INTRODUCTION

An electric submersible pump (ESP) is a centrifugal pump installed in a well's downhole. The purpose of an ESP is to lift the pressure of the fluid coming from the wellbore in order to reach the wellhead with the required pressure level.

The model developed supports adjusting the pump's performance due to viscosity and impeller rotational speed. The rotational speed is proportional to the pump frequency, following the conversion 60 rpm = 1 Hz. The main algorithms used to adjust the pump performance due to these variables are as follows:

- Frequency: by using the so-called affinity laws. These laws allow to compare the performance of pumps with similar characteristics, using dimensionless numbers and proportionality relationships to correlate the impeller rotational speed and diameter, the shaft power input, and the capacity and head of the pump.
- Viscosity: by using the Hydraulic Institute procedure (ANSI/HI Standard 9.6.7, 2010). This procedure allows to adjust the performance curve of a centrifugal pump, considering the service fluid viscosity up to 4000 cSt.

DOCUMENT OBJECTIVE

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

DOCUMENT SCOPE

Describe all properties, methods and events included in the ESPObj 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}

Q

Description	*Pump capacity* Volumetric flowrate of the pump given in m^3/h.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CURVEHQ

Description	*Head-capacity performance curve* Performance curve of the pump, indicating the pump head for a given capacity for a reference fluid (water) and at a reference impeller rotational speed (N). The curve is given as a set of points, head and capacity, in m and m^3/h respectively.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurvePQ

Description	*Power-capacity performance curve* Performance curve of the pump, indicating the pump power consumption for a given capacity. for a reference fluid (water) and at a reference impeller rotational speed (N). The curve is given as a set of points, power and capacity, in kW and m^3/h respectively. This curve must have the same number of points than the H-Q curve.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurveNQ

Description	*Efficiency-capacity performance curve* Performance curve of the pump, indicating the pump efficiency for a given capacity for a reference fluid (water) and at a reference impeller rotational speed (N). The curve is given as a set of points, efficiency and capacity, in % and m^3/h respectively. This curve must have the same number of points than the H-Q curve.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurveHQvc

Description	*Head-capacity performance curve, corrected by viscosity* Performance curve of the pump, indicating the pump head for a given capacity corrected by the service fluid viscosity and at a reference impeller rotational speed (N). The curve is given as a set of points, head and capacity, in m and m^3/h respectively. To create the curve, the method `ViscosityAdjustment` must be used.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurvePQvc

Description	*Power-capacity performance curve, corrected by viscosity* Performance curve of the pump, indicating the pump power consumption for a given capacity. corrected by the service fluid viscosity and at a reference impeller rotational speed (N). The curve is given as a set of points, power and capacity, in kW and m^3/h respectively. To create the curve, the method `ViscosityAdjustment` must be used.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurveNQvc

Description	*Efficiency-capacity performance curve, corrected by viscosity* Performance curve of the pump, indicating the pump efficiency for a given corrected by the service fluid viscosity and at a reference impeller rotational speed (N). The curve is given as a set of points, efficiency and capacity, in % and m^3/h respectively. To create the curve, the method `ViscosityAdjustment` must be used.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurveHQnc

Description	*Head-capacity performance curve, corrected by frequency* Performance curve of the pump, indicating the pump head for a given capacity corrected by the service fluid viscosity and at the current impeller rotational speed (Nc). The curve is given as a set of points, head and capacity, in m and m^3/h respectively. To create the curve, the method `FrequencyAdjustment` must be used.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

CurvePQnc

Description	*Power-capacity performance curve, corrected by frequency* Performance curve of the pump, indicating the pump power consumption for a given capacity. corrected by the service fluid viscosity and at the current impeller rotational speed (Nc). The curve is given as a set of points, power and capacity, in kW and m^3/h respectively. To create the curve, the method `FrequencyAdjustment` must be used.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

FCurveHQvc

Description	*Head-capacity performance curve function, corrected by viscosity* Polynomial expression for the H-Q performance curve, corrected using the service fluid viscosity. The polynomial expression is calculated as indicated in the section Algorithms. To create the curve, the method `PerformanceCurve` must be used, with the argument `'viscosity'`.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

