THERMODYNAMICS AND TRANSPORT PROPERTIES ANALYSIS OF NATURAL GAS FROM SONGOSONGO IN KILWA- TANZANIA

by

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ABSTRACT

Analysis of thermodynamics and transport properties was carried out for six natural gas samples from Songosongo field in Kilwa - Tanzania using PRO/II simulator. Properties of most interest in gas processing (due to their influence on the sales value) such as density, specific gravity, critical parameters, bubble point and dew point, enthalpy, latent heat of vaporisation, molecular weight, boiling point and phase were investigated. In addition composition of the gas was compared with that from elsewhere. The gas was assumed to be at a temperature of 3°C and a pressure of 150 bar before pressure let down station. Results indicated that Songosongo natural gas properties compare very closely with those of natural gas from other parts of the world. Cricondenbar values ranged from 86.4 bar to 90.7 bar while cricondentherm values ranged from 1.15°C to 5.56°C. Maximum pressure and temperature ranged the same region as cricondenbar and cricondentherm values. These values suggest reasonable flexibility in operating pipeline and other associated process units.

INTRODUCTION

At present when human kind is facing the worst pollution dangers in history, natural gas offers (partly) a solution in that it is the cleanest burning fossil fuel known. It emits almost no sulphur or particulate matter when burned. This combined with increased competition among fuels has rendered natural gas very convenient fuel both industrially and domestically. Efforts to search for cheaper energy sources started in Tanzania even before the oil crisis of the seventies. In the middle / late seventies, large natural gas deposits were discovered and reported in Songosongo - Kilwa district, Tanzania. At that time there were plans to set up an ammonia / fertiliser plant . Unfortunately the idea failed. Towards the end of the eighties, the government decided to construct a pipeline that would transport the gas from the well site to Dar-es-salaam city presumably for industrial and domestic use. It is reported that if all goes on well, the gas will be in the city by 1994[7] and work is progressing steadily.

The quantity of proven reserves is reported to be about 20.531E09 m^3 (or 725E09 ft^3)[7]. Probable reserves is about 32.32192E09 m^3 (or 1106E09 ft^3). The gas is dry and of good quality for the burner (very rich in methane). It has gross calorific value (GCV) of 38,153.33 kJ/m^3 or net calorific value (NCV) of 37,221.74 kJ/m^3 . The amounts of liquids in the gas is about 5.6140E-06 m^3/m^3 natural gas or 3.5311E-06 bb/m^3 natural gas of which 50% is white oil of 42 - 44 API gravity, while the rest is water[7].

For an engineer who will be involved with the sales and / or design and construction of transportation equipment (pipelines, trucks, tankers etc.), process, gas wells, meters, storage equipment and end user handling equipment, it is important he / she has thorough knowledge of the thermodynamics and transport properties of the gas because they influence sales value as well as flow. The importance of this knowledge for safe and economic handling of natural gas systems has been the main motivation behind this study.

LITERATURE REVIEW

Natural gas, like air is imperceptible to the sense. It has no odour, cannot be seen, heard or felt although we can smell the contaminants and observe the effects of its presence. It has a relative density of about 0.6 compared to air. Natural gas of different composition will have different properties and hence different desirable qualities. This gas has been used commercially as a fuel for over two hundred years in America and for centuries in China[3]. The production and distribution of natural gas has become an important component of our domestic economy and is expected to remain so for many years to come. Engineering methods and technology have developed for designing facilities to produce the gas from the earth, to separate it from containing impurities, diluents and other liquid hydrocarbons, to store and to deliver it to the market.

