INTRODUCTION

In order to describe qualitatively a fluid from a production system, petroleum engineers use two main methodologies: black oil and compositional. Each method has its advantages and drawbacks, and depending on the precision required and data available, specialists would select one or the other.

The black oil methodology characterizes three main phases from an oil sample: gas, oil and water phase, and proposes a set of properties to describe the behavior of any sample. These set of properties describe the phases' behavior depending on temperature and pressure. For this methodology, there are two main approaches: correlations with tuning factor, or model development using equations of state (EOS).

The compositional methodology uses EOS to reproduce the behavior of the fluid. One of the main drawbacks is that requires a known composition for the oil sample. If the sample is from light oils, it is possible to use lighter hydrocarbons as main components, but if the samples is more complex, then a previous decomposition in pseudo-components is required. Additional to the components, the following parameters are required:

- Properties such as critical pressure and temperature, acentric factor, and critical compressibility factor must be available.
- Binary interaction parameters (BIP) should also be available for a more accurate fluid characterization.

Specialists in oil production prefer the black oil model, since it is more comprehensive in physical terms and requires less information to predict the behavior of the fluid. One of the downsides is that could be less accurate. On the other hand, process-engineering specialists prefer the compositional method, since it can be easily used to calculate thermodynamic properties for process design, and provide a large variety of EOS depending on the conditions of the fluid.

Considering that the model is more related to oil production, the black oil methodology was preferred in the class' development. Since our focus is not oil characterization and we did not have data related to oil samples, we took the methodology traditional approach including correlations to calculate properties and tuning factors. In a further stage, it is possible to develop a black oil model based on sampling adjustment using EOS, or compositional methods, including additional modules to the class BOObj.

This report includes the details about the correlations used for calculating both thermodynamic and transport properties in the BOObj. In addition, it will cover other correlations that are not related to the black oil model per se, but are used in property calculations.

DOCUMENT OBJECTIVE

Describing the main features, algorithms and calculations perform by the BOObj class.

DOCUMENT SCOPE

Describe all properties, methods and events included in the BOObj class, in its version 02. Additional to this, provide a detailed explanation on the major algorithms applied to solve the object depending on the variable configurations.

Class developed in MATLAB R2015a.

PROPERTIES

An attribute table describes each property. This table is a simplified version of the property attributes available in MATLAB, and it purpose is for any user or programmer with no previous experience in MATLAB have a better understanding of the property functionality.

For information, the attribute descriptions are as follows:

Property attribute	Description	Values
Access	Property accessibility once a class instance is created. · Public: unrestricted access · Protected: access from classes and subclasses · Private: access from class member only	{public | protected | private}
Dependent	Property auto-calculated by class instance, once all dependencies have been set. When true, the property does not store any value, and it is calculated in every callback.	{true | false}
Hidden	Property visibility for a class instance. When true, the property is not listed in the available class instance's properties.	{true | false}
Set access	Property ability to be written by the user in a class instance. · Public: unrestricted access · Protected: access from classes and subclasses · Private: access from class member only · Immutable: access from class constructor only	{public | protected | private | immutable}
Get access	Property ability to be read by the user in a class instance. · Public: unrestricted access · Protected: access from classes and subclasses · Private: access from class member only	{public | protected | private}

P

Description	*Pressure* Pressure of the black oil fluid, given in psi.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

T

Description	*Temperature* Temperature of the black oil fluid, given in F.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

TBGSC

Description	*Temperature at bubble point, pseudo critical gas phase* Bubble point temperature at standard conditions, gas phase given in F.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

TBOSC

Description	*Temperature at bubble point, pseudo critical oil phase* Bubble point temperature at standard conditions, oil phase given in F.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

GOR

Description	*Gas-in-oil ratio* Gas-in-oil ratio at standard conditions, in the reservoir [Sft^3/STB]. Value by default = 130				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

WC

Description	*Water cut* Water fraction or water cut, expressed in parts per 100 (%), associated with the production fluid. Value by default = 0				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

