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A NEW APPROACH CALCULATE OIL-GAS RATIO FOR GAS CONDENSATE AND VOLATILE OIL RESERVOIRS USING GENETIC PROGRAMMING

K.A. Fattah

Petroleum and Natural Gas Engineering Department, College of Engineering, King Saud university, P.O. 800, Riyadh 11421, Saudi Arabia
e-mail:kelshreef@ksu.edu.sa

Abstract. *In this work, we develop a new approach to calculate oil-gas ratio (R_v) by matching PVT experimental data with an equation of state (EoS) model in a commercial simulator (Eclipse simulator) using genetic programming algorithm of commercial software (Discipulus). More than 3000 data values of R_v obtained from PVT laboratory analysis of eight gas condensate and five volatile oil fluid samples; selected under a wide range of composition, condensate yield, reservoir temperature and pressure, were used in this study.*

The hit-rate (R^2) of the new approach was 0.9646 and the fitness variance for it was 0.00025 and the maximum absolute error was 7.73 %. This new approach was validated using the generalized material balance equation calculated with data generated from a compositional reservoir simulator (Eclipse simulator).

The new approach depends only on readily available parameters in the field and can have wide applications when representative lab reports are not available.

Keywords: *oil-gas ratio, PVT lab report, gas condensate, volatile oil, modified black oil simulation, genetic program*

Introduction

The Modified Black Oil (MBO) simulation approach (also called Extended Black-Oil) was introduced by Spivak and Dixon (1973). These MBO simulations approach consider three components (dry gas, oil, and water). The main difference between the conventional black-oil simulation and the MBO simulation lies in the treatment of the liquid in the gas phase. The PVT functions for modified black oil (MBO) simulation and material balance calculations of gas condensate and volatile oil are: oil-gas ratio, R_v; solution gas-oil ratio, R_s; oil formation volume factor, B_o; and gas formation volume factor, B_g. The MBO approach assumes that stock-tank liquid component can exist in both liquid and gas phases under reservoir conditions. It also assumes that the liquid content of the gas phase can be defined as a sole function of pressure called vaporized oil-gas ratio, R_v. This function is similar to the solution gas-oil ratio, R_s, normally used to describe the amount of gas-in-solution in the liquid phase.

Whitson and Torp (1983) developed a procedure to calculate MBO properties from laboratory constant volume depletion (CVD) data of gas condensate. Coats (1985) developed a different procedure for gas condensate fluids by using EOS PVT program and a regression package to match laboratory PVT data. McVay (1994)

extended Coats procedure for volatile oil fluids. Walsh and Towler (1995) also presented a simple method to calculate MBO PVT properties from the CVD experiment data of Gas Condensate reservoir fluids.

Fevang *et al.* (2000) presented guidelines to help engineers choose between MBO and compositional approaches. Fattah *et al*. (2006) showed that both Whitson and Torp, and Coats procedures provide excellent match with compositional simulation results when PVT experimental data are matched with an EoS model and then used to output the MBO PVT properties. Fattah *et al*. (2009) also presented new correlations to develop MBO PVT properties of gas condensate and volatile oil when fluid samples are not available.

Genetic programming

Genetic algorithms, evolution strategies and genetic programming belong to the class of probabilistic search procedures known as Evolutionary Algorithms that use computational models of natural evolutionary processes to develop computer-based problem solving systems. Solutions are obtained using operations that simulate the evolution of individual structures through mechanism of reproductive variation and fitness based selection. Due to their reported robustness in practical applications, these techniques are gaining popularity and have been used in a wide range of problem domain. The main difference between genetic programming and genetic algorithm is the representation of the solution. Genetic programming creates computer programs as solution whereas genetic algorithm creates a string of numbers to represent the solution. Genetic programming is based on the Darwinian principle of reproduction and survival of the fittest and analogs of naturally occurring genetic operations such as crossover and mutation (Koza, 1998). Genetic programming uses four steps to solve a problem (Koza, 1992):

1. Generate an initial population of random compositions of the functions and terminals (input) of the problem

2. Execute each program in the population and assign a fitness value.

3. Create a new offspring population of computer programs by copying the best programs and creating new ones by mutation and crossover.

