A Four Coefficient Model for Extending the Heptanes-Plus Fraction for Gas Condensate Systems

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Extended analysis:

A description of pseudo-component or SCN composition (Mole %, mole fraction, Wt %)

An integral part of the reservoir fluids characterization process

A fundamental requirement for EOS predictions

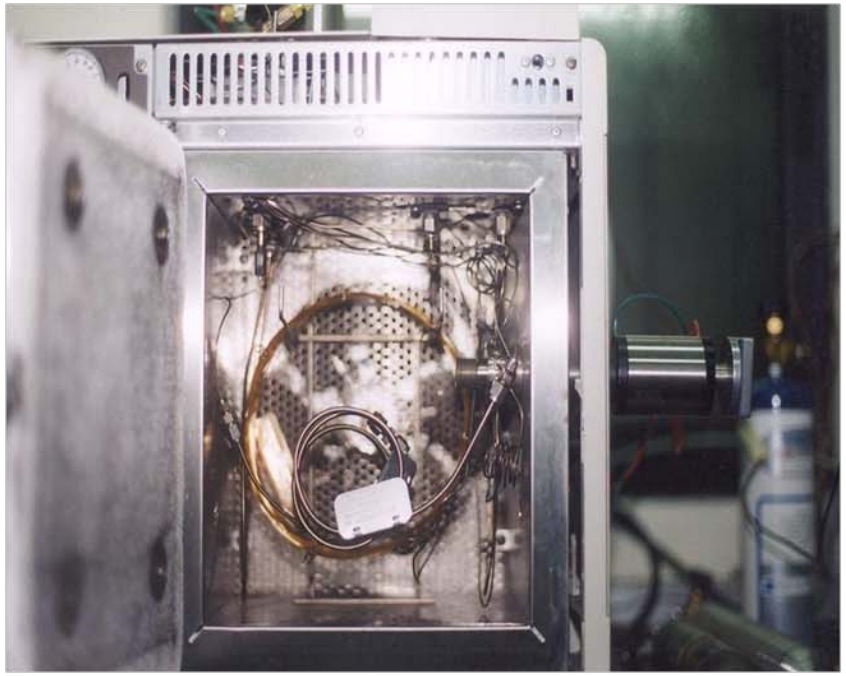
Extended analysis is obtained :

- Experimentally from Chromatographic analysis.
- Mathematical relationships between Composition and SCN or Molecular Weight.

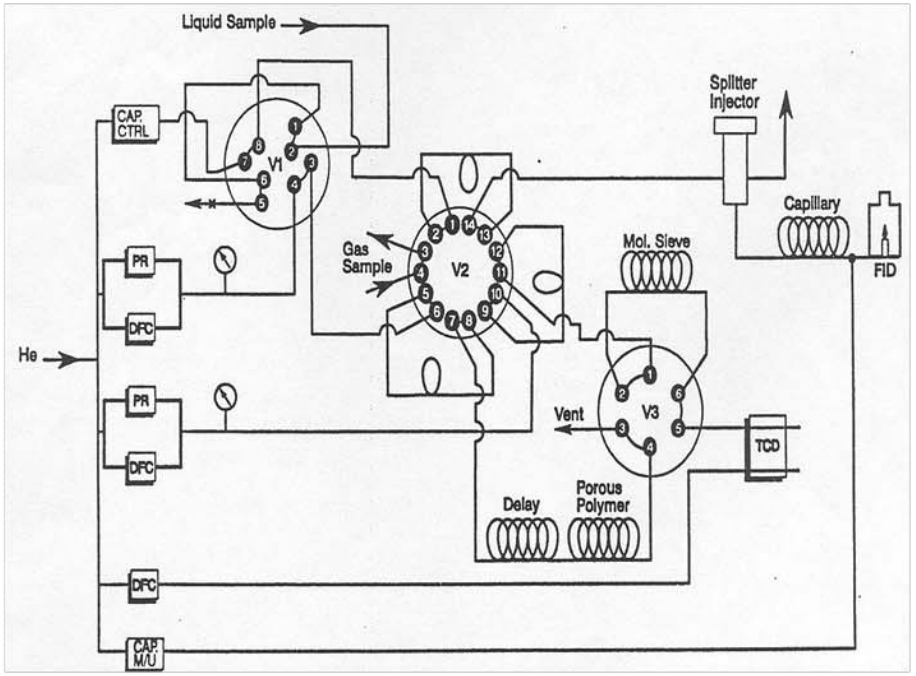
— Yarborough (1978), Pedersen et el. (1984): Continuous Exponential relation

— Whitson (1983): Gamma Probability Function

— Ahmed (1985): Two coefficient Splitting Scheme



Gas Chromatograph



Schematic of Gas Chromatograph

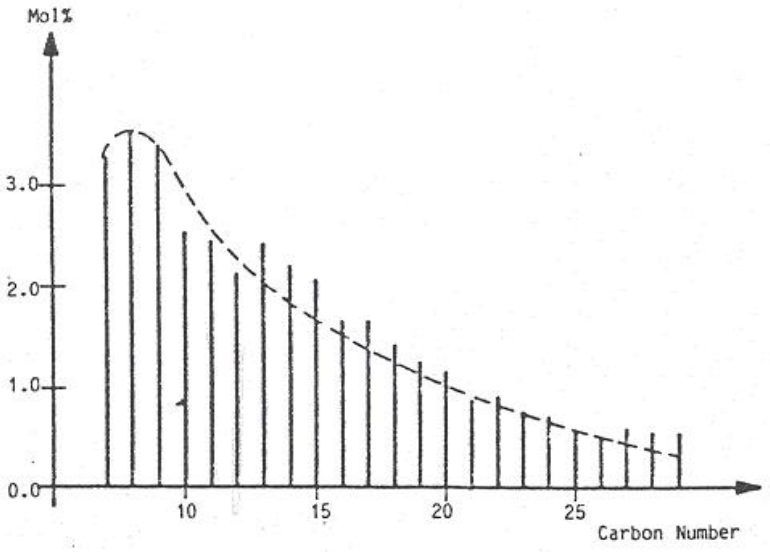
Table 1: Compositions of the SCN Groups and the Properties of the C_{7+} Fractions of the 20 Samples used in this work.

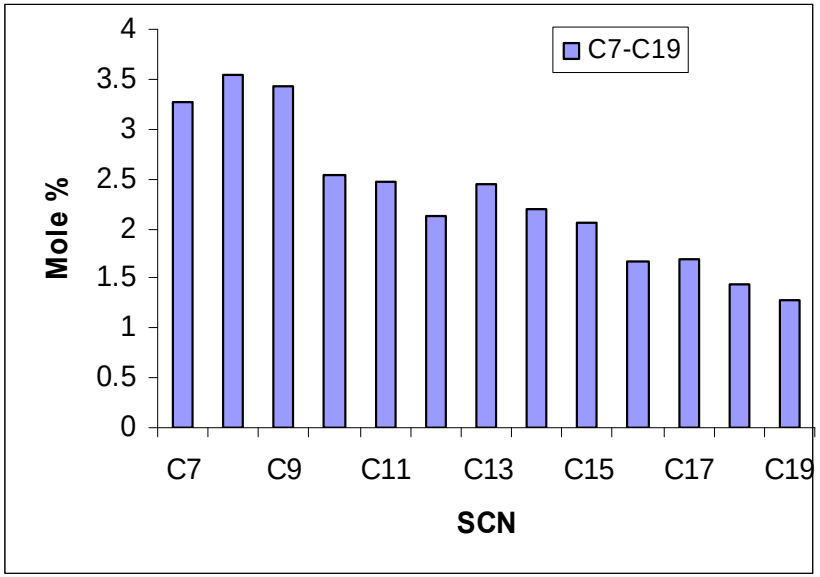
SCN	DS1 Mole % (Ref. 7)	DS2 Mole % (Ref. 7)	DS3 Mole % (Ref. 7)	DS4 Mole % (Ref. 7)	DS5 Mole % (Ref. 7)	DS6 Mole % (Ref. 7)	DS7 Mole % (Ref. 7)	DS8 Mole % (Ref. 7)	DS9 Mole % (Ref. 7)	DS10 Mole % (Ref. 7)
7	0.294	0.307	0.368	0.346	0.353	0.414	0.390	0.523	0.458	0.508
8	0.367	0.380	0.471	0.444	0.457	0.504	0.486	0.633	0.583	0.652
9	0.234	0.205	0.297	0.308	0.304	0.310	0.322	0.352	0.319	0.353
10	0.159	0.157	0.208	0.231	0.222	0.215	0.225	0.238	0.245	0.286
11	0.112	0.113	0.141	0.165	0.162	0.162	0.171	0.196	0.196	0.194
12	0.070	0.071	0.089	0.108	0.118	0.100	0.115	0.110	0.127	0.134
13	0.080	0.079	0.101	0.122	0.129	0.112	0.123	0.123	0.148	0.146
14	0.056	0.062	0.079	0.095	0.101	0.090	0.106	0.099	0.105	0.121
15	0.046	0.053	0.069	0.084	0.088	0.079	0.093	0.086	0.093	0.103
16	0.039	0.039	0.052	0.068	0.068	0.064	0.069	0.066	0.074	0.077
17	0.032	0.032	0.045	0.059	0.059	0.056	0.059	0.055	0.066	0.065
18	0.027	0.028	0.037	0.049	0.052	0.047	0.054	0.047	0.054	0.052
19	0.019	0.021	0.031	0.040	0.044	0.039	0.043	0.039	0.045	0.041
C20+	0.057	0.069	0.134	0.149	0.232	0.218	0.222	0.184	0.240	0.187
$zC_{7+\,(Mole\ \%)}$	1.592	1.616	2.122	2.268	2.389	2.41	2.478	2.751	2.753	2.919
SG_{7+}	0.785	0.7869	0.7918	0.7967	0.8049	0.801	0.802	0.793	0.8004	0.7939
MW_{7+}	141	143	148	153	162	157	159	148	157	150

SCN	DS11 Mole % (Refs. 2, 9)	DS12 Mole % (Ref. 7)	DS13 Mole % (Ref. 7)	DS14 Mole % (Refs. 7)	DS15 Mole % (Refs. 4, 7)	DS16 Mole % (Refs. 2, 17)	DS17 Mole % (PVT Report)	DS18 Mole % (Ref. 7)	DS19 Mole % (Refs. 4, 7)	DS20 Mole % (PVT Report)
7	0.750	0.588	0.561	0.990	1.090	1.214	1.090	1.130	1.700	1.170
8	0.750	0.729	0.789	1.020	1.470	1.173	1.390	1.220	1.950	1.420
9	0.490	0.491	0.491	0.680	0.950	0.860	0.890	1.010	1.460	1.120
10	0.310	0.327	0.354	0.520	0.650	0.687	0.730	0.870	1.050	0.910
11	0.220	0.246	0.267	0.390	0.440	0.568	0.560	0.660	0.740	0.760
12	0.150	0.156	0.176	0.310	0.330	0.478	0.430	0.530	0.570	0.550
13	0.120	0.169	0.197	0.270	0.310	0.407	0.420	0.470	0.570	0.590
14	0.090	0.151	0.170	0.230	0.240	0.350	0.370	0.410	0.450	0.470
15	0.070	0.121	0.144	0.190	0.200	0.302	0.360	0.350	0.380	0.410
16	0.050	0.098	0.119	0.140	0.140	0.262	0.270	0.300	0.300	0.340
17	0.040	0.085	0.104	0.120	0.120	0.228	0.250	0.260	0.260	0.300
18	0.030	0.076	0.099	0.120	0.110	0.199	0.220	0.230	0.240	0.300
19	0.020	0.064	0.080	0.100	0.090	0.174	0.210	0.220	0.210	0.270
C20+	0.030	0.344	0.373	0.430	0.390	1.307	1.650	1.680	0.990	2.370
$zC_{7+\,(Mole\ \%)}$	3.210	3.645	3.924	5.51	6.53	8.210	8.840	9.340	10.870	10.980
SG_{7+}	0.774	0.8021	0.8031	0.793	0.793	0.816	0.831	0.828	0.810	0.863
MW_{7+}	132	159	160	154	148	184	198	185	173	218

Continuous Exponential relation

- Yarborough (1978)
- Pedersen et al (1984, 1987)





Molar Distribution of SCN Fractions for North Sea Sample (Source: Pedersen et al. 1987)