The gas occurs as dry gas, wet gas or condensate in solution with crude oil. A distinction can also be made between sweet and sour gas. Wet gas contains some of the heavier hydrocarbons and water vapour. Dry gas on the other hand does not contain enough heavier hydrocarbons to form a liquid at the surface conditions. Sweet gas has a very low concentration of sulphur compounds (H_2S) whereas sour natural gas contains excessive sulphur compounds. Whichever form it occurs, properties of most interest are those having an important role in processing like density, relative density, critical parameters, bubble and dew point, enthalpy, specific heat, latent heat of vaporisation, molecular weight, boiling point, viscosity, heating value, composition, thermal conductivity and phase. Basically the gas is made up of combustible components and exist as a family of hydrocarbons[1]. Each family member contains some carbon and hydrogen - hence the name hydrocarbons. In addition to combustibles, hydrocarbons contain diluents and contaminants. For this reason, a certain degree of conditioning, separation and purification is always necessary. Diluents are non-combustible gases that are always associated with hydrocarbons in fairly small percentages. Most prevalent diluents are CO_2, N_2 and H_2O vapour. They have no heat energy (kJ) value. Detriments caused by diluents are associated with power, pipeline capacity, corrosion, freezing (hydrates) etc. Most problems in gas processing arise from contaminants than from diluents. The following are the major contaminants associated with gas processing:

- H_2O vapour above certain concentration.
- Entrained free water (condensed water).
- Fluids in liquid form like lube oil, scrubber oil, methanol, glycol, heavier end hydrocarbons, well inhibitors.
- Solid matter in any form.
- Acid gases like H_2S and CO_2.
- Sludge (amalgamation of any one of the other contaminants).

Typically pipeline quality natural gas consists of four main groups of compounds[1]:

- 90% - 95% Methane (CH_4)
- 2% - 4% Ethane (C_2H_6)
- 2% - 3% Propane to Hexane (C_3H_8) - C_6H_{16})
- 0.5% - 4% CO_2 and N_2 (as diluents)
- Traces of H_2O vapour and other contaminants.

While methane and ethane are usually separated out for heating purposes (fuel), propane and heavier fractions are on the other hand processed for their value as either refrigerants, gasoline blending stock or chemical plant raw feed stock. Any successful separation and subsequent processing, storage and transportation to market sites relies on accurate thermodynamics information of the particular stock being handled.

EXPERIMENTAL WORK

Samples from five different wells in Songosongo were simulated using PRO/II simulation program version 3.30 from SIMCI International[5]. Gas samples from the five different wells was assumed to be at a pressure of 150 bar and a temperature of about 3 °C before pressure letdown station. K-values, enthalpy and entropy for the liquid and vapour, together with vapour density were calculated using SRK equation of state[5]. Liquid density was calculated using Lee-Kesler equation while viscosity and conductivity of the vapour and liquid were calculated from ideal gas equation. The same was true for the surface tension of the liquid[5]. An advantage was taken of the phase envelope features of PRO/II[5] to generate properties reported in this work.

RESULTS

Results of the simulation indicate that natural gas from the five individual wells and that from the mixed stream (sample-6) is very lean, dry and high in methane content - an advantage during firing. The composition compares favourably with that of lean natural gas from elsewhere[3] as indicated in Tables 1.1 and 1.2.

Phase characteristics as well as transport properties of the gas were also determined and are tabulated in tables 1.3 and 1.4 respectively.

Table 1.1 COMPOSITION OF NATURAL GAS FROM U.S.A.[1,2]

	Composition of different wells in mol %					
Component	Hugoton	Austin	Leduc	Viking	Lusiana	Deeplak
N_2	15.5	7.3	7.41	0.24	-	-
CO_2	-	-	0.72	2.26	0.3	0.3
H_2S	-	-	-	-	-	-
He	0.58	0.4	-	-	-	-
CH_4	71.51	79.74	72.88	88.76	96.65	98.5
C_2H_6	7	9.1	9.97	4.76	2.05	0.87
C_3H_8	4.4	2.8	5.09	2.67	0.47	0.17
$I\text{-}C_4H_{10}$	0.29	0.1	0.72	0.42	0.08	0.04
$N\text{-}C_4H_{10}$	0.7	0.4	1.76	0.21	0.09	0.02
$C_5H_{12}(t)$	0.02	0.1	0.99	0.38	0.05	0.02
C_6H_{14}		0.05	0.46	0.3	0.31	0.08
$C_7H_{16}^+$	0.01	-	-	-	-	-
Total	100	100	100	100	100	100