EWC

Description	*Emulsion water cut* Emulsion inversion point, expressed as water cut (volume in parts per 100). Value by default = 60.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

GSG

Description	*Specific gravity, gas phase* By definition, gSG is the gas density at standard conditions divided into the air density at standard conditions (1,205 kg/m^3 @ 1 bara, 15,56 F). Value by default = 0,6400				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

OSG

Description	*Specific gravity, oil phase* By definition, oSG is the oil density at standard conditions divided into the water density at standard conditions (1.000 kg/m^3 @ 1 bara, 4 C). Value by default = 0,8762				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

WSG

Description	*Specific gravity, water phase*

	By definition, wSG is the water density at standard conditions divided into the water density at standard conditions (1.000 kg/m^3 @ 1 bara, 4 C). Value by default = 1,0200				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

RICHARDSONO

Description	*Richardson coefficient, W/O emulsion* Richardson coefficient for W/O emulsion (dominant phase: oil). Value by default = 3,215				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

RICHARDSONW

Description	*Richardson coefficient, O/W emulsion* Richardson coefficient for O/W emulsion (dominant phase: water). Value by default = 3,089				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F01

Description	*Tuning factor* To be used in a further version.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F02

Description	*Tuning factor* To be used in a further version.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F03

Description	*Tuning factor* To be used in a further version.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F04

Description	*Tuning factor* To be used in a further version.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F05

Description	*Tuning factor: oil viscosity* This factor fits the dead-oil viscosity, in order to represent the viscosity of a given sample. For more information, review (Ensalzado, TEP4905-RP-02-01: BOObj class - Viscosity tuning, 2016).				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F06

Description	*Tuning factor: oil viscosity* This factor fits the dead-oil viscosity, in order to represent the viscosity of a given sample. For more information, review (Ensalzado, TEP4905-RP-02-01: BOObj class - Viscosity tuning, 2016).				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

F07

Description	*Tuning factor* To be used in a further version.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

API

Description	API gravity API gravity of oil, calculated by its definition.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

BG

Description	*Formation volume factor, gas phase* Formation volume factor, gas phase given in rft3/STB.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

BO

Description	*Formation volume factor, oil phase* Formation volume factor, gas phase given in rft3/STB.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

BW

Description	*Formation volume factor, water phase* Formation volume factor, water phase given in rft3/STB.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CO

Description	*Compressibility factor, oil phase* Compressibility factor, oil phase given in 1/psi.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

PB

Description	*Pressure at bubble point* Bubble point pressure of black oil at a given pressure and temperature, given in psia.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

RS

Description	*Gas in oil ratio* Gas in oil ratio, for a given pressure and temperature given in Sft3/STB.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

Z

Description	*Compressibility factor* Compressibility factor of the fluid. This factor is dimensionless, e.g. it does not have units.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

GRHO

Description	*Density, gas phase* Density of the gas phase given in lb/ft3.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

ORHO

Description	*Density, oil phase* Density of the oil phase given in lb/ft3.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

WRHO

Description	*Density, water phase* Density of the water phase given in lb/ft3.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

GMU

Description	*Viscosity, gas phase* Viscosity of the gas phase given in cP.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

OMU

Description	*Viscosity, oil phase* Viscosity of the oil phase given in cP.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

WMU

Description	*Viscosity, water phase* Viscosity of the water phase given in cP.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

EMU

Description	*Viscosity, emulsion* Viscosity of the W/O or O/W emulsion given in cP. For calculating this property, the Richardson correlation. W/O or O/W is calculated depending on the WC of the fluid/element.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

GCP

Description	*Specific heat, gas phase* Specific heat capacity of gas phase given in BTU/lb.F.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

OCP

Description	*Specific heat, oil phase* Specific heat capacity of oil phase given in BTU/lb.F.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

WCP

Description	*Specific heat, water phase* Specific heat capacity of water phase given in BTU/lb.F.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

PSC

Description	*Pressure, pseudocritical fluid* Pseudo-critical pressure of the black oil model given in psia.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

