/94	2,870	167	87	4,500	2,500
30	Occidental	Central Mallet Unit	TX	Hockley	1984	6,412	182	136	2,750	1,930
31	Occidental	Cogdell	TX	Scurry/Kent	10/01	2,684	93	59	5,600	5,500
32	Occidental	El Mar	TX	Loving	4/94	6,000	29	29	308	301
33	Occidental	Frazier Unit	TX	Hockley	12/84	1,600	67	52	1,059	650

Table 3.1 -- Continued

34	Occidental	GMK South	TX	Gaines	1982	1,143	18	14	490	140
35	Occidental	Igoe Smith	TX	Cochran	9/05	1,235	52	24	790	430
36	Occidental	Levelland	TX	Hockley	9/04	1,179	95	62	1,800	950
37	Occidental	Mid Cross – Devonian Unit	TX	Crane/Upton/ Crockett	7/97	1,326	11	5	430	376

	Operator	Field	State	County	Start Date	Area, Acres	No. Wells Prod.	No. Wells Inj.	Total Prod., b/d	Enh. Prod., b/d
38	Occidental	N Cross – Devonian Unit	TX	Crane/Upton	4/72	1,155	26	16	1,225	1,223
39	Occidental	North Cowden	TX	Ector	2/95	465	40	17	535	326
40	Occidental	North Dollarhide Devonian	TX	Andrews	11/97	1,280	29	20	1,150	650
41	Occidental	North Hobbs	NM	Lea	3/03	3,100	125	75	7,300	5,300
42	Occidental	S. Cross – Devonian Unit	TX	Crockett	6/88	2,090	71	38	5,922	5,859
43	Occidental	Salt Creek	TX	Kent	10/93	12,000	150	102	7,450	6,600
44	Occidental	Sharon Ridge	TX	Scurry/Kent	2/99	1,400	25	26	600	450
45	Occidental	Slaughter (H T Boyd Lease)	TX	Cochran	8/01	1,240	35	23	950	630
46	Occidental	Slaughter Estate Unit	TX	Hockley	12/84	5,700	184	166	3,800	2,270
47	Occidental	Slaughter North West Mallet	TX	Cochran/Hockley	2008	1,048	39	24	1,085	180
48	Occidental	Slaughter West RKM Unit	TX	Hockley	2006	1,204	51	33	1,764	325
49	Occidental	Smith Igoe	TX	Cochran	8/05	177	6	2	210	100
50	Occidental	South Wasson Clearfork	TX	Yoakum	10/84	4,720	104	56	1,400	0
51	Occidental	South Welch	TX	Dawson	9/93	1,160	87	73	720	670
52	Occidental	T-Star (Slaughter Consolidated)	TX	Hockley	7/99	1,700	51	31	2,500	1,000
53	Occidental	Wasson Bennett Ranch Unit	TX	Yoakum	6/95	1,780	197	160	5,440	4,715
54	Occidental	Wasson Denver Unit	TX	Yoakum/Gaines	4/83	27,848	1,008	580	28,500	25,274
55	Occidental	Wasson ODC Unit	TX	Yoakum	11/84	7,800	326	289	9,348	8,682
56	Occidental	Wasson Willard Unit	TX	Yoakum	1/86	8,500	271	212	4,511	3,700
57	Occidental	West Welch	TX	Gaines	10/97	240	0	0	0	0
58	OrlaPetco	East Ford	TX	Reeves	7/95	1953	8	4	128	128
59	Whiting Petroleum	North Ward Estates	TX	Ward/Winkler	5/07	16,300	816	816	7,800	4,700
60	XTO Energy	Goldsmith	TX	Ector	12/96	330	16	9		
61	XTO Energy	Cordona Lake	TX	Crane	12/85	2,084	44	23	1,050	350
62	XTO Energy	Wasson (Cornell Unit)	TX	Yoakum	7/85	1,923	96	64	1,700	875
63	XTO Energy	Wasson (Mahoney)	TX	Yoakum	10/85	640	49	27	875	1,350
				Total Miscible		268,443	7,447	5,182	216,468	171,967
CO_2 Immiscible										
64	Kinder Morgan	Yates	TX	Pecos	3/04	26,000	551	121	26,295	4,000
				Total Immiscible		26,000	551	121	26,295	4,000
	TOTAL MISCIBLE + IMMISCIBLE					294,443	7,998	5,303	242,763	175,967

3.1.3. Production estimations for the future

The possibility of combining horizontal drilling with hydraulic fracturing has allowed exploration companies to access and produce large volumes of oil in formations that were not economically viable to drill. Oil production in Texas has increased by more than 850,000 bbl/day since January 2009 with a production of 1.132 million bbl/day just in November of that same year (Oil & Gas Journal, 2012).

The Permian Basin has seen increased production of both conventional oil and shale gas. According to the Texas Railroad Commission, the Permian Basin production in 2011 accounted for nearly 71% of total oil production Texas statewide and 14% of the U.S. total oil production. Currently, there are nearly 82,000 active production wells in the Permian Basin. The number of horizontal rigs increased from 362 in February of 2011 to 1104 at the beginning of November (Oil & Gas Journal, 2012). It is obvious that the transition to horizontal drilling is now at the center of petroleum producers to tight formations.

With the continuously increasing number of horizontal wells drilled as well as the application of CO2 EOR to both vertical and horizontal wells, predictions are very optimistic. It is however difficult to obtain a number as the number of wells increase daily and the technology evolves just as fast.

3.2 The Gabon Basin

3.2.1. Geology and history of the Gabon Basin

As shown in figure 3.2, the Gabon Basin is located on the east coast of Gabon in the Gulf of Guinea. This area was moderately researched and even if some geological researches are available to the public, most of the data is kept secret by the government and international companies due to the economic interest of the region (hydrocarbon reservoirs). The Gabon Basin is located at the boundary of two old cratons which have been stable since about 2Ga. the Sao Francisco Craton and the Congo craton (Castro, 1987; Reyre, 1984) (Figure 3.3).

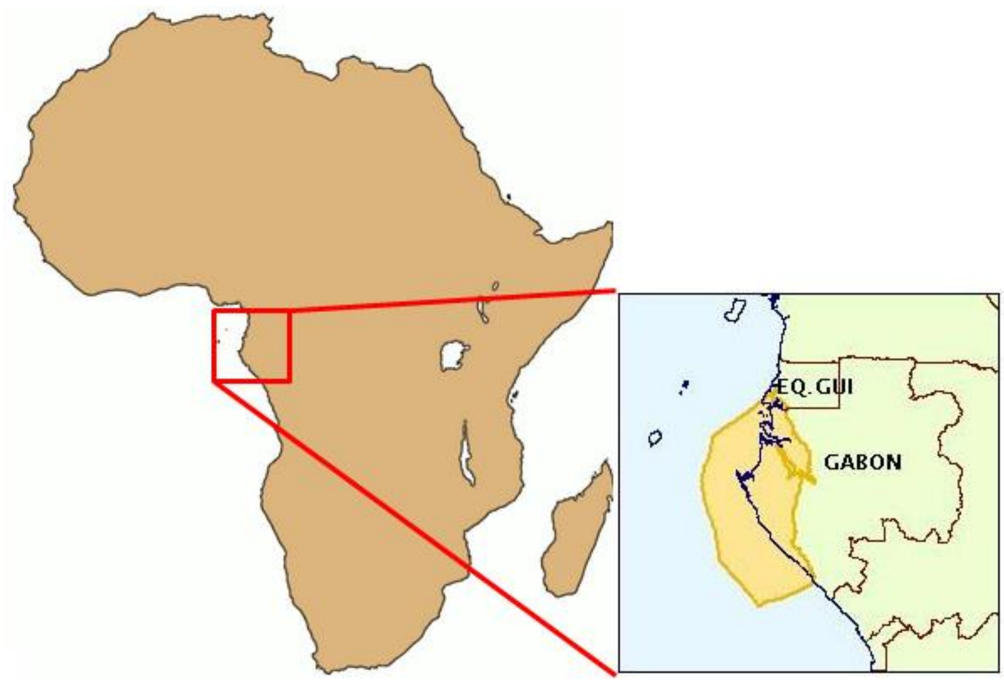

Figure 3-2 Location of the Gabon Basin today.

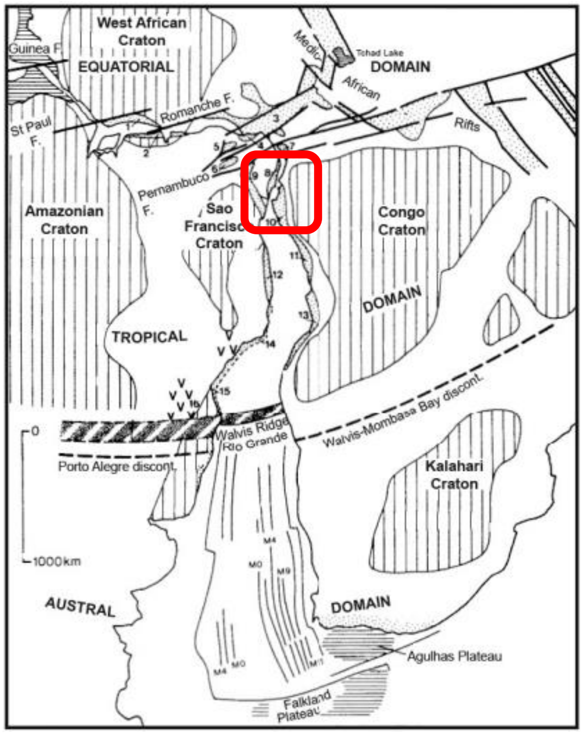

Figure 3-3 Location of the Gabon Basin 2Ga (Dupre S. et al, 2006)

Along the Gabon margin, rifling began around 144Ma based on the dating of older rifling sediments (Reyre. 1984). It is segmented by major faults parallel to the coastline and the NE-SW trending strike-slip faults.

The direct result of the formation of the south basin of Gabon, due to distension of the African plate and South America, is the Chaillu Massif. This massif is about 3,300 feet high and has a width ranging from 20 to 125 miles. Its highest point is Mount Iboundji (about 3200 feet).

In their articles, Dupre et al, 2006, used 15 wells located onshore and offshore 100 km along the southern coast of Gabon and 60 km along the NE-SW axis. They were able to determine that the sedimentation rate of 100 and 1000 m/Myr on average. These numbers are considered minima because they were obtained using present day thicknesses and do not take into account periods of erosion during basin formation.

3.2.2. Stratigraphy of the Gabon Basin

As previously stated, the Gabon margin is segmented by large normal faults parallel to the present day and by NE-SW trending strike-slip faults defining areas with partly different tectonic and stratigraphic histories. The N'Komi fracture zone divides the Atlantic basin into the North sub-basin and the South sub-basin.

The oldest pre-rift sediments along the Gabon margin are found in the north. In the interior of the basin, which is separated from the oil shore Atlantic basin the Lambarene Horst, these sediments consist of Late Carboniferous to Triassic-Jurassic fluvial and lacustrine sediments. Rifting began in the Berriasian time 144 ma and led to the formation of extensional faults and thus a series of horst and graben which was deposited in the Gabon sedimentary section. An overview of the Gabon Basin sedimentary column is shown in figure 3.4 below.

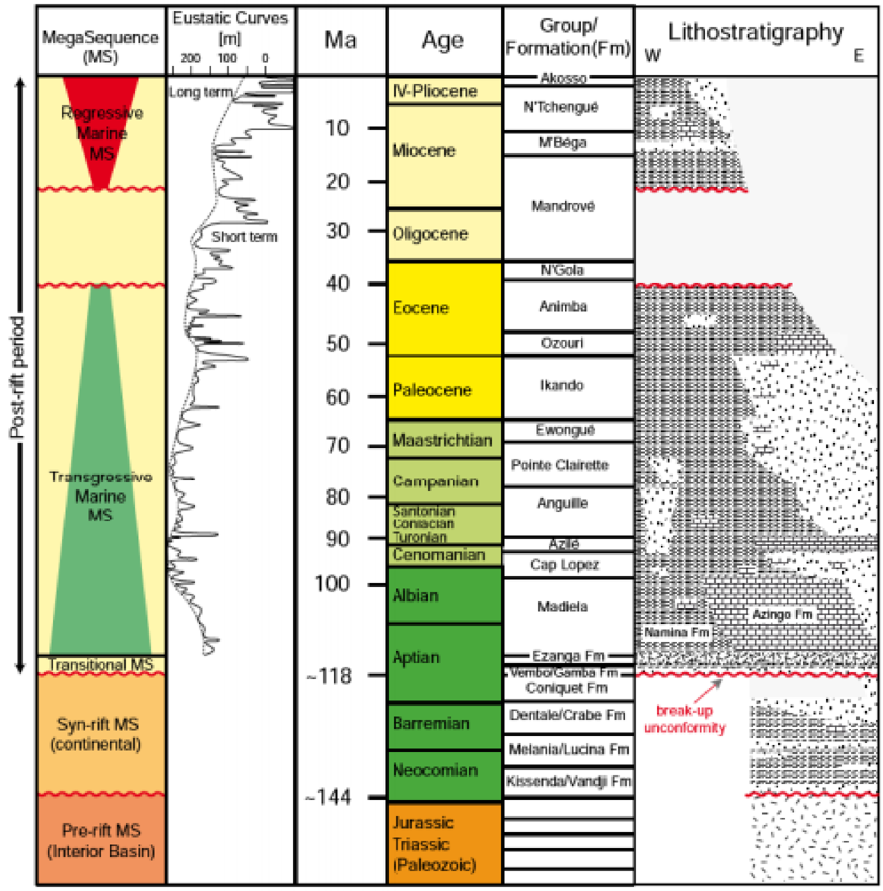

Figure 3-4 Stratigraphic Column of the Gabon Basin (Dupre et al, 2006)

The Rabi-Kunga and Gamba-Ivinga reservoirs belong to the pre-salt Gamba sequence and Dentale sequence of the Dianongo Basin which is part of the Lower Cretaceous of African-South American rift valley system. Both reservoirs have been exploited for over 30 years and are the core of oil production in Gabon.

The Rabi-Kounga field is dipping into a North-South Fault which bounds the field to the East. The west side is much flatter, and in this direction, the edge of the local field remains to be determined. In the Gamba-Ivinga reservoir, the oil comes mainly from organic rich lacustrine Melania shales which can be traced to the base Gamba unconformity over large areas of the Gamba Horst.

3.2.3. Oil and gas production overview

According to Oil & Gas Journal, Gabon had 2 billion barrels of proven reserves of oil at the end of the year 2012, the fifth largest in sub-Saharan Africa activities after Nigeria, Angola, Sudan and South Sudan (combined), and Uganda. Most of Gabon's oil fields are located in the Port-Gentil region (on the west coast) and are both onshore and offshore. The US EIA (US Energy Information Administration) shows that Gabon's oil production has declined by one third compared to the production peak of 370,000 barrels per day (bbl/d) in 1997, dropping to 244,000 bbl/d by 2012. The consumption of oil remained low in Gabon, averaging only 14,000 bbl/d during the last decade. This low consumption means that more than 90 percent of production is exported. The data were obtained from the US Energy Information Administration website and compiled in figure 3.5.

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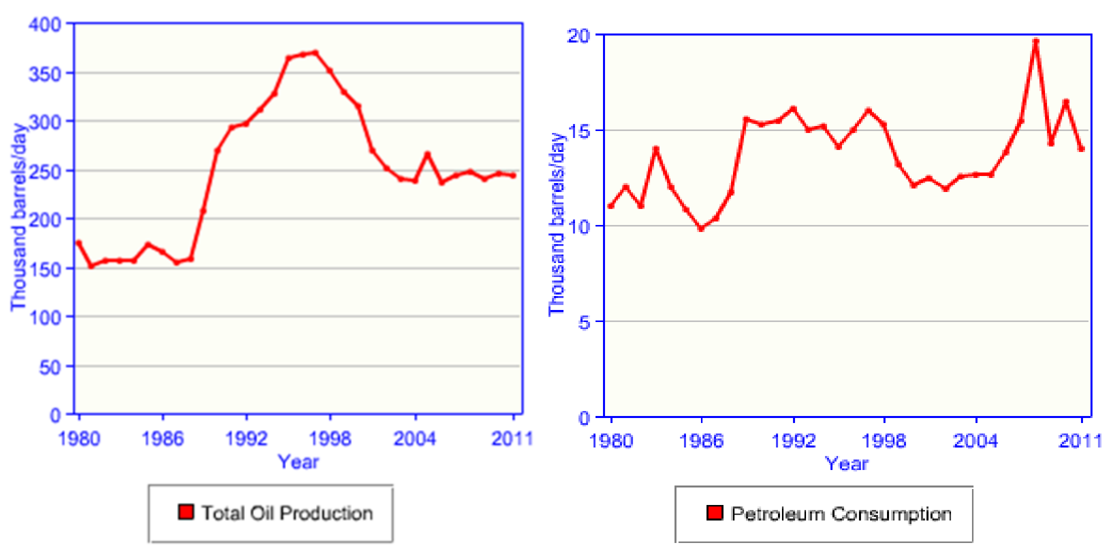

Figure 3-5 Overview of Oil Production and Local Consumption in Gabon (US EIA, Country Analysis Brief Overview, 2013)

The country's resources of natural gas have not been exploited as Gabon does not have the infrastructure to use natural gas for local consumption. Almost all of the 2.5 billion cubic feet of natural gas produced in 2011 (as shown on figure 3.6) was vented and burned and the proven reserve of natural gas is estimated to be about 1 trillion cubic feet. Such a high quantity of natural gas produced on such a small area could mean the possibility of significant improvement in oil production. In this next section, we will try, using BOAST NFR, to predict what could be the impact of CO_2 EOR on oil production on a specific well.