Continuous Logarithmic Distribution

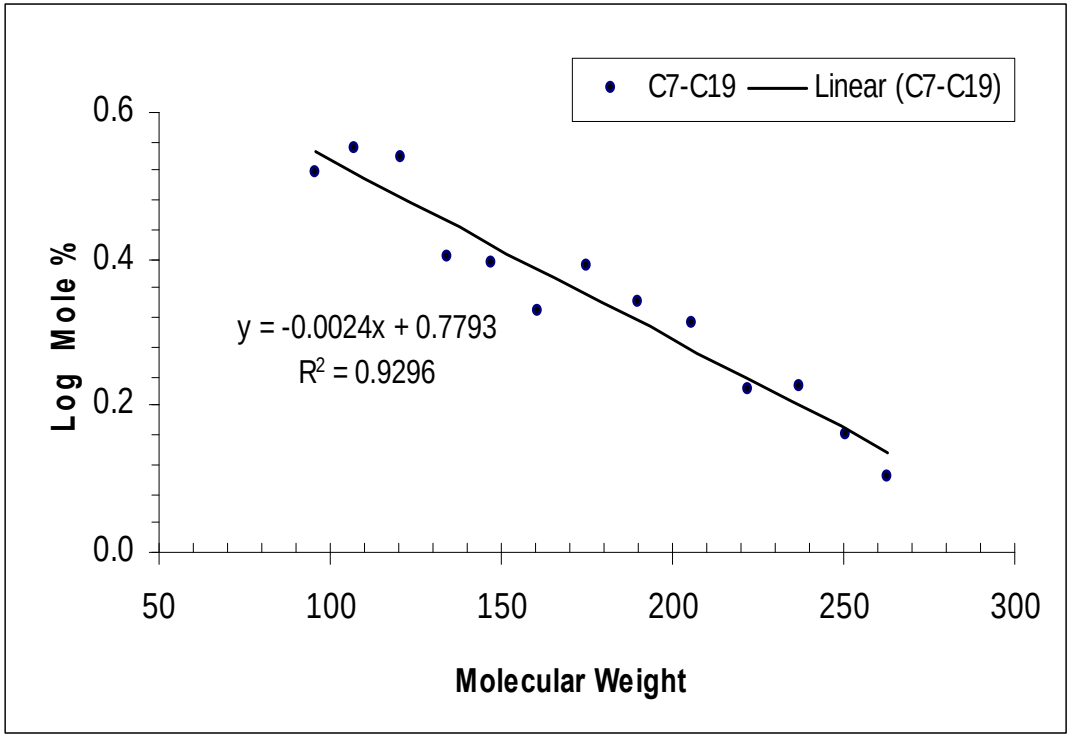
$\log z_n = A + B(MW_n)$

Where:

z_n = mole percent

MW_n = molecular weight

A, B = constants



Molar Distribution of SCN Composition for North Sea Sample (Source: Pedersen et al. 1987)

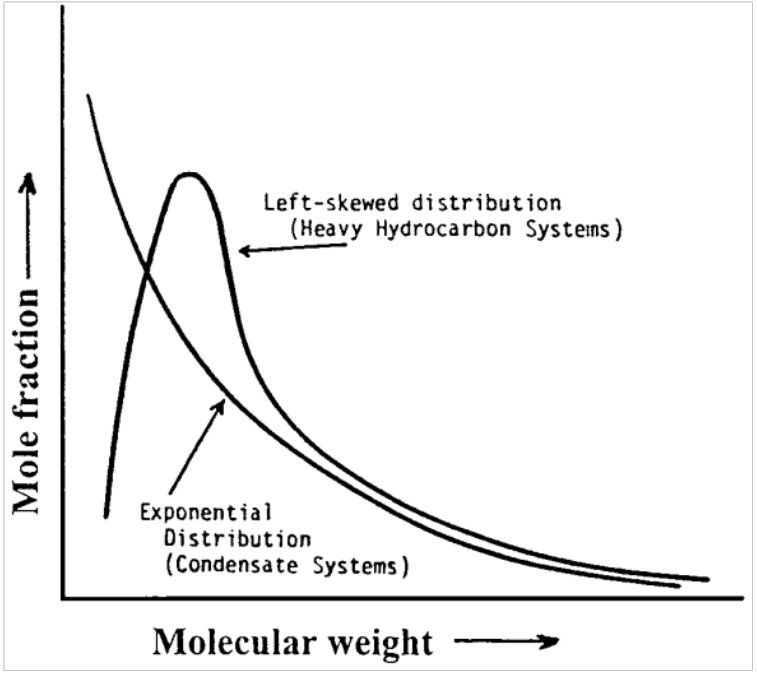
Gamma Probability Function

$$P(x) = (x-\eta)\alpha-1 \exp[-(x-\eta)/\beta] / \beta \alpha \Gamma(\alpha)$$

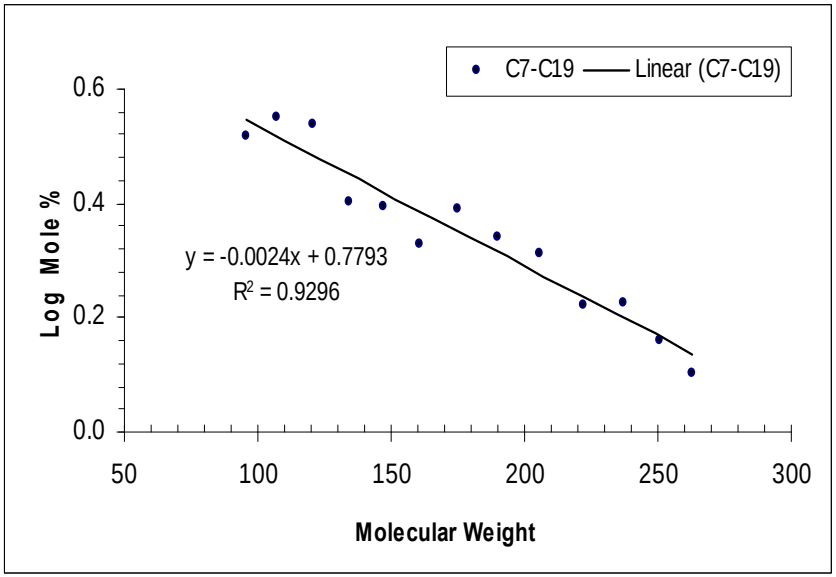
Where: α, β and η are parameters defining the distribution (Whitson 1983)

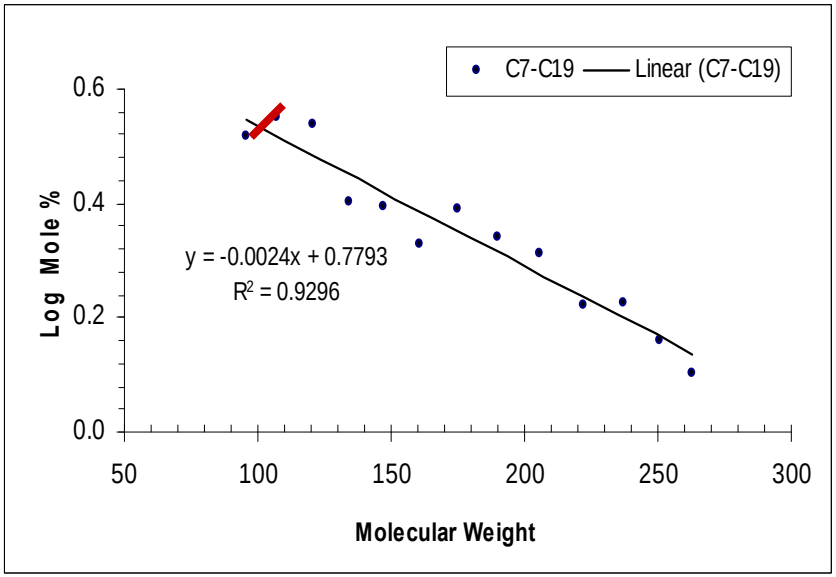
Basic assumption:

a continuous exponential relation between mole percent and SCN when α = 1



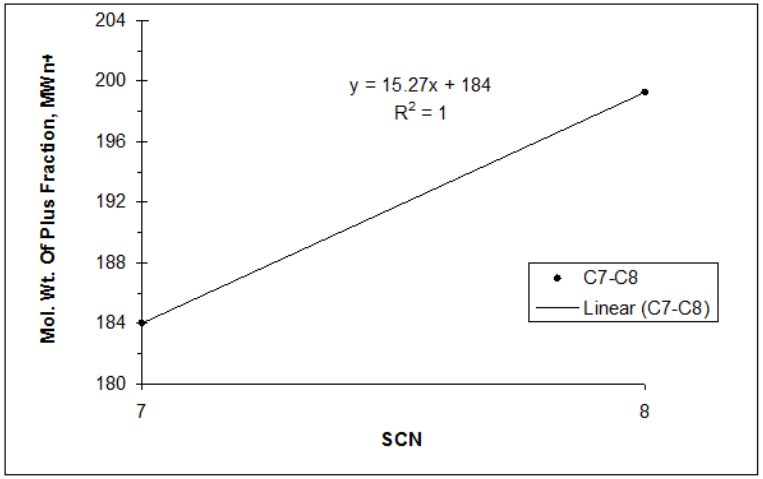
Ahmed et al "Splitting Scheme", (1984)

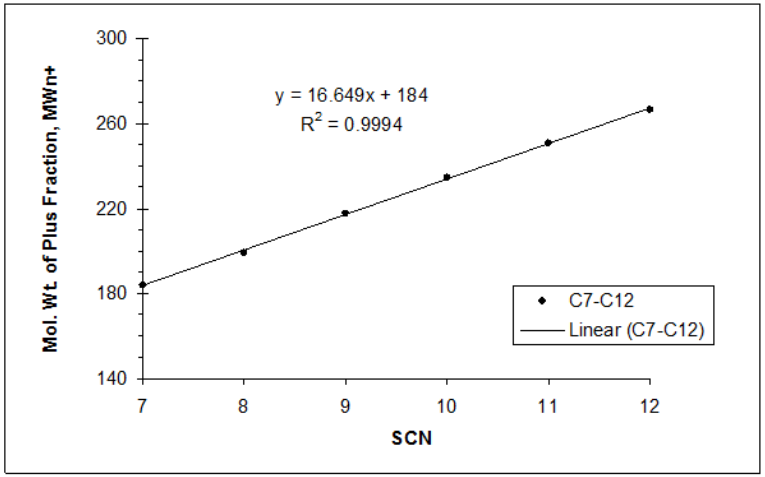




Molar Distribution of SCN Fractions for North Sea Sample (Source: Pedersen et al. 1987)

Ahmed et al "Splitting Scheme", (1984)





Molecular Weight of Plus Fraction vs SCN (Source: Ahmed et al. 1985)

$$MW_{n+} = MW_{7+} + S\,(n\text{-}7)$$

Coefficient S

S = 15.5 for n = 8 and

S = 17.0 for n > 8

Ahmed et. al. "Marching Technique", (1985)

$$z_n = \left(z_{7+} - \sum_{i=7}^{n-1} z_i\right)\left[\left(MW_{(n+1)+} - MW_{n+}\right) / \left(MW_{(n+1)+} - MW_n\right)\right] \times 100$$

z_n = composition of extended SCN fraction n, mole percent

MW_n = average molecular weight, Katz and Firoozabadi (1978).

MW_{n+} = molecular weight of the n plus fraction (C_{8+}, C_{9+}……), as follows:

$$MW_{n+} = MW_{7+} + S\,(n-7)$$

$MW_{(n+1)+}$ is the molecular weight of the next plus fraction, i.e. n = n + 1.

Table 2: Average Absolute Deviation between SCN Compositions predicted by the Exponential, Gamma and Ahmed et al. Models and measured SCN Compositions for the 20 Samples in Table 1.

SCN	No. of Data	AAD, % EXPON.	AAD, % GAMMA	AAD, % AHMED et al.
7	20	4.5	8.7	23.0
8	20	26.2	26.8	11.6
9	20	8.7	10.6	7.0
10	20	4.2	6.4	4.7
11	20	14.1	14.2	5.4
12	20	35.1	31.6	18.4
13	20	7.8	11.3	8.3
14	20	7.6	13.6	7.4
15	20	3.2	10.9	9.7
16	20	3.1	19.0	7.1
17	20	4.9	15.5	9.2
18	20	9.9	9.5	13.3
19	20	8.2	8.1	15.2

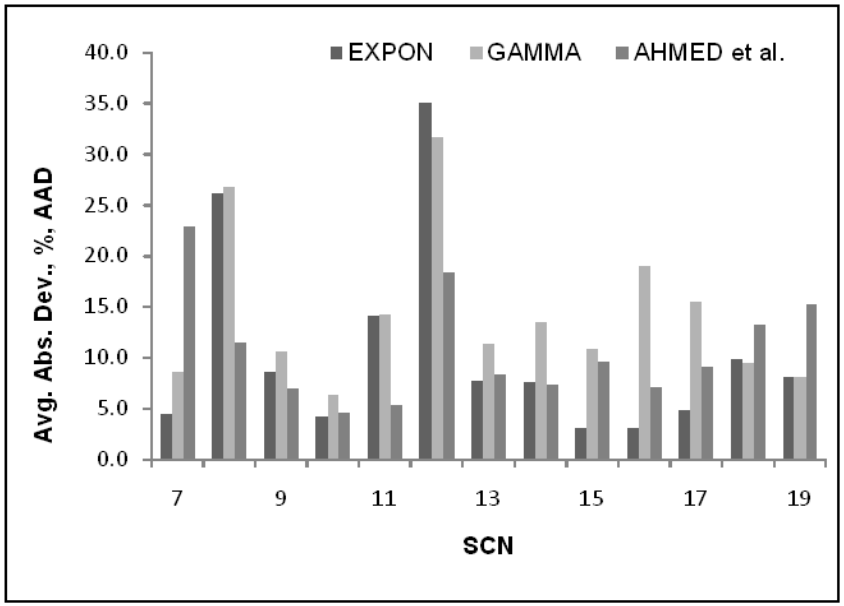


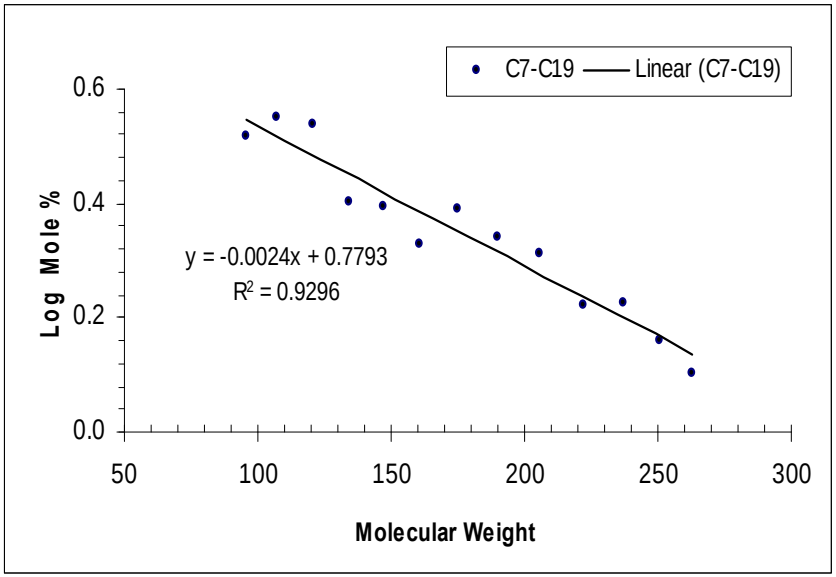
Fig. 3: Average Absolute Deviation among predicted and measured SCN Compositions for the 20 Samples in Table 1.