FCURVEHQNC

Description	*Head-capacity performance curve function, corrected by frequency* Polynomial expression for the H-Q performance curve, corrected using the current impeller rotational speed. The polynomial expression is calculated as indicated in the section Algorithms. To create the curve, the method `PerformanceCurve` must be used, with the argument `'frequency'`.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

BEP

Description	*Best efficiency point* Best efficiency point (BEP) reported by the pump manufacturer. The BEP is a pair H-Q values, from the H-Q pump original curve. H is given in m, and Q is given in m^3/h.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

N

Description	*Pump frequency, reference* Reference impeller rotational speed at which the H-Q performance curve is given. N is given in rpm.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

VNU

Description	*Fluid kinematic viscosity* Viscosity of the service fluid given in cSt. The viscosity must be given at the pump inlet conditions.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

SG

Description	*Fluid specific gravity* Specific gravity of the service. The specific gravity must be given at the pump inlet conditions.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

Nc

Description	*Pump frequency, corrected* Current impeller rotational speed of the pump. Nc is given in rpm.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

H

Description	*Pump head* Pump head given at m. This variable is calculated using the pump performance curve corrected by viscosity and by frequency if they are available.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

G

Description	*Gravity acceleration* Acceleration of gravity. It is a constant value, 9.81 m/s^2.				
Access	Public	**Dependent**	False	**Set access**	Public
Hidden	False	**Class**	Double	**Get access**	Public

Pf

Description	*Auxiliary function, standard ANSI/HI 9.6.7* Auxiliary function, to calculate the pump shaft input power, given by equation number 8 from HI standard (ANSI/HI Standard 9.6.7, 2010).				
Access	Protected	**Dependent**	False	**Set access**	Immutable
Hidden	True	**Class**	Handle	**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}

PLOTHQNADJUSTMENT

Description	*Plotting method, H-Q performance curve adjusted by frequency* When using this method, the object displays a plot including the H-Q performance curve of the pump adjusted by the pump frequency. In this case, the method uses the impeller rotational speed instead of the pump frequency. Consider the conversion 60 rpm = 1 Hz.				
Access	Public	**Hidden**	False	**Static**	False

PLOTHQVADJUSTMENT

Description	*Plotting method, H-Q performance curve adjusted by viscosity* When using this method, the object displays a plot including the H-Q performance curve of the pump adjusted by the service fluid viscosity.				
Access	Public	**Hidden**	False	**Static**	False

PLOTPQVADJUSTMENT

Description	*Plotting method, p-Q performance curve adjusted by viscosity* When using this method, the object displays a plot including the p-Q performance curve of the pump adjusted by the service fluid viscosity. In this case, the pump head is replaced by pressure using the conversion $p = \rho \cdot g \cdot H$, where ρ is the fluid density, g is the gravity acceleration and H is the pump head, all quantities in SI units.				
Access	Public	**Hidden**	False	**Static**	False

FREQUENCYADJUSTMENT

Description	*Frequency adjustment* When using this method, the object applies the affinity laws to adjust the pump performance curve based on the current impeller rotational speed, given in rpm. The method requires that the properties `BEP`, `CurveHQ`, `N`, and `Nc` are defined by the user in advance.				
Access	Public	**Hidden**	False	**Static**	False

VISCOSITYADJUSTMENT

Description	*Viscosity adjustment* When using this method, the object applies the viscosity adjustment procedure suggested by the Hydraulic Institute (ANSI/HI Standard 9.6.7, 2010) to adjust the pump performance curve based on the service fluid viscosity. The method requires that the properties `BEP`, `CurveHQ`, and `vnu` are defined by the user in advance.				
Access	Public	**Hidden**	False	**Static**	False

PERFORMANCECURVE

Description	*Performance curve adjustment* When using this method, the object performs a fitting procedure to the adjusted performance curve, either by viscosity or frequency. The fitting procedure is based on least minimum squares polynomial fitting; the algorithm selects the lowest polynomial degree (from 3 to 9), based on the R^2 dispersion parameter.				
Access	Public	**Hidden**	False	**Static**	False

ESPPROPERTYCHANGE

Description	*Event control, Nc* This static method is designed to monitor the variable Nc, in order to update the FCurveHQnc property. When this variable is changed by the user, the property FCurveHQnc is recalculated.				
Access	Protected	**Hidden**	True	**Static**	True

