



Determination of Production Contribution from each Reservoir in a Commingled System through Geochemical Fingerprinting Variation

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ABSTRACT

This work investigates the contribution of each reservoir in a commingled production through natural variation in geochemical fingerprinting of each reservoir fluid. Two oil samples and one gas sample were taken from three different locations in Niger Delta field; Well X of field A, Well Y of field B and Well Z of field C. Each well is producing from two commingled reservoirs through a single string as follows Res X1 and X2 for Well X, Res Y1 and Y2 for Well Y and Res Z1 and Z2 for Well Z respectively. The samples were analyzed with Agilent Gas Chromatographic instrument equipped with Flame Ionization Detector (GC-FID) and HP-PONA capillary column. ASTM D2887 and GPA 2286 standard were used for oil and gas samples respectively. Artificial mixes were prepared using the end-members at different proportions and they were analyzed and quantified to generate allocation ratios. Production allocation plots were used to determine the percentage contribution of each reservoir in the commingled crude. The results showed that in field A, the contribution of Res X1 and Res X2 was 10% and 90%, respectively. In field B, Res Y1 contributed 60% and that of Res Y2 was 40% while in field C, Res Z1 and Z2 contribution was 30% and 70% respectively. The study showed that geochemical fingerprinting analysis using GC-FID is a proven alternative method for reservoir fluid production contribution in a commingled system. The method is time and cost efficient when compared with production logging approach.

Key words: Production Contribution, Geochemical Fingerprinting, Commingled Production, End-members, Gas Chromatography

1. INTRODUCTION

Allocating Production to each reservoir in a commingled production is necessary for accountability and adequate revenue allocation in a joint system. Several methods have been proposed and among the most accepted is geochemical fingerprinting. Hydrocarbon geochemical fingerprinting is a technique that uses hydrocarbon fluids composition to provide valuable and unique information for well and reservoir management [1, 2]. The theory behind hydrocarbon fingerprinting technique is that every reservoir fluid has a unique signature referred to as "fingerprint". When reservoir fluids produced from discrete zones are commingled, subtle chemical differences in their fingerprint can be used to assess the contribution from each pay zone [3,4,5,6]. Subsurface commingle production where different reservoirs are produced through a single tubing is one of the cost-effective and completion simplicity technique that have been adopted in recent time [7]. In the course of transferring fluid from production site to the commingling or shared facility, factors like measurement uncertainty in metering device, fluid expansion or shrinkage, loss due to pipeline leakage or crude theft can contribute to imbalance during volume reconciliation at the sharing terminal. For these reasons, the quantity obtained before commingling takes place at the shared facility is called an estimate [8]. The actual contribution of each stream in the commingled point is better determined through production allocation. Taxes and royalties are paid according to the volume of hydrocarbon in place or hydrocarbon produced and profits are recorded according to the volume of oil or gas sold or exported and in a commingle production or shared facilities, payment are made to the government according to the contributions of each stream in the commingled system [9]. Profits are also shared by users of the shared facility using the same contribution formula as stipulated in contract terms. It is therefore pertinent that proper allocation is constantly carried out to ensure transparency in manner in which expenses and profits are being shared [8]. In an oil field, allocation is necessary to determine the contribution of each well or zones for effective reservoir management and production optimization [10,11]. It is crucial to determine the contribution of

each of the streams accurately to satisfy the owners and the industry regulator [12]. Allocation should be executed fairly; to ensure that operators do not experience revenue loss otherwise the peaceful coexistence between the operators will be threatened [13]. Many methods based on the allocation structure have been used to carry out back allocation in order to ascertain the appropriate quantity contributed by each stream in the commingled fluid. Gas chromatography has been identified as an effective reservoir management tool for elucidating reservoir continuity, allocating commingled production to discrete reservoir zones and identifying reservoir fluid type prior to testing [14, 15]. This work will analyze the reliability of geochemical fingerprinting (GC-FID) for production contribution of each member of a commingled crude and gas samples in Niger Delta field

2. MATERIALS AND METHOD

2.1 Materials

The materials and equipment used in this work are End member and commingled crude oil samples, End member and commingled gas samples, Prosab sampling bottles, Chandler PVT Cell for oil sample, Vinci PVT Cell for gas sample, Gas meter, Agilent Gas Chromatographic equipment -GC-7890B for gas analysis, GC-7890A with auto sampler for liquid hydrocarbon and Manual injection string and sample vial.

2.2 Procedure

2.2.1 Sample Collection

Samples were obtained from three fields (Field Alpha, Field Beta and Field Gamma). In field Alpha, duplicate samples of commingled crude (X^1) were taken from well X. Well X is a commingled production well comprises of Res X1 and X2. Each reservoir was isolated and flown at constant rate before duplicate samples of each fluid (Res-X1 and Res. X2) were taken respectively. The sampling process lasted for two days and all the samples were taken to PVT Laboratory for analysis.

For field Beta, duplicate sample of commingled crude Y^1 were taken at the well Y well head. Well Y was also a commingle production well consisting of well Y1 and Y2. Each reservoir was isolated and flown at constant rate just as that of field Alpha before duplicate samples of Y1 and Y2 were taken from well head respectively. The sampling process lasted longer than the first trip because of some challenges encountered during zonal or reservoir isolation.

Gas samples were obtained from field Gamma, duplicate samples of commingled gas Z^1 was taken at the well Z well head. The procedures mentioned above were applied to obtain samples from Res Z1 and Z2 respectively.

2.2.2 Sample Integrity Checks

Opening pressure check was carried out on all samples to ascertain their integrity, i.e., to ensure that laboratory opening pressure was equal to field closing pressure. Water was drained from the oil sample before it was restored (heated) to sampling temperature. A subset of each homogenized sample was charged into the PVT cell and later flashed at well head condition.

2.2.3 Samples Preparation

For GC analyses, the flashed oil samples were quickly transferred into a refrigerator on reception for proper preservation. Artificial mixes of different end member oils were prepared in the following ratios; (80% ResX1+20% Res X2), (60% ResX1+40% Res X2), (40% ResX1+60% Res X2), (20% ResX1+80% ResX2). The same was done on sample Z1 and Z2 respectively.

Afterwards, an aliquot of each sample mix was measured with manual string into the GC vial, one at a time for analysis.

The artificial mixes of gas sample were carried out inside Vinci PVT Cell at different ratio as was done in oil samples. Thereafter, a subset of the mixed sample was flashed into gas meter for gas chromatographic analysis.

2.2.4 Gas Chromatographic Flame Ionization (GC-FID) analysis

0.5 μ L of the oil sample was injected into the Agilent 7890A Gas Chromatograph, provided with flame ionization detector (GC FID), auto sampler 7683 and HP-PONA capillary column. The GC instrument separates hydrocarbon fluid sample into different components based on their boiling points. The initial oven temperature was at 35°C and held for 4 minutes and increased to 150°C at a rate of 10°C/min for proper separation and elution. It was later increased to 320°C at a rate of 3°C/min and was held for 20mins. The total run time was 90 minutes. Helium was used as the carrier gas. Prepared mixes of different end member oils were analyzed to develop the calibration points for evaluation of contribution each stream in commingled crude.

For gas analysis, same Agilent gas chromatographic equipment was used. It is equipped with two detectors, flame ionization and thermal conductivity detectors. The injection was done manually from gas meter through the liner into the inlet. The equipment was programmed to inject 1.0 μ L of gas into the column. The oven temperature was maintained at 60°C all through the analysis for 40 minutes. The work flow for Production allocation for gas and Crude oil is presented in Figure 1 and 2 respectively.

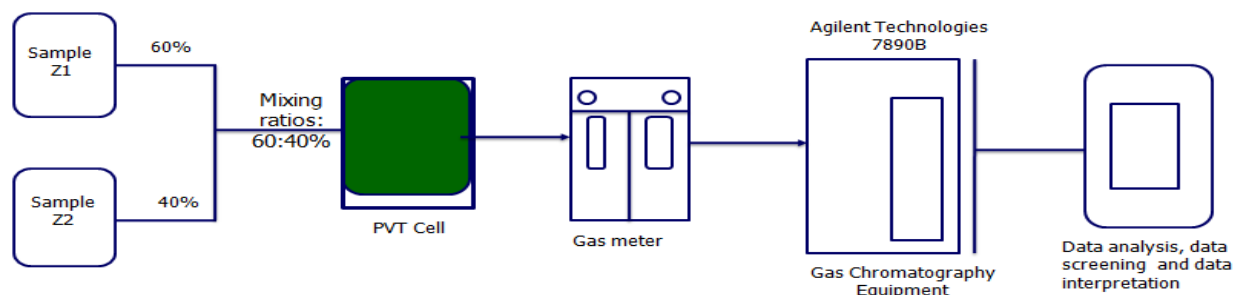


Fig. 1 Work flow diagram for production allocation for natural gas

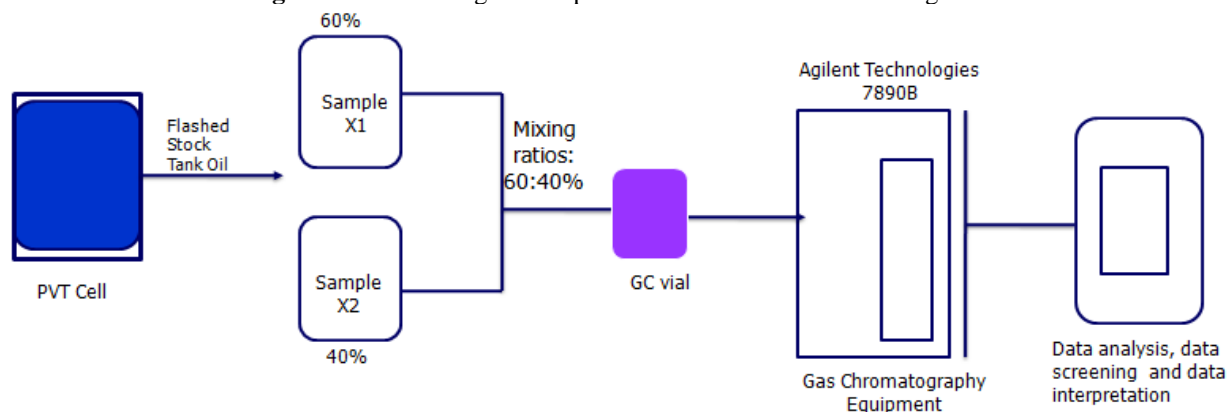


Fig. 2 Work flow diagram for production allocation for crude oil

2.2.5 Quality Control and Quality Assurance Measures

Prior to the analysis, the equipment was calibrated using North Sea oil and Linde standard gas for oil and gas GC respectively. A blank run was done to clear the column of any hydrocarbon residues and also to ensure that the equipment has attained stability before commencing the analysis. Each sample was run three times and the average peak height taken. Outliers were expunged during computation. Pure DCM (dichloromethane) was used by auto sampler to clean the injector string. Helium gas of 99% purity was used as carrier gas.

3. RESULTS AND DISCUSSION

3.1 Identification of Components and Integration of Peak Height

3.1.1 Res X1, X2 and commingled crude-X¹ from field A

From the chromatograms of crude from Res X1 presented in Figure 3, the scanty light ends (C_1 - C_9) indicates that the oil is biodegraded. The mid (C_{10} - C_{20}) and heavy ends (C_{21} - C_{35}) are well populated. The doom shape of chromatogram depict that the sample is of waxy nature, the reason why it congeals at room temperature.

The overlaid of the chromatograms of crude from Res. X1 and commingled X¹ does not have a perfect match. As the commingled seems to dominant in the mirror image as seen in Figure 3.

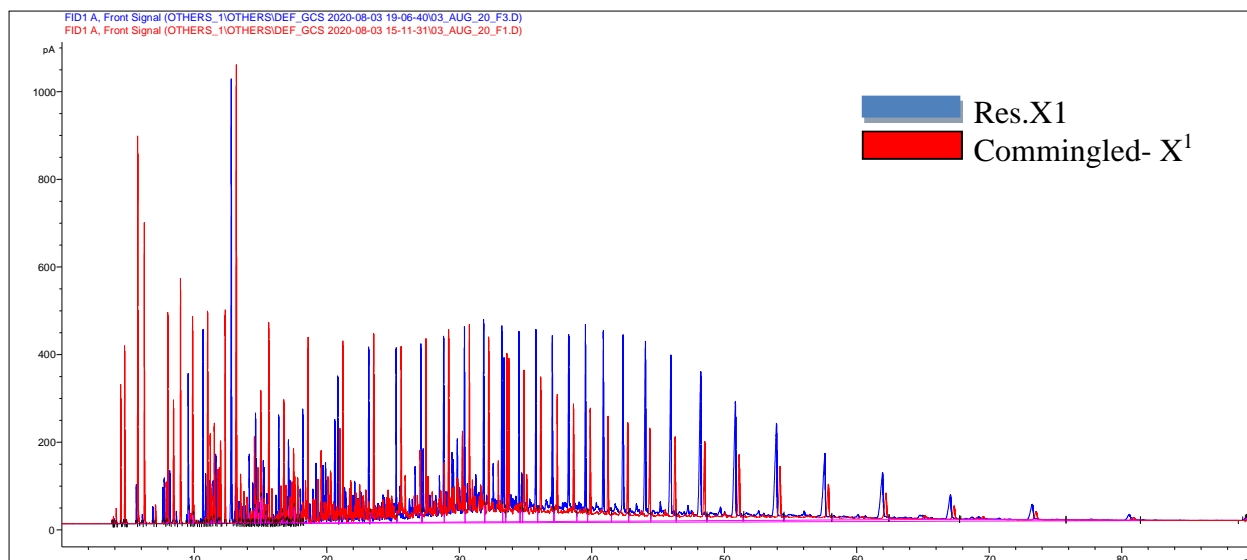


Fig. 3 Mirror image of chromatogram of Res. X1 crude with that of Commingled crude X^1

The chromatogram of Res. X2 shown in Figure 4 shows appreciable abundance of light ends (C_1 - C_9) which indicates early stage of biodegradation. The mid (C_{10} - C_{20}) and heavy ends (C_{21} - C_{35}) are not as populated as that of Res X1. The sample flows at room temperature. The chromatogram of commingled crude X^1 have much resemblance to that of Res X2. The sample also flows at room temperature.

The mirror image of chromatogram of Res. X2 crude and that of commingled crude X^1 shows that there is a perfect match between the two as seen in Figure 4.

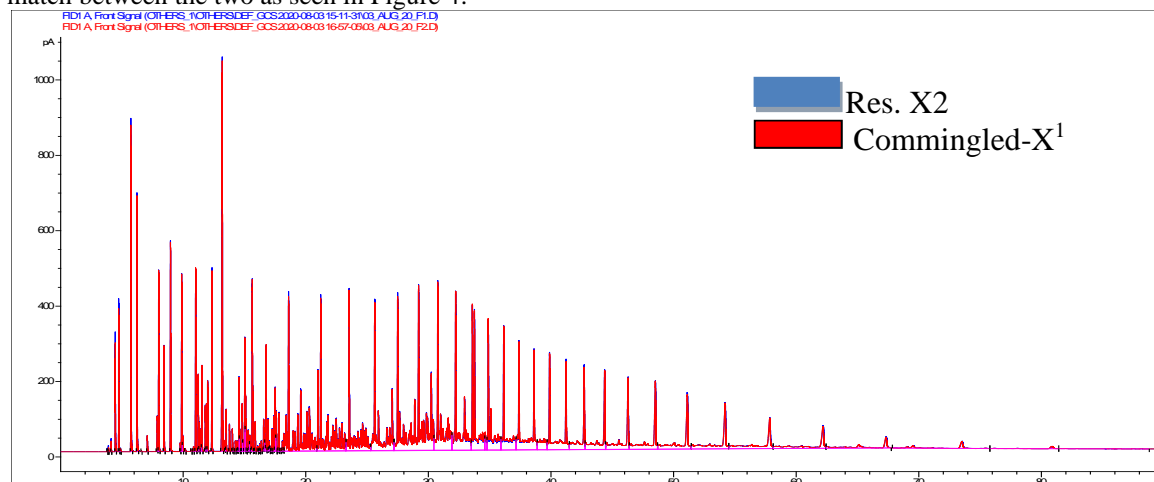


Fig. 4 Mirror image of chromatogram of Res. X2 crude and that of Commingled crude X^1

The chromatograms of the three analyzed oil samples are shown in the Figure 5. The fingerprints of the commingled and Res X2 are similar. They are lightly biodegraded, particular in the light hydrocarbon ends. Methylcyclohexane (MCC_6) is the dominant hydrocarbon in the distribution. The commingled is closely related to Res.X2. They are less degraded than the Res X1, C_7 is clearly visible in the commingled and Res X2 samples, where it is hardly noticeable in Res X1.

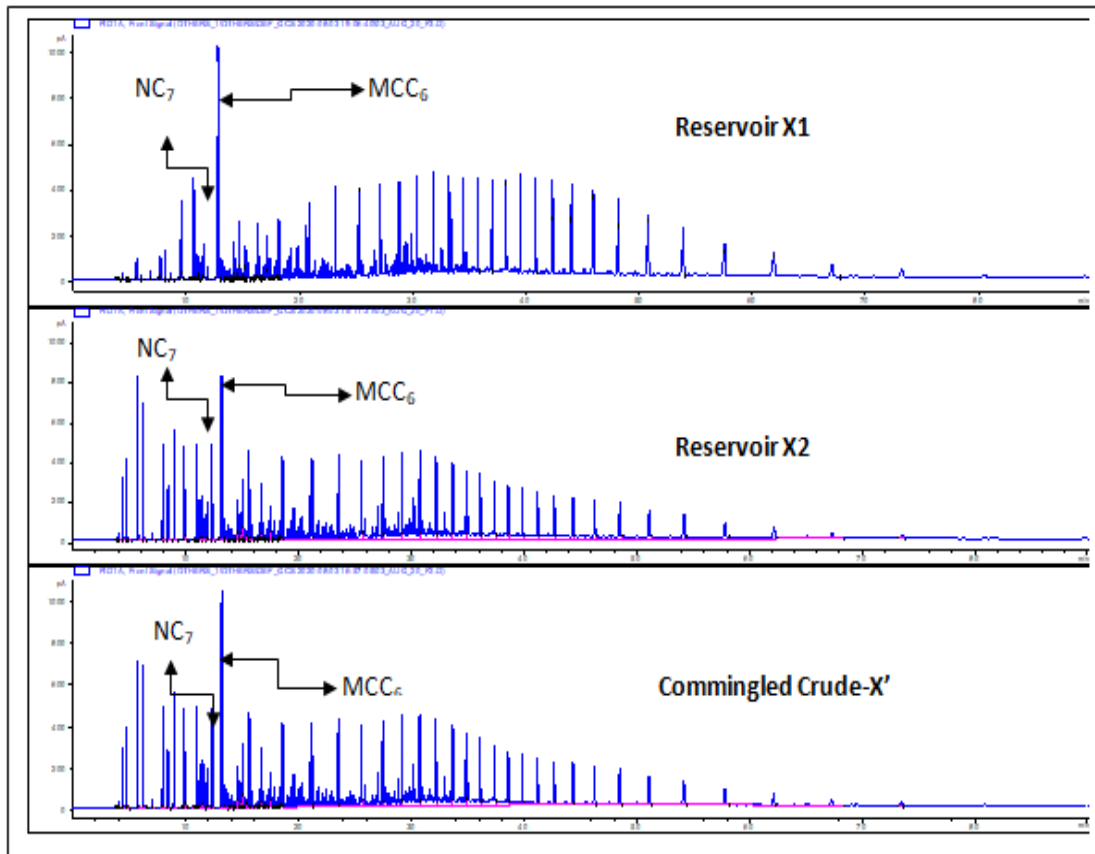


Fig. 5 Chromatogram of Res-X1 crude, Res.-X2 crude and Commingled crude(X¹)

3.1.2 Res Y1, Y2 and commingled crude-Y¹ from field B

The chromatogram of crude from Res.Y1 in Figure 6 is heavily populated with light ends (C₂-C₉) which informed absence of biodegradation. It is also rich in mid components (C₁₀-C₂₀). There is presence of unresolved complex mixture (UCM) hump within the region of C₁₀ to heavy end. This could be as a result of presence of contamination which GC was unable to separate and resolve.

The light ends (C₂-C₉) and the mid (C₁₀-C₂₀) of crude from Res.Y2 chromatogram in Figure 6 is not as heavily populated as that of crude Y1. This could be an indication of early stage of biodegradation. There is presence of unresolved complex mixture (UCM) hump within the region of C₁₀ to heavy end. The signature of crude from Res. Y1 and Y2 have close resemblance which indicate that both crudes shared the same source rock and depositional environment. A critical look at the chromatogram of commingled crude showed that the commingle stream contains more of Res-Y1 crude than that of Res-Y2 crude. The mirror image of chromatogram of Res.Y1 crude and Res.Y2 crude and that of commingled crude -Y¹ shows that crude from Res. Y1 dominant in the commingled production stream as seen in Figure 6.

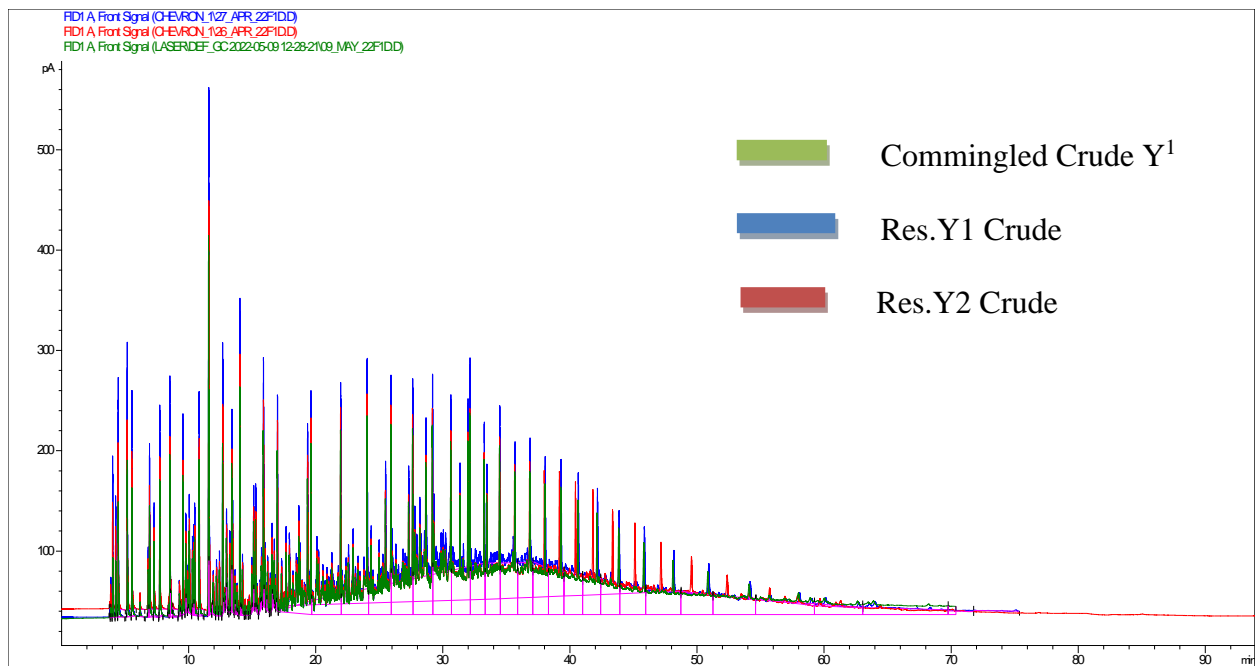


Fig. 6 Overlaid chromatogram of crude Y1, Y2 and commingled crude (Y¹)

3.1.3 Gas well Z (Res Z1, Res Z2 and commingled-Z¹) from field C

The chromatograph of Gas from Res Z1, Res Z2 and the commingled that there is an appreciable amount of carbon dioxide (CO₂) and small amount of Nitrogen (N₂) in Gas from Res. Z1, appreciable amount of Nitrogen (N₂) and small amount of carbon dioxide (CO₂) in Gas from Res.Z2 and the commingled Gas Z¹ as shown in Figure 7.

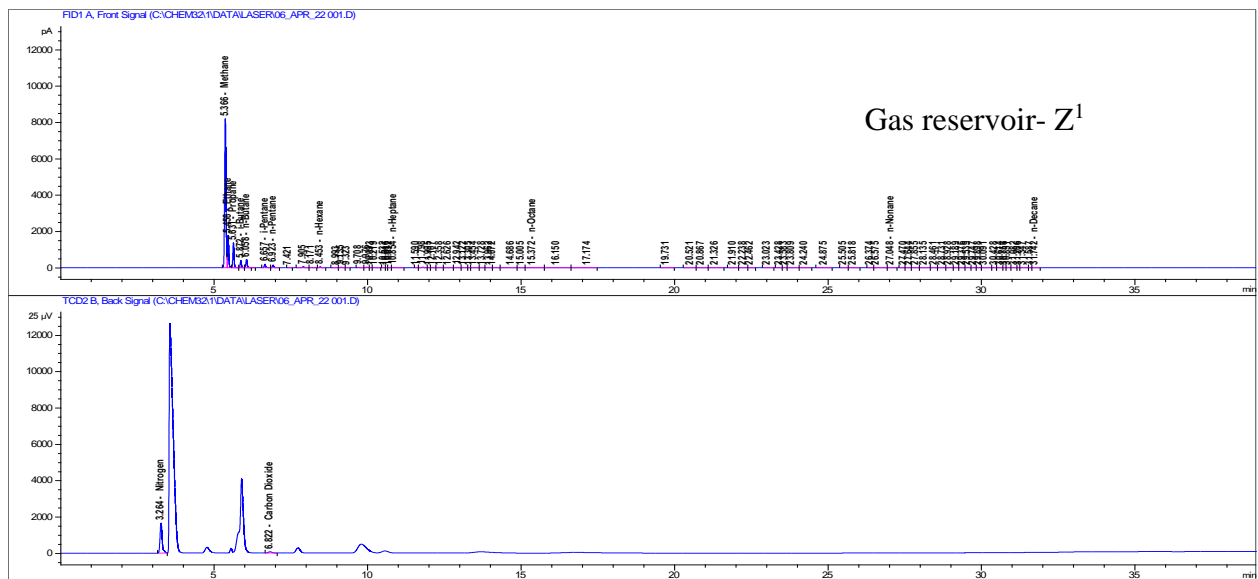


Fig. 7 Chromatograph of commingled gas- Z¹

3.2 Generation of Allocation Ratios and Plots

The diagnostic ratios were generated in the end members, commingled and all the mixes using the peak heights. So many ratios were generated and screening was done to eliminate the outlier. The mid and heavy ends were not used due to unresolved complex mixtures issues. The following components were used at the end of screening test to generate the allocation ratios;

- (i) Cyclohexane/ Normal heptane (CC₆/NC₇)
- (ii) Cyclohexane/ 3Methylepentane (CC₆/3MC₅)
- (iii) Isobutane/Normal butane (IC₄/NC₄)
- (iv) Iso pentane/Normal pentane (IC₅/NC₅)

3.2.1 Reservoir-X1 Crude, X2 Crude and Commingled X¹Crude

At the end of GC analysis, peak height in pico area (pA) and retention time (minutes) were exported. Table 1 shows the exported heights of used components and Table 2 the Allocation ratios for Res X1, X2 and Comingled crude.

Table 1- GC-FID generated peak heights for Res-X1, X2 and X¹(pA)

Ratio	100% (RES.X1)	80%X1+ 20%X2	60%X1+ 40%X2	40%X1+ 60%X2	20%X1+ 80%X2	100% RES(X2)	COMMINGLED X ¹
3MC ₅	117.1780	107.5398	110.1750	124.1056	155.5407	456.6936	343.0777
CC ₆	440.5893	329.4962	270.1978	219.5924	216.6060	434.6936	413.2371
NC ₇	123.3218	106.1459	100.8256	116.3249	275.6008	404.5459	331.3852

Table 2-Allocation ratios for Res-X1, X2 and X¹(pA)

Ratio	100% (RES.X1)	80%X+ 20%X2	60%X1+ 40%X2	40%X1+ 60%X2	20%X1+ 80%X2	100% RES(X2)	COMMINGLED X ¹
CC ₆ /3MC ₅	3.7601	3.0680	2.4524	1.1694	1.0926	0.9529	1.2045
CC ₆ /NC ₇	3.5727	3.1041	2.6799	1.8878	1.4853	1.0745	1.2470

The commingled value of 1.2470 as seen in Figure 8 shows that the contribution of crude from Res. X1 is about 10% which implies that crude from Res. X2 contributed 90%.

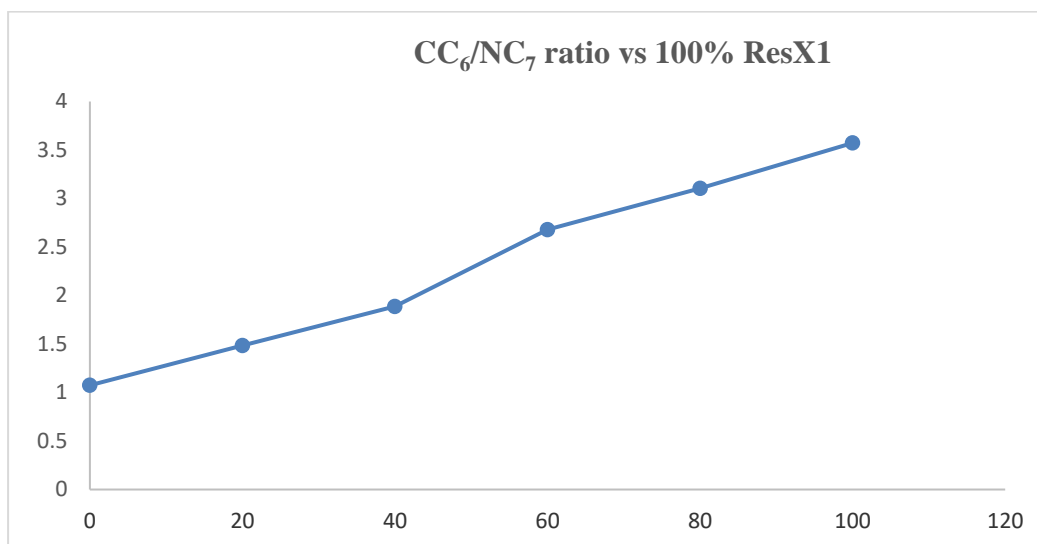


Fig. 8 CC₆/NC₇ ratio vs. 100% Res.X1

Figure 9 also shows that the contribution of Res X1 is about 10% (Commingled X¹= 1.2045) which implies that Res X2 contributes 90%.

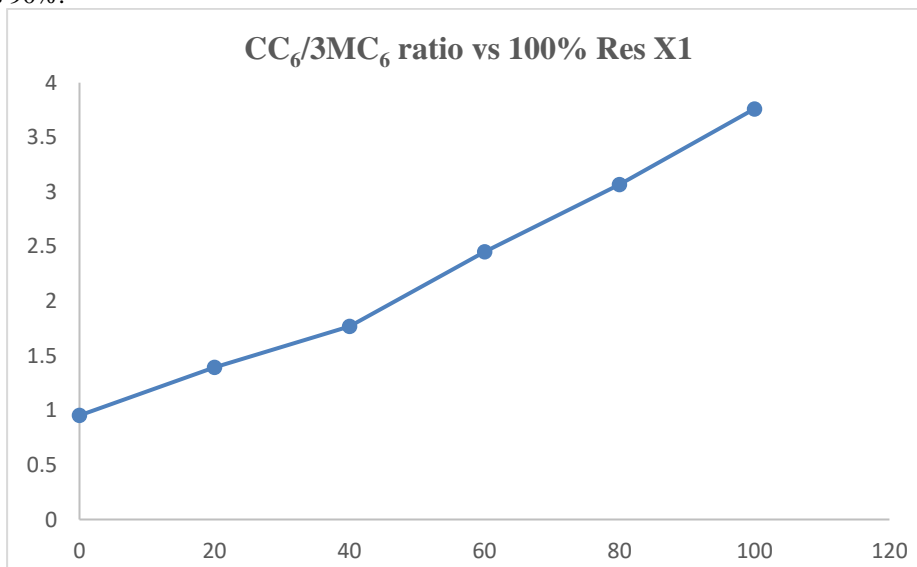


Fig. 9 CC₆/3MC₅ratio vs. 100% Res X1

3.2.2 Reservoir-Y1 Crude, Y2 Crude and Commingled Y¹Crude

The exported heights of used components for Reservoir Y1,Y2 and Commingled Y1 are presented in Table 3 and the Allocation ratio shown in Table 4.

Table -3 GC-FID generated peak height (pA) for Res-Y1, Y2 and Y¹

Ratio	100% (RES.Y1)	80%Y1+ 20%Y2	60%Y1+ 40%Y2	40%Y1+ 60%Y2	20%Y1+ 80%Y2	100% RES(Y2)	COMMINGLED Y ¹
3MC ₅	292.1773	250.2195	283.299	307.7590	408.5443	321.9369	278.5471
CC ₆	336.8804	283.849	280.834	298.834	369.610	271.425	302.8086
NC ₇	343.0205	317.3625	317.1832	377.4586	521.2381	422.6487	346.4232

Table 4- Allocation ratios for Res-Y1, Y2 and Y¹

Ratio	100% (RES.Y1)	80%Y1+ 20%Y2	60%Y1+ 40%Y2	40%Y1+ 60%Y2	20%Y1+ 80%Y2	100% RES(Y2)	COMMINGLED Y ¹
CC ₆ /3MC ₅	1.1530	1.1344	0.9913	0.9710	0.9047	0.8431	1.0871
CC ₆ /NC ₇	0.9821	0.8944	0.8854	0.7917	0.7091	0.6422	0.8741

Figure 10 shows that the contribution of ResY1 in the commingled is 60% which was validated by plot CC₆/NC₇ ratio in Figure 11.

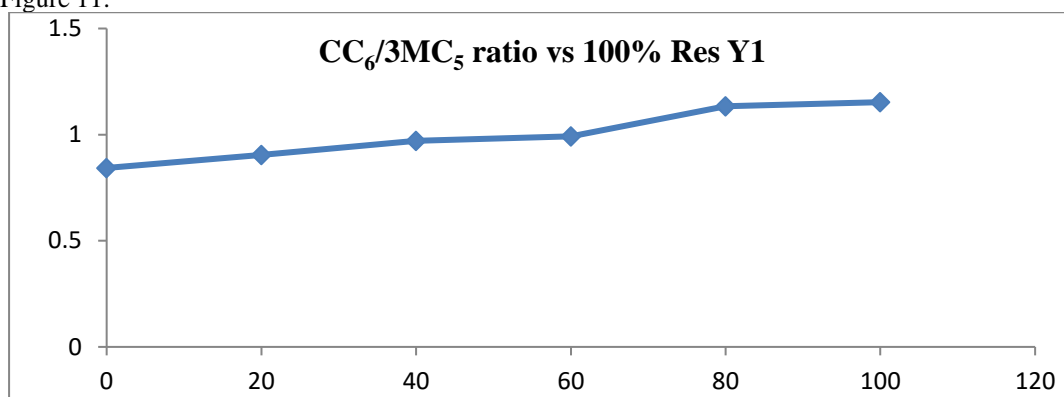


Fig. 10 CC₆/3MC₅ ratio vs. 100% Res Y1

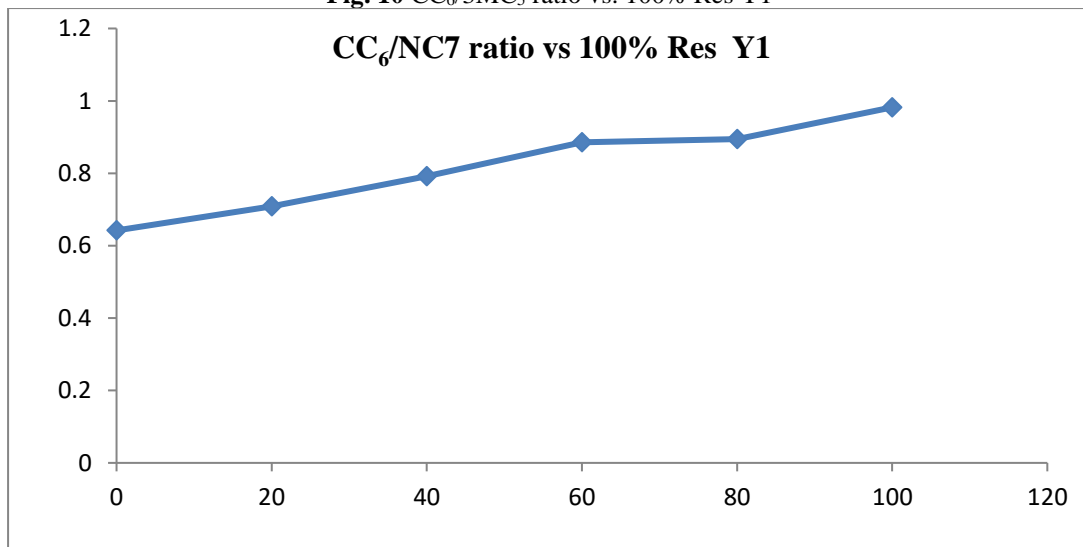


Fig. 11 CC₆/NC₇ ratio vs. 100% ResY1

3.2.3 Gas Reservoir-Z1, Z2 and Commingled Z¹

The component peak height for the Gas samples are presented in Table 5 and Allocation ratio shown in Table 6

Table -5 GC-FID generated component peak height (pA) for gas sample Z1, Z2 and Z¹

Ratios	100% (RES.Z1)	80%Z1+ 20%Z2	60%Z1+ 40%Z2	40%Z1+ 60%Z2	20%Z1+ 80%Z2	100% RES(Z2)	COMMINGLED Z ¹
IC4	282.9517	322.871	328.2442	365.6458	405.9600	710.5702	391.9433
NC4	233.8535	340.9601	357.9454	418.5889	485.9847	877.6016	458.2638
IC5	214.5322	202.7193	191.1228	192.8003	193.7479	312.8449	191.6499
NC5	143.007	157.9762	142.1772	134.0772	137.9463	227.1226	138.2520

Table 6- Allocation Ratio for gas sample Z1, Z2 and Z¹

Ratios	100% (RES.Z1)	80%Z1+ 20%Z2	60%Z1+ 40%Z2	40%Z1+ 60%Z2	20%Z1+ 80%Z2	100% RES(Z2)	COMMINGLED Z ¹
IC ₄ /IC ₅	1.318924	1.5927	1.7175	1.8965	2.0953	2.2713	2.0451
NC ₄ /NC ₅	1.635258	2.1583	2.517581	3.1220	3.5230	3.8640	3.3147

Figure 12 and 13 shows that the contribution of Res-Z1 in the commingle gas sample is 30% respectively.

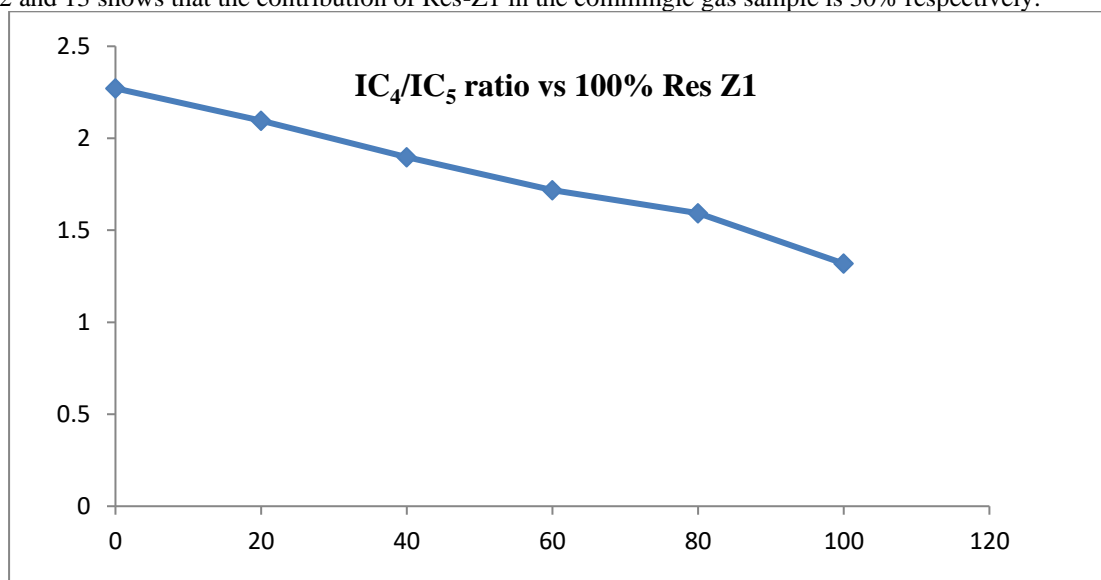


Fig. 12 IC₄/IC₅ ratio vs. 100% Res Z1

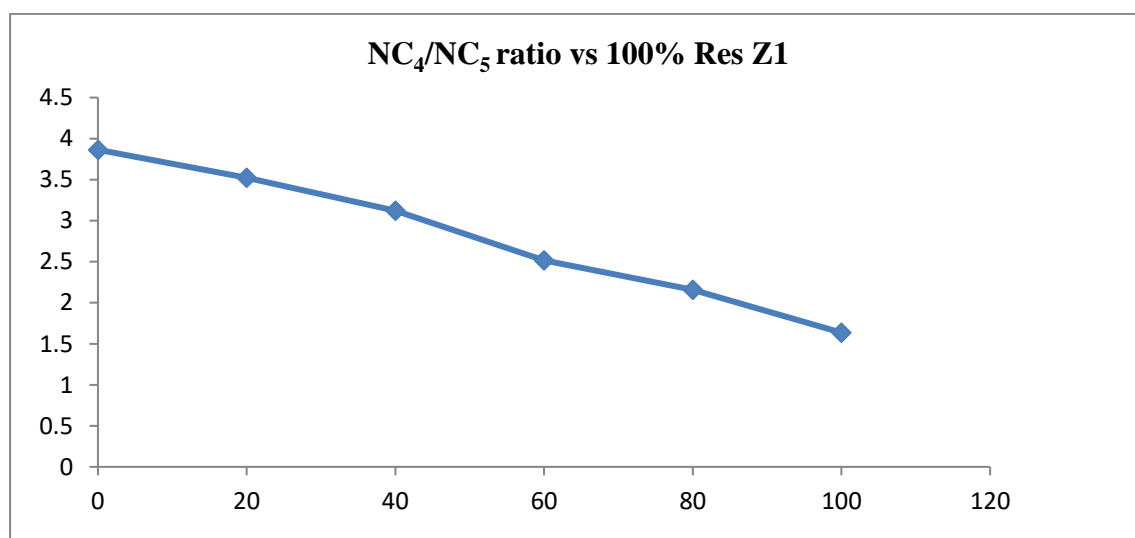


Fig. 13 NC₄/NC₅ ratio vs. 100% Res Z1

4. CONCLUSION

Production contribution of each reservoir using geochemical fingerprinting technique is a proven established technology that is getting better with improved analysis methods. In this study, production contribution was carried out on three wells; Well-X (Res-X1 and Res-X2), Well-Y (Res-Y1 and Res-Y2) and Well-Z (Res-Z1 and Res-Z2) which are located in field A, B and C in Niger Delta respectively.

- i. For field A, Reservoir-X2 has the higher contribution of 90% while Reservoir-X1 contributed 10% to the commingled system
- ii. For field B, Reservoir-Y1 contributed 60% while Reservoir- Y2 contributed 40% in the commingled system
- iii. For Field C, Reservoir-Z2 contributed 70% while Reservoir-Z1 contributed 30% in the commingled system

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