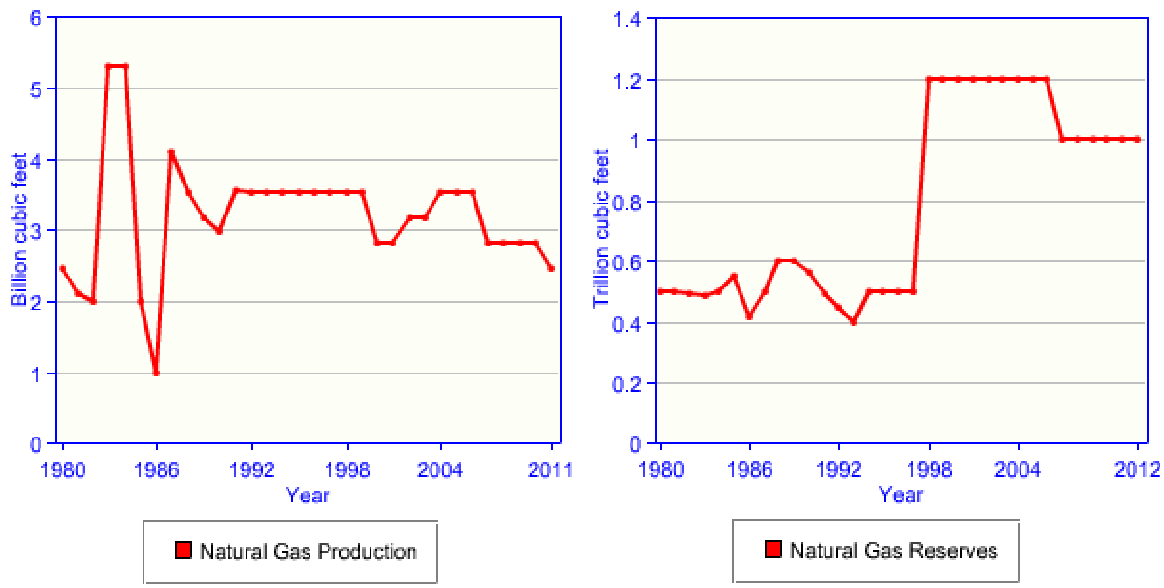

Figure 3-6 Overview of Natural Gas Production and Proven reserve in Gabon (US EIA, Country Analysis Brief Overview, 2013)

Chapter 4

Method

4.1. BOAST NFR – The software

Black Oil Applied Simulation Tool for Naturally Fractured Reservoirs (BOAST NFR) is a three dimensional, three phase “black oil” simulator developed for use on a personal computer under Windows environment. Reservoir simulators such as BOAST NFR are used before, during and sometimes after exploiting a reservoir. The purpose of using such simulators is to predict future performances of reservoirs. In the case that a given reservoir has already been depleted by primary and secondary recovery, simulators can be used to predict reservoir performance with tertiary recovery, in order to determine whether further exploitation is feasible.

The bases for reservoir simulators are:

- Reservoir engineering principles,
- A set of partial differential equations to describe the flow of fluids through porous media,
- Finite difference techniques to obtain numerical solutions for the partial differential equations for fluid flow, and
- Computer programming to perform the calculations electronically.

BOAST NFR particularly determines reservoirs’ performances using MS Excel spreadsheet for input and output of data in Windows environment (Almengor et al., 2002). According to the User’s Guide, BOAST NFR can be used in up-dip gas injection, vertical water influx, simulation of large multi-well structures, gravity segregation effects and heterogeneity effects… The first 3 Chapters of the BOAST NFR software (which present the software in more details) are found in Appendix A (Almengor et al., 2002).

BOAST NFR is not typically used for CO_2 flooding but, as in the next section, by modifying pressure and oil viscosity, one can simulate CO_2 injection in the reservoir and compare the results obtained from the simulator. The software can be freely downloaded from the National Energy Technology Laboratory website.

4.2. Application of the simulator to the Gabon Basin

4.2.1. Pressure

The first step before implementing CO_2 flooding in a reservoir is to determine the CO_2 MMP (CO2 Minimum Miscibility Pressure). This can be done using Equation 1.

Equation 1: MMP= 15.988*T(0.744206+0.0011038*MW C5+); *with MW C5+ being the molecular weight of hydrocarbons containing 5 or more carbon atoms*.

However, using table 4.1 showing data of a water injection well (provided by a Gabonese engineer who requested to remain anonymous) we were able to obtain the reservoir pressure and temperature at the desired depth (reservoir pressure= 3540 psi, temperature= 120-140 F). Furthermore, using figure 4.1, we determined that the MMP at 120-140 F for a light crude oil like the one found in the Rabi-Kounga oil field, with API 37.7^{o} (List of Crude Oil, 2013), ranges from 1900 to 2300 psi. Considering that the reservoir itself has a pressure of 3540 psi and that the water was injected with a pressure of 5400 psi, the latter two pressures cited were used as pressure range in the simulator.

Table 4-1 Data from an injection well in the Gabon Basin, Rabi-Kounga oil Filed (Anonymous)

7	1. Main Formation - Sandstone or Carbonate ?	sandstone	sandstone	sandstone
8	2. Vertical or Horizontal ? Hole survey, if available	slanted (30° over reservoir)		
9	3. Oil / Gas / Water (Ratio)	0 / 0 / 100 (water injector)	0 / 0 / 100 (water injector)	0 / 0 / 100 (water injector)
10	4. Is the well producing water ?	No - water injector	No - water injector	No - water injector
11	5. Water Cut % ? (and Source if possible)	100% (formation water)	100% (formation water)	100% (formation water)
12	6. Mineralogy per zone - below table	see table	see table	see table
13	7. Current flow rate STB/D	injection rate: < 2,0 bpm with WHP = 1500 psi, no PLT was performed so this injectivity performance is valid for the 3 perforations sets together, without distinction of individual injectivity performances		
14	8. Reservoir pressure (psi) ?	3540 psi	3420 psi	3200 psi
15	9. Bottom hole injecting pressure (psi) ?	5400 psi	5260 psi	5040 psi
16	10. Frac Gradient (psi/ft)	0,74 psi/ft		
17	11. Bottom hole temperature (F) ?	130 to 140 °F	125 to 135 °F	120 to 130 °F
18	12. Viscosity (CP) , API , Oil Sample ?	viscosity of water at reservoir conditions P & T : around 0,9 cP		
19	13. Net Pay (ft) ?			
20	14. perforated interval (ft) ?	30 ft, 12 spf	30 ft, 12 spf	30 ft, 12 spf
21	15. Permeability (md), porosity and Skin ?	30 mD	30 mD	40 mD
22	16. Kv/Kh ratio			
23	17. Water/Oil/Gas Saturation % ? (Water Sample)	100 % / 0 / 0	100 % / 0 / 0	100 % / 0 / 0
24	18. Formation damage type ? (Sample)	not precisely characterized (see report), so treatment must address a large spectrum of damage		
25	19. well history ? (Drilling fluid - water/oil based Mud, brine??)	Well was drilled with a complex brine, which is a water based mud. Please refer to attached document for additional information regarding mud (page 3 of NZOB-MWI5 Mud recap)		
26	20. primary formation damage ?			
27	21. was a thief zone identified by logs ?	No		

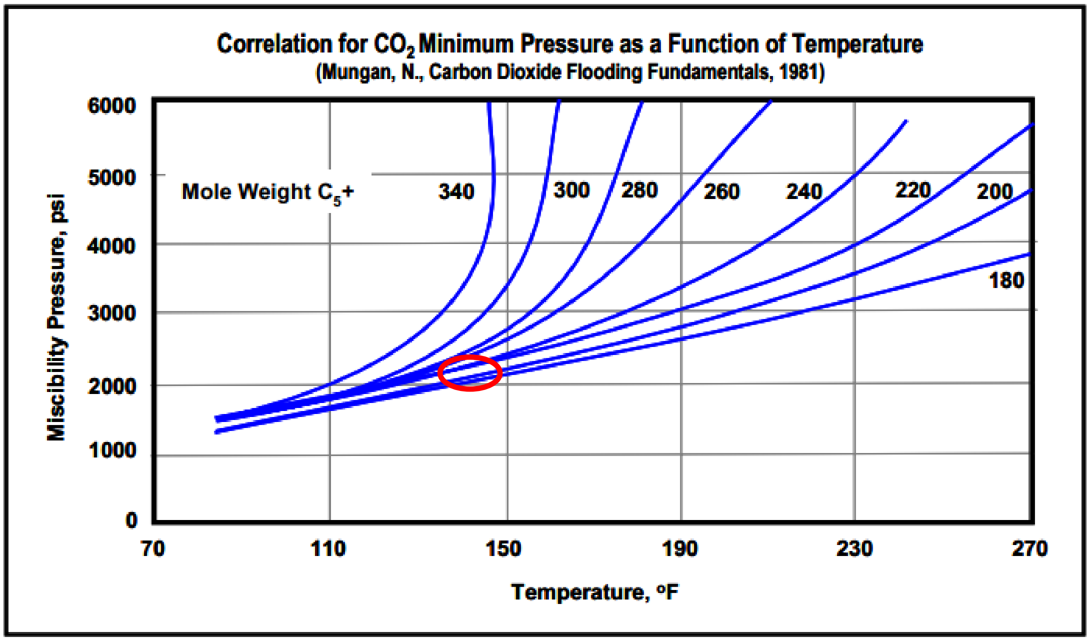

Figure 4-1 Graph showing MMP change with temperature and MW C5+ (Modified from Advanced Resources International, 2006)

4.2.2 Viscosity vs Temperature

The second most important thing to determine is the oil viscosity in the reservoir and its potential viscosity once mixed with CO_2. Figure 4.2 was used to determine the original crude oil viscosity in the Rabi-Kounga field. Using the temperature from the injecting well and the fact that Rabi-Kounga's crude oil is considered light, we were able to read from the chart that the original viscosity is about 2.4 cp (centipoise).

Determining the viscosity of oil once mixed with CO_2 was more complicated to obtain, as it depends on many factors such as the reservoir rock's composition, temperature, pressure, Dykstra-Parson coefficient (degree of homogeneity of the reservoir), gradient of the reservoir; and most of these data were not available. In an attempt to predict the change in oil production between crude oil viscosity and CO_2 mixed oil viscosity, we decided to use the injected water viscosity provided by the Gabonese engineer. With a viscosity of 0.9 cp (< 2.4 cp), we should be able to observe a difference in the simulator's response. Tables 4.2 and 4.3 show the BOAST NFR excel spreadsheets for the simulation with normal oil viscosity first, then with lower oil viscosity.

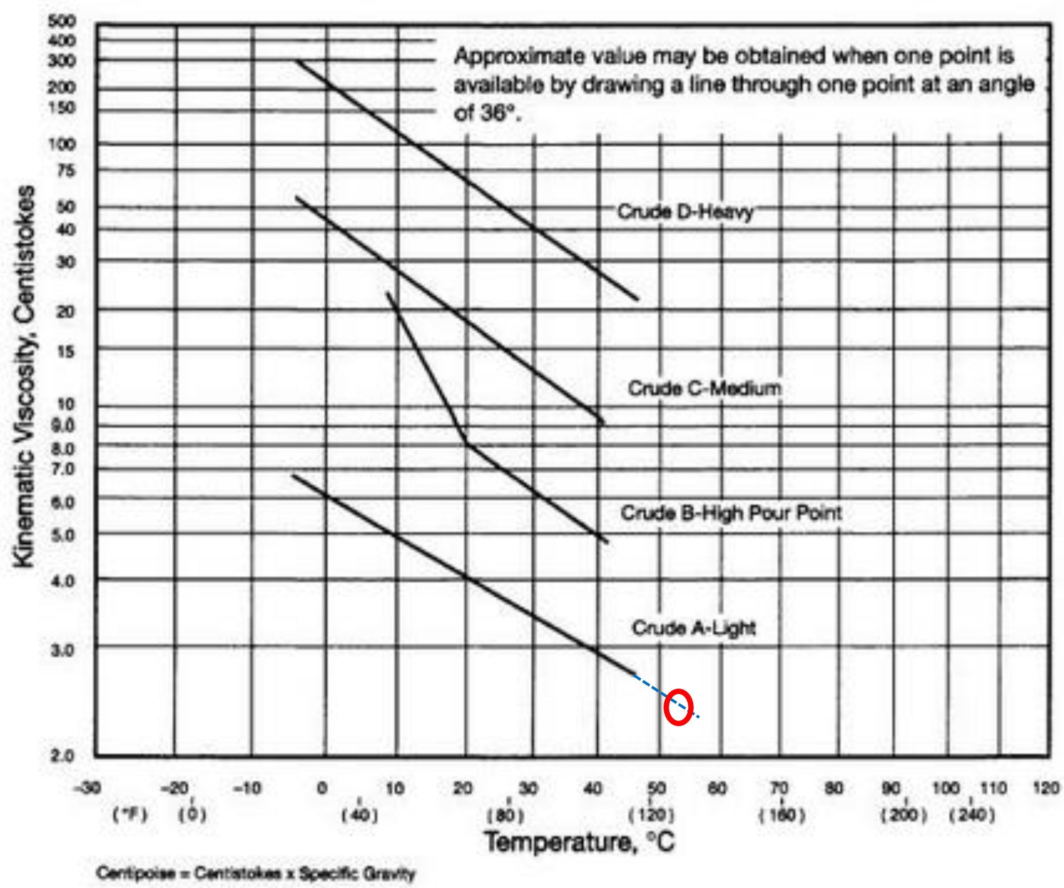

Figure 4-2 Graph showing kinematic viscosity of different types of crude oil (Modified from Oil and Gas Separator, 2009)

Tables 4-2 BOAST NFR excel spreadsheets for the simulation with normal oil viscosity.

BOAST-NFR	RUN	BOAST-NFR

Initial Time: 3/18/2013 21:10
End Time: 3/18/2013 21:18
Diff.(Hrs): -14-13

DATA

nx	ny	nz
15	1	1
NDT	RESTART	ITIME
100	1	0

GRID

	-1	-1	-1
Δx	200		
Δy	1500		
Δz	50		

CAPROCK BASE DEPTH TO THE TOP SAND

ELEVATIO	0
	2000

MATRIX POROSITY AND PERMEABILITY

	-1	-1	-1	-1
φm	0.29			
kx	1			
ky	1			
kz	1			

FRACTURE POROSITY AND PERMEABILITY

	-1	-1	-1	-1
φf	0.01			
σf	0.05			
L	5.00			
kxx	90			
kyy	90			
kzz	90			
kxy	0			
kxz	0			
kyz	0			

INTER-POROSITY FLOW MODEL

1

FAULTS

0		
X	Y	N/E
0	0	N/E

MATRIX S 14

	SAT	KRO	KRW	KRG	PCOW	PCGO
1	0	0	0	0	1	0
2	0.1	0	0	0.015	1	0
3	0.2	0	0	0.05	1	0
4	0.25	0	0.005	0.0765	0.5	0
5	0.3	0.042	0.01	0.103	0.3	0
6	0.35	0.1	0.02	0.1465	0.15	0
7	0.4	0.154	0.03	0.19	0	0
8	0.45	0.22	0.045	0.25	-0.2	0
9	0.5	0.304	0.06	0.31	-1.2	0
10	0.6	0.492	0.11	0.538	-4	0
11	0.7	0.723	0.18	0.538	-10	0
12	0.75	0.86	0.23	0.538	-40	0
13	0.8	1	0.23	0.538	-40	0
14	1	1	0.23	0.538	-40	0

FRACT. S 2

	SAT	KRO	KRW	KRG	PCOW	PCGO
1	0	0	0	0	0	0
2	1	1	1	1	0	0

Tables 4.2 -- Continued

INTERFACE					
Swr	0.25				
Swc	0.2				
krw*	0.03				
nw	1.47				
dPcdSw	3				
ROCK	2				
	P	Cm	Cf		
1	15	3.5E-06	3.5E-06		
2	5400	3.5E-06	3.5E-06		
PVT	PBO	MUSLOPE	BSLOP	RSLOPE	IREPRS
	5000	0.0000172	-4.00E-05	0	1
OIL-PVT	11				
	P	MUO	BO	RSO	
1	3540	2.5	1.3001	367	
2	3710	2.4	1.3359	447	
3	3880	2.3	0.3891	564	
4	4050	2.2	0.14425	679	
5	4220	2.1	1.5141	832	
6	4390	2	1.5938	1000	
7	4560	1.9	1.663	1143	
8	4730	1.8	1.7315	1285	
9	4900	1.7	1.7953	1413	
10	5070	1.6	1.854	1530	
11	5240	1.5	2.1978	2259	
WATER-P	2				
	P	MUW	BW	RSW	
1	1674	0.35	1.07	0	
2	7000	0.35	1.09	0	
GAS-PVT	11				
	P	MUG	BG		
1	3540	0.0162	0.0111177		
2	3710	0.0171	0.0090963		
3	3880	0.0184	0.0072995		
4	4050	0.0197	0.00623265		
5	4220	0.0213	0.00538479		
6	4390	0.023	0.00480083		
7	4560	0.0244	0.00446393		
8	4730	0.0255	0.00421687		
9	4900	0.0265	0.0040428		
10	5070	0.0274	0.00390804		
11	5240	0.033	0.003369		
DENSITY	OIL	WATER	GAS		
	51.14	65	0.058		

Tables 4-3 BOAST NFR excel spreadsheets for the simulation with reduced oil viscosity.

BOAST-NFR | RUN | **BOAST-NFR**

DATA

nx	ny	nz
15	1	1
NDT	RESTART	ITIME
100	1	0

Initial Time:	3/18/2013 21:04
End Time:	3/18/2013 21:14
Diff.(Hrs):	0:09:53

GRID

	-1	-1	-1
Δx	200		
Δy	1500		
Δz	50		

CAPROCK BASE DEPTH TO THE TOP SAND

ELEVATION	0
	2000

MATRIX POROSITY AND PERMEABILITY

	-1	-1	-1	-1
φm	0.29			
kx	1			
ky	1			
kz	1			

FRACTURE POROSITY AND PERMEABILITY

	-1	-1	-1	-1
φf	0.01			
σf	0.05			
L	5.00			
kxx	90			
kyy	90			
kzz	90			
kxy	0			
kxz	0			
kyz	0			

INTER-POROSITY FLOW MODEL

1

FAULTS

0		
X	Y	N/E
0	0	N/E

MATRIX S 14

	SAT	KRO	KRW	KRG	PCOW	PCGO
1	0	0	0	0	1	0
2	0.1	0	0	0.015	1	0
3	0.2	0	0	0.05	1	0
4	0.25	0	0.005	0.0765	0.5	0
5	0.3	0.042	0.01	0.103	0.3	0
6	0.35	0.1	0.02	0.1465	0.15	0
7	0.4	0.154	0.03	0.19	0	0
8	0.45	0.22	0.045	0.25	-0.2	0
9	0.5	0.304	0.06	0.31	-1.2	0
10	0.6	0.492	0.11	0.538	-4	0
11	0.7	0.723	0.18	0.538	-10	0
12	0.75	0.86	0.23	0.538	-40	0
13	0.8	1	0.23	0.538	-40	0
14	1	1	0.23	0.538	-40	0

FRACT. S 2

	SAT	KRO	KRW	KRG	PCOW	PCGO
1	0	0	0	0	0	0
2	1	1	1	1	0	0

Tables 4.3 -- Continued

INTERFACE

Swr	0.25
Swc	0.2
krw*	0.03
nw	1.47
dPcdSw	3

ROCK 2

	P	Cm	Cf
1	15	3.5E-06	3.5E-06
2	5400	3.5E-06	3.5E-06

PVT

PBO	MUSLOPE	BSLOP	RSLOPE	IREPRS
5000	0.0000172	-4.00E-05	0	1

OIL-PVT 11

	P	MUO	BO	RSO
1	3540	0.9	1.3001	367
2	3710	0.85	1.3359	447
3	3880	0.8	0.3891	564
4	4050	0.75	0.14425	679
5	4220	0.7	1.5141	832
6	4390	0.65	1.5938	1000
7	4560	0.6	1.663	1143
8	4730	0.55	1.7315	1285
9	4900	0.5	1.7953	1413
10	5070	0.45	1.854	1530
11	5240	0.4	2.1978	2259

WATER-PVT 2

	P	MUW	BW	RSW
1	1674	0.35	1.07	0
2	7000	0.35	1.09	0

GAS-PVT 11

	P	MUG	BG
1	3540	0.0162	0.0111177
2	3710	0.0171	0.0090963
3	3880	0.0184	0.0072995
4	4050	0.0197	0.00623265
5	4220	0.0213	0.00538479
6	4390	0.023	0.00480083
7	4560	0.0244	0.00446393
8	4730	0.0255	0.00421687
9	4900	0.0265	0.0040428
10	5070	0.0274	0.00390804
11	5240	0.033	0.003369

DENSITY

OIL	WATER	GAS
51.14	65	0.058

Chapter 5

Results

As previously stated, BOAST NFR is a software that is based on a MS Excel spreadsheet. The version of the software used in this study is free and available for download on the internet. The original spreadsheet is very complex and is composed of hundreds of boxes to be filled with data. Due to the complexity and unavailability of all the data required, the main focus was made on modifying pressure and oil viscosity to match the reservoir conditions in the Rabi-Kounga field; meanwhile, all other data were kept as provided by the software after download.