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
Q	Pump capacity	Required.
CurveHQ	Head-capacity performance curve	Required. Default value = zeros(10, 2)

Property	Name	Remarks
CurvePQ	Power-capacity performance curve	Optional.
CurveNQ	Efficiency-capacity performance curve	Optional.
CurveHQvc	HQ performance curve, corrected by viscosity	Calculated by method ViscosityAdjustment
CurvePQvc	PQ performance curve, corrected by viscosity	Calculated by method ViscosityAdjustment
CurveNQvc	NQ performance curve, corrected by viscosity	Calculated by method ViscosityAdjustment
CurveHQnc	HQ performance curve, corrected by frequency	Calculated by method FrequencyAdjustment
CurvePQnc	PQ performance curve, corrected by frequency	Calculated by method FrequencyAdjustment
FCurveHQvc	HQ performance curve function	Calculated by method PerformeCurve
FCurveHQnc	HQ performance curve function	Calculated by method PerformeCurve
BEP	Best efficiency point	Required. Default value = [0 0]
N	Impeller rotational speed, reference	Required.
vnu	Fluid kinetic viscosity	Required.
SG	Fluid specific gravity	Required. Default value = 0.895
Nc	Impeller rotational speed, actual	Required.
H	Pump head	Dependent.
g	Gravity acceleration	Constant. Value = 9.81

Application

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

Example 1: defining an object

In the following example, an ESPObj instance is created. In this example, the ESP has 30 stages, and a capacity multiplier of 3 is used. The pump properties are as follows:

- Fluid viscosity is 300 cSt, and specific gravity is 0,9496.
- Reference impeller rotational speed for the performance curve is 3600 rpm and corrected rotational speed is 3000 rpm.

```
SN = 30;
CM = 3;
H1 = SN*[24.1; 24.1; 23.8; 23.1; 22.7; 22.3; 21.9; 21.9; ...
         22.0; 22.3; 22.4; 22.5; 22.5; 21.9; 21.1; 19.6; ...
         17.5; 14.2];
```

```
Q1 = CM*[0.0; 10.8; 21.7; 32.5; 43.3; 54.2; 65.0; 75.8; ...
         86.7; 97.5; 108.3; 119.2; 130.0; 140.8; 151.7; ...
         162.5; 173.3; 184.2];
PP = ESPObj;
PP.CurveHQ = [H1 Q1];
PP.BEP = [SN*21.1 CM*151.7];
PP.vnu = 300;
PP.SG = 0.9496;
PP.N = 3600;
PP.Nc = 3000;
```

EXAMPLE 2: USING THE FREQUENCYADJUSTMENT AND VISCOSITYADJUSTMENT METHODS

The following code refers to the object created in the previous example. The methods are invoked using the dot notation. After completing the pump performance adjustment due to frequency and viscosity, all properties are calculated these adjusted parameters.

In this example, after setting the pump capacity, the user gets the adjusted head.

```
PP.ViscosityAdjustment
PP.FrequencyAdjustment
PP.Q = 150;
PP.H
  ans =
  448.0924
```

EXAMPLE 3: USING THE PERFORMANCECURVE METHOD

By using this method, the user computes the fitting polynomial expression for the adjusted performance curve, either by viscosity or frequency. As an important remark, the frequency adjustment is done over the data adjusted by viscosity.

In the following example, there are two applications of the method, using the two possible arguments.