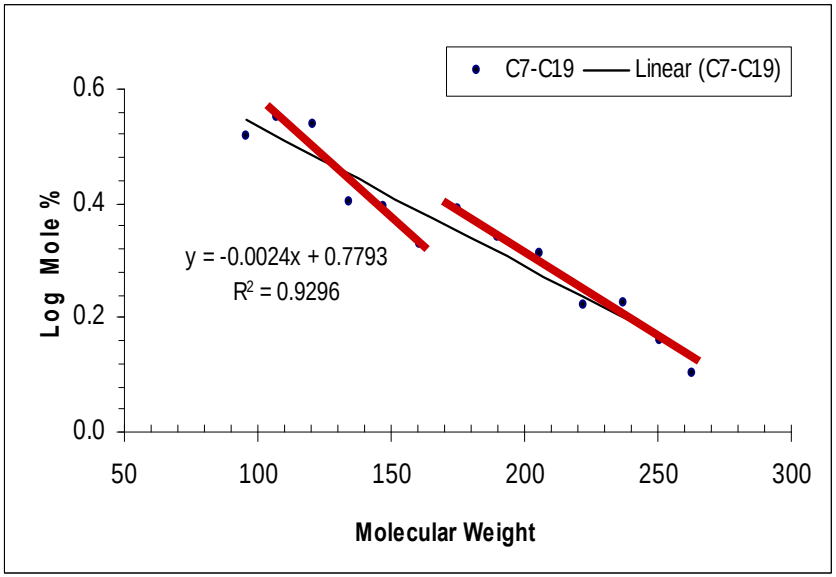
Limitations of Widely Used Extended Models

- Under Predict the C_8 Mole %
- Over Predict the C_{12} Mole %
- A Partial Experimental analysis is required.

How to extend the C_{7+} fraction for Gas Condensate Systems?

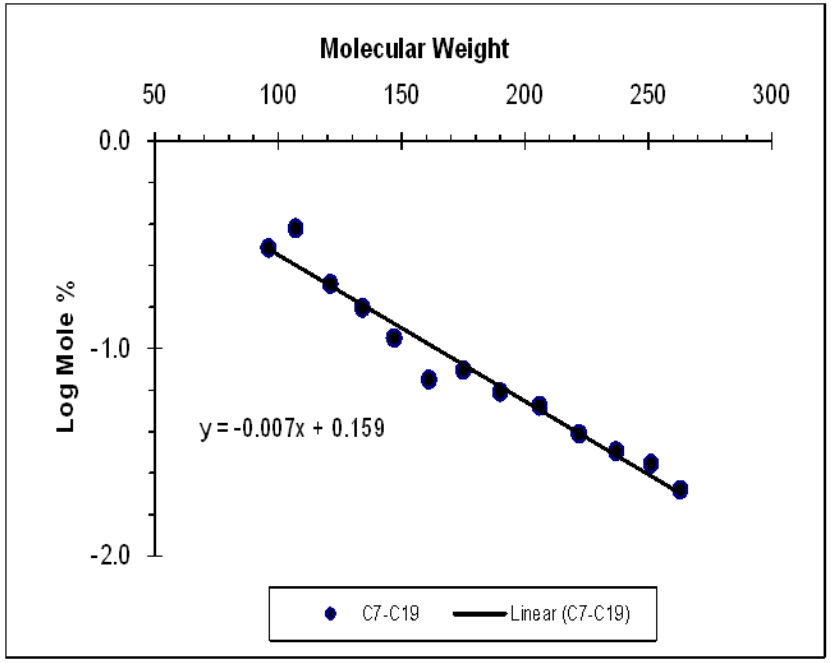
New Observation (Hosein. and McCain 2009)

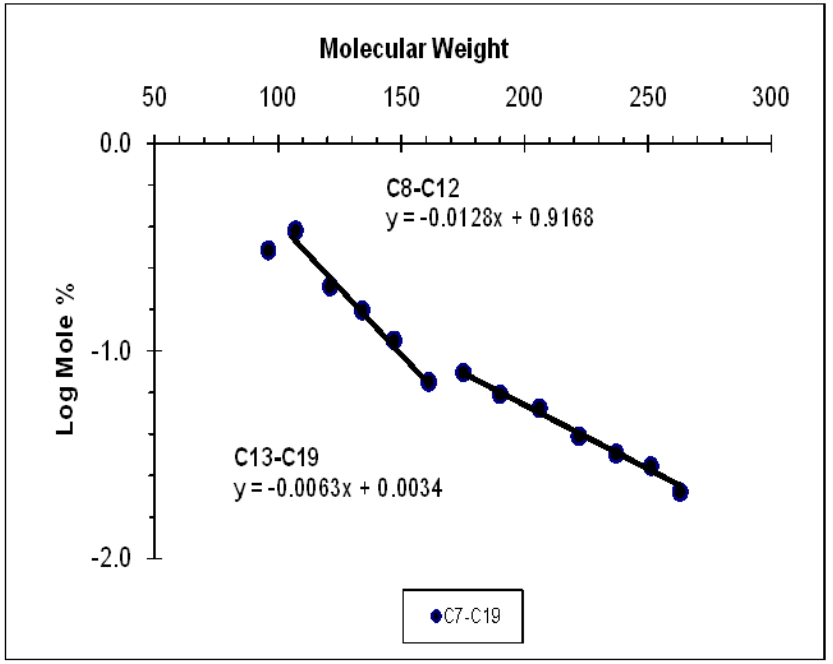




Molar Distribution of SCN Fractions for North Sea Sample (Source: Pedersen et al. 1987)

New Observation (Hosein. and McCain 2009)





Log Mole % vs Molecular Weight for Trinidad Sample DS2

A New "Four Coefficient" Model (4CM) for Splitting the C_{7+} .