5.1. Oil production curve with original crude oil viscosity (2.5 cp)

A look at the oil production curve obtained from the simulator shows that oil production, indicated by the red line (red, top declining curve), is very high and stable for a very short period of time; during the 1st quarter of year 1, production only decrease from 800 STB/D to 780 STB/D. During that same time frame, the well produces little to no water (from 0 STB/D to 18 STB/D). Then suddenly, for a short period, oil production significantly drops from 780 STB/D to 582 STB/D; a loss a 200 STB/D in only 6 months. During that time, water production jumps from 18 STB/D to 217 STB/D. After those 2 unstable phases, production stabilizes with a constant declining rate of about 43 STB/D each year. It is also noticed that almost exactly 3 years and 9 months after initial production, the well starts producing more water than oil; the equilibrium is 400 STB/D. Figure 5.1 shows the graph output from the simulation.

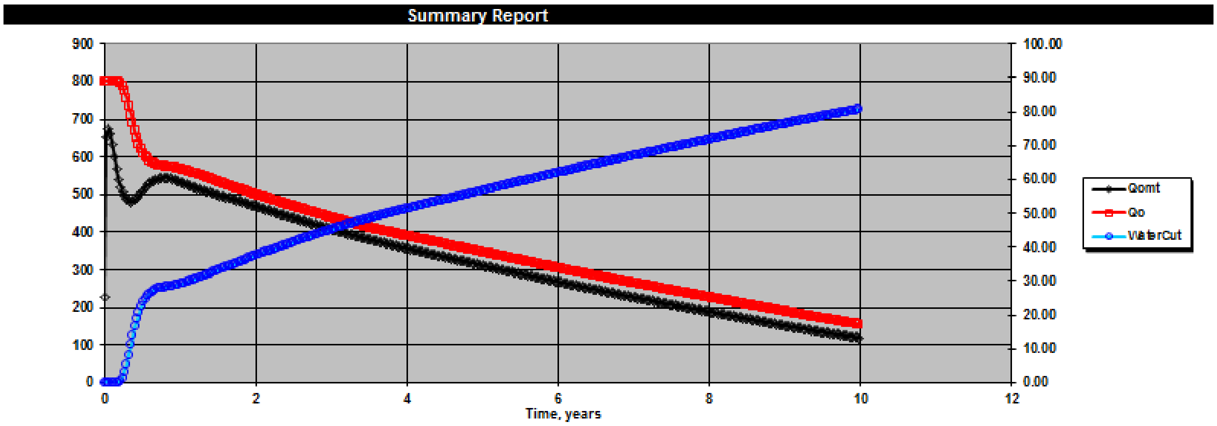

Figure 5-1 Oil production curve with original oil viscosity (2.4 cp)

5.2 Oil production curve with reduced oil viscosity (0.9cp)

The oil production curve obtained with the modified oil viscosity is slightly different from the previous one. Just as the case above, oil production starts at 800 STB/D, however it only decreases to just under 700 STB/D during the first 2 years. Water production does exactly the opposite, rising from 0 to 106 STB/D. It was also noticed that in the last 2 years of the simulation, both oil and water production behave exactly the same as during the first 2 years, dropping from 137 STB/D to 45 STB/D in the case of oil, and rising from 663 STB/D to 744 STB/D in the case of water. Between Year 2 and 8, however, the decline in oil production is quite significant, averaging about 94 STB/D each year. The well only starts producing more water than oil after 5 years and the equilibrium point is also about 400 STB/D. Figure 5.2 shows the graph output from the simulation.

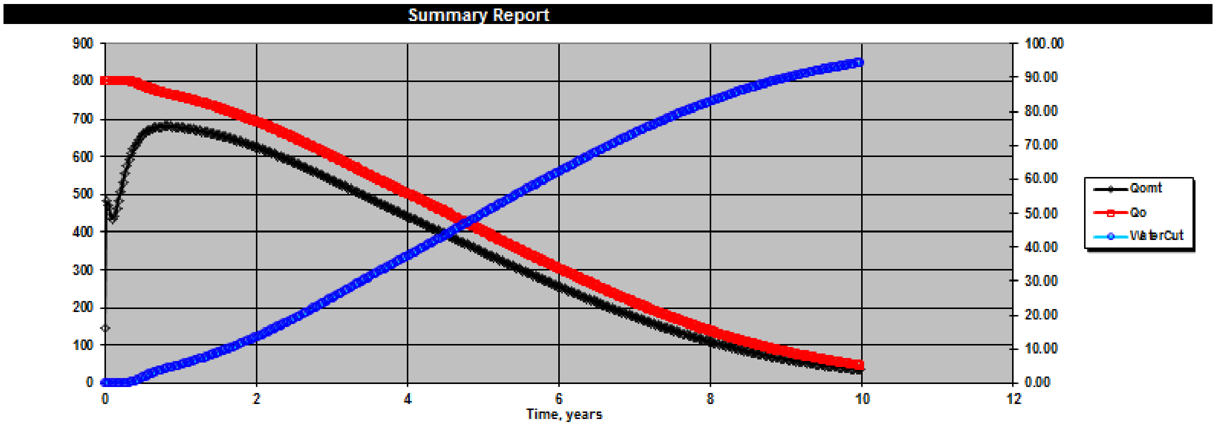

Figure 5-2 Oil production curve with reduced oil viscosity (0.9 cp). **Detailed data points on each graph are shown on Appendix B and C*

5.3 Calculations focused on the first 5 years

A detailed study of the oil production curves show that CO_2 EOR has the biggest impact on oil production during the first 5 years of its implementation. This section shows all the calculations regarding oil production and financial benefit of CO_2 EOR within that period of time.

Table 5-1 Year by year summary of oil and water production with original oil viscosity (5 years).

	Time	P ave	Qo	Qo	Qw	Qw
Approx Time	years	psi	STB/D	STB/Year	STB/D	STD/Year
1	1	5760.45	567.49	207135	232.507	84865.22
2	1.99	5810.89	500.66	182739	299.344	109260.6
3	3	5846.14	438.41	160019	361.59	131980.5
4	3.99	5872.46	390	142350	409.999	149649.6
5	5	5894.28	346.54	126486	453.462	165513.6
Total				818729		641269.5

Table 5-2 Year by year summary of oil and water production with reduced oil viscosity (5 years).

	Time	P ave	Qo	Qo	Qw	Qw
Approx Time	years	psi	STB/D	STB/Year	STB/D	STD/Year
1	1	5888.58	757.6	276524	42.402	15476.73
2	1.99	5901.67	693.51	253131.2	106.486	38867.39
3	3	5915.43	600.68	219248.2	199.32	72751.8
4	3.99	5928.35	502.54	183427.1	297.456	108571.4
5	5	5940.54	401.26	146459.9	398.74	145540.1
Total				1078790		381207.5

- Oil production per year with original oil viscosity

(∑Qo x 365) / 5 = [(567.49+500.66+438.41+390+346.54) x 365] / 5 = 163,745.8 STD/Year

- Overall oil production per day with original oil viscosity

[(∑Qo x 365) / 5] / 365 = 448.62 STB/D

- Oil production per year with reduced oil viscosity

(∑Qo x 365) / 5 = [(757.6+693.51+600.68+502.54+401.26) x 365] / 365 = 215,758.08 STB/Year

- Overall oil production per day with reduced oil viscosity

[(∑Qo x 365) / 5] / 365 = 591.12 STB/D

- Difference in oil production per year between original and reduced oil viscosity

(1,078,790 – 818,729) / 5 = 52,012.2 STB/Year

- Difference in oil production per year between original and reduced oil viscosity

[(1,078,790 – 818,729) / 5] / 365 = 142.5 STB/D

Net economical profit at oil price $100/bbl:

(Production increase x $100) = 260,062.5 x 100 = $26,062,500

Chapter 6

Discussion

6.1 Screening Reservoirs

In order to determine whether a reservoir is suitable for CO_2 EOR, its physical characteristics must be determined in a process called "reservoir screening". This process includes determining the following parameters:

- Reservoir depth: Some reservoirs in the Gabon Basin can be as deep as 11,000 ft but a significant number of them fall in the required range of 2,000-9,800 ft
- Reservoir temperature: Temperatures must not be less than 250 F but must remain high enough for CO_2 to be in its supercritical state. In this study, temperatures ranging from 120 to 140 F satisfy this criteria
- Reservoir pressure: Pressure must remain higher than 1,200 psi. here again, with a bottom hole pressure of 3450 psi, the well considered in this study satisfy the criteria
- Oil gravity: Must be at least 27^o and most oil produced in the Rabi-Kounga has a API of 37.7
- Oil viscosity: oil viscosity must be lower than 10 cp and it was estimated that the reservoir had a viscosity of 2.4 cp
- Residual oil saturation: residual oil saturation must be greater than 25% of pore space. Unfortunately, details about the residual oil saturation in the studied reservoir could not be obtained.

A summary of the desired values for these criteria is shown on table 6.1 obtained from the National Energy Technology Laboratory.

Table 6-1 Criteria for CO2 EOR suitability (National Energy Technology Laboratory, 2004)

Depth, ft	< 9,800 and > 2,000
Temperature, °F	<250, but not critical
Pressure, psia	>1,200 to 1,500
Permeability, md	>1 to 5
Oil gravity, °API	>27 to 30
Viscosity, cp	≤10 to 12
Residual oil saturation after waterflood, fraction of pore space	>0.25 to 0.30

6.2 Natural Gas in Gabon

As previously stated, Gabon is believed to still hold 1 trillion cubic feet of natural gas and in an effort to prevent most of it to be flared; Gabon joined GGFR (Global Gas Flaring Reduction) in 2007. According to the NADC report sheet of 2011 (Netherland-Africa Business Council), since joining the GGFR, Gabon has significantly reduced the volume of gas flared from 181 cubic feet in 2009 to 165 cubic feet in 2011. The government aims to achieve a 60% reduction by 2015. Two ministerial decrees were also adopted in 2009 and 2010 prohibiting gas flaring in Gabon and specifying penalties for non-compliance with the guideline. Governments are very clear on their goal to develop the use of greenhouse gas to produce electricity, petrochemicals and liquefied for export.

Most of Gabon's natural gas resources are closing linked to oil fields as most of these oil fields do produce high quantity of gas. Figure 6.1 shows a map of the locations of oil fields associated to high natural gas content and production.

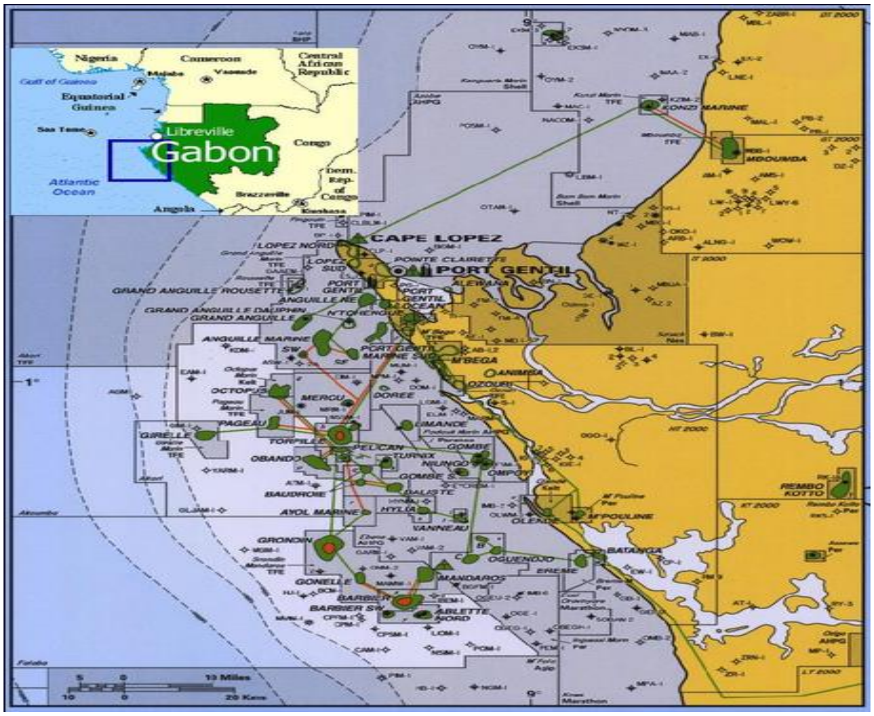

Figure 6-1 Oil fields associated with high natural gas content (Van Der Merwe C, 2007)

<u>6.3 Impact of CO2 EOR on oil production in the Gabon Basin</u>

As we could see in the results, the oil production curve of a reservoir is closely related to the viscosity of the oil within this reservoir. In the example used in this research, we observed that the maximum volume of liquid-phase production is about 800 STB/D, which of course means that the equilibrium between oil and water production is about 400 STB/D. The most important difference between the two oil production curves is how fast this equilibrium is reached, or how fast the well starts producing more water than oil. With an oil viscosity of 2.5 cp we observe that this equilibrium is reached after 3.75 years (3 years and 9 months) only and that the oil production declined fast. On the other hand, with an oil viscosity reduced to 0.9 cp after potential CO_2 flooding, the equilibrium is only reached after little bit more than 5 years and overall, the production curve remains above the previous one. In other words, it is clearly observable that with oil viscosity reduction, the reservoir produced more oil, and for a longer period of time. A look at figures 6.2 and 6.3 show a difference of 129,244 bbl (or 35 STB/D) between the total productions over 10 years given the two oil viscosities. This difference may not be considered to be significant enough over a period of 10 years; however, the real impact of implementing CO_2 EOR on such a reservoir is represented by the amount of oil produced until equilibrium is reached (5 years). Over that period, when oil viscosity is reduced, as it would be when mixed with CO_2, the reservoir produce 1,078,790 bbl (or 591 STB/D) compared to only 818,729 bbl (448 STB/D) with original viscosity. The difference here is more significant as it represents an increase of 260,061 bbl (or 142 STB/D). These numbers show that during its effective period of 5 years, CO_2 EOR increased oil production on the reservoir by 5 times. Tables 6.2 and 6.3 show all the results year by year for 10 years.

Table 6-2 Year by year summary of oil and water production with original oil viscosity.

	P ave	Qo	Qo	Qw	Qw
Year	psi	STB/D	STB/Year	STB/D	STB/Year
1	5,760	567	207,135	233	84,865
2	5,811	501	182,739	299	109,261
3	5,846	438	160,019	362	131,981
4	5,872	390	142,350	410	149,650
5	5,894	347	126,486	453	165,514
6	5,912	304	110,874	496	181,126
7	5,927	264	96,360	536	195,640
8	5,939	225	82,223	575	209,777
9	5,949	189	68,893	611	223,107
10	5,958	154	56,289	646	235,711
Total			1,233,369		1,686,631

Table 6-3 Year by year summary of oil and water production with reduced oil viscosity.

	P ave	Qo	Qo	Qw	Qw
Year	psi	STB/D	STB/Year	STB/D	STB/Year
1	5,889	758	276,524	42	15,477
2	5,902	694	253,131	106	38,867
3	5,915	601	219,248	199	72,752
4	5,928	503	183,427	297	108,571
5	5,941	401	146,460	399	145,540
6	5,952	302	110,068	498	181,932
7	5,961	212	77,521	588	214,479
8	5,969	136	49,713	664	242,287
9	5,975	82	29,801	718	262,199
10	5,978	46	16,720	754	275,280
Total			1,362,613		1,557,384

Chapter 7

Conclusion

All around the world, efforts are being made by governments and oil companies to revitalize oil production. It is not a secret that production as been on the decline in the recent years, as all major fields are believed to have been discovered and have reached maturity. However, researches have shown that through primary and secondary recovery, only up to 40% of OOIP can be recovered.

CO_2 EOR is a technique that has been proven to be very promising for the future. CO_2 in its super-critical state mixes with residual oil reducing its viscosity. After oil viscosity is reduced, it can then be more easily displaced towards a producing well, being pushed by water in a process called WAG.

The implementation of CO_2 EOR requires some modification to the original infrastructures on site which can be costly. The Permian Basin is a clear example that such investment is to be considered as CO_2 EOR accounts for 850,000 bbl/day. Moreover, researches are being pursued in order to apply CO_2 EOR all the way to the Residual Oil Zones (ROZs) which could boost oil production by up to 80% of OOIP in a reservoir.

Oil production has been on the decline in the Gabon Basin, dropping from 370,000 bbb/day in 1997 to 244,000 bbl/day in 2012. Keeping in mind that the availability of CO_2 in the region is not a problem (with 1 trillion cbf of estimated reserve); studies like this one should be applied to all the reservoir in order to prove how tertiary recovery could boost oil production in the area.

Using data provided by a local engineer, we were able to gather information such as reservoir pressure and temperature. These data, combined with literature research in order to determine potential original and reduced oil viscosities, allowed us to run the BOAST NFR software.

The results obtained from running the BOAST NFR show that that CO_2 EOR has the most impact on oil production during the first 5 years after its implementation. During this time frame, the studied reservoir from the Rabi-Kounga oil field produced a total volume of 1,078,790 bbl (or 591 STB/D) with reduced viscosity, compared to only 818,729 bbl (448 STB/D) with original viscosity. This difference represents 260,061 bbl which could account for increase revenue of $26,006,140 for this single well with oil price at $100/bbl.