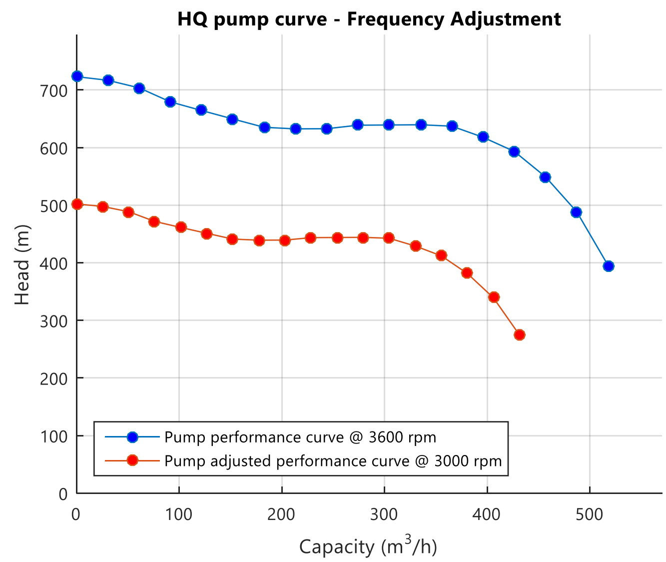
```
PP.PerformanceCurve('viscosity')
PP.FCurveHQvc
ans =
   -0.0000    0.0068   -1.4834  749.3086

PP.PerformanceCurve('frequency')
PP.FCurveHQnc
ans =
   -0.0000    0.0068   -1.2362  520.3532
```

EXAMPLE 4: USING THE PLOTHQNADJUSTMENT METHOD

By calling this method, the user will be able to display a plot from the H-Q performance curve adjusted by the actual pump impeller rotational speed.

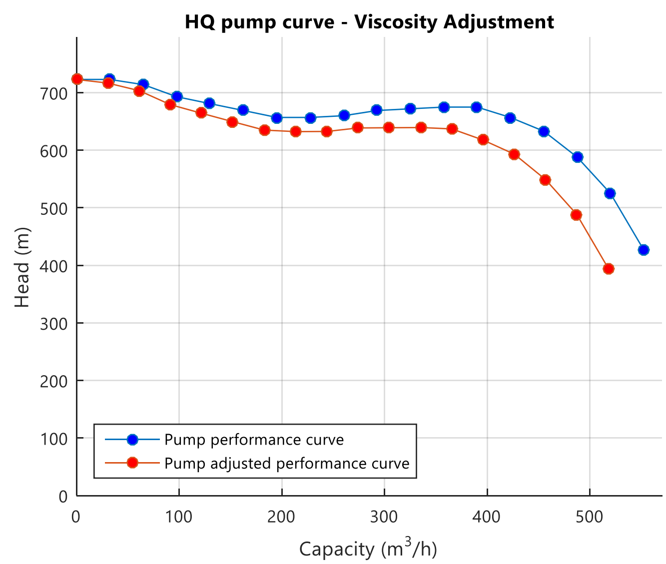
```
PP.PlotHQnAdjustment
```



EXAMPLE 5: USING THE PLOTHQVADJUSTMENT METHOD

By calling this method, the user will be able to display a plot from the H-Q performance curve adjusted by the service fluid viscosity.

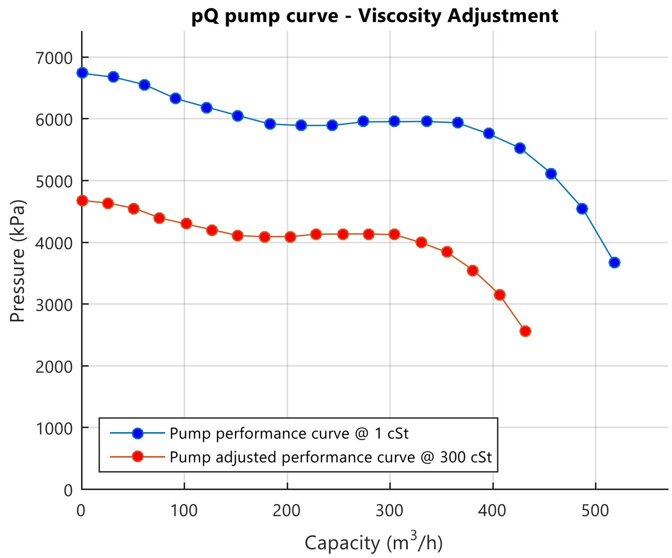
```
PP.PlotHQvAdjustment
```



EXAMPLE 6: USING THE PLOTPQVADJUSTMENT METHOD

By calling this method, the user will be able to display a plot from the p-Q performance curve adjusted by the service fluid viscosity.

```
PP.PlotpQvAdjustment
```



REFERENCES

ANSI/HI Standard 9.6.7. (2010). *Effects of Liquid Viscosity on Rotodynamic (Centrifugal and Vertical) Pump Performance*. American National Standards Institute, Inc.