TSC

Description	*Temperature, pseudocritical fluid* Pseudo-critical temperature of the black oil model given in R.				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

RHOSC2AC

Description	*Density transformation matrix, from standard to actual conditions* Actual condition density values are calculated from standard condition density values. $\begin{bmatrix}\rho_g\\ \rho_o\\ \rho_w\end{bmatrix} = \begin{bmatrix}1/B_g & 0 & 0\\ R_s/B_o & 1/B_o & 0\\ 0 & 0 & 1/B_w\end{bmatrix} \cdot \begin{bmatrix}\rho_{g,sc}\\ \rho_{o,sc}\\ \rho_{w,sc}\end{bmatrix}$				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

QSC2AC

Description	*Flowrate matrix transformation, from standard to actual conditions* Actual condition flowrates are calculated from standard condition flowrates. $\begin{bmatrix}\dot{q_g}\\ \dot{q_o}\\ \dot{q_w}\end{bmatrix} = \begin{bmatrix}B_g & -B_g \cdot R_s & 0\\ 0 & B_o & 0\\ 0 & 0 & B_w\end{bmatrix} \cdot \begin{bmatrix}\dot{q_{g,sc}}\\ \dot{q_{o,sc}}\\ \dot{q_{w,sc}}\end{bmatrix}$				
Access	Public	**Dependent**	True	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

PCF05

Description	*Tuning factor F05, polynomial fitting expression* Approximation polynomial expression for the viscosity tuning factor F05. For more information about this procedure, review (Ensalzado, TEP4905-RP-02-01: BOObj class - Viscosity tuning, 2016).				
Access	Protected	**Dependent**	False	**Set access**	Protected
Hidden	True	**Class**	Double	**Get access**	Protected

PCF06

Description	*Tuning factor F06, polynomial fitting expression* Approximation polynomial expression for the viscosity tuning factor F06. For more information about this procedure, review (Ensalzado, TEP4905-RP-02-01: BOObj class - Viscosity tuning, 2016).				
Access	Protected	**Dependent**	False	**Set access**	Protected
Hidden	True	**Class**	Double	**Get access**	Protected

METHODS

An attribute table describes each method. This table is a simplified version of the method attributes available in MATLAB, and it purpose is for any user or programmer with no previous experience in MATLAB have a better understanding of the method functionality.

For information, the attribute descriptions are as follows:

Method attribute	Description	Values
Access	Method accessibility once a class instance is created. · Public: unrestricted access · Protected: access from classes and subclasses · Private: access from class member only	{public | protected | private}
Hidden	Method visibility for a class instance. When true, the property is not listed in the available class instance's methods.	{true | false}
Static	Method independency on a class object. Relative to methods inherent to the class code, such as error/exception handling. When true, the method is only available inside the class code only and does not require arguments related to the class instance.	{true | false}

TUNEVISCOSITY

Description	*Calculate viscosity tuning factors* By using this method, an object from this class calculates the tuning factors based on reference viscosity data. The user must supply 5 reference points for the fluid viscosity at a given temperature. The method requires the following arguments: · mrmu: a 5x1 array with 5 viscosity values given in cP · mrT: 5x1 array with 5 reference temperature values given in F. Both matrixes can be also calculated using the BlendingReference from an InjectionObj class object For more information, review (Ensalzado, TEP4905-RP-02-07 InjectionObj class - Class description, 2016).				
Access	Public	**Hidden**	True	**Static**	Public

CLEARTUNEVISCOSITY

Description	*Resetting viscosity tuning factors* By using this method, an object from this class resets the values of the tuning factors F05 and F06. These factors can be calculated using the `TuneViscosity` method.				
Access	Public	**Hidden**	True	**Static**	Public

STRUCTURE BRIEFING

In the following table, there is a list of all public properties included in every object created from this class.