This case study clearly showed that beyond environmental advantages through CO_2 sequestration, CO_2 EOR has a bright future and should be implementated in the Gabon Basin sooner than later. The ground work still remains to be done as all of the Gabon Basin reservoir should go through "screening" in order to determine their eligibility. Criterias, however could change quickly, leading to more reservoirs falling into the category of eligible reservoir, as the CO_2 EOR technique moves from "State-Of-The-Art" to "Second Generation EOR Technology".

Appendix A

BOAST NFR User's Guide

Appendix A

1. Introduction

1.1 Background

Reservoir studies are performed to predict the future performance of a reservoir based on its current state and past performance and to explore methods for increasing the ultimate recovery of hydrocarbons from a reservoir. Reservoir simulators are routinely used for these purposes. A reservoir simulator is a sophisticated computer program, which solves a system of partial differential equations describing multiphase fluid flow (oil, water, and gas) in a porous reservoir rock.

Simulators can be classified according to the systems they are capable to model based on:

1. Number of phases and components in the reservoir.

2. Type of reservoir process.

3. The direction(s) of fluid flow.

4. Formulation to be used to solve the flow equations.

5. Type of reservoir model implemented.

According to the number of phases, a reservoir simulator can be a one-, two-, or three-phase model (gas, oil and/or water) and the number of components could vary from 1 to N. According to the type of process, a reservoir simulator can be classified as a black oil, compositional, or enhanced oil recovery (EOR) simulator. According to the direction of fluid flow, a reservoir simulator can be one-, two-, or three-dimensional. According to the formulation, a reservoir simulator can be an IMPES (implicit in pressure - explicit in saturation) model, a fully implicit model, or an adaptive implicit model. According to the type of reservoir model implemented, it can be a single-porosity, dual-porosity, or a dual-porosity, dual-permeability reservoir simulator.

The bases for reservoir simulators are:

- reservoir engineering principles,

- a set of partial differential equations to describe the flow of fluids through porous media,

- finite difference techniques to obtain numerical solutions for the partial differential equations for fluid flow, and

- computer programming to perform the calculations electronically.

1.2 Mechanics of Simulation

The reservoir is first divided into segments, or blocks, using X-, Y-, and Z-axes. Rock and fluid properties are then assigned to each block to describe the reservoir system. Computations are carried out for all phases in each block at discrete timesteps. The results, or output, usually consist of production volumes and rates, pressure and saturation distributions, material balance errors, and other process specific information provided at selected timesteps.

1.3 Black-Oil Simulators

The most routinely used type of reservoir simulator is the "black oil simulator." Black oil simulators describe multiphase flow in porous media without considering the composition of the hydrocarbon fluid. They assume that the liquid hydrocarbon phase consists of only two components: oil and gas in solution. The gas phase consists of only free hydrocarbon gas. Mass transfer of oil components from the liquid to the gas phase is not considered. Phase behavior is represented by formation volume factor and solution gas/oil ratio curves.

The reservoir fluid approximations are found to be acceptable for a large percentage of the world's oil reservoirs. Thus, black oil simulators have a wide range of applicability and are routinely used for solving field production problems. Example applications include: aquifer behavior, up-dip gas injection, flank water injection, vertical water influx, vertical equilibrium, single well operations, simulation of large multi-well structures, reservoir cross sectional analysis, gravity segregation effects, heterogeneity effects, simulation of large reservoirs of several non-communicating producing horizons, multiple completions with or without commingled production, stratified flow patterns, and analysis of migration across lease lines.

Although black oil simulators are well suited for studies of numerous problems, they do have some limitations in their scope of applications. They cannot be used to study cases where mass transfer between phases is important. For example, black oil simulators cannot be used to study problems associated with gas condensate and volatile oil reservoirs. In these reservoirs, the composition and physical properties of the phases change with pressure. Similarly black oil simulators cannot be used to simulate EOR processes, such as thermal (steam and in situ combustion), chemical (surfactant and polymer), hydrocarbon miscible, and CO_2 flooding.

2. BOAST-NFR

2.1 Model Overview

Black Oil Applied Simulation Tool for Naturally Fractured Reservoirs (BOAST-NFR) is a three-dimensional, three-phase, finite-difference black oil simulator developed for use on a personal computer under Windows environment. The model is based on the widely known, public domain, black-oil model BOAST, which was published by the Department of Energy (DOE) in 1982. The fracture system added to BOAST-

NFR can be used to simulate the production and injection from any combination of vertical, horizontal, and slanted wells in a naturally fractured reservoir that can be represented by a dual-porosity,

dual-permeability model. Most of the features added to BOAST in the BOAST II version and that were not incorporated in BOAST-VHS are not in BOAST-NFR version.

The BOAST-NFR program simulates isothermal, Darcy flow in three dimensions. The simulator assumes that the reservoir fluids can be described by three fluid phases (oil, water, and gas) of constant composition whose properties are functions of pressure only. BOAST-NFR can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and imbibition mechanisms using constant shape factors to describe the interporosity flow. However, when time-dependent shape factors are used, only one-dimensional interporosity flow in water-oil systems is available.

BOAST-NFR employs the implicit pressure - explicit saturation (IMPES) formulation for solving its system of finite-difference equations. The IMPES method finds the pressure distribution for a given timestep first, then the saturation distribution for the same timestep. The IMPES formulation is straightforward, requires less arithmetic per timestep, and hence is faster than other formulations. Further, the IMPES formulation requires less storage than a fully implicit formulation. This permits the simulation of larger problems on a small computer such as a microcomputer.

Because of the explicit treatment of saturation in the IMPES method, the solution obtained by use of this method may not be stable for some cases. This is especially true for cases where rapid changes in saturation result from high flux rates or the use of small gridblocks. In such cases, the stability can be restored by reducing the timestep size drastically. This then can cause computing time requirements to become excessive. Since near-wellbore coning problems result in rapid saturation changes, models based on IMPES formulations are unsuitable for the study of such problems. Therefore, BOAST-NFR is not recommended for use in simulating single-well coning phenomena. The same stability problem is observed while simulating reservoir regions with very low fracture porosity. In these cases, the use of small timesteps is recommended until stability is obtained.

BOAST-NFR employs the line-successive, over-relaxation (LSOR) iterative solution technique to solve the system of pressure equations. This method requires less storage and usually is faster for larger problems than other methods. The central processing unit (CPU) time for the iterative methods depends on the type of problem to be solved and the selection of the iterative parameter. This is the main disadvantage of the iterative method.

2.2 Model Features

BOAST-NFR is recommended as a cost-effective reservoir simulation tool for the study of such problems as primary depletion, pressure maintenance (by water and/or gas injection) and basic secondary recovery operations (such as waterflooding) in a naturally fractured black oil reservoir using slanted or horizontal wells, in addition to conventional vertical wells. The model is a modification of the DOE BOAST-VHS simulator with some added user-friendly features. Like BOAST-VHS, BOAST-NFR can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and capillary imbibition mechanisms. BOAST-NFR can also handle time-dependent flow correction factors for the description of interporosity flow in water-oil systems.

The well model in BOAST-NFR permits specification of rate or pressure constraints on well performance. The model also allows the user to add or re-complete wells during the period represented by the simulation. Several other features are included in the model, such as flexible initialization capabilities, a bubble point pressure tracking scheme, an automatic timestep control method, a zero transmissibility option to model sealed faults, and a material balance check on solution stability.

The program permits the input of all data using a spreadsheet in a MS EXCEL file. Relevant comments help users remember the type of data and units for each reservoir parameter. The main advantage of this data entry is that it simplifies the preparation, review, and visual checking of the data, thus minimizing input errors.

Another feature present in BOAST-NFR is to allow the user to stop the program, modify the data file, and then restart the simulation run. This feature can be useful to reduce the computing time for a study that determines the best operating conditions for a reservoir.

2.3 Dynamic Redimensioning

The purpose of the dynamic redimensioning is to allow the user to set the gridblock number in three-dimensional simulation using the data input file. This allows the user to tailor the simulation to the level of data available and his specific requirements. The more gridblocks in a simulation the more accurate the representation of the reservoir, and therefore the better the prediction of reservoir performance. However, the larger the number of gridblocks, the more time required for the computer to complete the simulation. Unlike BOAST-VHS, BOAST-NFR does not have any restriction regarding the maximum number of gridblocks to be used in a simulation study.

Dynamic redimensioning is the ability of the program to adjust the three-dimensional gridblocks of the reservoir arrays. The main program has an array with non-adjustable bounds that can call a subroutine with a reservoir array having adjustable dimensions.

This allows variables such as pressure, fluid saturation, porosity, and permeability to be passed to the subroutine as arguments for each gridblock. The size and bounds of this reservoir array are determined by the set of arguments also passed to the subroutine and are controlled from the input file.

2.4 Restart Capabilities

An important program feature to BOAST is the restart capability after a normal reservoir simulation run. The program can be instructed to run a simulation for a given time period and then, after normal termination, be restarted from that point in time with a new set of operating conditions. This feature is activated by entering the flag for restart in the initial input data file. This flag will cause the program to generate input data in a restart spreadsheet. This new restart data needs to be modified to enter the new operating conditions for the time period from the end on the first simulation until the new ending time. These changes usually occur in the recurrent data records.

2.5 Program Limitations

BOAST-NFR does have certain limitations, which must be recognized to be able to use the program effectively. The major limitation of BOAST-NFR is that the program is not recommended for simulating coning phenomena. Further, because of the memory limitations of a microcomputer, this simulator cannot be used to perform very large simulations. The program also is not recommended for estimating the performance of a reservoir under active waterdrive or for modeling gas production wells. These limitations are inherent in IMPES solutions. BOAST has some mathematical instabilities that are self-correcting, so that cumulative productions and average rates are reasonably accurate. Unfortunately, some of the instantaneous production rates are not reasonable and can show sharp spikes in the graphed curves when ratios, such as GOR, are plotted against time. Smaller timesteps can reduce this effect. As long as the application does not involve rapid pressure changes that are a problem with IMPES, BOAST-NFR should give reasonable results in the range of those obtained by other horizontal well simulators.

While BOAST-NFR does have some limitations, it is versatile enough to handle a large number of commonly encountered black-oil simulation problems on microcomputers. It can be used to simulate single wells in different geometry throughout a reservoir. The angle of penetration can be varied from 90º to 180º. The example problems included with BOAST-VHS and this manual illustrate the scope and capabilities of BOAST-NRF simulator.

2.6 Restart Limitations

Under the RESTART option, a run with a short time limit followed by a restart run with a long time limit will show production rates noticeably different from those of a continuous simulation run over the total time period. On the other hand, a restart run with a long time limit period followed by a restart with a short time limit would show much closer agreement to one continuous simulation over the total period.

This problem arises because the restart parameters are stored in an editable text file similar to the original input data file. Only a binary file of all simulation variables being used could overcome this "butterfly" effect. Another problem is the inherent mathematical instability of BOAST. If the first simulation ends on a spike in the gas production, the restarted simulation suffers an additional inaccuracy.

3. Getting Started with BOAST-NFR

3.1 Minimum Requirements

The minimum system requirements to run BOAST-NFR on a personal computer are as follows:

- Computer - IBM PC/AT, PS-2, or compatible.
- Operating system - Windows NT, Windows 1998 or later.
- Software: MS-EXCEL 98 spreadsheet or later.

3.2 Simulation Run

BOAST-NFR is a program implemented in EXCEL that needs a spreadsheet labeled Input Data, which is included in the original software. Simulator program writes the output data in spreadsheets labeled Output Data and Summary Report, also included in the software.

Using BOAST-NFR is a two-step process. First you modify the input spreadsheet and run the simulator by clicking the “RUN” icon located at the top the Input Data spreadsheets. While the program is running, it writes on the Output Data and Summary Report spreadsheet the results from the simulation in printable form. You can then plot the output data, export data to another EXCEL file and/or print out a hard copy of the Output Data and Summary Report sheets.

3.3 Loading the BOAST-NFR Program

The BOAST-NFR program may be copied onto any directory in your computer. In the following, an example of loading is provided where the program is copied onto the hard disk under the directory Windows, subdirectories Start Menu, Programs, BOAST-NFR. The program should be ready to use as soon as it is copied onto the computer. From the desktop, go to the Start icon, select Programs, BOAST-NFR, and the EXCEL program BOAST-NFR as shown in Fig. 3.1.

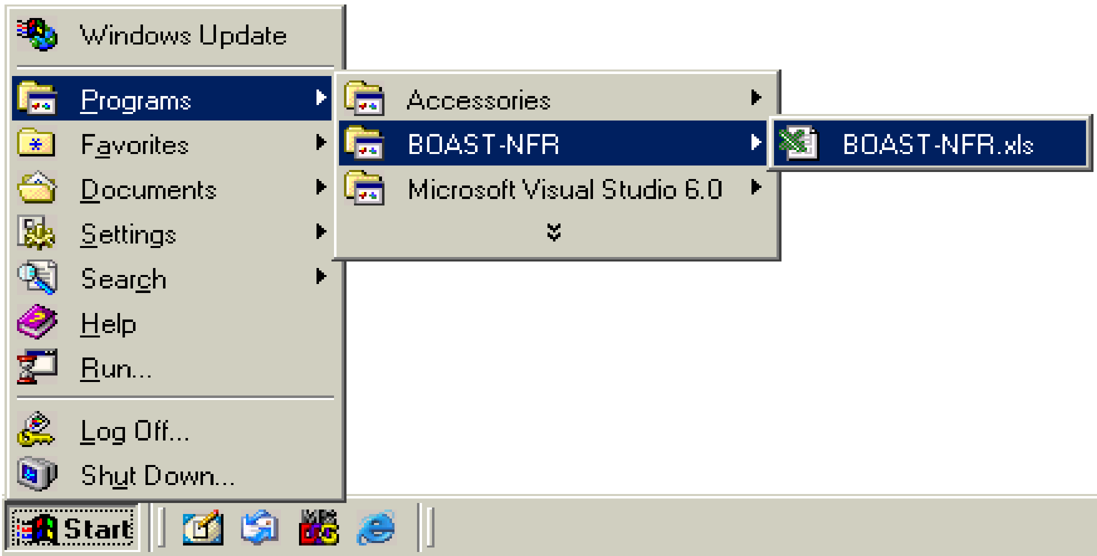

Figure 3.1. Starting up BOAST-NFR in Windows.

3.4 Data Input Requirements

This section describes briefly the input requirements for BOAST-NFR. A complete description of the input data required to run BOAST-NFR is given here and in Section 4.

All input data for the simulator are contained in a single spreadsheet. This data can be divided into two groups: (a) initialization data and (b) recurrent data. The initialization data include reservoir geometry, interporosity flow model, matrix and fracture porosity and permeability, initial pressure and saturation data, relative permeability and capillary pressure tables for the matrix and the fracture media, and PVT data for the fluid system. Also included in this section are the necessary run control parameters and solution specifications.

The recurrent data include the location and initial specifications of wells in the model, timestep control information for advancing the simulation through time, a schedule of individual well rates and/or pressure performance, changes in well completions and operations over time, and controls on the type and frequency of printout information provided by the simulator.

Throughout the description of input data in Sections 3 and 4, the term "header" is used to refer to specific input data records. These records are designed to serve as delineators and/or as data identifiers. The header record may be used to conveniently identify specific data items on the subsequent record or records.

All data values are identified by a name that, most of the time, corresponds to the actual variable name in the model. Input data must be entered in a sequence, and a value must be specified for each input datum in an individual cell in the spreadsheet.

3.5 <u>Data Input Conventions</u>

If a full grid of input values of rows (x-direction), columns (y-direction), and layers (z-direction); II, JJ, and KK values respectively, must be read for a particular parameter, the following input order must be followed:

To read in a full grid of input values for a particular parameter (II = number of gridblocks in x-direction, JJ = number of gridblocks in y-direction, KK = number of gridblocks in z-direction), Layer 1 (K = 1) is read first. The data in each layer are read in by rows, starting with Row 1 (J = 1). Values of the parameter for Columns I = 1 to II are read for the first row, starting with column 1 (I = 1). After II values have been read for the first row, values are read for the second row (J = 2), etc. until JJ rows of data are read. This process is repeated for Layer 2 (K = 2), etc. until KK layers of data are read.

BOAST-NFR uses a right-handed coordinate reference. The z-direction values will increase going down. For K = 1, II x JJ values must be read in the following order.

J = 1, I = 1,2 II

J = 2, I = 1,2 II

J =...................... II

J = JJ, I = 1,2 II

Because II x JJ x KK values are required for each reservoir parameter, the complexity and size of the input file grows in direct proportion with the number of gridblocks.

3.6 <u>Running the BOAST-NFR Program</u>

BOAST-NFR is a sophisticated simulation tool that permits the study of a variety of problems encountered in naturally fractured reservoir management and production operations. The program contains several options, and to be able to use it most effectively to predict the performance of a reservoir, the user must be familiar with them.

Perhaps the best way to become acquainted with BOAST-NFR, and to have a feel for the operating parameters, is to run the program with different sets of input data. It is suggested that the user first scan through the data input sections (Sections 3 and 4) to become familiar with the general format of the input and then look at the examples in Section 7. Examples illustrated in the BOAST-VHS program guide and this manual display the capability of the model to simulate multi-well, multidimensional reservoir engineering and production problems. These examples can be used as a general guide.

BOAST-NFR contains an automatic timestep control feature and material balance calculations for each fluid phase. Although timesteps can be controlled, it is recommended that automatic timestep control be used for most runs. This feature allows the program to maintain a step size that is large enough for the problem being simulated, yet small enough to avoid pressure and/or saturation oscillations and to give acceptable solutions. The maximum recommended saturation changes are 1 to 5 % for typical problems. Maximum pressure change is normally less critical and typically may be 1 to 10 psi. To help determine if saturation and pressure changes are acceptably small, the user should study both timestep and material balances. Previous recommended maximum changes in pressure and saturation need to be adjusted depending on the reservoir problem on hand.

BOAST-NFR performs material-balance calculations at the end of each timestep, as a check to determine the degree to which the finite-difference solutions obtained from the IMPES procedure actually satisfy the conservation equations. This basically involves comparing the change of each fluid phase over time with the quantities of fluid produced and injected over the same time period. The change in fluid content (STB

or MCF) is estimated directly from calculated pressures and saturations. Quantities produced and/or injected are determined from the production and injection rates at all wells.

Timestep material balances are printed on each summary report in the Output Data spreadsheet and should always be checked carefully before accepting any run as a 'final' result. In general, timestep material balance errors should normally be less than 0.1%.