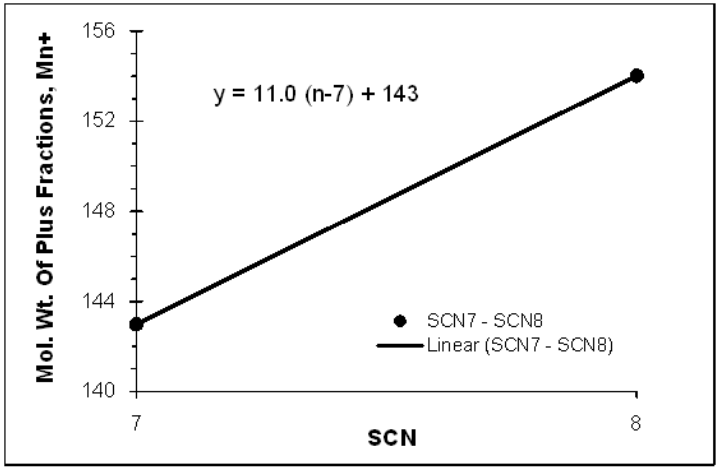


Fig. 6a: Molecular Weight of Plus Fraction vs SCN for Sample DS2 (Coefficient S = 11.0 for n = 8)

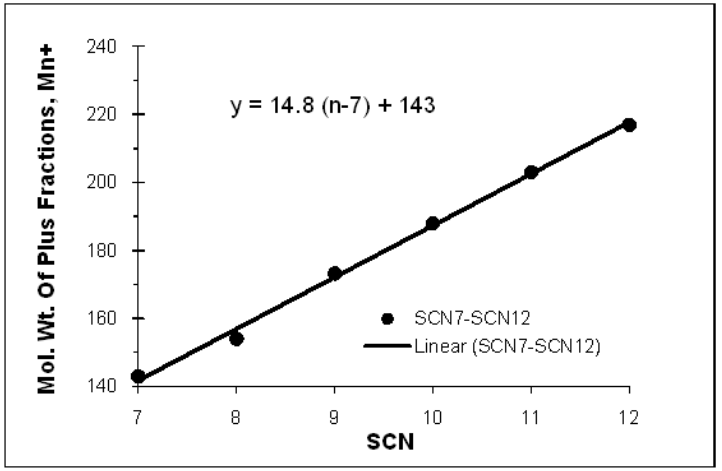


Fig. 6b: Molecular Weight of Plus Fraction vs SCN for Sample DS2 (Coefficient, S = 14.8 for 8 < n <13)

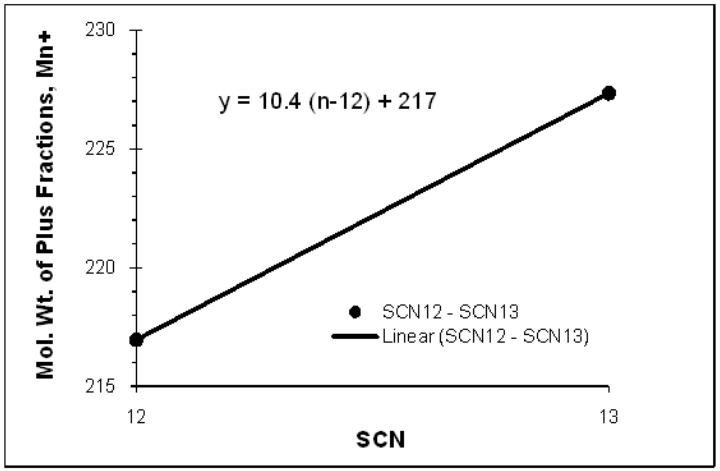


Fig. 7a: Molecular Weight of Plus Fraction vs SCN for Sample DS2 (Coefficient S = 10.4 for n = 13)

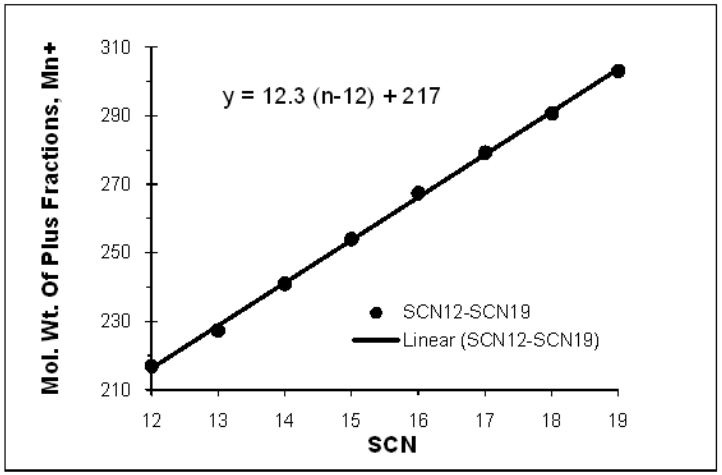


Fig. 7b: Molecular Weight of Plus Fraction vs SCN for Sample DS2 (Coefficient, S = 12.3 for n > 13)

Table 4: Deviation Between Predicted and Experimental SCN Composition for Sample DS2

SCN	Expt., Mole %	Pred., Mole % 4CM	Dev., %
7	0.307	0.306	-0.2
8	0.380	0.371	-2.3
9	0.205	0.209	2.0
10	0.157	0.158	0.8
11	0.113	0.121	6.8
12	0.071	0.071	-0.7
13	0.079	0.081	2.5
14	0.062	0.057	-7.3
15	0.053	0.049	-7.0
16	0.039	0.042	7.1
17	0.032	0.034	7.3
18	0.028	0.027	-2.3
19	0.021	0.021	-1.1

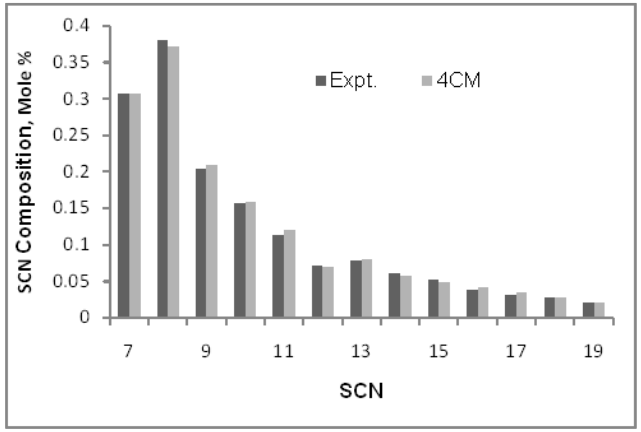


Fig.8: Predicted and Experimental SCN Composition for Sample DS2

Table 5: Coefficients S for each Data Set from the Four Segment Approach

SAMPLE	n = 8 S	8< n <13 S	n = 13 S	n >13 S		SAMPLE	n = 8 S	8< n <13 S	n = 13 S	n >13 S
DS1	10.2	13.9	10.3	11.8		DS11	11.4	15.3	16.6	18.4
DS2	11.0	14.8	10.4	12.3		DS12	12.1	16.6	11.4	13.3
DS3	10.9	15.6	10.6	12.1		DS13	10.7	15.1	10.1	11.5
DS4	10.3	14.2	10.3	12.0		DS14	11.8	15.8	11.5	13.5
DS5	11.4	15.7	12.1	13.8		DS15	11.5	16.2	10.3	13.3
DS6	12.7	17.0	11.5	13.4		DS16	10.4	15.6	13.6	14.3
DS7	11.8	15.8	11.5	13.5		DS17	15.3	16.6	15.6	15.0
DS8	12.2	16.6	10.8	12.5		DS18	14.3	18.5	15	16.2
DS9	12.2	16.1	11.6	13.6		DS19	12.3	14.7	13.4	12.3
DS10	11.4	15.4	11.1	13.3		DS20	14.3	19.6	18.4	19.8

Table 6: Coefficients for Predicting SCN Compositions, S by the "Four Coefficient" Model (4CM)

SCN Number, n	n = 8	8< n <13	n = 13	n > 13
Coefficient	S = 12.5	S = 16.0	S = 13.0	S = 14.5

Table 7: Average Absolute Deviation between SCN Compositions predicted by Ahmed et al. and the 4CM splitting models and measured SCN Compositions from Table 1.

SCN	No. of Data	AAD, % AHMED et al.	AAD, % 4CM
7	20	23.0	8.2
8	20	11.6	6.5
9	20	7.0	7.7
10	20	4.7	4.5
11	20	5.4	6.5
12	20	18.4	8.8
13	20	8.3	6.3
14	20	7.4	5.5
15	20	9.7	6.0
16	20	7.1	8.0
17	20	9.2	7.1
18	20	13.3	7.6
19	20	15.2	8.5

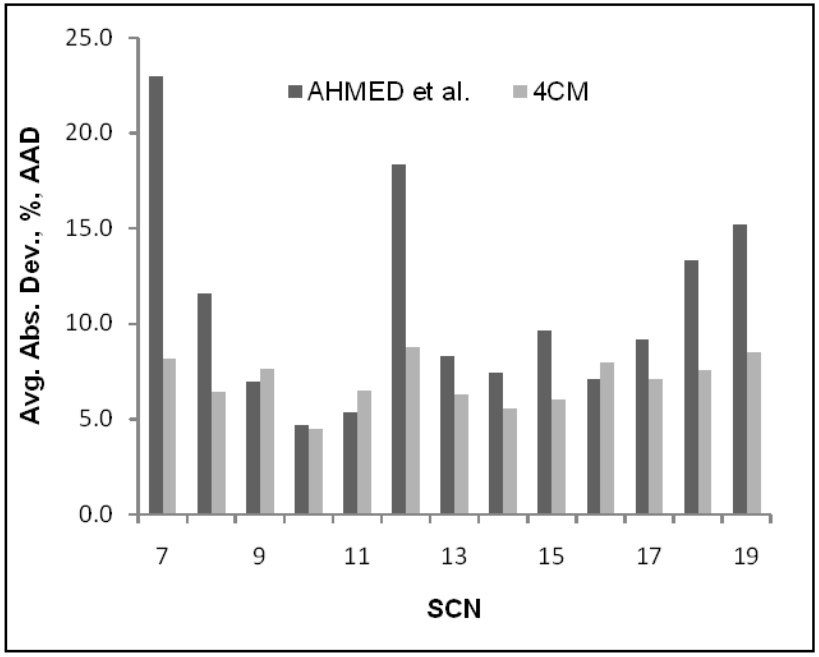


Fig. 9: Average Absolute Deviation between predicted and measured SCN Compositions from Table1.

Table 8: Deviation Between Compositions of SCN Groups Predicted by Ahmed et al. Model (1985), 4CM Model and Measured Values

SCN	DS2 (Trinidad Sample) Ref. 7		DS11 (Middle East Sample) Ref. 2, 9		DS15 (USA Sample) Ref. 4, 7		DS16 (North Sea Sample) Ref. 2, 16		DS19 (Venezuela Sample) Ref. 4, 7	
	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM
7	30.5	10.6	25.2	7.2	37.6	16.1	1.3	-15.9	20.1	0.5
8	-15.5	-3.7	-8.8	5.6	-15.6	-4.3	-0.8	9.6	-6.9	4.1
9	1.6	1.5	-16.2	-15.7	-13.1	-13.4	0.9	-1.1	-12.2	-13.2
10	-3.6	-1.9	-9.7	-7.6	-5.5	-4.2	3.8	3.2	-4.3	-3.9
11	-0.7	2.2	-10.9	-7.8	5.5	8.3	3.9	4.5	7.5	9.3
12	20.4	5.7	-5.2	-15.9	9.1	-4.7	3.7	-12.2	12.7	-2.9
13	-16.7	-5.9	-12.7	0.0	-9.1	2.1	2.7	10.8	-8.3	1.0
14	-16.5	-13.3	-11.9	-7.8	-6.3	-3.3	2.1	1.5	-4.1	-2.6
15	-21.9	-16.2	-12.5	-5.5	-8.9	-2.8	2.0	4.4	-5.0	-0.5
16	-14.8	-6.2	-5.1	4.8	5.8	15.9	1.5	6.6	0.8	8.5
17	-17.4	-7.6	-8.9	1.4	-0.5	10.9	0.1	7.4	-3.3	6.4
18	-25.3	-16.0	-7.1	2.7	-13.0	-2.1	-2.1	7.0	-13.3	-3.2
19	-22.1	-13.0	5.3	13.8	-15.7	-5.5	-5.5	4.4	-18.9	-9.0
zC_{7+} (Mole %)	1.616		3.210		6.53		8.210		10.870	
Classification	lean gas		lean gas		rich gas		rich gas		rich gas	
SG_{7+}	0.7869		0.774		0.793		0.816		0.810	
MW_{7+}	143		132		148		184		173	

Table 9: Predicted and Experimental SCN Compositions for a North Sea Sample (Pedersen et al. 1985)

SCN	Expt. Mole % (Ref. 9)	Pred. Mole % Ahmed et al	Dev., %	Pred. Mole % 4CM	Dev., %
7	0.950	1.11	16.4	0.921	-3.0
8	1.080	1.02	-5.5	1.134	5.0
9	0.780	0.74	-4.5	0.733	-6.0
10	0.592	0.60	1.4	0.600	1.3
11	0.467	0.49	4.6	0.493	5.7
12	0.345	0.40	17.0	0.344	-0.2
13	0.375	0.34	-10.5	0.365	-2.6
14	0.304	0.28	-7.1	0.283	-6.8
15	0.237	0.24	1.5	0.249	5.0
16	0.208	0.21	-1.3	0.218	4.8
17	0.220	0.17	-21.0	0.189	-14.2
18	0.169	0.15	-13.3	0.162	-4.3
19	0.140	0.12	-12.7	0.136	-2.7
zC_{7+} (Mole %)	6.700				
Clasification	rich gas				
MW_{7+}	174				

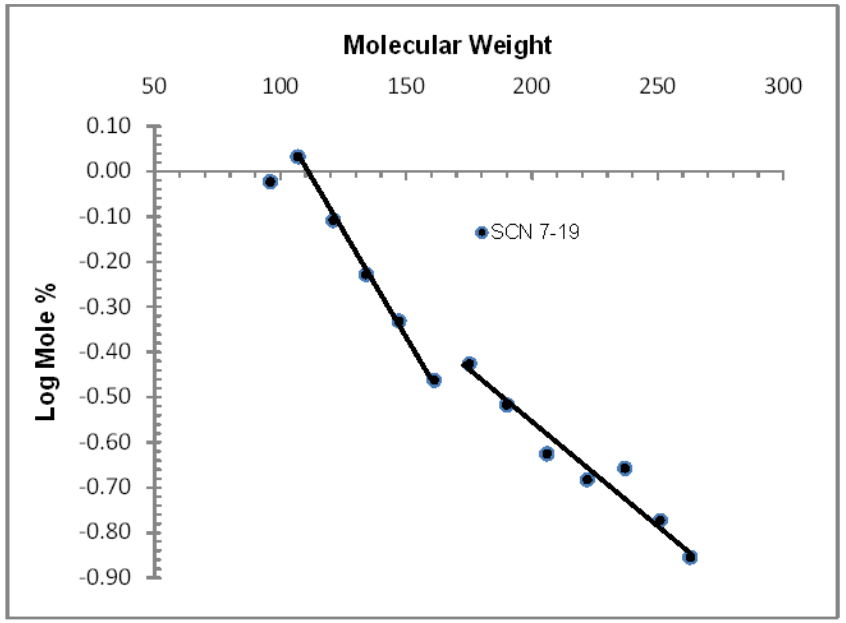


Fig. 10: Log Mole % vs Molecular Weight for a North Sea Sample (Pedersen et al. 1985)

Table 10: Experimental and Predicted Compositions of SCN Groups beyond SCN19

SCN	DS7 (Trinidad Sample)		DS11 (Former Russian State)		DS16 (North Sea Sample)		DS17 (USA)		S19 (Middle East)	
	Expt. Mole % (PVT Report)	Pred. Mole % 4CM	Expt. Mole % (PVT Report)	Pred. Mole % 4CM	Expt. Mole % Ref. 2, 17	Pred. Mole % 4CM	Expt. Mole % (PVT Report)	Pred. Mole % 4CM	Expt. Mole % (PVT Report)	Pred. Mole % 4CM
20	0.035	0.035	0.070	0.067	0.153	0.158	0.170	0.177	0.210	0.180
21	0.029	0.030	0.060	0.057	0.134	0.138	0.210	0.158	0.170	0.160
22	0.026	0.025	0.050	0.047	0.118	0.121	0.130	0.139	0.160	0.140
23	0.022	0.021	0.040	0.039	0.104	0.106	0.120	0.122	0.130	0.122
24	0.019	0.018	0.030	0.032	0.092	0.093	0.100	0.106	0.120	0.106
25	0.017	0.015	0.030	0.027			0.090	0.094	0.110	0.093
26	0.014	0.013	0.020	0.023			0.090	0.083	0.090	0.082
27	0.013	0.011	0.020	0.019			0.080	0.074	0.090	0.072

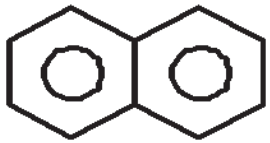
Table 11: Deviations between Compositions of SCN Groups Predicted by Ahmed et al. Model (1985), 4CM Model and Measured Values.

SCN	DS7 (Trinidad Sample)		DS11 (Former Russian State)		DS16 (North Sea Sample)		DS17 (USA)		S19 (Middle East)	
	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM	Dev., % Ahmed et al.	Dev., % 4 CM
20	-11.7	-0.6	-14.7	-4.3	-8.4	2.2	-0.1	4.1	-23.1	-14.3
21	-8.7	3.5	-15.7	-4.9	-8.1	3.5	-28.1	-24.5	-16.4	-5.7
22	-14.1	-2.7	-15.5	-5.2	-9.5	2.7	2.0	7.2	-22.9	-12.4
23	-14.7	-4.0	-12.2	-2.6	-11.2	1.1	-3.2	1.4	-17.9	-6.5
24	-16.4	-6.9	-2.0	7.2	-12.9	-0.5	2.0	6.4	-22.7	-11.9
25	-20.0	-11.7	-16.8	-10.3			0.5	4.4	-26.0	-15.6
26	-16.6	-8.9	6.3	12.7			-10.7	-7.8	-20.5	-9.4
27	-22.0	-15.8	-8.4	-4.4			-10.1	-7.6	-29.5	-19.7

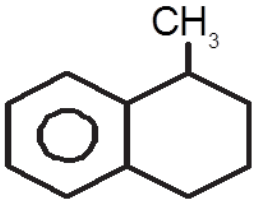
Discontinuities Observed at SCN8

- Methylcyclopentane, benzene, and cyclohexane show up in SCN7 and
- Methylcyclohexane and toluene (methylbenzene) appear in SCN8, often in large quantities.

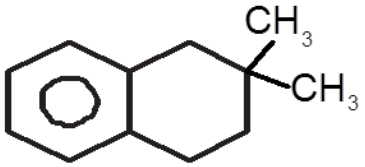
Discontinuities Observed at SCN13



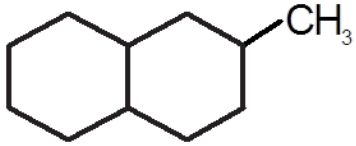
Naphthalene



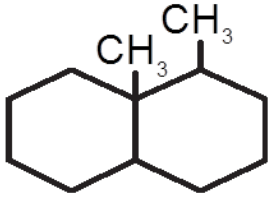
1-methyltetrahydronaphthalene



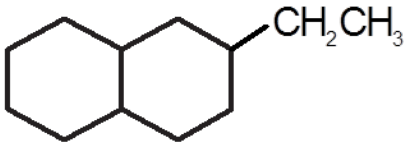
2, 2-dimethyltetrahydronaphthalene



2-methyldecahydronaphthalene



1, 10-dimethyldecahydronaphthalene



2-ethyldecahydronaphthalene

CONCLUSIONS

1. The exponential and gamma distribution function under predict the SCN8 mole percent and over predict the SCN12 mole percent by more than 25 percent

2. The two coefficient method described by Ahmed et al (1985) resolved the discontinuity at SCN8 to less than 12 percent. However the SCN12 group was over predicted by more than 18 percent.

3. The new “Four Coefficient” Model described in this study resolves these discontinuities in the molar relationships at both SCN8 and SCN12 with an Average Absolute Deviation between the predicted and experimental compositions of less than 10 percent.

4. This model can quite easily be included in Equation of State packages for a more accurate description of compositions for Trinidad gas condensates for performing compositional simulation studies.

5. A partial analysis beyond the C_{7+} fraction is not required with this new model.

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