FST030 Hydrocarbon software
Oil table

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This description refers to firmware version 1.03.00-01. Older versions do not support all functions described in this document.

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Rev. 2.0

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1. Introduction and Overview

The viscosity and density of hydrocarbon liquids such as diesel, kerosene or crude oil are highly temperature dependent and must therefore be taken into consideration when measuring flow.
The same can be said for pressure but to a much lesser degree.

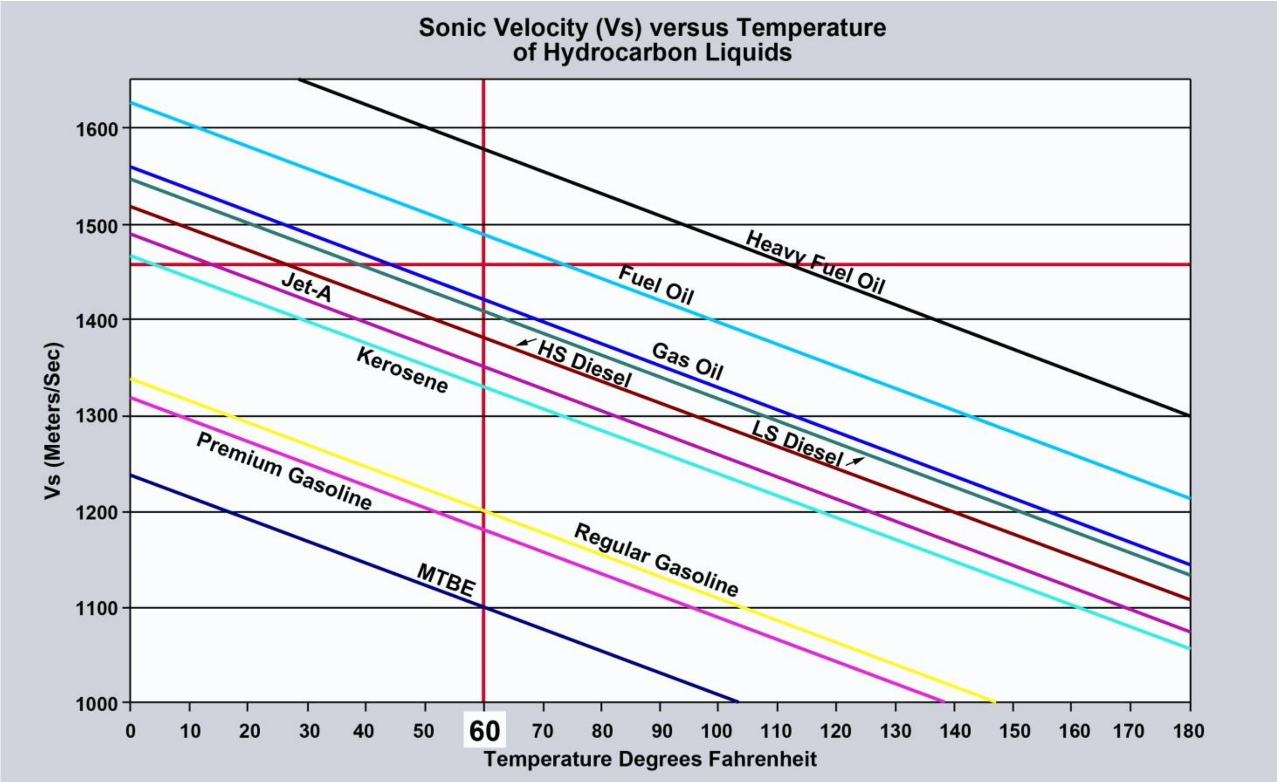
For the SITRANS FST030 to maintain its high accuracy requirement, it must be able to detect these dynamic changes in application conditions, identify the liquid type currently under measurement, and compensate for Reynolds number, density, and/or standard volume correction. These abilities set the **Hydrocarbon Software (Option B39)** apart from the standard software.
The main function of the Hydrocarbon software is the **Oil Table**.

The oil table applies to most hydrocarbon applications and is required for the following tasks:

- **Product identification**
- **Standard volume correction**
- **Live Reynolds number compensation**
- **Density calculation**
- **Multiple product measurement**
- **Mass flow measurement**

2. Liquident (Liquid Identification) Description

Liquid petroleum products behave in a very predictable and linear manner with regard to the relationship between sound speed and temperature. The graph below (Graph 1-1) illustrates this relationship for a wide range of common petroleum products, where sound speed decreases linearly with increasing temperature. Additionally, the VoS(Temp) slope is nearly identical between most petroleum liquids. Pressure also has a predictable yet relatively small influence on sound speed, but with a proportional relationship (i.e. VoS increases with pressure).



Graph 1-1: Sound velocity Vs temperature of Hydrocarbon liquids

This relationship between temperature, pressure and sound speed is used to create the parameter "Liquident". Liquident represents the expected sound speed (VoS) for the measured liquid at standard (Reference) conditions and is used to identify the type and properties of the liquid.
Reference Conditions are defined as: 60°F / 15.5 °C and 14.7 PSIA / 101.325 KPa.
The Liquident VoS is calculated from the actual (measured) speed of sound (Vs) using fixed temperature and pressure slope factors for a given application (i.e. slope factor does not change for different liquids flowing through the same pipeline).

2.1. Calculation of the Liquident

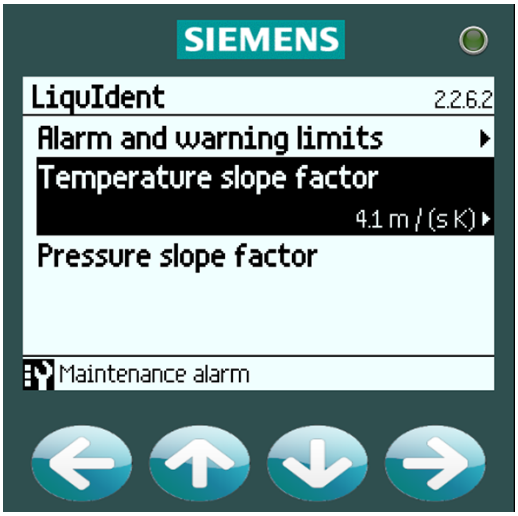
In this case the Liquident equation can be simply written as:

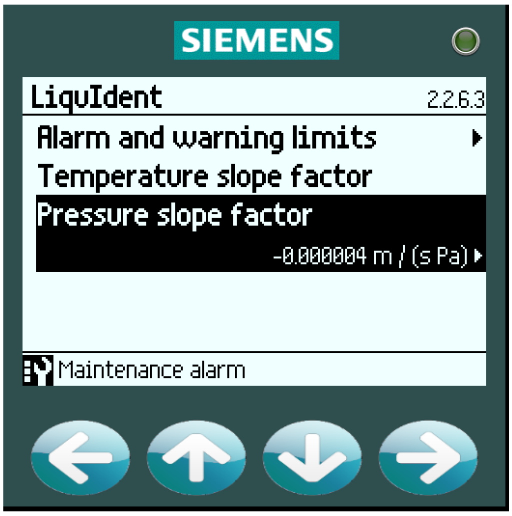
$$\boldsymbol{Liquident = Vs + Temp.slope\ x\ (T - TS) + Press.slope\ x\ (P - PS)}$$

LIQUIDENT	= Temperature and pressure compensated liquid sound speed [m/s]
Vs	= measured liquid sound speed [m/s]
T - TS	= difference between measured and standard temperature [K]
P - PS	= difference between measured and standard pressure [Pa]
Temp. slope	= temperature slope factor [m/(K s)]
Press. slope	= pressure slope factor [m/(Pa s)]

2.2. Temperature & pressure slope factor

The slope factor for temperature and pressure can be found in menu 2.2.6.2 and 2.2.6.3.





2.3. Optimization of the temperature & pressure slope factor

The default slope factors for temperature and pressure have historically proven to be accurate for most hydrocarbon applications and it is generally unnecessary to make adjustments to them. However, it is possible that the slopes may not be exact for your specific liquids.
This would be evidenced by observing a change in Vs that does not correspond to the equivalent change in temperature or pressure.
However, in most cases this problem is not related to an incorrect slope factor, but to an erroneous temperature measurement. Therefore, this parameter should only be changed if an incorrect temperture measurement can be ruled out.

The temperature and pressure slope factor can be calculated and optimized by the following equations:

$$\boldsymbol{Temperature\ slope\ factor} = \frac{(\boldsymbol{Vs\ @Tmin}) - \boldsymbol{Vs\ @\ Tmax})}{\boldsymbol{Tmin} - \boldsymbol{Tmax}}$$

$$\boldsymbol{Pressure\ slope\ factor} = \frac{(\boldsymbol{Vs\ @Pmin}) - \boldsymbol{Vs\ @\ Pmax})}{\boldsymbol{Pmin} - \boldsymbol{Pmax}}$$

2.4. Oil table settings

The remaining settings for the oil table can be found in menu 2.1.9

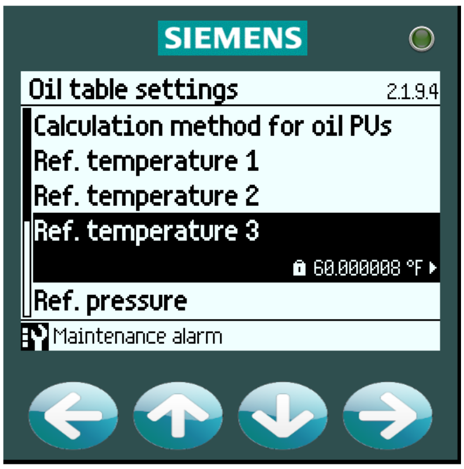
2.5. Standard/Reference temperature 3 & pressure

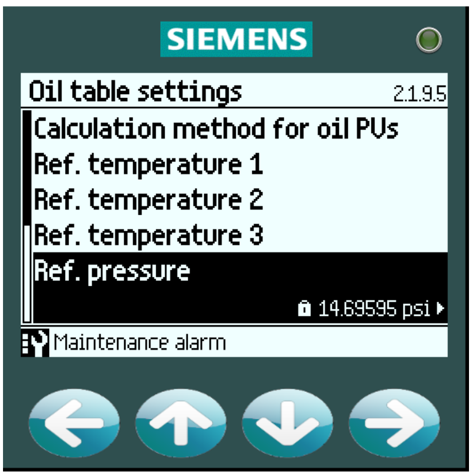
Ref. Temperature 1 and 2 are required to create the viscosity characteristic curve and are explained in chapter 3.3.

The standard temperature is defined as **Ref. temperature 3** and relates to the Liquident as well as the density values (standard density, coefficient K0, K1, K2)

This parameter can be found in menu 2.1.9.4.

The ref. pressure which also relates to the Liquident and the density values can be found in menu 2.1.9.5.





2.6. Default oil table

The oil table contains 10 well defined products. This table is suitable for many applications.

Liquident [m/s]	Liquid identifier (0-255)	Standard Density [kg/m³]	Reference Viscosity 1 at 0 °C[1] [m²/s]	Reference Viscosity 2 at 40 °C[2] [m²/s]	K0 [kg²/m⁶*K]	K1 [kg/m³*K]	K2 [1/K]
1100	1 - MTBE	647.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1180	2 - LFP (distil-late)	717.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1200	3 - LR (petrol ether)	733.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1330	4 - KEROSENE	775.0	0.0000035	0.0000022	594.5418	0.0	0.0
1350	5 - AVJET	818.0	0.0000035	0.0000022	594.5418	0.0	0.0
1380	6 - HS Diesel	819.0	0.0000055	0.0000035	186.9696	0.4862	0.0
1410	7 - LS Diesel	885.0	0.0000055	0.0000035	186.9696	0.4862	0.0
1420	8 - GASOIL	959.0	0.0000200	0.0000080	186.9696	0.4862	0.0
1490	9 - FO	930.0	0.0001190	0.0000300	186.9696	0.4862	0.0
1579	10 - HFO	985.0	0.0010490	0.0003000	186.9696	0.4862	0.0

Table 2-1: Default oil table

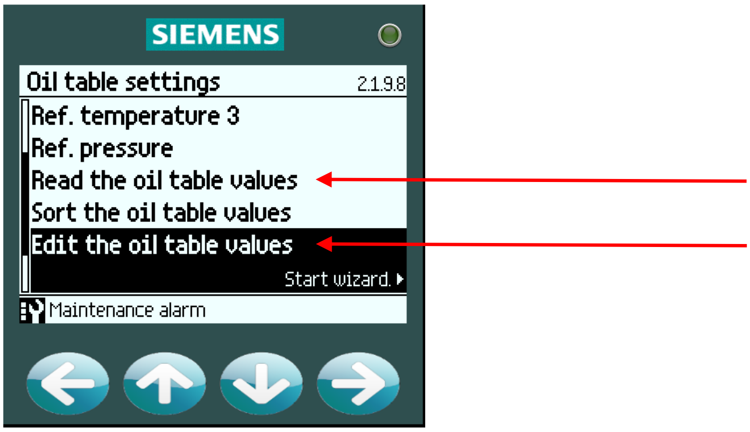
2.7. Parameters of oil table

A total of 30 Liquidents can be created.
Each row represents one Liquident (one type of oil), which includes parameters for the calculation of density, viscosity and the identification.

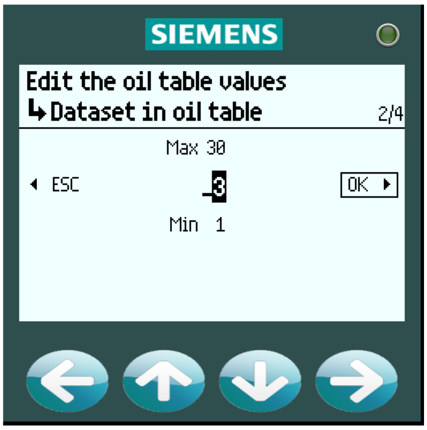
Dataset in oil table	1 to 30 (selecting table row to read)
Oil Liquident	0 to 2500 m/s (entering a zero value disables the row entry)
Oil Liquident Identifier	1 to 255 (nurmeric identifier for the liquid type)
MPMS Ref. Density	600 to 1200 kg/m³ (density associated with the Oil LiquIdent value)
Oil ref. viscosity 1	0.01 to 1e7 m2/s (viscosity associated with Ref. temperature 1)
Oil ref. viscosity 2	0.01 to 1e7 m2/s (viscosity associated with Ref. temperature 2)
Coefficient K0	0 to 2000 kg2/(m6*K)
Coefficient K1	0 to 2000 kg2/(m6*K)
Coefficient K2	0 to 2000 1/K

2.8. Reading & editing the oil table

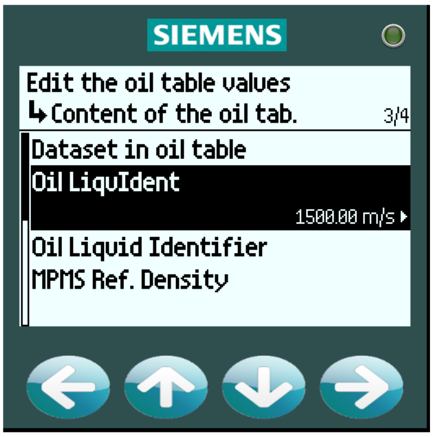
The content of each row/Liquident can either be read or edited.



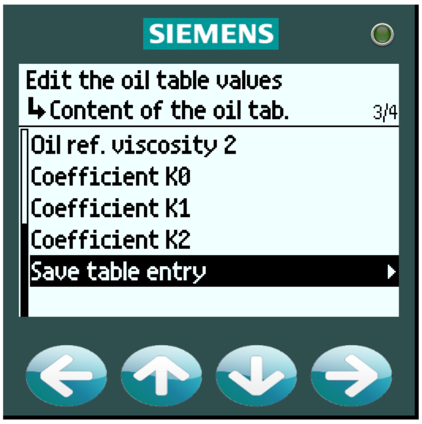
After selecting read or edit the oil table values, the dataset (Liquident number) must be entered.



The content of the row or Liquident can now be changed/optimized (if edit was selected).

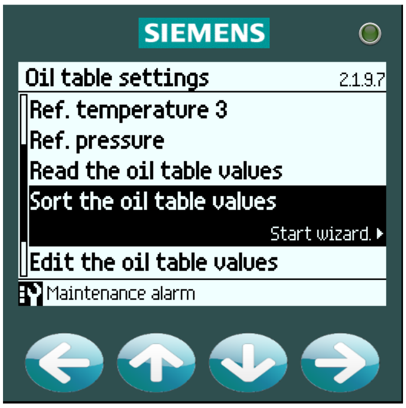


After each change, the table must be saved at the end.



2.9. Deleting & sorting the oil table

The default oil table is suitable for well-defined products.
In some cases, it may be necessary to change the table or even create a new table.
After a change, it must be ensured that the oil table is sorted by Liquident in numerically ascending order.
Therefore, if the oil table is not sorted after a change, the command "Sort oil table" (Menu 2.1.9.7) must be performed before saving and leaving the oil table settings.



In some applications not all available Liquidents inside the oil table are required.
In order to deactivate Liquidents, the first unused Liquident must be set to 0.
This will also force the lookup function to ignore all rows/Liquidents after that point.

The example below shows how to deactivate the Liquident 3.
Once the Liquident 3 is set to 0, the transmitter will only use Liquident 1 and 2 for the calculation.

2.10. Optimization / Modification of the oil table

Since the temperature largely determines the liquident and the pressure only contributes a small part, in most applications the default pressure slope factor is sufficient and need not be changed.

Therefore, in the following equation, the pressure is not taken into consideration:

$$\boldsymbol{Liquident = Vs + Temp.slope\ x\ (actual\ temp.in\ Kelvin - standard\ temp.in\ Kelvin)}$$

273.15 K = 0°C = 32°F
288.65 K = 15.5°C = 60°F = Reference Conditions

Example:
Kerosene is runing through the pipeline.
According to the oil table, we expect a liquident of 1330 m/s (sound velocity @ standard conditions)
The current liquid temperature is 37°C (98.6° F) and the current measured sound velocity is 1250 m/s.

What is the actual liquident?

Measured Vs = 1250 m/s

Liquid temperature = 37° C (98.6° F)

Standard temp = 15.5° C (60.0°F)

Liquident = 1250 m/s + 4.1 m/(K s) x (310.15 K - 288.65 K)

Liquident = 1338.15 m/s

In this example, the calculated Liquident differs slighty from the theoretical and should be modified accordingly.

3. Viscosity Determination

The operating kinematic viscosity is mainly used to improve the accuracy of the flow rate measurement, especially for a clamp-on system where the profile compensation is more sensitive to changes of the Reynolds number.

3.1. Flow equation

$$Q = K(Re)x\left(\frac{\pi}{4\ x\ Di^2}\right)x\ V$$

Q = Volumetric flow rate
V = Flow velocity
K(Re) = Reynolds number compensation
Di = Pipe inside diameter

As you can see by the equation above, in order to compute flow rate the FST030 must apply a compensation factor for Reynolds number. This factor represents the theoretical flow profile and is derived from the liquid viscosity. Since viscosity is a variable related to liquid temperature and liquid type, it is imperative for the FST030 to know these values in order to produce accurate results over changing application conditions.

3.2. Reynolds number equation

Reynolds Number (Re)

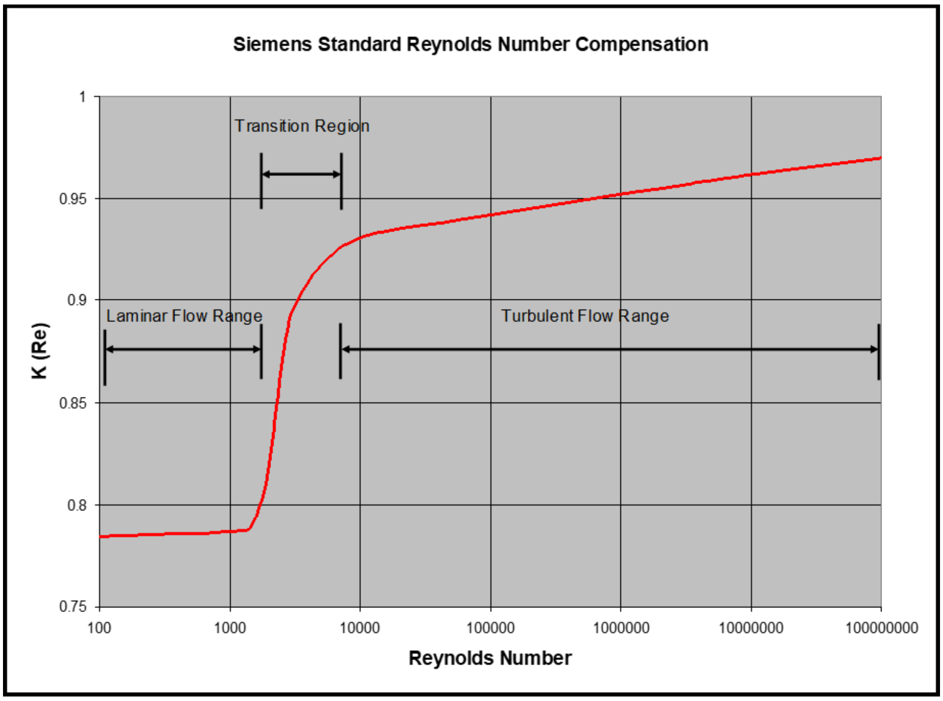
A dimensionless quantity associated with the smoothness of flow of a fluid. At low velocities fluid flow is smooth, or laminar, the fluid is a series of parallel layers, or lamina, moving at different velocities. The fluid friction between these layers gives rise to viscosity. As the fluid flows more rapidly, it reaches a velocity, known as the critical velocity, at which the motion changes from laminar to turbulent with the formation of eddy currents and vortices that disturb the flow.

The Basic Reynolds number equation appears below:

$$\boldsymbol{Re = Di * V/Vis}$$

Re = Reynolds number
V = Flow velocity
Vis = Kinematic viscosity (M2/s, Ft2/s) = (μ / ρ = (dynamic viscosity / density))

In a standard FST020/30 flowmeter, Reynolds number is computed based on actual flow rate and a fixed viscosity value. For the single product applications normally associated with these meters this solution is acceptable. In hydrocarbon pipelines where products and temperatures are varied and ultra-high accuracy is required, dynamic flow profile compensation is necessary. The Hydrocarbon software therefore utilizes temperature measurement and its liquid table to identify the measured liquid and its viscosity in order to compute the precise Reynolds number and apply the most accurate compensation factor. Through the use of the oil table the FST030 is able to exactly compensate for the actual flow profile conditions even for multiple liquids.

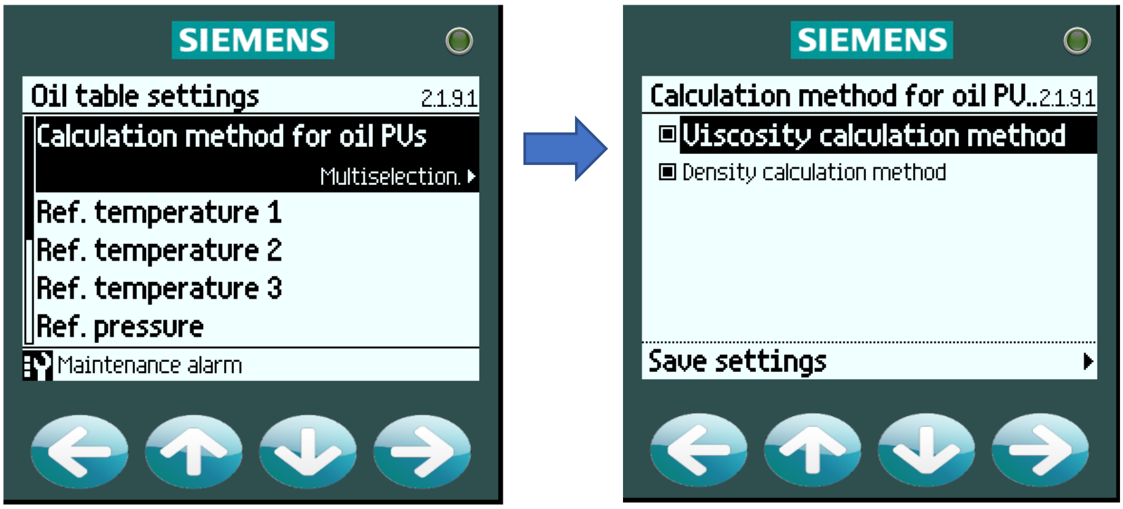


3-1: Reynolds number compensation

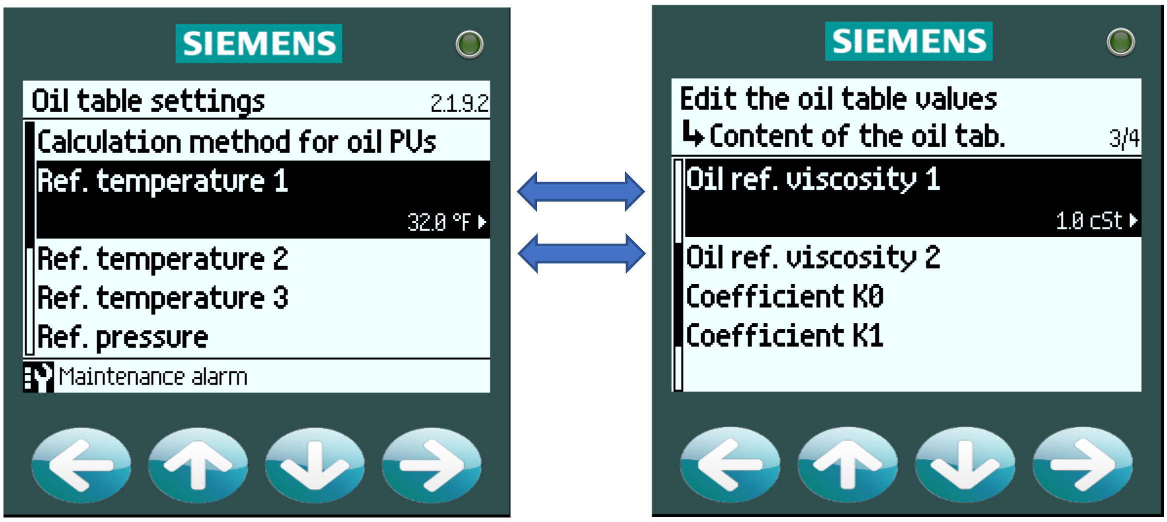
3.3. Creating the viscosity characteristic curve

Kinematic viscosity is derived in accordance with ASTM standard D341. This standard uses two known viscosity values at two different reference temperatures to derive the viscosity at any given temperature.

The calculation for the viscosity must be enabled first by checking the box “Viscosity calculation method”. When the viscosity calculation method is disabled, the kinematic viscosity will be derived from the fixed "Kinematic viscosity" entry of the “Medium characteristics” menu.



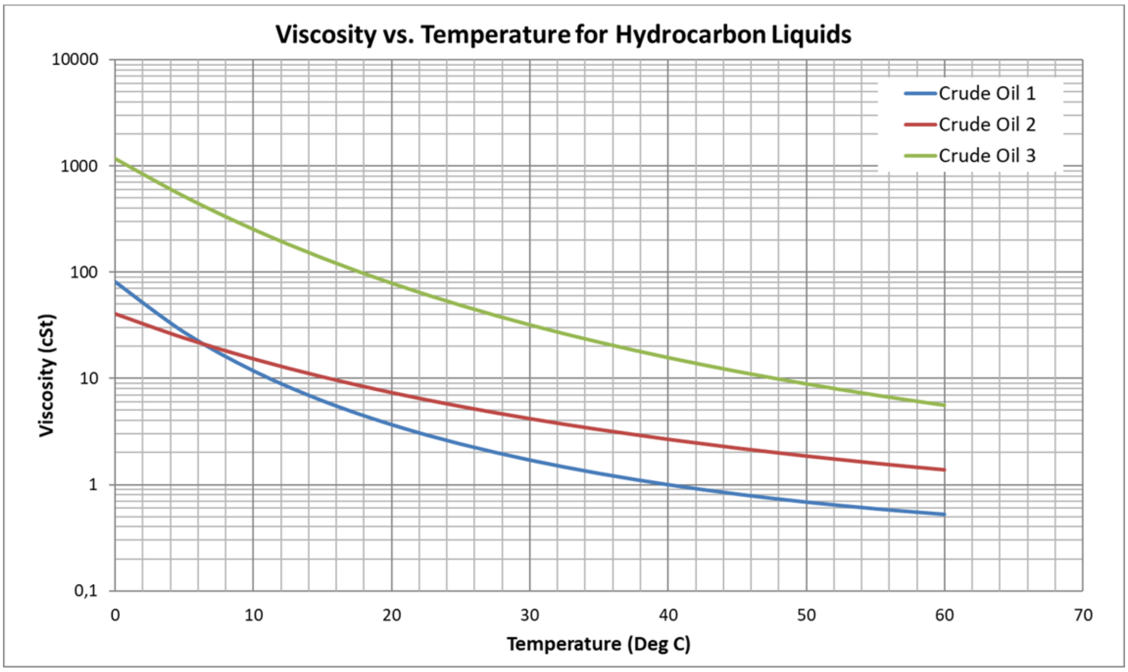
The Ref. Temperature 1 relates to viscosity 1 and must be defined in menu 2.1.9.2
The Ref. Temperature 2 relates to viscosity 2 and must be defined in menu 2.1.9.3



The corresponding viscosities can be found in the oil table and must be set individually for each used Liquident.
With these two defined points, the flowmeter is able to create the viscosity characteristic curve, as illustrated in the graph 3-3 below.

	cSt	deg C	cSt	deg C
Liquid Name	V1	T1	V2	T2
Crude oil 1	5.8	15.5	1.0	40
Crude oil 2	10.0	15.5	2.68	40
Crude oil 3	128.58	15.5	15.7	40

Table 3-2: Viscosity/Temperature points for three different types of crude oil



Graph 3-3: Viscosity characteristic curve derived from the table 3-2 above

4. Density/Standard volume

During normal operation the flowmeter will calculate the Liquident value based on the measured liquid sound speed, temperature and pressure. From the calculated Liquident value, the liquid name and associated standard density and compressibility factors would be referenced via the lookup table (with interpolation between density or SG values). The standard density and compressibility factors are then used to calculate the volume compensation factor CTPL, standard volume and density at operating conditions.

After the MPMS (API standard) reference density and compressibility coefficients (K0, K1, K2) are determined for the flowing oil, the FS230 applies the API MPMS 11.1 algorithms. These algorithms calculate the density for the measured pressure and temperature, as well as the correction for standard volume flow rate.

The corresponding compressibility coefficients K0, K1 and K2 for different hydrocarbon liquids can be found in the table 4-1 and 4-2 below:

Liquident [m/s]	Liquid identifier (0-255)	Standard Density [kg/m³]	Reference Viscosity 1 at 0 °C¹⁾ [m²/s]	Reference Viscosity 2 at 40 °C²⁾ [m²/s]	K0 [kg²/m⁶*K]	K1 [kg/m³*K]	K2 [1/K]
1100	1 - MTBE	647.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1180	2 - LFP (distil-late)	717.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1200	3 - LR (petrol ether)	733.0	0.0000010	0.0000006	346.4228	0.4388	0.0
1330	4 - KEROSENE	775.0	0.0000035	0.0000022	594.5418	0.0	0.0
1350	5 - AVJET	818.0	0.0000035	0.0000022	594.5418	0.0	0.0
1380	6 - HS Diesel	819.0	0.0000055	0.0000035	186.9696	0.4862	0.0
1410	7 - LS Diesel	885.0	0.0000055	0.0000035	186.9696	0.4862	0.0
1420	8 - GASOIL	959.0	0.0000200	0.0000080	186.9696	0.4862	0.0
1490	9 - FO	930.0	0.0001190	0.0000300	186.9696	0.4862	0.0
1579	10 - HFO	985.0	0.0010490	0.0003000	186.9696	0.4862	0.0

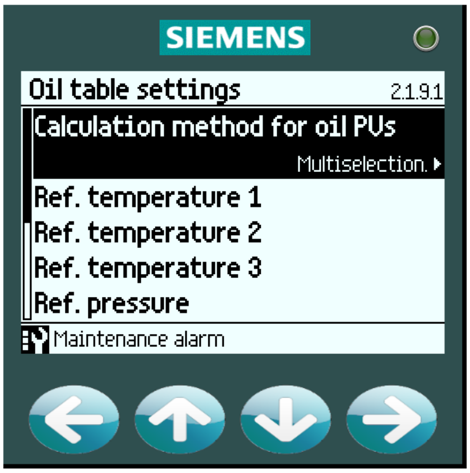
Table 4-1: Default oil table

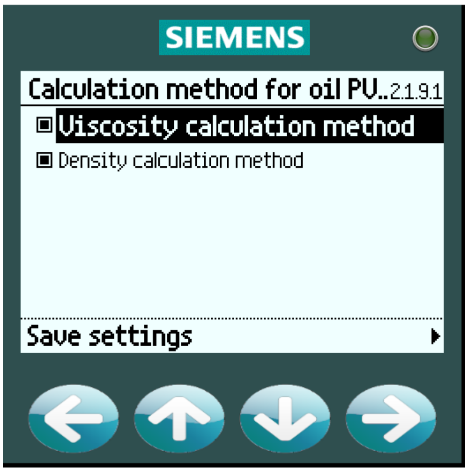
Product	Density Range [kg/m³]	K0 [kg²/m⁶*K]	K1 [kg/m³*K]	K2 [1/K]
Crude Oil	610.6-1163.5	613.9723	0.0	0.0
Fuel Oils	838.3127-1163.5	186.9696	0.48618	0.0
Jet Fuels	787.5195-838.3127	594.5418	0.0	0.0
Transition Zone	770.3520-787.5195	2680.3206	0.0	-0.003363
Gasoline	610.6-770.3520	346.4228	0.43884	0.0
Lubricating Oil	800.9-1163.5	0.0	0.62780	0.0

Table 4-2: Standard density and coefficient K0, K1, K2 for common liquid classes

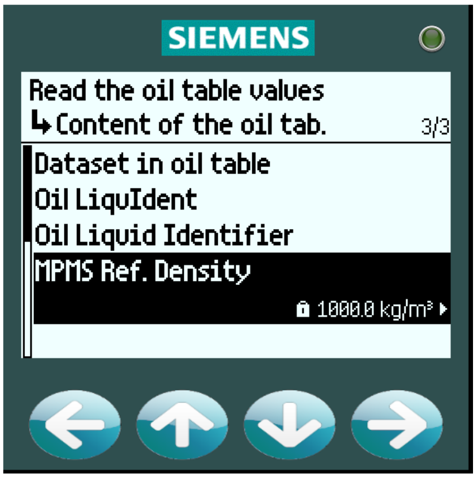
4.1. Standard density & Coefficient K0, K1 and K2

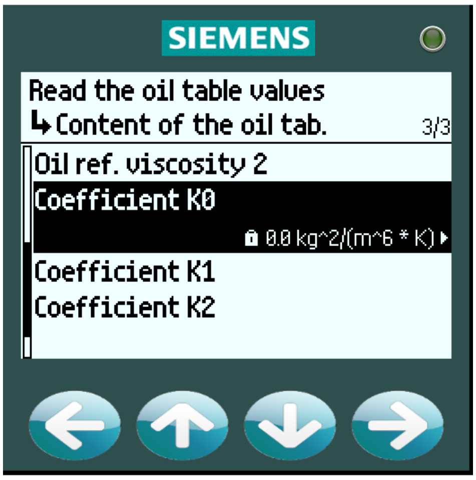
The calculation for the density must be enabled first by checking the box “Density calculation method”. When the density calculation method is disabled, the density will be derived from the fixed "Density" entry of the “Medium characteristics” menu.





The standard density (density at 15.5 ° C or 60 ° F) and the coefficients K0, K1 and K2 must be set individually for each Liquident.





4.2. Specific gravity & API gravity

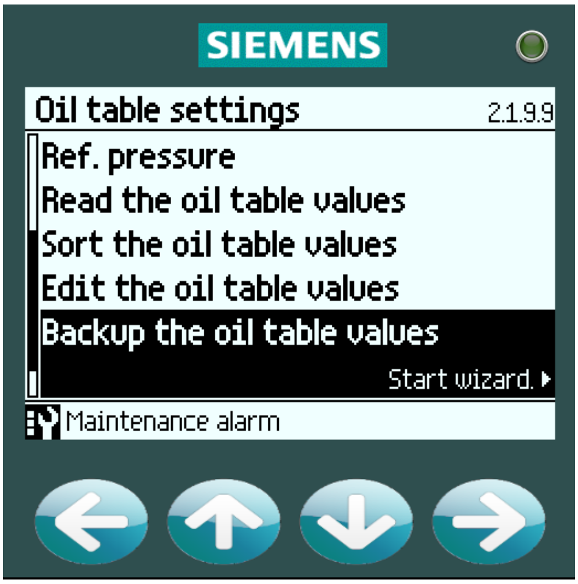
Based on the density, the specific gravity and API gravity are calculated as follows:

$$\boldsymbol{Specific\ Gravity = \frac{actual\ density}{density\ of\ water}}$$

$$\boldsymbol{API\ Gravity = \left(\frac{141.5}{SG}\right) - 131.5}$$

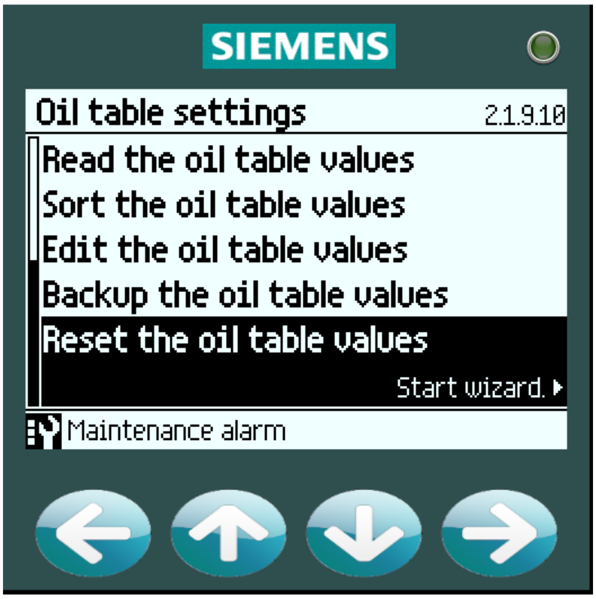
5. Backup the oil table value

CAUTION! Once a change has been made in the oil table, the table must be saved to the internal flash memory of the transmitter, otherwise all changed data will be lost after a restart.



The command "Backup the oil table" saves the data on the internal flash memory.
This command can be found in menu 2.1.9.9

In order to restore the default oil table, the command "reset the oil table" must be executed.
This command can be found in menu 2.1.9.10



6. Example: Creating a new oil table

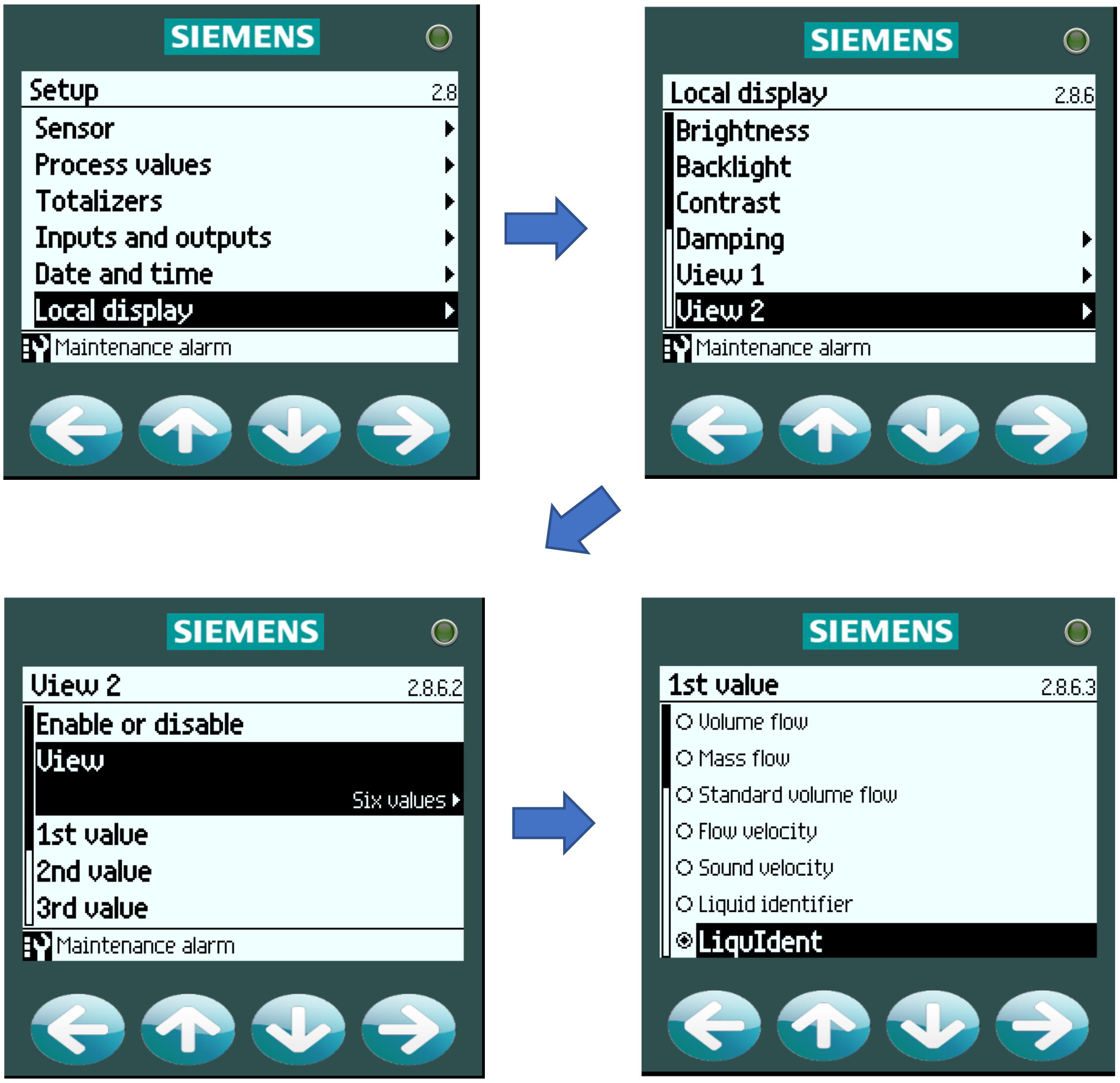
In this example two different crude oils must be measured by the FST030 Flowmeter"
Since the two types of crude oil are not included in the default oil table, a new table must be created.

Only the following data sheet of the two crude oils is available:

	Crude oil 1	Crude oil 2
Viscosity @ 20°C (68°F)	10.5 cSt	21 cSt
Viscosity @ 40°C (104°F)	3.8 cSt	unknown
Density @ 15.5°C (60°F)	744 kg/m3	888 Kg/m3

The first step is to determine the two Liquidents.

The current Liquident value can be shown on the main screen of the FST030 transmitter.
In the following example, main screen 2 is used for the configuration.



After the configuration, the current Liquident can now be observed in the main view 2.

It is always recommended to add the following parameters in the main view for a later possible diagnosis:

- Liquident
- Liquid identifier
- Medium temperature
- Sound velocity
- Kinematic viscosity
- Standard kinematic viscosity
- Density / Specific gravity / API gravity (Selection depending on the customer)
- