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Allocation of commingled pipeline oils to field production

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Abstract

This paper presents a case study of using oil fingerprinting technology to correctly back allocate commingled pipeline crude to production from six contributing fields in an offshore southeast Asia basin. A large number of oil and pipeline samples were collected over time and analyzed by gas chromatography for their oil fingerprints. In this case, production from each field pipeline could easily be distinguished by their whole-oil fingerprints that changed little with time. However, oils collected from the commingled pipelines showed significant chromatographic variation with time, indicating production contribution from the different fields to the pipelines varied with time. Quantitative results were attained using a proprietary computer program which mathematically calculates relative contributions (±3%) of oil mixes based on a best-fit least-squares regression of selected chromatographic peak ratios. This allocation method assisted operations to more accurately determine production for each field or a group of fields in the basin. The technique, which provides a new approach to supplement and cross-check production metering necessary for defining tax liability, has helped save significant tax dollars for field operation units. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Oil fingerprinting; Production allocation; Pipeline; Commingled oil; Monitoring; Production metering

1. Introduction

Organic geochemistry has historically focused on petroleum exploration issues such as hydrocarbon generation, source facies, thermal maturity, and oil migration. More recently, organic geochemistry has been applied to solving many reservoir and production related problems (Kaufman et al., 1990; Hwang et al., 1994; Hwang and Baskin, 1994; Nederlof et al., 1994; Baskin et al., 1995; Halpern, 1995; Hwang and Elsinger, 1995; Nicolle et al., 1997). These authors have shown that gas chromatography (oil fingerprinting) can be an effective reservoir management tool for elucidating reservoir continuity, allocating commingled production to discrete reservoir zones (Kaufman et al., 1987, 1990; Hwang and Elsinger, 1995), and identifying reservoir fluid type prior to testing (Baskin et al., 1995).

Commingling is a common practice in the petroleum industry for sharing facilities and production equipment to reduce costs. Producing two or more reservoirs through a single tubing string, mixing gas/oil/water from several wells in a single separator tank, or using a single pipeline for transporting production from several fields are examples of commingling. Crude oils originating from different producing zones, wells, or fields are mixed through commingling operation. For technical reasons, it is sometimes necessary to quantitatively deconvolute these mixtures to facilitate monitoring of individual zones, wells, or fields. For example, where multiple pipelines commingle, an accurate assessment of individual field contributions may be essential for establishing sales value or tax liability because oil quality or tax rates can be different between neighboring fields that share a transport pipeline to facilities terminals. The ability to back allocate helps in effectively managing reservoirs and production operations.

This paper presents a case study of using oil fingerprinting technology to correctly back allocate commingled pipeline crude to production from a number of

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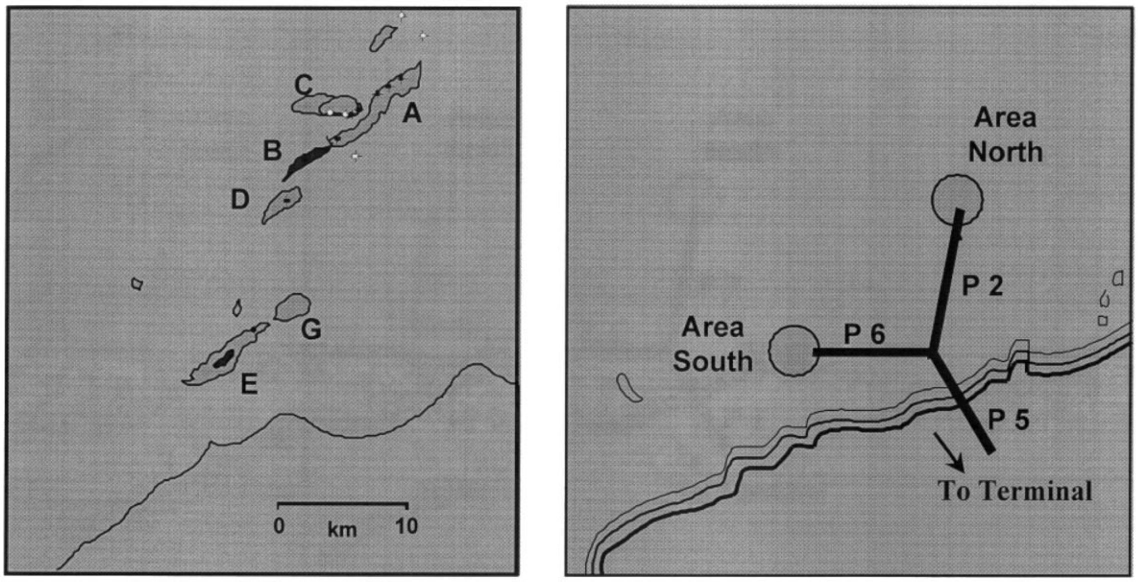
fields in a Southeast Asia basin. Normally, field allocation is done by monitoring individual field production with flow meters. However, in this case, there was a lack of dedicated metering for production from some fields for a period of time. Moreover, the tax liability was different for those neighboring fields that shared a pipeline to transport oil to facilities terminals. Thus, it was necessary to investigate alternative methods for re-allocating production from these fields in order to derive an accurate field factor for relative field contribution. The use of oil fingerprinting presented here is one method to re-assess and crosscheck individual field contributions of commingled pipeline oils. In addition, the oil fingerprinting method offers facility engineers an additional method to: (1) calibrate the oil flow meters, (2) measure oil flow vs. oil + water flow, (3) measure oil flow where flow meters are inaccessible, and (4) compensate for an insufficient number of flow meters.

2. Background

In an offshore basin located in Southeast Asia, oil and gas trapped against low relief, northeast trending faults are produced from A–D fields to the north, and E and G fields to the south (Fig. 1a). Production in the four northern fields started in late 1980s while production from southern fields began in mid-1990. Prior to 1994, oil produced from the four northern fields was transported to separators and production tanks through pipelines P2 and P5. Production from fields A and D was subject to excise tax at that time, while that from fields B and C was not. But, since B and C are small single well fields with limited production, impact of their production to pipeline allocation is relatively small.

However, from June 1994, E and G fields were developed, producing through pipeline P6, which commingles with P2 production on route to the terminal facilities via pipeline P5 (Fig. 1b). New productions from these two fields were not immediately subject to excise tax. The majority (~60%) of this offshore production comes from these fields. Because production from these wells is large and the oil properties very different, the volumes of oil contributed from northern and southern field groups were substantially different. Furthermore, the terminal tanks were the first point at which production was measured. Because of differential taxation for these fields, it was necessary to develop a method to reliably allocate production back to the two groups of oil fields. Based on early reservoir simulation studies, it was suspected that there was over-allocation to field A.

This report documents a geochemical approach that has helped production engineers to successfully solve the back allocation problem. Specifically, the approach uses oil fingerprinting to: (1) evaluate production from the same fields over time to ensure composition consistency, (2) determine relative proportions of north vs. south field oils in the pipeline P5 mixture, (3) determine relative proportions of E vs. G field oils in the pipeline P6 mixture, and (4) evaluate feasibility of using gas



(a) (b)

Fig. 1. (a) Location map of offshore producing fields, (b) and a sketch of pipeline routes.

chromatography to allocate pipeline mixes to field production for assessing tax liability.

3. Samples

As previously discussed, oils in this study were obtained from two groups of fields and pipelines in the basin. Based on geographic locations and timing of development, fields are grouped as the north production area consisting of fields A–D, and the south production area including fields E and G. The north production group produces light oil (gravity ~ 45–46°API) which contributes to pipeline P2. These fields, developed in late 1980s share the same production facilities including production and test separators, pipeline, storage tanks, and terminals. The south group produces crude with an intermediate gravity (~ 28–29°API) and contributes to pipeline P6 oils.

The first allocation study included a large number of oils from various producing fields and pipelines, which were analyzed for allocating pipeline P5 oil to production from contributing southern and northern fields that display distinctive oil fingerprints. Fourteen of the oils were from southern fields, E and G, while 16 oils came from northern fields (Table 1). Several of these oils were sampled on different dates to evaluate hydrocarbon composition changes over production time. Samples of unknown mixes from the pipelines were periodically collected. One sample consists of a mix of E and G oils

Table 1
Oil samples from various fields and pipelines in an offshore basin, Southeast Asia

ID	Field	Well	Sample date	Remark
Northern production area				
560191	E	#6	25/9/1994	Well head sample
560192	E	#6	3/11/1995	Well head sample
560201	E	#7	20/9/1994	Well head sample
560202	E	#7	3/11/1995	Well head sample
560211	E	#8	3/11/1995	Well head sample
560212	E	#8	20/9/1994	Well head sample
560221	E	#9	20/9/1994	Well head sample
560222	E	#9	3/11/1995	Well head sample
560231	E	#10	3/11/1995	Well head sample
560241	E	#11	20/9/1994	Well head sample
560242	E	#11	3/11/1995	Well head sample
560261	G	#5	20/9/1994	Well head sample
560262	G	#5	3/11/1995	Well head sample
538932	G	#1	26/11/1991	Well head sample
Southern production area				
559831	A	#13	16/9/95	Well head sample
559832	A	#13	3/11/1995	Well head sample
545611	A	#1	26/11/1994	Well head sample
545612	A	#1	7/11/1994	Well head sample
548641	A	#2	25/9/1994	Well head sample
548651	A	#4	3/11/1995	Well head sample
545621	A	#5	20/9/1994	Well head sample
548661	A	#5	3/11/1995	Well head sample
548671	A	#6	20/9/1994	Well head sample
548681	A	#7	20/9/1994	Well head sample
548682	A	#7	18/7/1995	Well head sample
548691	B	#6	3/11/1995	Well head sample
548701	C	#1	20/9/1994	Well head sample
548702	C	#1	18/7/1995	Well head sample
548703	D	#11	3/11/1995	Well head sample
545631	D	#3	20/9/1994	Well head sample
Pipelines				
560253	P6	Mix of E and G fields	3/11/1995	Pipeline sample
560271	P2	Mix of A,B,C,D fields	3/11/1995	Pipeline sample
560281	P5	Mix of all six fields	3/11/1995	Pipeline sample

(P6), a mix of oils produced from fields of A–D (P2), and the third a mixture of south (E and G fields) and north (A–D fields) production groups (P5). The second study focused on allocating pipeline P6 oils to contributing E and G fields that show somewhat similar oil fingerprints. The commingled E/G pipeline (P6) oil samples collected at four different times were analyzed along with produced oils from E and G fields to define pipeline allocation for E field versus G field production.

4. Methods

4.1. *Oil fingerprinting*

In this study, production allocation is based primarily on the interpretation and quantification of oil fingerprints (molecular composition) generated by capillary gas chromatographic analysis of whole oil. Gas chromatographic (GC) analyses were carried out using a HP 5890 GC equipped with a 15 m×0.32 mm DB-1 column (J&W Scientific, Inc.) with a film thickness of 1 μm. The GC oven was programmed from 50 to 300°C at 3.5°C/min. The helium flow rate was 2.6 ml/min, and the split ratio was 10:1. Typically, 0.8 μl of oil samples were injected. Chromatographic reproducibility is better than 5% and generally within 3%. GC–MS analyses of the oils and fractions were performed with an HP 5790 mass selective detector (MSD), a bench top quadrupole mass spectrometer, coupled directly to an HP 5790 gas chromatograph. Selected samples were analyzed for biomarker distributions in a SIM (selective ion monitoring) mode for the MS data acquisition. Details in oil fractionation and GC–MS analyses have been described by Hwang (1990).

In many case studies, it has been demonstrated that oils from a single reservoir have nearly identical fingerprints, whereas oils from separate reservoirs and fields have consistent fingerprint differences (Kaufman et al., 1990; Hwang et al., 1994). Composition differences of oils from different fields is usually much larger than between reservoirs of the same field. The magnitude of the differences between oils is determined by comparing ratios of corresponding peak heights of capillary gas chromatograms with an in-house developed computer program.

A set of peak ratios, chosen to maximize the differences among the oils, are the basis for 'star diagrams' which plot the ratios in polar configuration for ease of comparison, and for 'cluster diagrams' (dendrogram) which group the oils based on composition similarity or dissimilarity. The smaller the cluster distance (i.e. tighter the groups), the more similar the elements of the group, in this case oil composition. Analytical precision of the chromatograph is about 1–3%. Thus, peak ratio differences of 5–10% (or more) cannot be attributed to analytical error and must represent real compositional differences among the oils. Eight to 10 such ratios are sufficient to separate the oils in meaningful groups. Details of peak selection for oil correlation and grouping were described by Hwang et al. (1994).

4.2. *Allocation of commingled oils*

Allocation of a pipeline oil to individual fields was conducted by identifying end-member oils (fields) first. This was followed by preparing laboratory mixtures of known proportions of end-member oils that were analyzed along with unknown pipeline oil mixtures. Quantitative results were attained using an in-house developed computer program which mathematically calculates relative contributions (±3%) of oil mixes based on a best-fit least-squares regression of selected chromatographic peak ratios (Hwang and Elsinger, 1995). The allocation results of the chromatographic method are compared with those based on API gravity.

5. Results and discussion

5.1. *Geochemical characterization of crude oils*

Source and thermal maturity characteristics of the oils were assessed by their biomarker distributions. Despite that southern field oils are biodegraded (Fig. 2), biomarkers remain intact in these oils. The oils produced from northern and southern fields share the same source as indicated by very tight sterane and diasterane distributions (Table 2A). Other biomarker source parameters including hopanes/steranes and triaromatic steroids ratios, C_{26}/C_{28} 20*S* and C_{27}/C_{28} 20*R*, are also highly similar supporting that the oils have originated from the same source. Slight differences in a few source parameters such as C_{29}/C_{30} hopanes and abundance in C_{30} steranes suggest minor variation in source faices among the oils.

Both northern and southern field oils are moderate in thermal maturity as evidenced by their low values in sterane isomerization ratios, $20S/(20R+20S)$ and $\alpha\beta\beta/(\alpha\beta\beta+\alpha\alpha\alpha)$ of C_{29} steranes, that have not reached equilibrium (Table 2B). However, northern field oils are consistently higher in all thermal maturity parameters indicating northern field oils are more mature than southern field oils.

5.2. *Chromatographic oil fingerprints*

Variation in fingerprints among the oils produced from northern and southern fields appears mainly due to differences in thermal maturity and biodegradation. In general, fingerprints of oils from field E (Fig. 2) sampled at different dates are remarkably similar despite the fact that they are moderately biodegraded. The oils are characterized by the absence of *n*-paraffins, the predominance of branched and cyclic hydrocarbons and a significant 'unresolved complex mixture' (UCM) hump shown on the chromatograms. The fingerprint similarity among the oils from various wells in field E suggests a laterally continuous reservoir that is in fluid communication (Kaufman et al., 1990; Hwang et al., 1994).

Oils from field G are also biodegraded to the same degree as those from field E. Although similar in hydrocarbon profiles, G-field oils contain slightly more abundant light hydrocarbons (gasoline range) than E-field oils (Fig. 2). Small but consistent composition differences in the range of light to intermediate hydrocarbons allow easy differentiation between G- and E-field oils. These small differences in relative abundance rather than chemical nature of the hydrocarbons

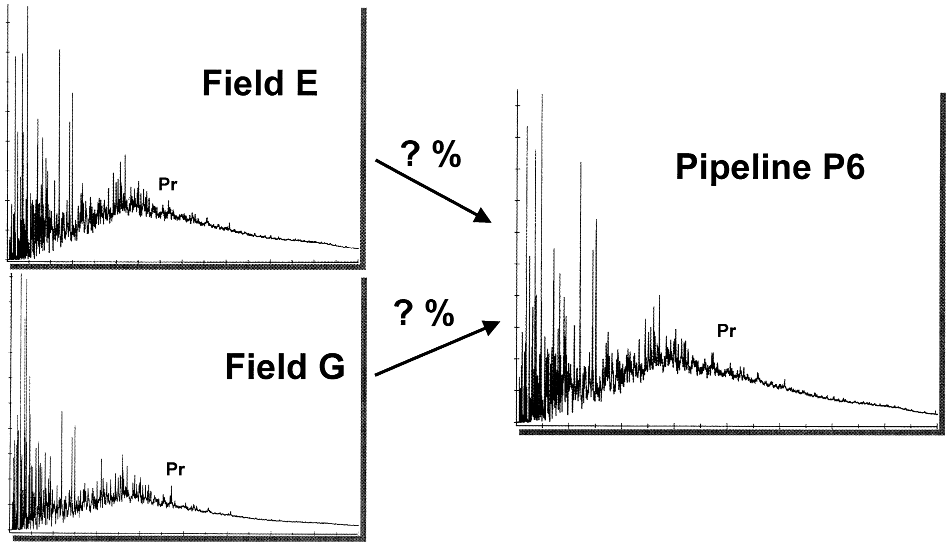


Fig. 2. Gas chromatograms showing similarities of hydrocarbon composition between E and G field production (Pr, pristane). Production in fields E and G is commingled into pipeline P6.

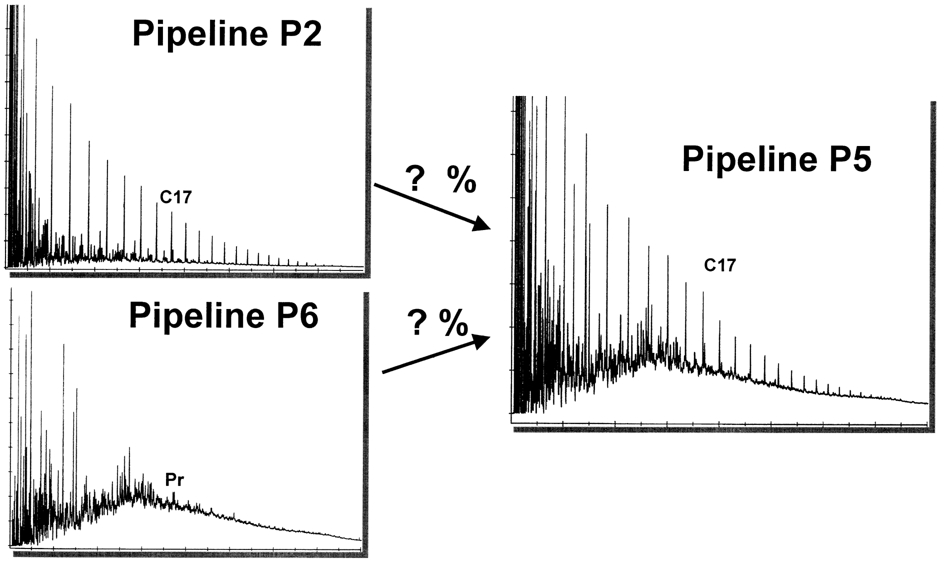


Fig. 3. Allocation of individual pipeline oils back to field production can be achieved by deconvoluting oil fingerprints. Pipeline P2 (fields A–D) and pipeline P6 (fields E and G) are commingled into pipeline P5.

Table 2

(a) Biomaker source parameters of oils from an offshore basin, Southeast Asia[a]

ID	Field	Steranes				Diasteranes				C29/C30H	Hop/St	Triaromatic steroids[b]	
		C27%	C28%	C29%	C30%	C27%	C28%	C29%	C30%			C26/C28	C27/C28
559831	North	31.14	22.41	46.46	5.06	42.46	16.60	40.95	1.56	0.32	2.75	0.50	0.89
560211	South	32.38	23.96	43.66	3.61	45.26	15.92	38.83	1.49	0.13	2.82	0.47	0.76

(b) Biomaker maturity parameters of oils from an offshore basin, Southeast Asia[c]

ID	Field	20*S*/20*R*	abb/aaa	Diast/St	Ts/Ts+Tm	C29Ts/C29H	H/H+MC29	H/H+MC30	22S/R C31	22S/R C32	Tri/Hop	I/I+II MA	I/I+II TA
559831	North	0.48	0.52	1.00	0.60	0.42	0.84	0.86	0.61	0.53	0.32	0.52	0.69
560211	South	0.38	0.42	0.38	0.57	0.39	0.82	0.84	0.57	0.53	0.13	0.36	0.49

[a] C30% steranes: C30/(C27+C28+C29+C30)×100; C30% diasteranes: C30/(C27+C28+C29+C30)×100; C29/C30 H: C29/C30 hopane; Hop/St: hopanes (C27–C35)/steranes (C27–C29).

[b] C26/C28: C26/C28 20*S*; C27/C28: C27/C28 20*R*.

[c] 20*S*/20*R*: 20*S*/20*S*+20*R* C29 steranes; αββ/ααα: αββ/ααα+αββ C29 steranes; Diaast/St: diasteranes/steranes; C29Ts/C29H: C29s/C29Ts+C29H; 22*S*/*R*: 22*S*/22*S*+22*R* C31; 22*S*/22*S*+22*R* C32; Tri/Hop: tricyclics (C28+C29)/C30 hopane; I/I+II MA or TA: short side chain vs long side chain of mono- or tri-aromatic steroids.

provide the basis for allocating P6 pipeline oils (Fig. 2) to production of individual E and G fields, which will be discussed below.

The oil from field A (represented by pipeline P2) is dramatically different from E- and G-field oils (Fig. 3). It is not biodegraded, contains significant amounts of *n*-paraffins through C_{35}, abundant isoprenoids through C_{20}, and has a high pristane/phytane ratio of about 3.5. Like the oils in the E-field, the oils produced from the G-field are highly similar in fingerprints indicating a laterally and vertically continuous reservoir for the field. The oils produced from adjacent fields, B–D resemble A-field oils and thus their fingerprints can be pretty much represented by those of A-field oils (Fig. 3). Both B and C are one-well fields and their contribution to P2 pipeline oils is small (Fig. 3).

The oils in the pipeline P5 which are mixes of oils from pipelines P2 and P6 display a high content of *n*-paraffins with a significant UCM hump of non-paraffinic hydrocarbons centered around C_{15}–C_{16}. These are combined features of oils produced from fields in the north and south production areas (Fig. 3).

5.3. Oil–oil correlation

Oil–oil correlation was completed by detailed comparison of oil fingerprints (capillary gas chromatograms) using a computer program that generates and ranks chromatographic peak ratios for their ability to separate oils into groups. The initial comparison consists of 14 oils produced from southern fields and 16 oils produced from northern fields. The results of this correlation show three distinct groups (Fig. 4). Eleven of the oils have a distinct E-field signature, three a G-field signature, and 16 a northern-fields (or A-field) signature. The distances between the groups (along the *x*-axis) are a relative measure of the magnitude of differences among the oils. Here, E- and G-field oils are clearly separable with small compositional differences, whereas the northern-fields oils are compositionally very distinct. Chromatographic peaks selected for separating oils into groups have been chemically identified by GC–MS analyses and are listed in Table 3 for their compound identification.

The tight cluster distances within each group of oils clearly indicate that production from the wells of E-field has not changed in composition between September 1994 and November 1995, and from November 1991 to November 1995 for the wells of G-field. The E-field wells cluster tight enough to possibly be considered as producing from a laterally continuous reservoir. The distances between E- and G-clusters indicate oil compositions are sufficiently different as to be useful end-members for production allocation assessment of commingled E/G pipeline (P6) oils collected at different times.

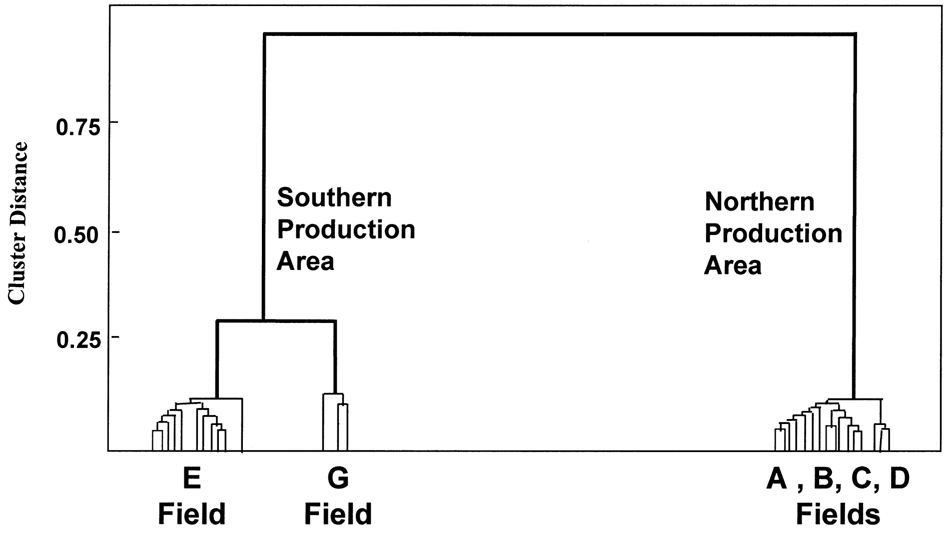


Fig. 4. Cluster diagram showing oil groups based on oil fingerprinting of hydrocarbon composition.

5.4. Production allocation

5.4.1. Allocating pipeline P5 oils — north vs. south production

Initially, there were no separators and metering devices dedicated to E- and G-fields for measuring their production rates. Thus, the development of a method to accurately allocate or cross check pipeline P5 oils back to field contribution was economically very important. The excise tax rate charged to the southern area production from fields E and G was much lower than that charged to the northern area production from fields A–D.

The commingled pipeline P5 oil sampled on 3 November 1995 was first analyzed by gas chromatography for fingerprint to test its feasibility for allocation evaluation (Table 4). Commingled oils from two other pipelines, P6 and P2, sampled at the same date as the P5 oil were also analyzed for comparison. Allocation calculation is achieved by choosing peak ratios known to change linearly between end-members and their laboratory mixes. Fig. 5 shows five peak ratios having high correlation coefficients indicating they vary in an almost linear fashion with laboratory mixes. When these ratios are used in allocation calculation, the pipeline P5 oil collected in early November 1995 allocates to 62% from the southern area production (fields E and G) and 38% from the northern area (fields A, B, C, and D) production (Table 5A). Verification that these ratios do in fact allocate correctly can be determined by using the same ratios to allocate the known mixtures prepared in the laboratory. The low percentage difference between the allocated mixtures and the actual mixtures indicate allocation for unknown pipeline samples has about a ±0–3% error (Table 4). Small errors seen in the allocation calculation of laboratory mixes cast a high degree of confidence on the oil fingerprinting method for allocation of commingled pipeline oils.

After establishing confidence on the gas chromatographic fingerprinting method, production allocation was performed on a series of oil samples collected from

Table 3
Chemical identification of chromatographic peaks used in allocation calculation[a]

Peak#	Retention time (min)	Compound ID
53	6.49	Dimethyl octane
54	6.56	C4-Subst. cyclohexane
56	6.74	2,5-Dumethyl octane
62	7.21	Dimethly octane
63	7.66	C5-Subst. cyclopentane
68	8.19	4-Methyl nonane
71	8.51	3-Methyl nonane
72	8.63	C3-Subst. methylcyclohexane
86	10.66	*n*-Butyl cyclohexane
112	14.38	2-Methyldecaline + dimethyl decane
123	16.11	4-Methyl undecane
140	18.64	Dimethyl undecane
142	18.83	Dimethyl undecane
166	22.12	C7-Subst. cyclohexane
168	22.34	C14 Branched alkane
179	24.41	2-Methyl tridecane
182	24.87	2,6,10-Trimethyl dodecane
196	26.95	C15 Branched alkane
198	27.04	C15 Branched alkane

[a] GC conditions: DB-1, 15 m×0.32 mm, 50–305°C@ 3.5°C/min.

Table 4
Samples of pipelines P5 and P6 and laboratory mixtures

ID no.	End member	Lab mix (%)	Calculated allocation (%)	% Difference	API gravity
Known laboratory mixtures for calibrating allocation of P5 pipeline oils					
55983AF	A	100	100	0.0	47.6
RS2080	A	80	80.3	0.3	46.0
	E	20	19.6	0.4	
Alpha.F	A	60	59.1	0.9	39.2
	E	40	40.8	0.8	
RS5050	A	50	51.6	1.6	37.9
	E	50	48.3	1.7	
Alpha2F	A	40	42.6	2.6	34.8
	E	60	57.3	2.6	
RS8020	A	20	20.4	0.4	31.3
	E	80	79.5	0.5	
560192F	E	100	100	0.0	28.8
Known laboratory mixtures for calibrating allocation of P6 pipeline oils					
560192	E-6	100			29.3
SR7525	E-6	77.2	78.2	1	29.6
	G-5	22.8	21.8	1	
SR5050	E-6	51.40	50.40	1.36	30.5
	G-5	48.60	49.96	1.36	
SR7525	E-6	26.70	27.53	0.83	31.0
	G-5	73.30	72.47	0.83	
560261	G-5	100			31.7
Pipeline oils			(sample date)		
560271	Pipeline P2	(mix of A, B, C, D fields)	3/11/95	48.0	
Unknown mixtures for production allocation					
560281	Pipeline P5	(mix of P2 and P6 pipelines)		3/11/1995 and later	33.4
560253	Pipeline P6	(mix of E and G fields)		3/11/95	30.2
5602510	Pipeline P6	(mix of E and G fields)		26/7/96	29.9
5602511	Pipeline P6	(mix of E and G fields)		26/9/96	30.1
5602512	Pipeline P6	(mix of E and G fields)		17/10/96	30.1

pipeline P5 at different times. Table 5A summarizes chromatographic analysis and allocation results of the P5 pipeline oils collected in a period of 4 months. The results clearly indicate contribution of production from two groups of fields to pipeline P5 changes through time (Fig. 6). During this period, production contribution from the northern group (or P2) to pipeline P5 oils varies from 34 to 46%. This variation is significant when compared to small errors (0–3%) associated with the method. To further validate the method, the chromatographic allocation results were compared with field production data based on production history of individual wells. The production data of individual wells were scarce because of limitation of measurement devices. Table 6A list production data of individual fields in a given day in December 1995. Allocation of pipeline P5 oils based on production data compares very favorably with the GC results on the December samples. The close agreement (within 3%) observed here indicates validity of the GC fingerprinting method.

API gravity can also be used to allocate commingled mixtures, particularly when the end-members have large differences in oil density. API gravity of the lab mixture oils was measured along with those of the pipeline oils P2, P6 and P5 and results plotted in Fig. 7. The gravity of the pipeline oil P5 at 33.4°API indicates a mixture of about 30% the northern area production and 70% the southern area production (E/G), which has about a 10% deviation from actual production data. As for oils from pipelines P2 and P6, their API gravities are very

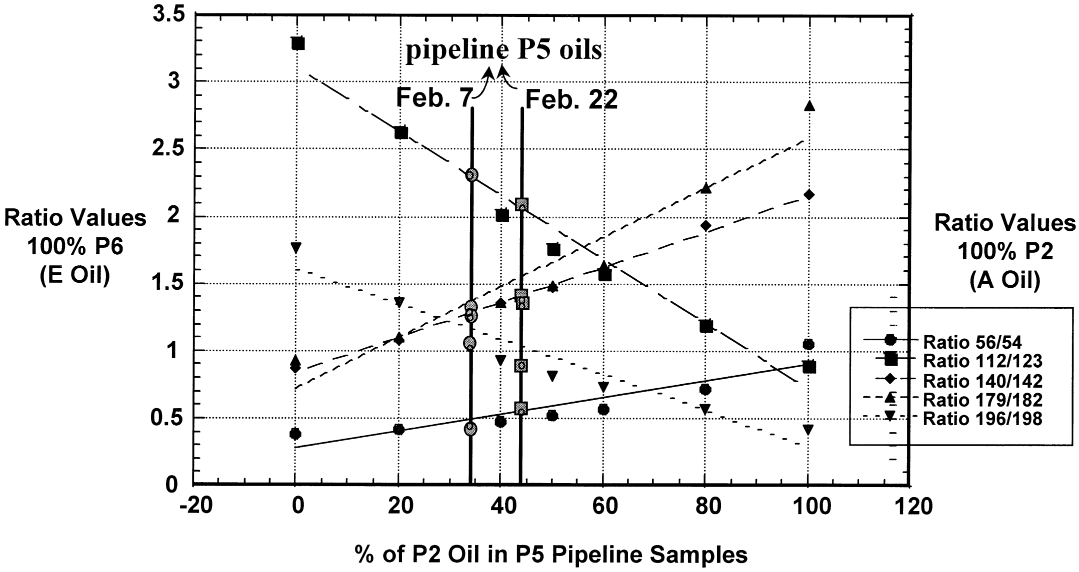


Fig. 5. Mixing program based on end member ratios of fields A and E oils indicating the Feb 7 sample of pipeline P 5 contains a 34–66% northern and southern oil mix whereas the Feb 22 sample a 43–57% mix.

Table 5

(a) Allocation results of pipeline P5 oils collected at different times

Sample	ID#	Sample date	56/54	112/123	140/142	179/182	196/198	P2 pipeline (%)	P6 pipeline (%)
End-member wells									
A-13	559831	2/11/95	1.0582	0.8929	2.1658	2.8363	0.4242	100	0
E-6	560192	28/11/95	0.3464	3.2881	0.8759	0.9339	1.7591	0	100
Pipeline oils									
Pipeline P5	560281	3/11/95	0.5156	2.1871	1.2139	1.2238	0.7973	38	62
Pipeline P5	560281	3/11/95[a]	0.5037	2.2607	1.2534	1.2524	0.9167	36	64
Pipeline P5	560284	5.12.95	0.4986	2.1797	1.2845	1.2778	0.9368	38	62
Pipeline P5	560285	23/12/95	0.5191	1.9805	1.3852	1.3963	0.8498	46	54
Pipeline P5	560286	13/1/96	0.5205	2.0397	1.3614	1.3852	0.8695	44	56
Pipeline P5	560287	7/2/96	0.4973	2.3355	1.2302	1.2698	1.0211	34	66
Pipeline P5	560288	22/2/96	0.5144	2.0694	1.3653	1.3601	0.8773	43	57
Pipeline P5	560289	5/3/96	0.4942	2.3054	1.2444	1.2342	0.9705	34	66
Pipeline P5	5602810	27/3/96	0.5099	2.0991	1.35	1.3235	0.8914	41	59

(b) Field allocation of pipeline P6 oils collected at different times

Sample	ID#	Sample date	62/63	72/86	68/71	53/56	168/166	Field E allocation (%)	Field G allocation (%)
End-member wells									
E-6	560192	28/11/95	2/3147	1.2553	1.3129	0.371	0.6011	100	0
G-5	560261	20/9/94	3.1665	0.744	0.7516	0.2899	1.3649	0	100
Pipelines									
Pipeline P6	560253	3/11/95	2.3419	1.2538	1.3036	0.3825	0.5653	100	0
Pipeline P6	5602510	26/7/96	2.3351	1.2847	1.3254	0.387	0.5696	100	0
Pipeline P6	5602511	26/9/96	2.5516	1.4110	1.1447	0.3763	0.7164	77.80	22.20
Pipeline P6	5602512	17/10/96	2.4352	1.1928	1.2141	0.3793	0.6211	89.80	10.20

[a] Duplicate analysis

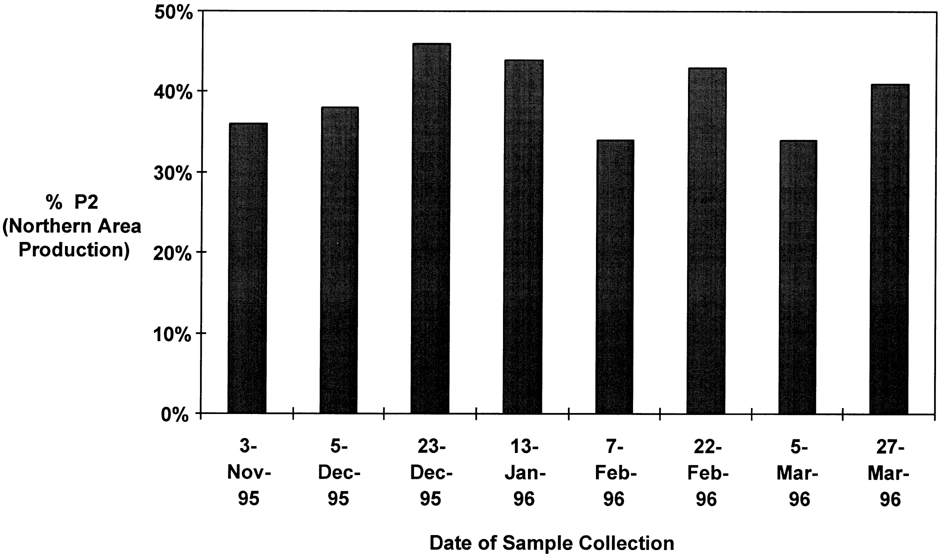


Fig. 6. Allocation of pipeline P5 oils over a 5-month interval using oil fingerprint.

Table 6
(a) Comparison of oil fingerprinting results and production data

Field	Production (BOPD)[a]	Pipeline	Proportion (%)[b]	Calculated allocation (%)[c]
Northern field				
A	17184	P2		
D	2439	P2		
B	383	P2		
C	549	P2		
			$\sim$41	38
Southern fields				
E	29075q	P6		
G	333	P6		
			$\sim$59	62
Total	499963			

(b) Comparison of different allocation approaches and production data for allocating pipeline P6 oils

Sample date	Production (%)[d]	Fingerprinting allocation (%)[e]	API gravity allocation (%)[f]
November 1995	–	0	45
July 1996	0	0	32
September 1996	15–20	22	43
October 1996	11	10	43

[a] Production data of a given day in December 1995.

[b] Proportion based on production data.

[c] Based on oil fingerprints of pipeline P5 oil samples obtained in December 1995.

[d] G field contribution to pipeline P6 based on spotty production data.

[e] Calculated allocation of field G production contribution was based on oil fingerprints of pipeline P6 oil samples.

[f] Allocation of field G production was based on API gravity measurements of oils.

close to end-member values (Fig. 7). In these cases, production allocation of the pipeline oils becomes extremely difficult since gravity measurement error (5–10%) masks small oil contributions.

5.4.2. Allocating pipeline P6 oil — fields E vs. G production

The need for allocating of pipeline P6 oils to production in fields E and G became apparent when significant fluctuation in field production was suspected. Monitoring the fluctuation can help devise the plan for effective reservoir management. Four commingled E/G pipeline (P6) oils collected at different times were analyzed for allocation evaluation (Table 4).