Property	Name	Remarks
P	Pressure	Required
T	Temperature	Required
Tbgsc	Temperature, bubble point gas phase	Optional.
Tbosc	Temperature, bubble point oil phase	Optional
GOR	Gas in oil ration, reservoir	Required. Default value = 130
WC	Water cut	Required. Default value = 0
eWC	Water cut, emulsion inversion point	Required. Default value = 60
gSG	Specific gravity, gas phase	Required. Default value = 0,6400
oSG	Specific gravity, oil phase	Required. Default value = 0,8762
wSG	Specific gravity, water phase	Required. Default value = 1,0200
RichardsonO	Richardson coefficient, W/O emulsion	Required. Default value = 3,215
RichardsonW	Richardson coefficient, O/W emulsion	Required. Default value = 3,089
F01	Tuning factor	Optional. Default value = 1
F02	Tuning factor	Optional. Default value = 1
F03	Tuning factor	Optional. Default value = 1
F04	Tuning factor	Default value = 1
F05	Tuning factor, oil viscosity	Default value = 1
F06	Tuning factor, oil viscosity	Default value = 1
F07	Tuning factor	Default value = 1
API	API gravity	Dependent
Bg	Formation volume, gas phase	Dependent
Bo	Formation volume, oil phase	Dependent
Bw	Formation volume, water phase	Dependent
Co	Compressibility factor, oil phase	Dependent
Pb	Pressure at bubble point	Dependent

Property	Name	Remarks
Rs	Gas in oil ratio	Dependent
Z	Compressibility factor	Dependent
grho	Density, gas phase	Dependent
orho	Density, oil phase	Dependent
wrho	Density, water phase	Dependent
gmu	Viscosity, gas phase	Dependent
omu	Viscosity, oil phase	Dependent
wmu	Viscosity, water phase	Dependent
emu	Viscosity, liquid emulsion	Dependent
gCp	Specific heat capacity, gas phase	Dependent
oCp	Specific heat capacity, oil phase	Dependent
wCp	Specific heat capacity, water phase	Dependent
Psc	Critical pressure, pseudo fluid	Dependent
Tsc	Critical temperature, pseudo fluid	Dependent
rhosc2ac	Density conversion matrix, standard to actual	Dependent
qsc2ac	Flowrate conversion matrix, standard to actual	Dependent

APPLICATION

In the next blocks of code, some applications of the class are shown

EXAMPLE 1: DEFINING AN OBJECT

The first command line for using any class is the variable definition. Take into account that the BOObj class is a subclass of the handle superclass; therefore, if the user wants to create multiple independent objects, each variable has to be defined using the class constructor.

```
BOSW = BOObj;
BOSW.Tbosc = 391;
BOSW.Tbgsc = -263;
BOSW.gSG = 0.64;
BOSW.wSG = 1.00;
BOSW.oSG = 0.9692;
```

EXAMPLE 2: DEFINING AN OBJECT WITH A GIVEN VISCOSITY REFERENCE

In this case, two additional matrixes with the new viscosity references must be provided by the user. The matrix dimensions must be 5x1, with the viscosity values in cP and temperature values in F. With this information, the user can use the TuneViscosity method.

```
mrmu = [1943.3; 1178.0; 743.4; 486.5; 329]; % in cP
mrT = [86; 95; 104; 113; 122]; %in F
BOSW = BOObj;
BOSW.Tbosc = 391;
BOSW.Tbgsc = -263;
BOSW.gSG = 0.64;
BOSW.wSG = 1.00;
BOSW.oSG = 0.9692;
BOSW.TuneViscosity(mrmu, mrT)
```

REFERENCES

Ensalzado, R. (2016). *TEP4905-RP-02-01: BOObj class - Viscosity tuning*. Technical Report, Norwegian University of Science and Technology, Department of Energy and Process Engineering, Trondheim.

Ensalzado, R. (2016). *TEP4905-RP-02-02 BOObj class – Class description*. Technical Report, Norwegian University of Science and Technology, Department of Energy and Process Engineering, Trondheim.

Ensalzado, R. (2016). *TEP4905-RP-02-07 InjectionObj class - Class description*. Norwegian University of Science and Technology, Department of Process Engineering and Energy, Trondheim.