An excessive material-balance error is an indication of a large saturation and/or pressure change that causes the results of BOAST to be an inaccurate simulation. The problem can usually be overcome by reducing the timestep size. This can be performed by specifying a smaller minimum step-size and reducing saturation and pressure tolerances.

Appendix B

BOAST NFR Data Output With Original Oil Viscosity

Appendix B

(BOAST NFR data output with simulated original oil viscosity)

N	**Time**	**P ave**	**Qo**	**Np**	**Qg**	**Gp**	**GOR**	**Qw**	**Qo+Qw**	**WaterCut**	**Qomt**	**Qwmt**	**niter**	**DPmax**
T.S	years	psi	STB/D	Bbl	MSCF/D	MSCF	MSCF/B	STB/D	STB	%	STB/D	STB/D	#	psi
1	0	5,999	800	0	1,185	0	1	0	800	0	229	0	26	0
100	0	5,969	800	5,200	1,185	7,705	1	0	800	0	652	31	31	2
200	0	5,922	800	13,200	1,185	19,560	1	0	800	0	675	67	31	1
300	0	5,875	800	21,200	1,185	31,414	1	0	800	0	663	101	31	1
400	0	5,833	800	29,200	1,185	43,268	1	0	800	0	634	143	30	1
500	0	5,794	800	37,200	1,185	55,123	1	0	800	0	600	195	30	1
600	0	5,761	800	45,199	1,185	66,976	1	0	800	0	568	259	30	0
700	0	5,733	799	53,194	1,184	78,823	1	1	800	0	541	332	30	0
800	0	5,710	796	61,170	1,179	90,641	1	4	800	1	521	411	29	0
900	0	5,692	788	69,092	1,168	102,380	1	12	800	2	506	494	28	0
1,000	0	5,679	774	76,908	1,148	113,961	1	26	800	3	495	576	27	0
1,100	0	5,670	756	84,561	1,120	125,302	1	44	800	6	487	655	26	0
1,200	0	5,665	734	92,009	1,087	136,338	1	66	800	8	482	727	24	0
1,300	0	5,663	711	99,158	1,053	146,932	1	89	800	11	481	792	24	0
1,400	0	5,664	689	106,153	1,020	157,296	1	111	800	14	482	848	26	0
1,500	0	5,667	668	112,933	990	167,342	1	132	800	17	486	895	26	0
1,600	0	5,672	650	119,519	963	177,102	1	150	800	19	492	933	27	0
1,700	0	5,678	634	125,937	940	186,612	1	166	800	21	498	962	27	0
1,800	0	5,685	621	132,212	921	195,911	1	179	800	22	506	983	27	0
1,900	1	5,691	611	138,369	905	205,034	1	189	800	24	513	998	27	0
2,000	1	5,698	602	144,429	892	214,014	1	198	800	25	520	1,007	27	0
2,100	1	5,705	595	150,413	882	222,879	1	205	800	26	526	1,011	26	0
2,200	1	5,711	590	156,335	874	231,655	1	210	800	26	530	1,010	26	0
2,300	1	5,717	586	162,211	868	240,362	1	214	800	27	534	1,007	26	0
2,400	1	5,722	582	168,050	863	249,015	1	218	800	27	537	1,002	26	0

2,500	1	5,727	580	173,862	860	257,627	1	220	800	27	538	995	17	0
2,600	1	5,732	578	179,654	857	266,209	1	222	800	28	541	990	17	0
2,700	1	5,736	577	185,430	855	274,767	1	223	800	28	544	984	17	0
2,800	1	5,739	576	191,193	853	283,307	1	224	800	28	545	978	17	0
2,900	1	5,743	575	196,946	852	291,833	1	225	800	28	545	970	17	0
3,000	1	5,746	574	202,691	851	300,345	1	226	800	28	545	963	17	0
3,100	1	5,748	573	208,428	850	308,846	1	227	800	28	544	955	17	0
3,200	1	5,751	573	214,158	848	317,336	1	227	800	28	542	947	17	0
3,300	1	5,753	572	219,880	847	325,815	1	228	800	29	540	940	17	0
3,400	1	5,755	571	225,593	846	334,280	1	229	800	29	539	934	17	0
3,500	1	5,757	570	231,296	844	342,732	1	230	800	29	537	929	17	0
3,600	1	5,759	569	236,989	843	351,168	1	231	800	29	536	924	17	0
3,700	1	5,760	567	242,670	841	359,586	1	233	800	29	534	919	17	0
3,800	1	5,762	566	248,339	839	367,985	1	234	800	29	531	914	17	0
3,900	1	5,764	565	253,993	837	376,363	1	235	800	29	529	910	17	0
4,000	1	5,765	563	259,632	834	384,719	1	237	800	30	527	905	17	0
4,100	1	5,767	561	265,254	832	393,050	1	239	800	30	524	901	17	0
4,200	1	5,768	560	270,860	829	401,357	1	240	800	30	522	898	17	0
4,300	1	5,770	558	276,448	827	409,637	1	242	800	30	521	895	17	0
4,400	1	5,772	556	282,018	824	417,890	1	244	800	30	519	892	17	0
4,500	1	5,773	554	287,569	821	426,116	1	246	800	31	517	888	17	0
4,600	1	5,775	552	293,101	818	434,313	1	248	800	31	515	885	17	0
4,700	1	5,776	550	298,613	815	442,481	1	250	800	31	513	882	17	0
4,800	1	5,778	548	304,106	812	450,620	1	252	800	31	511	878	17	0
4,900	1	5,779	546	309,578	810	458,729	1	254	800	32	509	875	17	0
5,000	1	5,781	544	315,031	807	466,809	1	256	800	32	507	872	17	0
5,100	1	5,782	542	320,464	804	474,860	1	258	800	32	506	869	17	0
5,200	1	5,784	540	325,878	801	482,881	1	260	800	32	504	866	17	0
5,300	1	5,785	538	331,271	798	490,873	1	262	800	33	502	863	16	0
5,400	1	5,787	536	336,644	795	498,835	1	264	800	33	500	859	16	0
5,500	2	5,788	534	341,998	792	506,768	1	266	800	33	499	856	16	0
5,600	2	5,790	532	347,332	789	514,672	1	268	800	33	497	853	16	0
5,700	2	5,791	530	352,646	786	522,547	1	270	800	34	496	850	16	0

5,800	2	5,792	529	357,941	783	530,393	1	271	800	34	494	847	16	0
5,900	2	5,794	527	363,217	780	538,210	1	273	800	34	493	844	16	0
6,000	2	5,795	525	368,473	777	545,999	1	275	800	34	491	841	16	0
6,100	2	5,797	523	373,711	775	553,760	1	277	800	35	490	838	16	0
6,200	2	5,798	521	378,929	772	561,493	1	279	800	35	488	835	16	0
6,300	2	5,799	519	384,129	769	569,197	1	281	800	35	486	831	16	0
6,400	2	5,800	517	389,310	766	576,874	1	283	800	35	485	828	16	0
6,500	2	5,802	515	394,472	764	584,524	1	285	800	36	483	825	16	0
6,600	2	5,803	513	399,616	761	592,146	1	287	800	36	481	822	16	0
6,700	2	5,804	512	404,741	758	599,740	1	288	800	36	480	818	16	0
6,800	2	5,805	510	409,848	755	607,308	1	290	800	36	478	815	16	0
6,900	2	5,806	508	414,937	753	614,848	1	292	800	37	476	812	16	0
7,000	2	5,808	506	420,007	750	622,361	1	294	800	37	474	808	16	0
7,100	2	5,809	504	425,059	747	629,847	1	296	800	37	472	805	16	0
7,200	2	5,810	502	430,092	745	637,305	1	298	800	37	471	802	16	0
7,300	2	5,811	501	435,108	742	644,737	1	299	800	37	469	799	16	0
7,400	2	5,812	499	440,105	739	652,142	1	301	800	38	467	796	16	0
7,500	2	5,813	497	445,085	737	659,521	1	303	800	38	466	793	16	0
7,600	2	5,814	495	450,046	734	666,872	1	305	800	38	464	790	16	0
7,700	2	5,815	493	454,989	731	674,197	1	307	800	38	462	787	16	0
7,800	2	5,816	492	459,915	729	681,495	1	308	800	39	461	784	16	0
7,900	2	5,817	490	464,822	726	688,767	1	310	800	39	459	780	16	0
8,000	2	5,818	488	469,712	723	696,013	1	312	800	39	457	777	16	0
8,100	2	5,819	486	474,584	721	703,232	1	314	800	39	455	774	16	0
8,200	2	5,820	485	479,438	718	710,425	1	315	800	39	454	771	16	0
8,300	2	5,821	483	484,275	715	717,592	1	317	800	40	452	768	16	0
8,400	2	5,822	481	489,094	713	724,733	1	319	800	40	450	765	16	0
8,500	2	5,823	479	493,895	710	731,848	1	321	800	40	448	762	16	0
8,600	2	5,824	478	498,679	708	738,937	1	322	800	40	447	759	16	0
8,700	2	5,825	476	503,446	705	746,000	1	324	800	41	445	756	16	0
8,800	2	5,826	474	508,196	703	753,038	1	326	800	41	443	753	16	0
8,900	2	5,827	472	512,928	700	760,051	1	328	800	41	442	750	16	0
9,000	2	5,828	471	517,644	697	767,038	1	329	800	41	440	747	16	0

9,100	2	5,829	469	522,342	695	773,999	1	331	800	41	438	745	16	0
9,200	3	5,830	467	527,023	692	780,936	1	333	800	42	437	742	16	0
9,300	3	5,831	466	531,688	690	787,848	1	334	800	42	435	739	16	0
9,400	3	5,832	464	536,335	687	794,735	1	336	800	42	433	736	16	0
9,500	3	5,833	462	540,966	685	801,597	1	338	800	42	432	733	15	0
9,600	3	5,834	461	545,581	683	808,435	1	339	800	42	430	730	15	0
9,700	3	5,835	459	550,179	680	815,248	1	341	800	43	428	727	15	0
9,800	3	5,836	457	554,760	678	822,037	1	343	800	43	427	724	15	0
9,900	3	5,837	456	559,325	675	828,801	1	344	800	43	425	721	15	0
10,000	3	5,838	454	563,874	673	835,542	1	346	800	43	423	718	15	0
10,100	3	5,838	452	568,407	670	842,258	1	348	800	43	422	715	15	0
10,200	3	5,839	451	572,923	668	848,951	1	349	800	44	420	713	15	0
10,300	3	5,840	449	577,424	666	855,620	1	351	800	44	419	710	15	0
10,400	3	5,841	448	581,909	663	862,266	1	352	800	44	417	707	15	0
10,500	3	5,842	446	586,378	661	868,888	1	354	800	44	415	704	15	0
10,600	3	5,843	445	590,832	659	875,487	1	355	800	44	414	702	15	0
10,700	3	5,844	443	595,269	656	882,062	1	357	800	45	412	699	15	0
10,800	3	5,844	441	599,691	654	888,615	1	359	800	45	411	696	15	0
10,900	3	5,845	440	604,098	652	895,145	1	360	800	45	409	693	15	0
11,000	3	5,846	438	608,445	650	901,587	1	362	800	45	408	691	15	0
11,100	3	5,847	437	612,822	647	908,072	1	363	800	45	406	688	15	0
11,200	3	5,848	435	617,183	645	914,534	1	365	800	46	404	685	15	0
11,300	3	5,849	434	621,529	643	920,975	1	366	800	46	403	682	15	0
11,400	3	5,849	432	625,861	641	927,392	1	368	800	46	401	680	15	0
11,500	3	5,850	431	630,177	638	933,788	1	369	800	46	400	677	15	0
11,600	3	5,851	429	634,478	636	940,162	1	371	800	46	398	675	15	0
11,700	3	5,852	428	638,765	634	946,514	1	372	800	47	397	672	15	0
11,800	3	5,853	427	643,037	632	952,845	1	373	800	47	396	670	15	0
11,900	3	5,853	425	647,295	630	959,154	1	375	800	47	394	667	15	0
12,000	3	5,854	424	651,539	628	965,443	1	376	800	47	393	664	15	0
12,100	3	5,855	422	655,769	626	971,710	1	378	800	47	391	662	15	0
12,200	3	5,856	421	659,984	624	977,956	1	379	800	47	390	659	15	0
12,300	3	5,856	419	664,185	621	984,181	1	381	800	48	388	657	15	0

12,400	3	5,857	418	668,372	619	990,385	1	382	800	48	387	654	15	0
12,500	3	5,858	417	672,545	617	996,568	1	383	800	48	385	652	15	0
12,600	3	5,859	415	676,704	615	1,002,732	1	385	800	48	384	649	15	0
12,700	3	5,859	414	680,850	613	1,008,875	1	386	800	48	382	647	15	0
12,800	4	5,860	413	684,983	611	1,014,999	1	387	800	48	381	644	15	0
12,900	4	5,861	411	689,061	609	1,021,041	1	389	800	49	380	642	15	0
13,000	4	5,862	410	693,166	607	1,027,125	1	390	800	49	378	639	15	0
13,100	4	5,862	409	697,259	605	1,033,189	1	391	800	49	377	637	15	0
13,200	4	5,863	407	701,338	603	1,039,233	1	393	800	49	376	635	15	0
13,300	4	5,864	406	705,404	602	1,045,258	1	394	800	49	374	633	15	0
13,400	4	5,864	405	709,457	600	1,051,264	1	395	800	49	373	630	15	0
13,500	4	5,865	403	713,497	598	1,057,251	1	397	800	50	372	628	15	0
13,600	4	5,866	402	717,525	596	1,063,220	1	398	800	50	370	626	15	0
13,700	4	5,866	401	721,541	594	1,069,170	1	399	800	50	369	623	15	0
13,800	4	5,867	400	725,544	592	1,075,101	1	400	800	50	368	621	15	0
13,900	4	5,868	398	729,534	590	1,081,014	1	402	800	50	366	619	15	0
14,000	4	5,869	397	733,512	588	1,086,908	1	403	800	50	365	616	20	0
14,100	4	5,869	396	737,477	587	1,092,783	1	404	800	51	363	614	20	0
14,200	4	5,870	395	741,429	585	1,098,640	1	405	800	51	362	612	20	0
14,300	4	5,871	394	745,370	583	1,104,480	1	407	800	51	361	610	20	0
14,400	4	5,871	392	749,299	581	1,110,302	1	408	800	51	360	608	20	0
14,500	4	5,872	391	753,216	580	1,116,107	1	409	800	51	358	605	20	0
14,600	4	5,872	390	757,122	578	1,121,894	1	410	800	51	357	603	14	0
14,700	4	5,873	389	760,978	576	1,127,607	1	411	800	51	356	601	14	0
14,800	4	5,874	388	764,860	574	1,133,360	1	412	800	52	355	599	14	0
14,900	4	5,874	387	768,731	573	1,139,096	1	413	800	52	354	597	14	0
15,000	4	5,875	385	772,590	571	1,144,814	1	415	800	52	352	595	14	0
15,100	4	5,876	384	776,438	569	1,150,516	1	416	800	52	351	593	14	0
15,200	4	5,876	383	780,273	568	1,156,199	1	417	800	52	350	590	14	0
15,300	4	5,877	382	784,097	566	1,161,866	1	418	800	52	349	588	14	0
15,400	4	5,878	381	787,910	564	1,167,515	1	419	800	52	347	586	14	0
15,500	4	5,878	379	791,710	562	1,173,147	1	421	800	53	346	584	14	0
15,600	4	5,879	378	795,499	561	1,178,761	1	422	800	53	345	582	14	0

15,700	4	5,879	377	799,276	559	1,184,358	1	423	800	53	344	580	14	0
15,800	4	5,880	376	803,042	557	1,189,937	1	424	800	53	342	578	14	0
15,900	4	5,881	375	806,795	555	1,195,499	1	425	800	53	341	576	14	0
16,000	4	5,881	374	810,537	554	1,201,044	1	426	800	53	340	573	14	0
16,100	4	5,882	372	814,267	552	1,206,571	1	428	800	53	339	571	14	0
16,200	4	5,882	371	817,985	550	1,212,080	1	429	800	54	337	569	14	0
16,300	4	5,883	370	821,691	548	1,217,572	1	430	800	54	336	567	14	0
16,400	4	5,884	369	825,386	547	1,223,047	1	431	800	54	335	565	14	0
16,500	5	5,884	368	829,032	545	1,228,449	1	432	800	54	334	563	14	0
16,600	5	5,885	367	832,703	543	1,233,889	1	433	800	54	332	561	14	0
16,700	5	5,885	365	836,362	541	1,239,311	1	435	800	54	331	559	14	0
16,800	5	5,886	364	840,010	540	1,244,716	1	436	800	54	330	556	14	0
16,900	5	5,886	363	843,646	538	1,250,104	1	437	800	55	329	554	14	0
17,000	5	5,887	362	847,270	536	1,255,474	1	438	800	55	327	552	14	0
17,100	5	5,888	361	850,882	534	1,260,826	1	439	800	55	326	550	14	0
17,200	5	5,888	359	854,482	533	1,266,161	1	441	800	55	325	548	14	0
17,300	5	5,889	358	858,071	531	1,271,479	1	442	800	55	324	546	14	0
17,400	5	5,889	357	861,648	529	1,276,779	1	443	800	55	323	544	14	0
17,500	5	5,890	356	865,213	527	1,282,062	1	444	800	56	321	542	14	0
17,600	5	5,890	355	868,766	526	1,287,327	1	445	800	56	320	540	14	0
17,700	5	5,891	354	872,308	524	1,292,575	1	446	800	56	319	538	14	0
17,800	5	5,892	352	875,837	522	1,297,805	1	448	800	56	318	536	14	0
17,900	5	5,892	351	879,355	520	1,303,018	1	449	800	56	316	533	14	0
18,000	5	5,893	350	882,862	519	1,308,213	1	450	800	56	315	531	20	0
18,100	5	5,893	349	886,356	517	1,313,392	1	451	800	56	314	529	20	0
18,200	5	5,894	348	889,839	515	1,318,552	1	452	800	57	313	527	20	0
18,300	5	5,894	347	893,276	514	1,323,645	1	453	800	57	311	525	20	0
18,400	5	5,895	345	896,735	512	1,328,771	1	455	800	57	310	523	20	0
18,500	5	5,895	344	900,183	510	1,333,879	1	456	800	57	309	521	20	0
18,600	5	5,896	343	903,619	508	1,338,971	1	457	800	57	308	519	20	0
18,700	5	5,896	342	907,043	507	1,344,045	1	458	800	57	307	517	20	0
18,800	5	5,897	341	910,455	505	1,349,101	1	459	800	57	305	515	20	0
18,900	5	5,897	339	913,856	503	1,354,140	1	461	800	58	304	513	20	0