Table 1.2 COMPOSITION OF NARURAL GAS FROM SONGOSONGO[7]

	Well composition in mol %					
Component	Well#1	Well#2	Well#3	Well#4	Well#5	Samp-6
N_2	0.68	0.60	0.68	0.65	0.65	
CO_2	0.35	0.29	0.47	0.47	0.47	
H_2S	-	-	-	-	-	-
CH_4	97.2	97.4	96.81	97.13	97.14	
C_2H_6	1.1	0.94	1.05	1.03	1.03	
C_3H_8	0.3	0.31	0.32	0.31	0.31	
$I-C_4H_{10}$	0.069	0.073	0.07	0.071	0.071	
$N-C_5H_{12}$	0.028	0.028	0.03	0.029	0.029	
C_6H_{14}	0.031	0.025	0.04	0.032	0.032	
C_7H_{16}	0.076	0.1	0.14	0.105	0.105	
C_8H_{18}	0.043	0.053	0.063	0.053	0.053	
C_9H_{20}	0.018	0.023	0.01	0.017	0.017	
Total	100	100	100	100	100	

Table 1.3 PHASE CHARACTERISTICS OF SONGOSONGO GAS

	Parameter values, T in °C, P in bar					
Parameter	Well#1	Well#2	Well#3	Well#4	Well#5	Samp-6
Crit. pt. T	-76.47	-76.76	-76.17	-76.33	-76.33	-76.4
P	52.1	51.9	52.5	52.3	52.3	52.2
Cric.ther.T	1.15	5.56	3.15	3.35	3.35	3.37
P	32.3	33.8	33.8	33.6	33.6	33.6
Cric.bar T	-36.82	-34.12	-34.68	-35.19	-35.19	-35.2
P	86.4	90.7	90.1	89.0	89.0	89.1
Maximum T	1.15	5.56	3.15	3.35	3.35	3.37
P	86.4	90.7	90.1	89.0	89.0	89.1

Table I.4 TRANSPORT PROPERTIES OF SONGOSONGO GAS

	Parameter values (SI),therm cond. kCal/h-m-C					
Property	Well#1	Well#2	Well#3	Well#4	Well#5	Samp-6
Molec. wt	16.615	16.598	16.708	16.667	16.667	16.65
Enthalpy	-154.8	-155.5	-153.1	-153.7	-153.7	-154.1
HeatCap.Cp	3.743	3.748	3.743	3.741	3.741	3.743
Density	140.92	140.80	142.13	141.58	141.58	141.40
Z from den	0.7703	0.7701	0.7680	0.7691	0.7691	0.7693
Therm.Cond	0.0275	0.0275	0.0274	0.0275	0.0275	0.0275
Viscos (Cp)	0.0104	0.0103	0.0104	0.0104	0.0104	0.0104
Reduced T	1.4307	1.4312	1.4279	1.4291	1.4291	1.4296
Reduced P	3.2607	3.2620	3.2594	3.2587	3.2587	3.2599
Acc factor	0.0134	0.0133	0.0139	0.0138	0.0138	0.0136
Watson K	19.114	19.132	19.042	19.069	19.069	19.085
API gravt.	328.03	328.51	325.95	326.73	326.75	327.20
Spec. grt.	0.574	0.573	0.577	0.575	0.575	0.575

Physical properties of the constituents of the natural gas is always required in order to obtain reliable calculations.

Table 1.5 PHYSICAL CONSTANTS OF NATURAL GAS COMPONENTS [2]

Comp	Mol.wt.		Cr. temp		Cr. pres			A.f
-	-	ZC	°R	K	Psia	MPa	EMR	Omeg
CH_4	16.043	0.29	343	191	668	4.6	14.19	.014
C_2H_6	30.070	0.29	550	305	708	4.88	24.37	.099
C_3H_8	44.097	0.28	665	370	616	4.25	34.63	.152
I-C_4H_{10}	58.124	0.28	735	408	529	3.65	44.74	.185
N-C_4H_{10}	58.124	0.27	766	425	551	3.8	44.24	.201
I-C_5H_{12}	72.151	0.27	829	460	490	3.38	55.30	.222
N-C_5H_{12}	72.151	0.27	846	470	489	3.37	55.27	.254
N-C_5H_{14}	86.178	0.26	914	507	437	3.01	65.58	.301
N-C_7H_{16}	100.205	0.2	973	540	397	2.74	75.88	.350
N-C_8H_{16}	114.232	0.26	1,024	569	361	2.49	86.19	.402
N-C_9H_{10}	128.259	0.25	1,0171	595	332	2.29	96.53	.446
N-$C_{10}H_{22}$	142.286	0.25	1,112	617	304	2.1	106.86	.489
N-$C_{11}H_{24}$	156.302	0.24	1,153	641	282	1.94	117.17	.501
N-$C_{12}H_{26}$	170.378	0.24	1,187	659	263	1.81	127.5	.539
N_2	28.016	0.29	227	126	493	3.4	9.71	.225
CO_2	44.01	0.28	548	304	1,077	7.38	14.44	.225
H_2S	34.076	0.28	673	374	1,306	9.01	20.28	.1
O_2	32.000	0.29	279	155	737	5.08	8.69	.0213
H_2	2.016	0.30	60	33	188	1.30	4.23	.0

DISCUSSION

The results of this work indicate that the composition of natural gas from Songosongo compares favourably with that of natural gas from elsewhere [3], (table 1.1 and table 1.2). It approximates more closely properties of gas from Louisiana field in West Cameron. This means that Songosongo natural gas is equally competitive as natural gas from other parts of the world. It is very rich in methane and thus very low in heavy fractions. This can be viewed as both an advantage and a disadvantage. An advantage in a sense that very little conditioning and processing will be required before firing, and a disadvantage in a sense that heavy fractions equally desirable and competitive for gasoline blending and for the chemical industry are at almost lowest level (table 1.2).

Table 1.2 indicates that natural gas from well-3 is richer in the heavy fractions than that from other wells. Consequently molecular weight, density and specific gravity of the gas follows the same trend. As expected these values are highest for well-3, (table 1.4). Enthalpy, conductivity, reduced temperature and compressibility factor for that gas show an opposite trend while there is no particular trend for specific heat capacity or viscosity of the gas. These values remain more or less constant for all wells as expected. Cricondentherm and cricondenbar values for the gas vary between 1.15°C & 5.56°C and 86.4 bar & 90.7 bar respectively, (table 1.3). As evident from table 1.3, cricondenbar values for all samples were below 95 bar. This is an advantage. It will be cheaper to operate the pipeline at low compression values. An added advantage is that fact that cricondentherm values for all samples were above 0°C,which is the condensation temperature for water at standard conditions. However it might be necessary to apply some heating during certain stages of gas conditioning, transportation and processing in order to avoid premature formation of liquids and / or hydrates. This will be delt with at a later stage.

CONCLUSION

Composition, thermodynamic as well as transport properties of Songosongo natural gas from Kilwa district have been examined. It was found that the composition of the gas compares favourably with that of natural gas from other parts of the world. Phase properties indicated that it is possible to operate that gas pipeline and other process equipment associated with gas processing at relatively low pressures as long as one is always above cricondenbar (86.4 bar) and cricondentherm (1.15°C). The composition of the gas indicated an added advantage of modest processing needs since the gas is very lean (rich in methane). This fact can also be viewed as a disadvantage when interest is on the equally competitive heavy fractions.

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