4. Designation of the best computer program in the generation.

R_v approach using genetic program

The Discipulus software, a commercial Genetic Programming system, was used to generate the new R_v approach. Discipulus output, from data given to it, is a computer program. These given data that provided to Discipulus program were classified into three data types: "training data," "validation data" and "testing data". These data files contained matched inputs and outputs data for R_v. From them, Discipulus created mo-

dels that allow us to predict outputs from similar inputs. The models were created as computer programs in Java, C, or assembler program. The input data for our new approach are:

– Reservoir pressure, psi;
– Reservoir temperature, R;
– Saturation reservoir pressure, psi;
– Oil density at standard conditions, lb/cu ft;
– Gas density at standard conditions, lb/cu ft;
– Condensate Yield, bbl/mm scf ;

The output data form it is oil-gas-ratio R_v.

After uploading the data files into the Discipulus and start the run, the program give different types of results that show how the run in progress improved its fitness and performance. The C code of the genetic program to calculate the new oil-gas-ratio R_v is given in the appendix.

Fluid Samples

Fattah (2005) presented PVT experiments for thirteen reservoir fluid samples [eight gas condensates, (GC), and five volatile oils, (VO)]. These PVT data were used in this study. The samples were obtained from reservoirs representing different locations and depth, and were selected to cover a wide range of oil and gas fluid characteristics. Some samples represent near critical fluids (VO 2, VO 5, GC 1, and GC 2) as explained by McCain and Bridges (1994)**.** Table 1 presents a description of the major properties of these thirteen fluid samples.

Approach

For every sample in Table 1, an EoS model that matches the experimental results of all available PVT laboratory experiments (CCE, DL, CVD, and separator tests) was derived. For consistency, all EoS models were developed using Peng and Robinson (1976) EoS with volume shift correction (3-parameter EoS) (Fattah (2005)). The procedure suggested by Coats and Smart (1986) to match the laboratory results was followed. Then the developed EoS model for each sample was used to output MBO PVT properties at different separator conditions using Whitson and Torp (1983) procedure. The MBO PVT properties include the four functions required for MBO simulation are (R_v, R_s, B_o, and B_g). Our database of R_v data consists of 1850 points from 8 different gas condensate samples and 1180 points from 5 volatile oil samples. PVTi module of Eclipse was used to generate our database of R_v data.

Table 1. Characteristics of fluid samples

Property	VO 1	VO 2	VO 3	VO 4	VO 5	GC 1	GC 2	GC 3	GC 4	GC 5	GC 6	GC 7	GC 8
Reservoir Temperature (°F)	249	246	260	190	197	312	286	238	256	186	312	300	233
Initial Reservoir Pressure (psig)	NA	5055	5270	NA	13668	14216	NA	6000	7000	5728	14216	5985	17335
Initial Producing Gas-Oil ratio (SCF/STB)	1991	2000	2032	2424	2416	3413	4278	NA	4697	5987	8280	6500	6665
Stock Oil gravity (° API)	45.5	51.2	NA	36.8	34.1	45.6	NA	NA	46.5	58.5	50.7	45.6	43
Saturation Pressure (psig)	4527	4821	4987	7437	9074	5210	5410	4815	6010	4000	5465	5800	11475
Components	**Composition (Mole %)**												
CO_2	2.14	2.18	2.4	0.1	0.34	2.66	4.48	0.14	0.01	0.18	2.79	6.98	0.36
N_2	0.11	1.67	0.31	0.16	0	0.17	0.70	1.62	0.11	0.13	0.14	1.07	0.31
C_1	55.59	60.51	56.94	69.84	72.47	59.96	66.24	63.06	68.93	61.72	66.73	65.25	81.23
C_2	8.7	7.52	9.21	5.37	4.57	7.72	7.21	11.35	8.63	14.1	10.22	8.92	5.54
C_3	5.89	4.74	5.84	3.22	2.79	6.50	4.00	6.01	5.34	8.37	5.90	4.81	2.66
iC_4	1.36	4.12	1.44	0.87	0.67	1.93	0.84	1.37	1.15	0.98	1.88	0.85	0.62
nC_4	2.69	0	2.73	1.7	1.33	3.00	1.76	1.94	2.33	3.45	2.10	1.75	1.06
iC_5	1.17	2.97	1.03	0.79	0.69	1.64	0.74	0.84	0.93	0.91	1.37	0.65	0.47
nC_5	1.36	0	1.22	0.88	0.82	1.35	0.87	0.97	0.85	1.52	0.83	0.69	0.52
C_6	1.97	1.38	1.96	1.41	1.52	2.38	0.96	1.02	1.73	1.79	1.56	0.83	0.84
C_{7+}	19.02	14.91	16.92	15.66	14.8	12.69	12.2	11.68	9.99	6.85	6.48	8.2	6.39