19,000	5	5,898	338	917,245	501	1,359,162	1	462	800	58	303	511	20	0
19,100	5	5,899	337	920,622	500	1,364,167	1	463	800	58	302	509	20	0
19,200	5	5,899	336	923,988	498	1,369,154	1	464	800	58	301	507	20	0
19,300	5	5,900	335	927,342	496	1,374,124	1	465	800	58	299	504	20	0
19,400	5	5,900	334	930,684	494	1,379,076	1	466	800	58	298	502	20	0
19,500	5	5,901	333	934,015	493	1,384,012	1	468	800	58	297	500	20	0
19,600	5	5,901	331	937,334	491	1,388,930	1	469	800	59	296	498	20	0
19,700	5	5,902	330	940,642	489	1,393,831	1	470	800	59	294	496	20	0
19,800	5	5,902	329	943,938	488	1,398,715	1	471	800	59	293	494	20	0
19,900	5	5,903	328	947,222	486	1,403,581	1	472	800	59	292	492	20	0
20,000	5	5,903	327	950,494	484	1,408,430	1	473	800	59	291	490	20	0
20,100	5	5,904	326	953,755	482	1,413,262	1	474	800	59	290	488	20	0
20,200	6	5,904	324	956,972	481	1,418,029	1	476	800	59	289	486	20	0
20,300	6	5,905	323	960,210	479	1,422,827	1	477	800	60	287	484	20	0
20,400	6	5,905	322	963,436	477	1,427,607	1	478	800	60	286	482	19	0
20,500	6	5,905	321	966,651	476	1,432,371	1	479	800	60	285	480	19	0
20,600	6	5,906	320	969,854	474	1,437,117	1	480	800	60	284	478	13	0
20,700	6	5,906	319	973,046	472	1,441,847	1	481	800	60	283	476	13	0
20,800	6	5,907	317	976,226	470	1,446,559	1	483	800	60	281	474	13	0
20,900	6	5,907	316	979,395	469	1,451,255	1	484	800	60	280	472	13	0
21,000	6	5,908	315	982,552	467	1,455,933	1	485	800	61	279	470	13	0
21,100	6	5,908	314	985,698	465	1,460,595	1	486	800	61	278	468	13	0
21,200	6	5,909	313	988,832	464	1,465,239	1	487	800	61	277	466	13	0
21,300	6	5,909	312	991,955	462	1,469,867	1	488	800	61	275	464	13	0
21,400	6	5,910	311	995,066	460	1,474,477	1	489	800	61	274	462	13	0
21,500	6	5,910	309	998,166	459	1,479,070	1	491	800	61	273	460	13	0
21,600	6	5,911	308	1,001,255	457	1,483,647	1	492	800	61	272	458	13	0
21,700	6	5,911	307	1,004,332	455	1,488,207	1	493	800	62	271	456	13	0
21,800	6	5,912	306	1,007,398	453	1,492,749	1	494	800	62	270	454	13	0
21,900	6	5,912	305	1,010,452	452	1,497,275	1	495	800	62	268	452	13	0
22,000	6	5,912	304	1,013,465	450	1,501,740	1	496	800	62	267	450	13	0
22,100	6	5,913	303	1,016,497	448	1,506,232	1	497	800	62	266	448	13	0
22,200	6	5,913	302	1,019,518	447	1,510,708	1	498	800	62	265	446	13	0

22,300	6	5,914	300	1,022,527	445	1,515,167	1	500	800	62	264	444	13	0
22,400	6	5,914	299	1,025,525	443	1,519,610	1	501	800	63	263	442	13	0
22,500	6	5,915	298	1,028,512	442	1,524,035	1	502	800	63	261	440	13	0
22,600	6	5,915	297	1,031,487	440	1,528,444	1	503	800	63	260	438	13	0
22,700	6	5,916	296	1,034,451	438	1,532,836	1	504	800	63	259	436	13	0
22,800	6	5,916	295	1,037,404	437	1,537,212	1	505	800	63	258	434	13	0
22,900	6	5,916	294	1,040,345	435	1,541,570	1	506	800	63	257	432	13	0
23,000	6	5,917	292	1,043,275	433	1,545,912	1	508	800	63	256	430	13	0
23,100	6	5,917	291	1,046,195	432	1,550,238	1	509	800	64	255	428	13	0
23,200	6	5,918	290	1,049,103	430	1,554,547	1	510	800	64	253	426	13	0
23,300	6	5,918	289	1,052,000	428	1,558,840	1	511	800	64	252	424	13	0
23,400	6	5,918	288	1,054,885	427	1,563,116	1	512	800	64	251	422	13	0
23,500	6	5,919	287	1,057,760	425	1,567,376	1	513	800	64	250	421	13	0
23,600	6	5,919	286	1,060,624	424	1,571,619	1	514	800	64	249	419	13	0
23,700	6	5,920	285	1,063,476	422	1,575,846	1	515	800	64	248	417	13	0
23,800	7	5,920	284	1,066,289	420	1,580,014	1	516	800	65	247	415	13	0
23,900	7	5,921	282	1,069,120	419	1,584,208	1	518	800	65	245	413	13	0
24,000	7	5,921	281	1,071,939	417	1,588,386	1	519	800	65	244	411	13	0
24,100	7	5,921	280	1,074,747	415	1,592,547	1	520	800	65	243	409	13	0
24,200	7	5,922	279	1,077,544	414	1,596,692	1	521	800	65	242	407	19	0
24,300	7	5,922	278	1,080,331	412	1,600,821	1	522	800	65	241	405	19	0
24,400	7	5,922	277	1,083,106	410	1,604,933	1	523	800	65	240	403	19	0
24,500	7	5,923	276	1,085,871	409	1,609,029	1	524	800	66	239	402	19	0
24,600	7	5,923	275	1,088,624	407	1,613,110	1	525	800	66	238	400	19	0
24,700	7	5,924	274	1,091,367	406	1,617,174	1	526	800	66	236	398	19	0
24,800	7	5,924	273	1,094,099	404	1,621,222	1	527	800	66	235	396	19	0
24,900	7	5,924	272	1,096,820	402	1,625,254	1	528	800	66	234	394	19	0
25,000	7	5,925	270	1,099,530	401	1,629,270	1	530	800	66	233	392	19	0
25,100	7	5,925	269	1,102,229	399	1,633,270	1	531	800	66	232	390	19	0
25,200	7	5,926	268	1,104,918	398	1,637,253	1	532	800	66	231	388	19	0
25,300	7	5,926	267	1,107,596	396	1,641,221	1	533	800	67	230	387	19	0
25,400	7	5,926	266	1,110,262	394	1,645,173	1	534	800	67	229	385	19	0
25,500	7	5,927	265	1,112,918	393	1,649,108	1	535	800	67	228	383	19	0

25,600	7	5,927	264	1,115,537	391	1,652,989	1	536	800	67	227	381	19	0
25,700	7	5,927	263	1,118,172	390	1,656,893	1	537	800	67	225	379	19	0
25,800	7	5,928	262	1,120,796	388	1,660,781	1	538	800	67	224	377	19	0
25,900	7	5,928	261	1,123,409	386	1,664,654	1	539	800	67	223	376	19	0
26,000	7	5,929	260	1,126,012	385	1,668,511	1	540	800	68	222	374	19	0
26,100	7	5,929	259	1,128,605	383	1,672,352	1	541	800	68	221	372	19	0
26,200	7	5,929	258	1,131,186	382	1,676,178	1	542	800	68	220	370	19	0
26,300	7	5,930	257	1,133,758	380	1,679,988	1	543	800	68	219	368	19	0
26,400	7	5,930	256	1,136,319	379	1,683,782	1	544	800	68	218	367	19	0
26,500	7	5,930	255	1,138,869	377	1,687,561	1	545	800	68	217	365	19	0
26,600	7	5,931	253	1,141,409	376	1,691,325	1	547	800	68	216	363	19	0
26,700	7	5,931	252	1,143,938	374	1,695,073	1	548	800	68	215	361	19	0
26,800	7	5,931	251	1,146,456	372	1,698,805	1	549	800	69	214	359	19	0
26,900	7	5,932	250	1,148,965	371	1,702,521	1	550	800	69	213	358	19	0
27,000	7	5,932	249	1,151,462	369	1,706,222	1	551	800	69	212	356	19	0
27,100	7	5,932	248	1,153,949	368	1,709,908	1	552	800	69	211	354	19	0
27,200	7	5,933	247	1,156,426	366	1,713,578	1	553	800	69	209	352	19	0
27,300	7	5,933	246	1,158,892	365	1,717,232	1	554	800	69	208	350	19	0
27,400	7	5,933	245	1,161,348	363	1,720,871	1	555	800	69	207	349	19	0
27,500	8	5,934	244	1,163,769	362	1,724,458	1	556	800	70	206	347	19	0
27,600	8	5,934	243	1,166,203	360	1,728,066	1	557	800	70	205	345	19	0
27,700	8	5,934	242	1,168,628	358	1,731,658	1	558	800	70	204	343	19	0
27,800	8	5,935	241	1,171,042	357	1,735,235	1	559	800	70	203	341	19	0
27,900	8	5,935	240	1,173,445	355	1,738,796	1	560	800	70	202	340	19	0
28,000	8	5,935	239	1,175,838	354	1,742,342	1	561	800	70	201	338	19	0
28,100	8	5,936	238	1,178,220	352	1,745,872	1	562	800	70	200	336	19	0
28,200	8	5,936	237	1,180,592	351	1,749,387	1	563	800	70	199	334	19	0
28,300	8	5,936	236	1,182,954	349	1,752,886	1	564	800	71	198	333	19	0
28,400	8	5,937	235	1,185,305	348	1,756,370	1	565	800	71	197	331	19	0
28,500	8	5,937	234	1,187,646	346	1,759,838	1	566	800	71	196	329	12	0
28,600	8	5,937	233	1,189,976	345	1,763,291	1	567	800	71	195	327	12	0
28,700	8	5,938	231	1,192,296	343	1,766,729	1	569	800	71	194	326	12	0
28,800	8	5,938	230	1,194,605	341	1,770,151	1	570	800	71	193	324	12	0

28,900	8	5,938	229	1,196,904	340	1,773,558	1	571	800	71	192	322	12	0
29,000	8	5,939	228	1,199,193	338	1,776,949	1	572	800	71	191	320	12	0
29,100	8	5,939	227	1,201,472	337	1,780,325	1	573	800	72	190	319	12	0
29,200	8	5,939	226	1,203,740	335	1,783,686	1	574	800	72	189	317	12	0
29,300	8	5,939	225	1,205,975	334	1,786,998	1	575	800	72	188	315	12	0
29,400	8	5,940	224	1,208,222	332	1,790,328	1	576	800	72	187	313	12	0
29,500	8	5,940	223	1,210,459	331	1,793,643	1	577	800	72	185	312	12	0
29,600	8	5,940	222	1,212,686	329	1,796,943	1	578	800	72	184	310	12	0
29,700	8	5,941	221	1,214,903	328	1,800,227	1	579	800	72	183	308	12	0
29,800	8	5,941	220	1,217,109	326	1,803,496	1	580	800	72	182	307	12	0
29,900	8	5,941	219	1,219,305	325	1,806,750	1	581	800	73	181	305	12	0
30,000	8	5,942	218	1,221,490	323	1,809,989	1	582	800	73	180	303	12	0
30,100	8	5,942	217	1,223,665	322	1,813,212	1	583	800	73	179	301	12	0
30,200	8	5,942	216	1,225,830	320	1,816,420	1	584	800	73	178	300	12	0
30,300	8	5,942	215	1,227,985	319	1,819,613	1	585	800	73	177	298	12	0
30,400	8	5,943	214	1,230,130	317	1,822,791	1	586	800	73	176	296	12	0
30,500	8	5,943	213	1,232,264	316	1,825,953	1	587	800	73	175	295	12	0
30,600	8	5,943	212	1,234,388	314	1,829,101	1	588	800	74	174	293	12	0
30,700	8	5,944	211	1,236,502	312	1,832,233	1	589	800	74	173	291	12	0
30,800	8	5,944	210	1,238,605	311	1,835,350	1	590	800	74	172	290	12	0
30,900	8	5,944	209	1,240,699	309	1,838,452	1	591	800	74	171	288	12	0
31,000	8	5,944	208	1,242,782	308	1,841,539	1	592	800	74	170	286	12	0
31,100	9	5,945	207	1,244,835	306	1,844,580	1	593	800	74	169	284	12	0
31,200	9	5,945	206	1,246,898	305	1,847,637	1	594	800	74	168	283	12	0
31,300	9	5,945	205	1,248,950	303	1,850,679	1	595	800	74	167	281	12	0
31,400	9	5,946	204	1,250,993	302	1,853,706	1	596	800	75	166	279	12	0
31,500	9	5,946	203	1,253,026	300	1,856,718	1	597	800	75	165	278	12	0
31,600	9	5,946	202	1,255,048	299	1,859,715	1	598	800	75	164	276	12	0
31,700	9	5,946	201	1,257,061	297	1,862,696	1	599	800	75	163	274	12	0
31,800	9	5,947	200	1,259,063	296	1,865,663	1	600	800	75	162	273	12	0
31,900	9	5,947	199	1,261,055	294	1,868,615	1	601	800	75	161	271	12	0
32,000	9	5,947	198	1,263,037	293	1,871,553	1	602	800	75	160	270	12	0
32,100	9	5,947	197	1,265,009	291	1,874,475	1	603	800	75	159	268	12	0

32,200	9	5,948	196	1,266,971	290	1,877,382	1	604	800	76	158	266	12	0
32,300	9	5,948	195	1,268,924	289	1,880,275	1	605	800	76	157	265	12	0
32,400	9	5,948	194	1,270,866	287	1,883,153	1	606	800	76	156	263	12	0
32,500	9	5,948	193	1,272,798	286	1,886,016	1	607	800	76	155	261	12	0
32,600	9	5,949	192	1,274,720	284	1,888,864	1	608	800	76	155	260	12	0
32,700	9	5,949	191	1,276,632	283	1,891,697	1	609	800	76	154	258	12	0
32,800	9	5,949	190	1,278,534	281	1,894,516	1	610	800	76	153	256	12	0
32,900	9	5,949	189	1,280,408	280	1,897,292	1	611	800	76	152	255	12	0
33,000	9	5,950	188	1,282,290	278	1,900,081	1	612	800	77	151	253	12	0
33,100	9	5,950	187	1,284,163	277	1,902,856	1	613	800	77	150	252	12	0
33,200	9	5,950	186	1,286,025	275	1,905,616	1	614	800	77	149	250	12	0
33,300	9	5,950	185	1,287,878	274	1,908,362	1	615	800	77	148	248	18	0
33,400	9	5,951	184	1,289,721	272	1,911,093	1	616	800	77	147	247	18	0
33,500	9	5,951	183	1,291,554	271	1,913,809	1	617	800	77	146	245	18	0
33,600	9	5,951	182	1,293,378	269	1,916,511	1	618	800	77	145	244	18	0
33,700	9	5,951	181	1,295,191	268	1,919,198	1	619	800	77	144	242	18	0
33,800	9	5,952	180	1,296,995	267	1,921,871	1	620	800	78	143	240	18	0
33,900	9	5,952	179	1,298,789	265	1,924,529	1	621	800	78	142	239	18	0
34,000	9	5,952	178	1,300,573	264	1,927,173	1	622	800	78	141	237	18	0
34,100	9	5,952	177	1,302,347	262	1,929,802	1	623	800	78	140	236	18	0
34,200	9	5,953	176	1,304,112	261	1,932,417	1	624	800	78	139	234	18	0
34,300	9	5,953	175	1,305,867	259	1,935,017	1	625	800	78	138	233	18	0
34,400	9	5,953	174	1,307,612	258	1,937,604	1	626	800	78	137	231	18	0
34,500	9	5,953	173	1,309,348	256	1,940,176	1	627	800	78	137	230	18	0
34,600	9	5,953	172	1,311,074	255	1,942,733	1	628	800	78	136	228	18	0
34,700	9	5,954	171	1,312,791	254	1,945,276	1	629	800	79	135	226	18	0
34,800	10	5,954	170	1,314,480	252	1,947,780	1	630	800	79	134	225	18	0
34,900	10	5,954	169	1,316,178	251	1,950,295	1	631	800	79	133	223	18	0
35,000	10	5,954	168	1,317,865	249	1,952,796	1	632	800	79	132	222	18	0
35,100	10	5,955	167	1,319,543	248	1,955,283	1	633	800	79	131	220	18	0
35,200	10	5,955	166	1,321,212	247	1,957,755	1	634	800	79	130	219	18	0
35,300	10	5,955	165	1,322,871	245	1,960,214	1	635	800	79	129	217	18	0
35,400	10	5,955	164	1,324,521	244	1,962,658	1	636	800	79	128	216	17	0

35,500	10	5,955	164	1,326,161	242	1,965,089	1	636	800	80	128	214	17	0
35,600	10	5,956	163	1,327,792	241	1,967,505	1	637	800	80	127	213	17	0
35,700	10	5,956	162	1,329,413	240	1,969,908	1	638	800	80	126	211	17	0
35,800	10	5,956	161	1,331,025	238	1,972,296	1	639	800	80	125	210	17	0
35,900	10	5,956	160	1,332,628	237	1,974,671	1	640	800	80	124	209	17	0
36,000	10	5,957	159	1,334,221	235	1,977,032	1	641	800	80	123	207	17	0
36,100	10	5,957	158	1,335,805	234	1,979,379	1	642	800	80	122	206	17	0
36,200	10	5,957	157	1,337,379	233	1,981,712	1	643	800	80	121	204	17	0
36,300	10	5,957	156	1,338,945	231	1,984,031	1	644	800	80	121	203	17	0
36,400	10	5,957	155	1,340,500	230	1,986,337	1	645	800	81	120	201	17	0
36,500	10	5,958	154	1,342,047	229	1,988,629	1	646	800	81	119	200	17	0

APPENDIX C

BOAST NFR DATA OUTPUT WITH SIMULATED REDUCED OIL VISCOSITY

APPENDIX C

(BOAST NFR data output with simulated reduced oil viscosity)

N	Time	P ave	Qo	Np	Qg	Gp	GOR	Qw	Qo+Qw	WaterCut	Qomt	Qwmt	niter	DPmax
T.S	years	psi	STB/D	Bbl	MSCF/D	MSCF	MSCF/B	STB/D	STB	%	STB/D	STB/D	#	psi
1	0	5,999	800	0	1,185	0	1	0	800	0	145	0	25	0
100	0	5,980	800	5,200	1,185	7,705	1	0	800	0	482	83	113	1
200	0	5,951	800	13,200	1,185	19,560	1	0	800	0	472	184	105	0
300	0	5,928	800	21,200	1,185	31,414	1	0	800	0	443	292	101	0
400	0	5,911	800	29,200	1,185	43,268	1	0	800	0	435	403	97	0
500	0	5,899	800	37,200	1,185	55,123	1	0	800	0	443	509	93	0
600	0	5,890	800	45,200	1,185	66,977	1	0	800	0	461	607	88	0
700	0	5,885	800	53,200	1,185	78,831	1	0	800	0	484	694	83	0
800	0	5,881	800	61,200	1,185	90,685	1	0	800	0	509	771	77	0
900	0	5,879	800	69,200	1,185	102,539	1	0	800	0	533	836	71	0
1,000	0	5,877	800	77,199	1,185	114,392	1	0	800	0	556	892	64	0
1,100	0	5,876	800	85,196	1,185	126,242	1	0	800	0	576	938	53	0
1,200	0	5,876	799	93,190	1,184	138,087	1	1	800	0	594	976	38	0
1,300	0	5,876	798	101,097	1,183	149,805	1	2	800	0	608	1,007	42	0
1,400	0	5,876	797	109,075	1,182	161,632	1	3	800	0	621	1,032	51	0
1,500	0	5,877	796	117,039	1,180	173,441	1	4	800	1	631	1,052	55	0
1,600	0	5,877	794	124,986	1,177	185,225	1	6	800	1	639	1,068	57	0
1,700	0	5,878	792	132,914	1,174	196,981	1	8	800	1	647	1,083	59	0
1,800	0	5,878	789	140,819	1,171	208,703	1	11	800	1	655	1,097	59	0
1,900	1	5,879	787	148,701	1,167	220,391	1	13	800	2	662	1,108	59	0
2,000	1	5,880	785	156,559	1,164	232,044	1	15	800	2	666	1,115	59	0
2,100	1	5,881	782	164,393	1,160	243,662	1	18	800	2	669	1,120	59	0
2,200	1	5,881	780	172,206	1,157	255,247	1	20	800	2	671	1,123	59	0
2,300	1	5,882	778	179,997	1,154	266,801	1	22	800	3	675	1,128	58	0
2,400	1	5,882	776	187,768	1,151	278,325	1	24	800	3	677	1,131	57	0

2,500	1	5,883	774	195,522	1,148	289,822	1	26	800	3	679	1,133	57	0
2,600	1	5,884	773	203,258	1,146	301,294	1	27	800	3	679	1,134	56	0
2,700	1	5,884	771	210,978	1,144	312,742	1	29	800	4	680	1,134	56	0
2,800	1	5,885	770	218,683	1,141	324,167	1	30	800	4	679	1,133	55	0
2,900	1	5,885	768	226,373	1,139	335,571	1	32	800	4	680	1,134	55	0
3,000	1	5,886	767	234,050	1,137	346,955	1	33	800	4	681	1,134	54	0
3,100	1	5,886	766	241,713	1,135	358,318	1	34	800	4	681	1,134	54	0
3,200	1	5,887	764	249,362	1,133	369,661	1	36	800	4	680	1,133	54	0
3,300	1	5,887	763	256,999	1,131	380,985	1	37	800	5	679	1,131	53	0
3,400	1	5,887	762	264,622	1,129	392,289	1	38	800	5	678	1,129	53	0
3,500	1	5,888	760	272,232	1,127	403,573	1	40	800	5	678	1,129	53	0
3,600	1	5,888	759	279,828	1,125	414,837	1	41	800	5	678	1,128	53	0
3,700	1	5,889	758	287,411	1,123	426,080	1	42	800	5	677	1,127	53	0
3,800	1	5,889	756	294,980	1,121	437,304	1	44	800	5	676	1,125	53	0
3,900	1	5,889	755	302,535	1,119	448,506	1	45	800	6	675	1,123	52	0
4,000	1	5,890	753	310,076	1,117	459,688	1	47	800	6	674	1,122	52	0
4,100	1	5,890	752	317,602	1,115	470,849	1	48	800	6	673	1,120	52	0
4,200	1	5,891	750	325,114	1,113	481,987	1	50	800	6	673	1,120	52	0
4,300	1	5,891	749	332,611	1,111	493,104	1	51	800	6	672	1,118	52	0
4,400	1	5,891	747	340,093	1,108	504,198	1	53	800	7	671	1,117	52	0
4,500	1	5,892	746	347,560	1,106	515,270	1	54	800	7	670	1,115	52	0
4,600	1	5,892	744	355,012	1,104	526,319	1	56	800	7	669	1,112	52	0
4,700	1	5,892	743	362,447	1,101	537,344	1	57	800	7	667	1,110	52	0
4,800	1	5,893	741	369,867	1,099	548,345	1	59	800	7	666	1,108	52	0
4,900	1	5,893	740	377,271	1,097	559,323	1	60	800	8	666	1,107	52	0
5,000	1	5,893	738	384,658	1,094	570,276	1	62	800	8	665	1,105	52	0
5,100	1	5,894	736	392,028	1,092	581,204	1	64	800	8	663	1,103	52	0
5,200	1	5,894	735	399,382	1,089	592,107	1	65	800	8	662	1,101	52	0
5,300	1	5,895	733	406,718	1,087	602,985	1	67	800	8	661	1,099	51	0
5,400	1	5,895	731	414,037	1,084	613,837	1	69	800	9	659	1,096	51	0
5,500	2	5,895	729	421,339	1,081	624,663	1	71	800	9	657	1,093	51	0
5,600	2	5,896	727	428,623	1,079	635,463	1	73	800	9	656	1,091	51	0
5,700	2	5,896	726	435,888	1,076	646,236	1	74	800	9	655	1,089	51	0

5,800	2	5,896	724	443,136	1,073	656,982	1	76	800	10	653	1,087	51	0
5,900	2	5,897	722	450,364	1,070	667,701	1	78	800	10	652	1,084	51	0
6,000	2	5,897	720	457,575	1,068	678,392	1	80	800	10	650	1,082	51	0
6,100	2	5,897	718	464,766	1,065	689,054	1	82	800	10	648	1,079	51	0
6,200	2	5,898	716	471,938	1,062	699,688	1	84	800	10	647	1,076	51	0
6,300	2	5,898	714	479,090	1,059	710,293	1	86	800	11	645	1,072	51	0
6,400	2	5,898	712	486,223	1,056	720,869	1	88	800	11	643	1,070	51	0
6,500	2	5,899	710	493,336	1,053	731,416	1	90	800	11	641	1,067	51	0
6,600	2	5,899	708	500,428	1,050	741,932	1	92	800	11	640	1,064	51	0
6,700	2	5,900	706	507,501	1,047	752,419	1	94	800	12	638	1,061	51	0
6,800	2	5,900	704	514,553	1,044	762,875	1	96	800	12	636	1,058	51	0
6,900	2	5,900	702	521,584	1,041	773,300	1	98	800	12	634	1,055	51	0
7,000	2	5,901	700	528,594	1,038	783,694	1	100	800	13	632	1,052	51	0
7,100	2	5,901	698	535,583	1,035	794,057	1	102	800	13	630	1,048	51	0
7,200	2	5,901	696	542,551	1,032	804,387	1	104	800	13	628	1,045	51	0
7,300	2	5,902	694	549,496	1,028	814,686	1	106	800	13	626	1,042	51	0
7,400	2	5,902	691	556,420	1,025	824,952	1	109	800	14	624	1,039	51	0
7,500	2	5,902	689	563,323	1,022	835,186	1	111	800	14	622	1,035	51	0
7,600	2	5,903	687	570,202	1,018	845,387	1	113	800	14	620	1,032	51	0
7,700	2	5,903	685	577,060	1,015	855,554	1	115	800	14	618	1,028	51	0
7,800	2	5,903	682	583,894	1,012	865,687	1	118	800	15	616	1,025	51	0
7,900	2	5,904	680	590,706	1,008	875,787	1	120	800	15	614	1,021	51	0
8,000	2	5,904	678	597,494	1,005	885,852	1	122	800	15	611	1,018	51	0
8,100	2	5,905	675	604,260	1,001	895,883	1	125	800	16	609	1,014	51	0
8,200	2	5,905	673	611,002	998	905,879	1	127	800	16	607	1,010	51	0
8,300	2	5,905	671	617,720	994	915,840	1	129	800	16	605	1,007	51	0
8,400	2	5,906	668	624,414	991	925,766	1	132	800	16	603	1,003	51	0
8,500	2	5,906	666	631,085	987	935,656	1	134	800	17	600	999	51	0
8,600	2	5,906	663	637,731	984	945,510	1	137	800	17	598	995	51	0
8,700	2	5,907	661	644,352	980	955,328	1	139	800	17	596	991	51	0
8,800	2	5,907	658	650,949	976	965,109	1	142	800	18	593	988	51	0
8,900	2	5,908	656	657,521	973	974,853	1	144	800	18	591	984	51	0
9,000	2	5,908	654	664,069	969	984,561	1	146	800	18	588	980	51	0

9,100	2	5,908	651	670,591	965	994,231	1	149	800	19	586	975	51	0
9,200	3	5,909	648	677,088	961	1,003,864	1	152	800	19	584	972	51	0
9,300	3	5,909	646	683,560	958	1,013,460	1	154	800	19	581	968	51	0
9,400	3	5,909	643	690,006	954	1,023,017	1	157	800	20	579	964	51	0
9,500	3	5,910	641	696,426	950	1,032,536	1	159	800	20	576	960	51	0
9,600	3	5,910	638	702,821	946	1,042,017	1	162	800	20	574	956	51	0
9,700	3	5,911	636	709,189	942	1,051,458	1	164	800	21	571	951	51	0
9,800	3	5,911	633	715,531	938	1,060,862	1	167	800	21	569	947	51	0
9,900	3	5,911	630	721,847	935	1,070,226	1	170	800	21	566	943	51	0
10,000	3	5,912	628	728,137	931	1,079,551	1	172	800	22	564	939	51	0
10,100	3	5,912	625	734,400	927	1,088,838	1	175	800	22	561	934	51	0
10,200	3	5,912	622	740,637	923	1,098,084	1	178	800	22	558	930	51	0
10,300	3	5,913	620	746,847	919	1,107,291	1	180	800	23	556	926	51	0
10,400	3	5,913	617	753,029	915	1,116,458	1	183	800	23	553	922	51	0
10,500	3	5,914	614	759,185	911	1,125,585	1	186	800	23	551	918	51	0
10,600	3	5,914	612	765,314	907	1,134,671	1	188	800	24	548	913	51	0
10,700	3	5,914	609	771,415	903	1,143,717	1	191	800	24	546	909	51	0
10,800	3	5,915	606	777,489	899	1,152,723	1	194	800	24	543	904	51	0
10,900	3	5,915	603	783,536	895	1,161,688	1	197	800	25	540	900	50	0
11,000	3	5,915	601	789,496	890	1,170,525	1	199	800	25	538	896	51	0
11,100	3	5,916	598	795,489	886	1,179,409	1	202	800	25	535	891	50	0
11,200	3	5,916	595	801,455	882	1,188,253	1	205	800	26	532	887	50	0
11,300	3	5,917	592	807,393	878	1,197,057	1	208	800	26	530	882	50	0
11,400	3	5,917	590	813,302	874	1,205,819	1	210	800	26	527	878	50	0
11,500	3	5,917	587	819,184	870	1,214,540	1	213	800	27	524	874	50	0
11,600	3	5,918	584	825,038	866	1,223,219	1	216	800	27	522	870	50	0
11,700	3	5,918	581	830,864	862	1,231,858	1	219	800	27	519	865	50	0
11,800	3	5,918	579	836,663	858	1,240,455	1	221	800	28	516	861	50	0
11,900	3	5,919	576	842,435	854	1,249,012	1	224	800	28	514	856	50	0
12,000	3	5,919	573	848,179	850	1,257,528	1	227	800	28	511	851	50	0
12,100	3	5,920	570	853,895	846	1,266,004	1	230	800	29	508	847	50	0
12,200	3	5,920	567	859,584	841	1,274,438	1	233	800	29	506	842	50	0
12,300	3	5,920	565	865,244	837	1,282,831	1	235	800	29	503	838	50	0

12,400	3	5,921	562	870,877	833	1,291,182	1	238	800	30	500	833	50	0
12,500	3	5,921	559	876,481	829	1,299,491	1	241	800	30	497	829	50	0
12,600	3	5,921	556	882,058	825	1,307,759	1	244	800	30	495	825	49	0
12,700	3	5,922	553	887,606	821	1,315,985	1	247	800	31	492	820	49	0
12,800	4	5,922	551	893,127	817	1,324,171	1	249	800	31	490	816	49	0
12,900	4	5,922	548	898,566	812	1,332,234	1	252	800	31	487	812	49	0
13,000	4	5,923	545	904,033	809	1,340,339	1	255	800	32	484	807	49	0
13,100	4	5,923	543	909,473	805	1,348,404	1	257	800	32	482	803	49	0
13,200	4	5,924	540	914,886	801	1,356,430	1	260	800	33	479	798	49	0
13,300	4	5,924	537	920,272	797	1,364,415	1	263	800	33	476	794	49	0
13,400	4	5,924	534	925,630	792	1,372,359	1	266	800	33	474	789	49	0
13,500	4	5,925	532	930,961	788	1,380,263	1	268	800	34	471	785	49	0
13,600	4	5,925	529	936,264	784	1,388,126	1	271	800	34	468	780	49	0
13,700	4	5,925	526	941,540	780	1,395,947	1	274	800	34	465	776	49	0
13,800	4	5,926	523	946,787	776	1,403,727	1	277	800	35	463	772	48	0
13,900	4	5,926	521	952,008	772	1,411,467	1	279	800	35	461	768	48	0
14,000	4	5,926	518	957,202	768	1,419,169	1	282	800	35	458	763	48	0
14,100	4	5,927	516	962,370	764	1,426,832	1	284	800	36	455	759	48	0
14,200	4	5,927	513	967,513	761	1,434,457	1	287	800	36	453	755	48	0
14,300	4	5,927	510	972,629	757	1,442,043	1	290	800	36	450	751	48	0
14,400	4	5,928	508	977,720	753	1,449,590	1	292	800	37	448	746	48	0
14,500	4	5,928	505	982,784	749	1,457,100	1	295	800	37	445	742	47	0
14,600	4	5,928	503	987,823	745	1,464,570	1	297	800	37	443	738	47	0
14,700	4	5,929	500	992,785	741	1,471,926	1	300	800	38	440	734	48	0
14,800	4	5,929	497	997,771	737	1,479,318	1	303	800	38	438	729	47	0
14,900	4	5,929	495	1,002,731	733	1,486,671	1	305	800	38	435	725	47	0
15,000	4	5,930	492	1,007,664	729	1,493,985	1	308	800	39	432	721	47	0
15,100	4	5,930	489	1,012,570	725	1,501,259	1	311	800	39	430	717	47	0
15,200	4	5,930	487	1,017,449	722	1,508,494	1	313	800	39	427	712	47	0
15,300	4	5,931	484	1,022,302	718	1,515,689	1	316	800	40	425	708	47	0
15,400	4	5,931	481	1,027,128	714	1,522,844	1	319	800	40	422	704	47	0
15,500	4	5,931	479	1,031,926	710	1,529,960	1	321	800	40	419	699	47	0
15,600	4	5,932	476	1,036,698	706	1,537,035	1	324	800	41	417	695	47	0

15,700	4	5,932	473	1,041,443	702	1,544,070	1	327	800	41	414	691	47	0
15,800	4	5,932	470	1,046,161	697	1,551,064	1	330	800	41	412	686	47	0
15,900	4	5,933	468	1,050,851	693	1,558,019	1	332	800	42	409	682	47	0
16,000	4	5,933	465	1,055,514	689	1,564,933	1	335	800	42	406	678	47	0
16,100	4	5,933	462	1,060,149	685	1,571,806	1	338	800	42	404	673	47	0
16,200	4	5,934	459	1,064,757	681	1,578,638	1	341	800	43	401	669	46	0
16,300	4	5,934	457	1,069,338	677	1,585,430	1	343	800	43	399	665	46	0
16,400	4	5,934	454	1,073,891	673	1,592,181	1	346	800	43	396	661	46	0
16,500	5	5,935	451	1,078,371	669	1,598,823	1	349	800	44	393	656	47	0
16,600	5	5,935	448	1,082,869	665	1,605,491	1	352	800	44	391	652	46	0
16,700	5	5,935	446	1,087,340	661	1,612,119	1	354	800	44	388	648	46	0
16,800	5	5,936	443	1,091,783	657	1,618,707	1	357	800	45	386	643	46	0
16,900	5	5,936	440	########	653	1,625,253	1	360	800	45	383	639	46	0
17,000	5	5,936	437	########	649	1,631,759	1	363	800	45	380	634	46	0
17,100	5	5,937	435	########	644	1,638,224	1	365	800	46	378	630	46	0
17,200	5	5,937	432	########	640	1,644,647	1	368	800	46	375	626	46	0
17,300	5	5,937	429	########	636	1,651,030	1	371	800	46	372	621	46	0
17,400	5	5,938	426	########	632	1,657,370	1	374	800	47	370	617	46	0
17,500	5	5,938	423	########	628	1,663,670	1	377	800	47	367	613	46	0
17,600	5	5,938	421	########	624	1,669,928	1	379	800	47	365	608	45	0
17,700	5	5,939	418	########	620	1,676,144	1	382	800	48	362	604	45	0
17,800	5	5,939	415	########	616	1,682,320	1	385	800	48	359	600	45	0
17,900	5	5,939	412	########	611	1,688,455	1	388	800	48	357	595	45	0
18,000	5	5,940	410	########	607	1,694,548	1	390	800	49	354	591	45	0
18,100	5	5,940	407	########	603	1,700,600	1	393	800	49	352	587	45	0
18,200	5	5,940	404	########	599	1,706,612	1	396	800	50	349	582	45	0
18,300	5	5,941	401	########	595	1,712,522	1	399	800	50	346	578	45	0
18,400	5	5,941	398	########	591	1,718,449	1	402	800	50	344	574	45	0
18,500	5	5,941	396	########	587	1,724,336	1	404	800	51	341	569	45	0
18,600	5	5,942	393	########	583	1,730,183	1	407	800	51	338	565	45	0
18,700	5	5,942	390	########	578	1,735,988	1	410	800	51	336	561	45	0
18,800	5	5,942	387	########	574	1,741,752	1	413	800	52	333	556	45	0
18,900	5	5,942	385	########	570	1,747,475	1	415	800	52	331	552	44	0

19,000	5	5,943	382	########	566	1,753,157	1	418	800	52	328	548	44	0
19,100	5	5,943	379	########	562	1,758,798	1	421	800	53	326	544	44	0
19,200	5	5,943	376	########	558	1,764,398	1	424	800	53	323	540	44	0
19,300	5	5,944	374	########	554	1,769,958	1	426	800	53	321	535	44	0
19,400	5	5,944	371	########	550	1,775,477	1	429	800	54	318	531	44	0
19,500	5	5,944	368	########	546	1,780,956	1	432	800	54	315	527	44	0
19,600	5	5,945	365	########	542	1,786,394	1	435	800	54	313	523	44	0
19,700	5	5,945	363	########	538	1,791,792	1	437	800	55	310	518	44	0
19,800	5	5,945	360	########	534	1,797,149	1	440	800	55	308	514	44	0
19,900	5	5,946	357	########	530	1,802,466	1	443	800	55	305	510	44	0
20,000	5	5,946	354	########	526	1,807,742	1	446	800	56	303	506	43	0
20,100	5	5,946	352	1,222,798	522	1,812,978	1	448	800	56	300	501	43	0
20,200	6	5,947	349	1,226,266	517	1,818,120	1	451	800	56	298	497	43	0
20,300	6	5,947	346	1,229,742	513	1,823,274	1	454	800	57	295	493	43	0
20,400	6	5,947	344	1,233,192	510	1,828,388	1	456	800	57	293	489	43	0
20,500	6	5,947	341	1,236,614	506	1,833,464	1	459	800	57	290	485	43	0
20,600	6	5,948	338	1,240,010	502	1,838,500	1	462	800	58	288	481	43	0
20,700	6	5,948	336	1,243,379	498	1,843,496	1	464	800	58	285	477	43	0
20,800	6	5,948	333	1,246,722	494	1,848,454	1	467	800	58	283	473	43	0
20,900	6	5,949	330	1,250,038	490	1,853,372	1	470	800	59	280	469	43	0
21,000	6	5,949	328	1,253,329	486	1,858,251	1	472	800	59	278	465	43	0
21,100	6	5,949	325	1,256,592	482	1,863,092	1	475	800	59	276	461	42	0
21,200	6	5,949	322	1,259,830	478	1,867,893	1	478	800	60	273	457	42	0
21,300	6	5,950	320	1,263,041	474	1,872,656	1	480	800	60	271	453	42	0
21,400	6	5,950	317	1,266,226	470	1,877,380	1	483	800	60	268	449	42	0
21,500	6	5,950	315	1,269,385	467	1,882,065	1	485	800	61	266	445	42	0
21,600	6	5,951	312	1,272,518	463	1,886,711	1	488	800	61	264	441	42	0
21,700	6	5,951	309	1,275,624	459	1,891,318	1	491	800	61	261	437	42	0
21,800	6	5,951	307	1,278,704	455	1,895,887	1	493	800	62	259	433	42	0
21,900	6	5,951	304	1,281,759	451	1,900,416	1	496	800	62	256	429	42	0
22,000	6	5,952	302	1,284,757	447	1,904,862	1	498	800	62	254	425	42	0
22,100	6	5,952	299	1,287,759	443	1,909,313	1	501	800	63	252	421	42	0
22,200	6	5,952	296	1,290,736	440	1,913,727	1	504	800	63	249	417	42	0

22,300	6	5,953	294	1,293,686	436	1,918,103	1	506	800	63	247	413	41	0
22,400	6	5,953	291	1,296,611	432	1,922,440	1	509	800	64	245	409	41	0
22,500	6	5,953	289	1,299,510	428	1,926,740	1	511	800	64	243	406	41	0
22,600	6	5,953	286	1,302,383	424	1,931,001	1	514	800	64	240	402	41	0
22,700	6	5,954	283	1,305,230	420	1,935,224	1	517	800	65	238	398	41	0
22,800	6	5,954	281	1,308,052	417	1,939,410	1	519	800	65	236	394	41	0
22,900	6	5,954	278	1,310,848	413	1,943,557	1	522	800	65	233	390	41	0
23,000	6	5,955	276	1,313,619	409	1,947,666	1	524	800	66	231	387	41	0
23,100	6	5,955	273	1,316,364	405	1,951,738	1	527	800	66	229	383	41	0
23,200	6	5,955	271	1,319,084	402	1,955,772	1	529	800	66	227	379	41	0
23,300	6	5,955	268	1,321,778	398	1,959,768	1	532	800	66	224	375	41	0
23,400	6	5,956	266	1,324,447	394	1,963,727	1	534	800	67	222	372	41	0
23,500	6	5,956	263	1,327,091	390	1,967,648	1	537	800	67	220	368	41	0
23,600	6	5,956	261	1,329,709	387	1,971,532	1	539	800	67	218	364	40	0
23,700	6	5,956	258	1,332,303	383	1,975,379	1	542	800	68	215	360	40	0
23,800	7	5,957	256	1,334,846	379	1,979,151	1	544	800	68	213	357	41	0
23,900	7	5,957	253	1,337,390	375	1,982,923	1	547	800	68	211	353	40	0
24,000	7	5,957	251	1,339,909	372	1,986,658	1	549	800	69	209	349	40	0
24,100	7	5,958	248	1,342,404	368	1,990,358	1	552	800	69	207	346	40	0
24,200	7	5,958	246	1,344,874	365	1,994,022	1	554	800	69	204	342	40	0
24,300	7	5,958	243	1,347,319	361	1,997,649	1	557	800	70	202	339	40	0
24,400	7	5,958	241	1,349,740	357	2,001,240	1	559	800	70	200	335	40	0
24,500	7	5,959	238	1,352,136	354	2,004,795	1	562	800	70	198	331	40	0
24,600	7	5,959	236	1,354,508	350	2,008,314	1	564	800	71	196	328	40	0
24,700	7	5,959	234	1,356,856	347	2,011,797	1	566	800	71	194	324	40	0
24,800	7	5,959	231	1,359,180	343	2,015,244	1	569	800	71	191	321	39	0
24,900	7	5,960	229	1,361,480	339	2,018,656	1	571	800	71	189	317	39	0
25,000	7	5,960	226	1,363,756	336	2,022,033	1	574	800	72	187	314	39	0
25,100	7	5,960	224	1,366,008	332	2,025,374	1	576	800	72	185	310	39	0
25,200	7	5,960	222	1,368,237	329	2,028,680	1	578	800	72	183	307	39	0
25,300	7	5,961	219	1,370,442	325	2,031,952	1	581	800	73	181	303	39	0
25,400	7	5,961	217	1,372,623	322	2,035,188	1	583	800	73	179	300	39	0
25,500	7	5,961	215	1,374,782	319	2,038,390	1	585	800	73	177	297	39	0

25,600	7	5,961	212	1,376,896	315	2,041,527	1	588	800	73	175	293	38	0
25,700	7	5,962	210	1,379,008	312	2,044,658	1	590	800	74	173	290	39	0
25,800	7	5,962	208	1,381,097	308	2,047,757	1	592	800	74	171	286	38	0
25,900	7	5,962	206	1,383,163	305	2,050,822	1	594	800	74	169	283	38	0
26,000	7	5,962	203	1,385,207	302	2,053,854	1	597	800	75	167	280	38	0
26,100	7	5,962	201	1,387,228	298	2,056,853	1	599	800	75	165	277	38	0
26,200	7	5,963	199	1,389,227	295	2,059,819	1	601	800	75	163	273	38	0
26,300	7	5,963	197	1,391,203	292	2,062,751	1	603	800	75	161	270	38	0
26,400	7	5,963	194	1,393,157	288	2,065,651	1	606	800	76	159	267	38	0
26,500	7	5,963	192	1,395,089	285	2,068,518	1	608	800	76	157	264	38	0
26,600	7	5,964	190	1,396,999	282	2,071,352	1	610	800	76	155	260	38	0
26,700	7	5,964	188	1,398,888	279	2,074,154	1	612	800	77	153	257	38	0
26,800	7	5,964	186	1,400,754	275	2,076,923	1	614	800	77	151	254	38	0
26,900	7	5,964	183	1,402,599	272	2,079,661	1	617	800	77	149	251	37	0
27,000	7	5,965	181	1,404,423	269	2,082,367	1	619	800	77	148	248	37	0
27,100	7	5,965	179	1,406,225	266	2,085,042	1	621	800	78	146	245	37	0
27,200	7	5,965	177	1,408,006	263	2,087,685	1	623	800	78	144	242	37	0
27,300	7	5,965	175	1,409,767	260	2,090,298	1	625	800	78	142	239	37	0
27,400	7	5,965	173	1,411,506	257	2,092,879	1	627	800	78	140	236	37	0
27,500	8	5,966	171	1,413,208	253	2,095,403	1	629	800	79	138	233	37	0
27,600	8	5,966	169	1,414,906	250	2,097,921	1	631	800	79	137	230	37	0
27,700	8	5,966	167	1,416,584	247	2,100,411	1	633	800	79	135	227	37	0
27,800	8	5,966	165	1,418,241	245	2,102,871	1	635	800	79	133	224	36	0
27,900	8	5,966	163	1,419,879	242	2,105,301	1	637	800	80	131	221	36	0
28,000	8	5,967	161	1,421,496	239	2,107,702	1	639	800	80	130	218	36	0
28,100	8	5,967	159	1,423,093	236	2,110,073	1	641	800	80	128	215	36	0
28,200	8	5,967	157	1,424,671	233	2,112,415	1	643	800	80	126	212	36	0
28,300	8	5,967	155	1,426,230	230	2,114,728	1	645	800	81	125	210	36	0
28,400	8	5,967	153	1,427,768	227	2,117,012	1	647	800	81	123	207	36	0
28,500	8	5,968	151	1,429,288	224	2,119,268	1	649	800	81	121	204	36	0
28,600	8	5,968	149	1,430,788	221	2,121,495	1	651	800	81	120	201	36	0
28,700	8	5,968	147	1,432,270	219	2,123,695	1	653	800	82	118	199	36	0
28,800	8	5,968	145	1,433,732	216	2,125,866	1	655	800	82	116	196	36	0

28,900	8	5,968	143	1,435,176	213	2,128,009	1	657	800	82	115	193	35	0
29,000	8	5,969	142	1,436,602	210	2,130,126	1	658	800	82	113	191	35	0
29,100	8	5,969	140	1,438,009	208	2,132,215	1	660	800	83	112	188	35	0
29,200	8	5,969	138	1,439,398	205	2,134,277	1	662	800	83	110	185	35	0
29,300	8	5,969	136	1,440,755	202	2,136,291	1	664	800	83	109	183	35	0
29,400	8	5,969	134	1,442,108	199	2,138,297	1	666	800	83	107	180	35	0
29,500	8	5,970	133	1,443,443	197	2,140,279	1	667	800	83	106	178	35	0
29,600	8	5,970	131	1,444,761	194	2,142,235	1	669	800	84	104	175	35	0
29,700	8	5,970	129	1,446,061	192	2,144,165	1	671	800	84	103	173	35	0
29,800	8	5,970	127	1,447,344	189	2,146,070	1	673	800	84	101	170	34	0
29,900	8	5,970	126	1,448,609	187	2,147,950	1	674	800	84	100	168	34	0
30,000	8	5,970	124	1,449,858	184	2,149,804	1	676	800	85	98	166	34	0
30,100	8	5,971	122	1,451,090	182	2,151,634	1	678	800	85	97	163	34	0
30,200	8	5,971	121	1,452,305	179	2,153,439	1	679	800	85	96	161	34	0
30,300	8	5,971	119	1,453,504	177	2,155,219	1	681	800	85	94	159	34	0
30,400	8	5,971	117	1,454,686	174	2,156,975	1	683	800	85	93	156	34	0
30,500	8	5,971	116	1,455,852	172	2,158,706	1	684	800	86	91	154	34	0
30,600	8	5,971	114	1,457,002	170	2,160,414	1	686	800	86	90	152	34	0
30,700	8	5,972	113	1,458,135	167	2,162,098	1	687	800	86	89	150	34	0
30,800	8	5,972	111	1,459,254	165	2,163,759	1	689	800	86	87	147	33	0
30,900	8	5,972	109	1,460,356	163	2,165,397	1	691	800	86	86	145	33	0
31,000	8	5,972	108	1,461,443	160	2,167,012	1	692	800	87	85	143	33	0
31,100	9	5,972	106	1,462,504	158	2,168,588	1	694	800	87	83	141	34	0
31,200	9	5,972	105	1,463,561	156	2,170,155	1	695	800	87	82	139	33	0
31,300	9	5,973	103	1,464,603	154	2,171,701	1	697	800	87	81	137	33	0
31,400	9	5,973	102	1,465,630	151	2,173,226	1	698	800	87	80	135	33	0
31,500	9	5,973	101	1,466,642	149	2,174,730	1	699	800	87	79	133	33	0
31,600	9	5,973	99	1,467,640	147	2,176,213	1	701	800	88	77	131	32	0
31,700	9	5,973	98	1,468,623	145	2,177,674	1	702	800	88	76	129	32	0
31,800	9	5,973	96	1,469,592	143	2,179,114	1	704	800	88	75	127	32	0
31,900	9	5,973	95	1,470,547	141	2,180,533	1	705	800	88	74	125	32	0
32,000	9	5,974	93	1,471,488	139	2,181,932	1	707	800	88	73	123	32	0
32,100	9	5,974	92	1,472,416	137	2,183,310	1	708	800	88	72	121	32	0

32,200	9	5,974	91	1,473,329	135	2,184,668	1	709	800	89	71	119	32	0
32,300	9	5,974	89	1,474,229	133	2,186,006	1	711	800	89	69	117	32	0
32,400	9	5,974	88	1,475,116	131	2,187,325	1	712	800	89	68	115	32	0
32,500	9	5,974	87	1,475,990	129	2,188,623	1	713	800	89	67	114	32	0
32,600	9	5,974	85	1,476,851	127	2,189,902	1	715	800	89	66	112	31	0
32,700	9	5,975	84	1,477,698	125	2,191,163	1	716	800	89	65	110	31	0
32,800	9	5,975	83	1,478,533	123	2,192,404	1	717	800	90	64	108	31	0
32,900	9	5,975	82	1,479,348	121	2,193,615	1	718	800	90	63	107	32	0
33,000	9	5,975	80	1,480,158	119	2,194,817	1	720	800	90	62	105	31	0
33,100	9	5,975	79	1,480,956	118	2,196,001	1	721	800	90	61	103	31	0
33,200	9	5,975	78	1,481,741	116	2,197,169	1	722	800	90	60	102	31	0
33,300	9	5,975	77	1,482,515	114	2,198,319	1	723	800	90	59	100	30	0
33,400	9	5,975	76	1,483,277	112	2,199,452	1	724	800	91	58	98	30	0
33,500	9	5,976	74	1,484,027	111	2,200,568	1	726	800	91	57	97	30	0
33,600	9	5,976	73	1,484,766	109	2,201,667	1	727	800	91	56	95	30	0
33,700	9	5,976	72	1,485,493	107	2,202,749	1	728	800	91	55	94	30	0
33,800	9	5,976	71	1,486,209	106	2,203,814	1	729	800	91	55	92	30	0
33,900	9	5,976	70	1,486,914	104	2,204,862	1	730	800	91	54	91	30	0
34,000	9	5,976	69	1,487,608	102	2,205,895	1	731	800	91	53	89	30	0
34,100	9	5,976	68	1,488,291	101	2,206,911	1	732	800	92	52	88	30	0
34,200	9	5,976	67	1,488,963	99	2,207,911	1	733	800	92	51	86	29	0
34,300	9	5,976	66	1,489,624	98	2,208,895	1	734	800	92	50	85	29	0
34,400	9	5,977	65	1,490,276	96	2,209,865	1	735	800	92	49	84	29	0
34,500	9	5,977	64	1,490,916	95	2,210,819	1	736	800	92	49	82	29	0
34,600	9	5,977	63	1,491,547	93	2,211,757	1	737	800	92	48	81	29	0
34,700	9	5,977	62	1,492,168	92	2,212,681	1	738	800	92	47	80	29	0
34,800	10	5,977	61	1,492,773	90	2,213,579	1	739	800	92	46	78	29	0
34,900	10	5,977	60	1,493,374	89	2,214,472	1	740	800	93	45	77	29	0
35,000	10	5,977	59	1,493,965	87	2,215,351	1	741	800	93	45	76	28	0
35,100	10	5,977	58	1,494,547	86	2,216,217	1	742	800	93	44	74	28	0
35,200	10	5,977	57	1,495,120	85	2,217,070	1	743	800	93	43	73	28	0
35,300	10	5,977	56	1,495,683	83	2,217,909	1	744	800	93	42	72	28	0
35,400	10	5,978	55	1,496,237	82	2,218,734	1	745	800	93	42	71	28	0

35,500	10	5,978	54	1,496,783	81	2,219,546	1	746	800	93	41	70	28	0
35,600	10	5,978	53	1,497,319	79	2,220,345	1	747	800	93	40	68	28	0
35,700	10	5,978	52	1,497,846	78	2,221,131	1	748	800	93	40	67	28	0
35,800	10	5,978	51	1,498,365	77	2,221,904	1	749	800	94	39	66	27	0
35,900	10	5,978	51	1,498,876	75	2,222,665	1	749	800	94	38	65	27	0
36,000	10	5,978	50	1,499,378	74	2,223,413	1	750	800	94	38	64	27	0
36,100	10	5,978	49	1,499,872	73	2,224,149	1	751	800	94	37	63	27	0
36,200	10	5,978	48	1,500,357	72	2,224,873	1	752	800	94	36	62	27	0
36,300	10	5,978	47	1,500,835	71	2,225,585	1	753	800	94	36	61	27	0
36,400	10	5,978	47	1,501,305	69	2,226,285	1	753	800	94	35	60	27	0
36,500	10	5,978	46	1,501,767	68	2,226,974	1	754	800	94	35	59	27	0

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Biographical Information

Christel Simon Obame Bivegue is a citizen of the Republic of Gabon. He arrived in the US in January of 2008 where he started his studies at Grayson County College (GCC), Denison TX. While at Grayson County College, the author of this research joined the GCC Honors College with which he travelled to meet with senators in Austin TX, in order to discuss financial difficulties encountered by Community Colleges students.

After obtaining his Associate of Science in Geology from Grayson County College in May 2009, Christel Simon Obame Bivegue transferred to Midwestern State University (MSU), Wichita Falls TX in august 2009. There he was given a position as a Teaching Assistant in physical geology. He was later elected Sigma Gamma Epsilon, Epsilon Zeta chapter Vice President in January 2010. He also volunteered several times as member of the Geosciences and Spanish clubs.

Christel Simon Obame Bivegue graduated from MSU with a Bachelors of Science in Geosciences in May 2011. He then transferred to the University of Texas at Arlington (UTA), Arlington TX where he pursued a Master's of Science in Geology orientated towards Petroleum Geology. He graduated in May 2013.