A new set of chromatographic peak ratios was selected because the end-members in this allocation were different from those in the allocation of pipeline P5 oils (Table 5B). Allocation calculation shows that the oil collected in September 1996 consists of about 78% E field production and 22% G field production whereas the oil collected in October 1996 contains about 90% of E field production and 10% G field production. Pipeline P6 oils collected on 27 November 1995 and 26 July 1996 contain only oils produced from the E field with no contribution from the G field (Table 5B). Laboratory

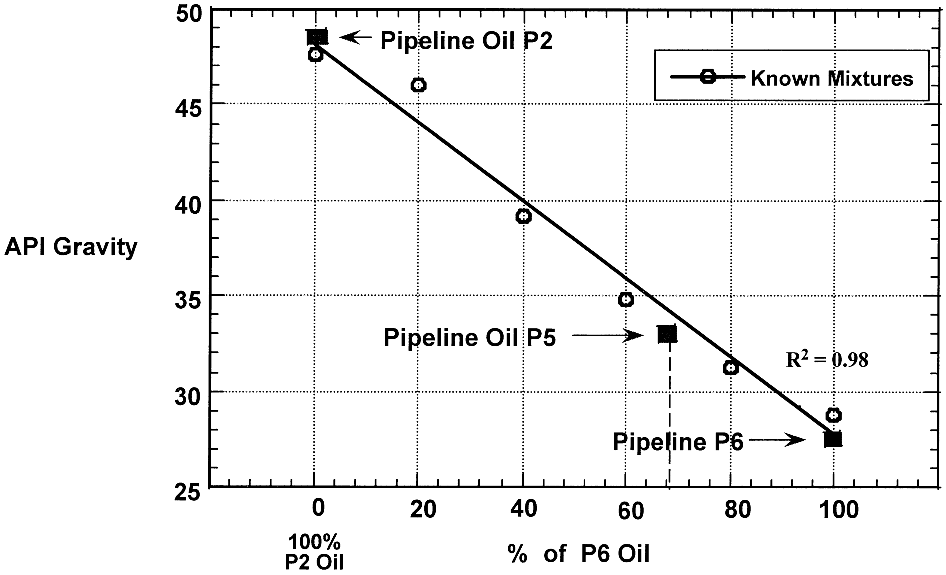


Fig. 7. Correlation between API gravity and known mixtures of fields A and E oils for estimating allocation of pipeline oil samples.

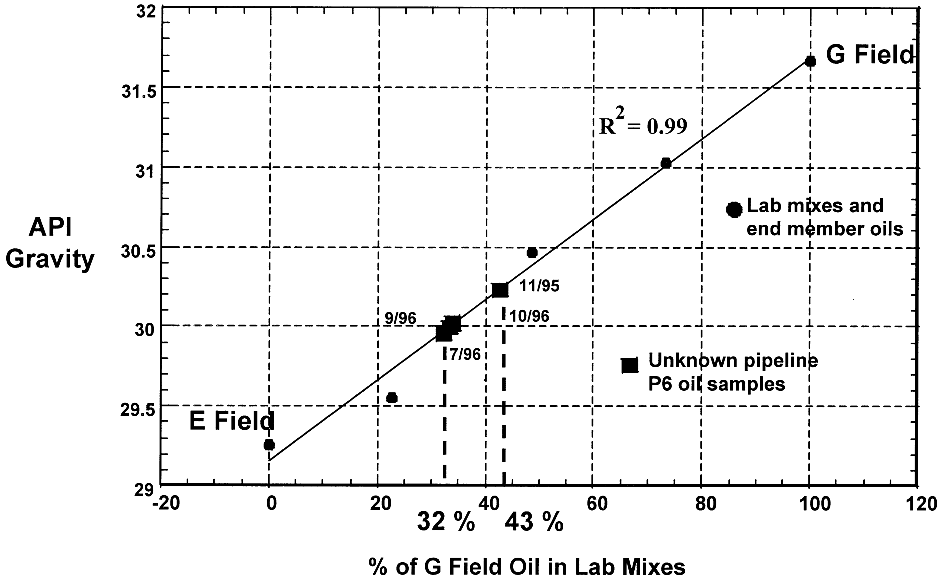


Fig. 8. Linear correlation between API gravity and known mixtures of E and G fields oils for estimating allocation of pipeline P6 oil samples. API data over-allocate contribution from G field (32–43%) compared to production and GC methods that indicate ~ 20% contribution from G field.

mixtures of the same two end-members were also analyzed and allocated accordingly. The small difference between the allocated mixtures and the actual mixtures indicate allocation for unknown pipeline P6 samples has about an error of less than 2% (Table 4). Again, the chromatographic allocation results were compared with spotty field production data for further validation. Table 6 list allocation results of pipeline P6 oils in 1995–1996 based on the production data that are in good agreement with fingerprinting results.

In comparison, allocation of P6 pipeline oils based on API gravities of oils from E and G fields yielded large errors, 20~45% (Table 4 and Fig. 8). Apparently, oil fingerprinting is the method of choice for allocating P6 pipeline oils to production in these two fields.

6. Conclusions

Based on the computerized comparison of capillary gas chromatographic fingerprints of pipeline oils and crude oils produced from various fields and the calibration using laboratory mixtures, the following conclusions have been reached.

1. Oil fingerprinting with gas chromatography is a viable method to accurately allocate commingled pipeline oils to production of contributing fields. It complements the widely used engineering method such as production metering and enables production monitoring to be conducted frequently and inexpensively.
2. The results of allocation calculation of commingled pipeline oils based on their chromatographic fingerprints are in excellent agreement (within 3%) with actual production data.
3. Production allocation based on API gravity measurements yielded relatively large errors (~10%) and was only feasible for end-member oils with large density differences. Allocation of pipeline oils with similar API gravities in end-member oils from contributing field led to large errors, 20~45%.
4. The oil fingerprinting technique for production allocation provides rapid results for an accurate assessment of tax liability and for taking measures in effective reservoir management. In addition to addressing allocation issues of current production, the technique can also work on allocation of the past production if oil samples from the past production are available. It not only complements production metering methods but also be a method of choice when meters are not available.

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