Results and Discussion

Fig. 1 shows the fitness of the genetic program with time. The hit-rate (R^2) of the new approach was 0.9646 and the fitness variance for the new approach was 0.00025. Figs. 2 - 4 show the match between the extracted R_v data and the predicted R_v data from the new genetic program.

Also, extracted R_v data from lab reports were statistically compared in this study with results predicted using Fattah et al. (2009) correlation and the new approach. Figs. 5 - 7 present cross-plots to see how the Fattah et al (2009) correlation and the new R_v approach values compared to the R_v values obtained from lab reports. The results indicate that the new approach almost completely matches the extracted R_v data.

In addition to cross-plots to see how the new approach values compared to the values obtained from the PVT lab reports, both reservoir simulation and material balance calculations were used to validate the new approach.

The generalized material balance equation as an equation of a straight-line suggested by Walsh (1995) and Walsh et al. (1994) was used to validate the new R_v approach (for both gas condensate and volatile oil samples).

The general material balance calculations using the PVT properties (R_s, B_o, and B_g extracted from lab reports and R_v from the new approach) were used to calculate original hydrocarbon in place. These values were compared to original hydrocarbon in place values obtained from compositional reservoir simulation for a tank model Fattah (2005). For simplicity, the original fluid in place was normalized to 1.0 BSTB for oil cases and 1 Bscf for gas cases.

Fig. 8 shows a plot of *F* versus the expansion term, *Eg*, for a gas condensate sample (GC 1), as suggested by Walsh procedure. The slope of the line passing through the calculated points gives the original fluid in place volume. The plot shows that the slope of the line is 1.0208, i.e. the error in gas in place calculation is approximately 2.08%.

Fig. 9 is a similar plot *F* versus the expansion term, *Eo*, for a volatile oil sample (VO 1). The plot shows a line slope of 0.999 which is equivalent to error in the oil in place calculation of approximately 0.1%. The error percent in fluid in place calculations were calculated for most of the fluid samples in our database, six case study (two volatile oil and four gas condensate), and reported the error percentages in Table 2. The reported error values prove the validity of the new approach. From this validation, the maximum absolute error was 7.73 % and the minimum absolute error was 0.1%.

The new approach presented in this work can be used with other set of correlations to generate MBO PVT properties without the need for fluid samples or elaborate procedure for EoS calculations. The application of these correlations is of particular importance especially when representative fluid samples are not available.

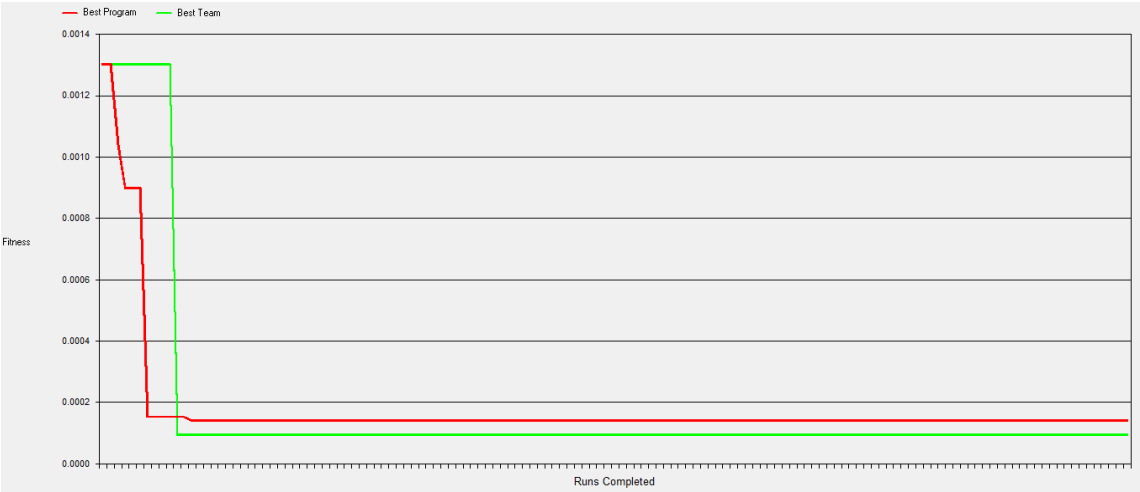

Fig. 1. The best program fitness improvement with time

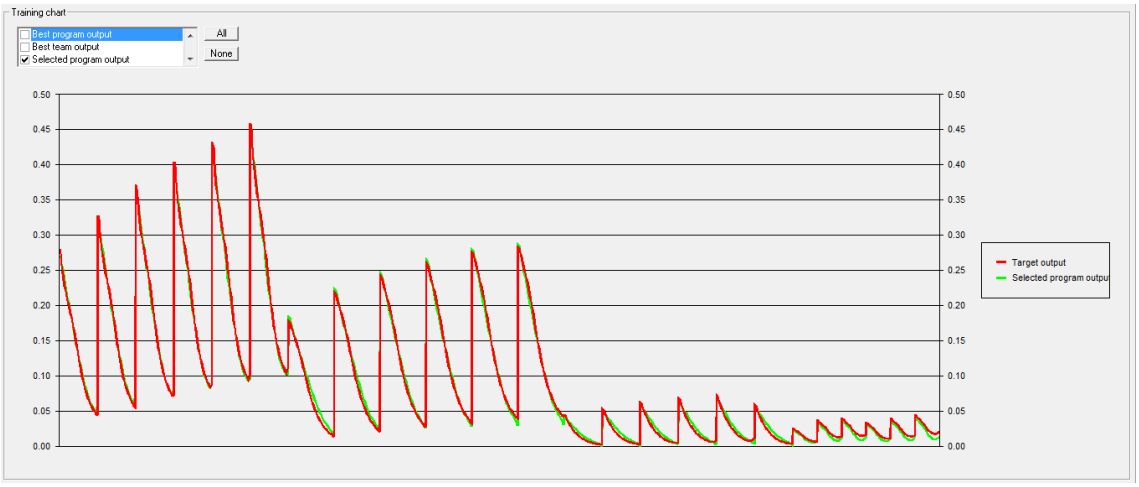

Fig. 2. The extracted VS calculated R_v data for training data from genetic program

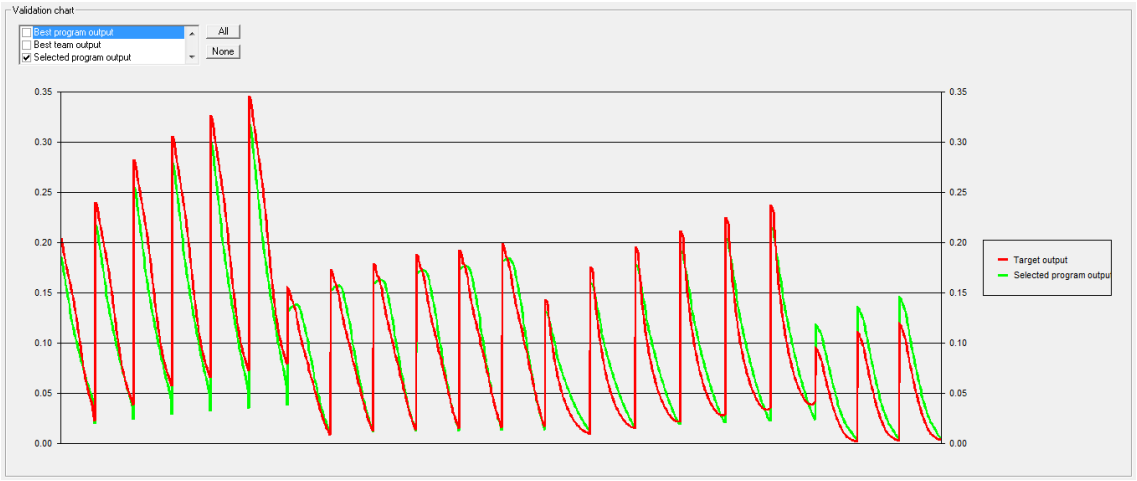

Fig. 3. The extracted VS calculated R_v data for validation data from genetic program

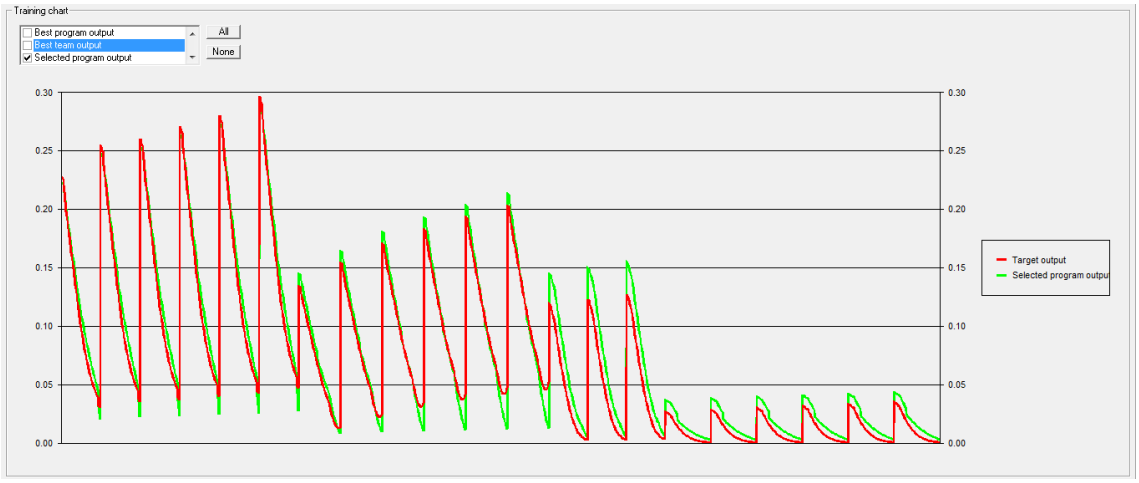

Fig. 4. The extracted VS calculated R_v data for applied data from genetic program

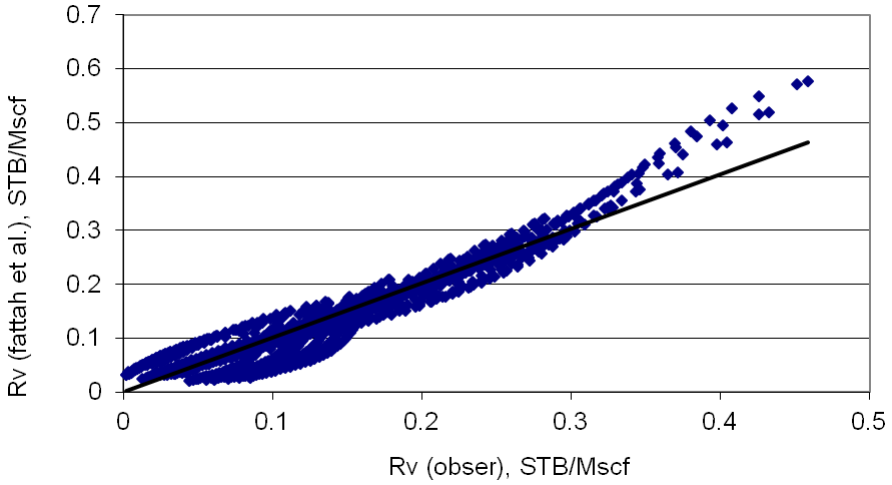

Fig. 5. Cross-plot for R_V (Fattah et al. correlation) vs. R_V (driven from the EOS model) for gas condensate samples

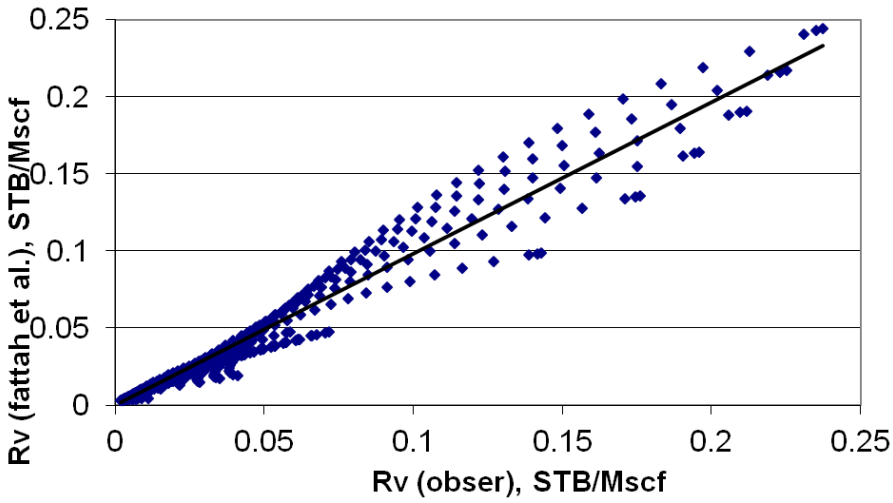

Fig. 6. Cross-plot for R_V (Fattah et al. correlation) vs. R_V (driven from the EOS model) for volatile oil samples

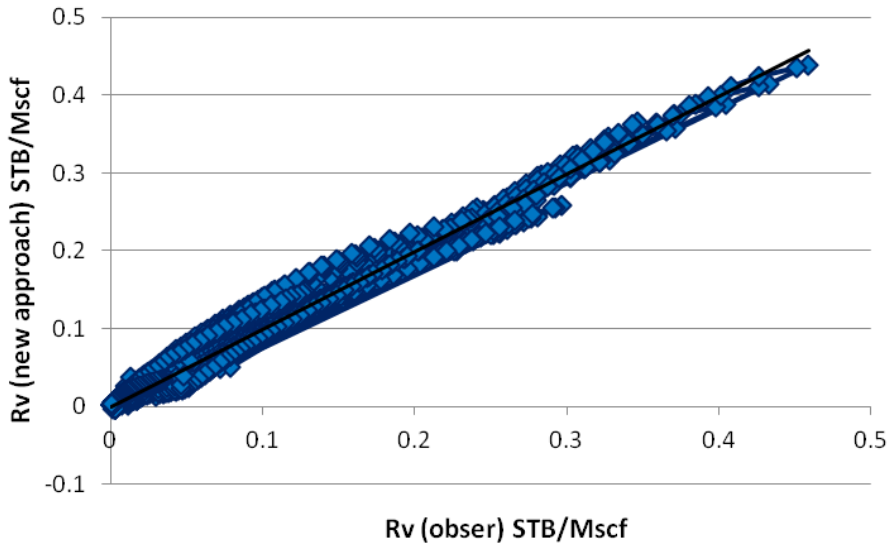

Fig. 7. Cross-plot for R_V (new approach) vs. R_V (driven from the EOS Model) for gas condensate and volatile oil samples

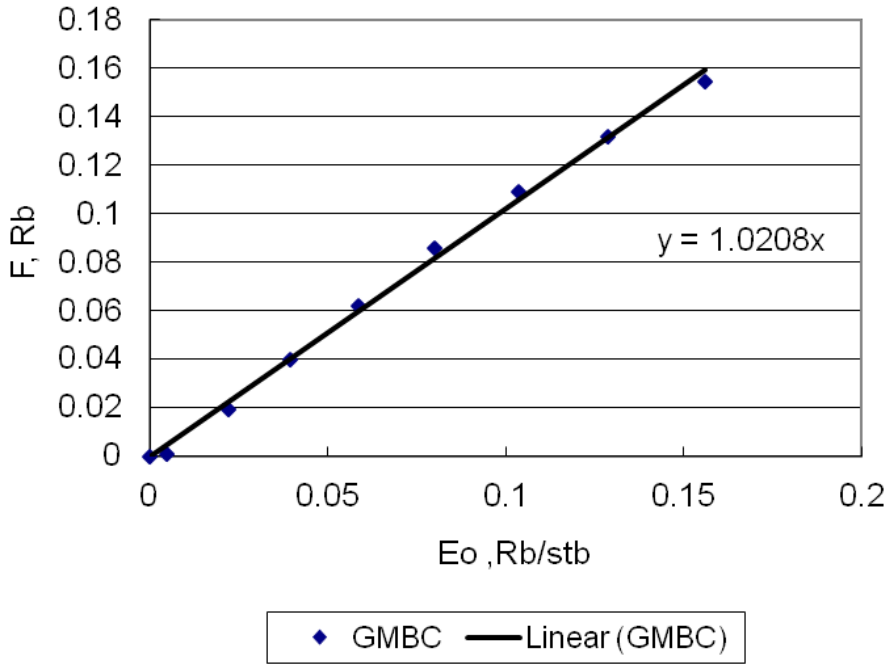

Fig. 8. Material balance as straight line calculations for a gas condensate sample (GC 1)

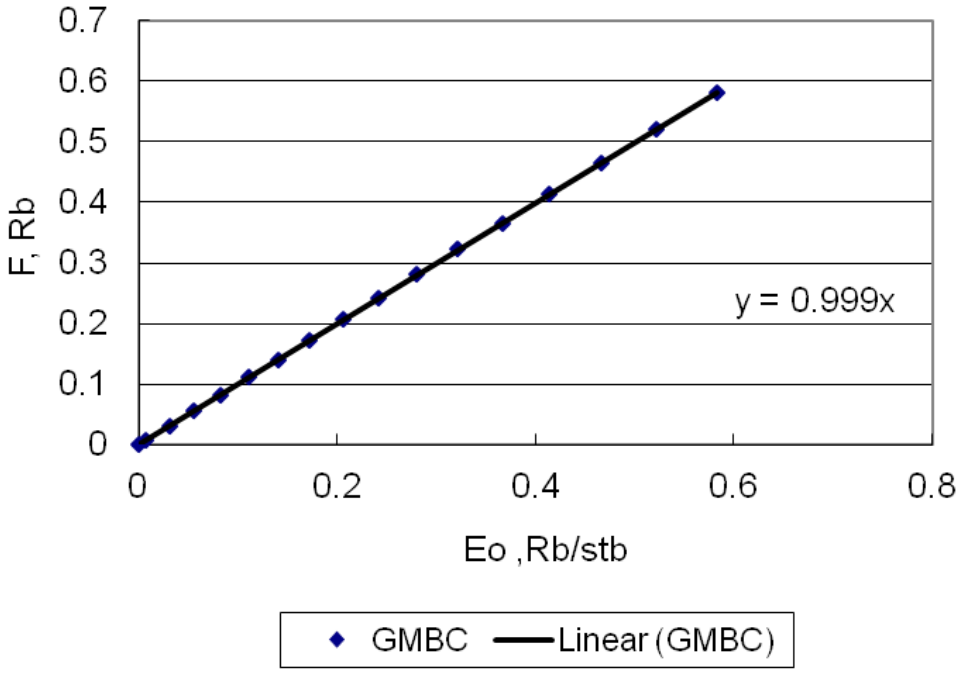

Fig. 9. Material balance as straight line calculations for a volatile oil sample (VO 1).

Table 2. Error in fluid in place calculation from generalized material balance calculations using the new R_v Approach

Fluid Sample	Original Fluid In Place	Error (%)
VO 1	0.999	0.1
VO 2	1.0445	4.45
GC 1	1.0208	2.08
GC 2	0.9227	7.73
GC 3	1.0563	5.63
GC 4	0.9689	3.11

Conclusions

1. New R_v approach was presented for oil-gas ratio of gas condensates and volatile oils. The Discipulus software, a commercial Genetic Programming system, was used to develop the new approach based on the concept of genetic algorithm.

2. The hit-rate (R^2) of the new approach was 0.9646 and the fitness variance for the new approach was 0.00025.

3. The new approach was validated using the generalized material balance equation calculations with data generated from a compositional reservoir simulator (Eclipse simulator) using six case study (two volatile oil and four gas condensate). From this validation, the maximum absolute error was 7.73 % and the minimum absolute error was 0.1 %.

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Appendix

This appendix gives the c code of the genetic program to calculate the new oil-gas ratio.

```
#define TRUNC(x)(((x)>=0) ? floor(x) : ceil(x))
#define C_FPREM (_finite(f[0]/f[1]) ? f[0]-(TRUNC(f[0]/f[1])*f[1]) : f[0]/f[1])
#define C_F2XM1 (((fabs(f[0])<=1) && (!_isnan(f[0]))) ? (pow(2,f[0])-1) : ((!
_finite(f[0]) && !_isnan(f[0]) && (f[0]<0)) ? -1 : f[0]))

float DiscipulusCFunction(float v[])
{
  long double f[8];
  long double tmp = 0;
  int cflag = 0;
```

```
  f[0]=f[1]=f[2]=f[3]=f[4]=f[5]=f[6]=f[7]=0;

  L0:    f[0]-=v[4];
  L1:    f[0]/=0.03275442123413086f;
  L2:    f[0]+=f[0];
  L3:    f[0]/=0.7790718078613281f;
  L4:    f[2]-=f[0];
  L5:    f[0]+=v[5];
  L6:    f[0]/=-0.9486191272735596f;
  L7:    f[0]-=v[0];
  L8:    f[0]*=-0.09100413322448731f;
  L9:    f[0]-=f[2];
  L10:   f[0]*=0.002621650695800781f;
  L11:   f[1]+=f[0];
  L12:   f[0]*=1.987620830535889f;
  L13:   f[2]-=f[0];
  L14:   f[0]*=f[0];
  L15:   f[0]*=pow(2,TRUNC(f[1]));
  L16:   f[0]-=f[1];
  L17:   f[0]*=f[2];
  L18:   f[0]+=v[5];
  L19:   f[0]*=f[1];
  L20:   f[0]*=1.987620830535889f;
  L21:   f[0]+=v[5];
  L22:   f[0]*=f[1];
  L23:   f[0]+=f[2];
  L24:   f[0]/=v[2];
  L25:

  if (!_finite(f[0])) f[0]=0;

  return f[0];
}

// This program was evolved with Discipulus(tm).
```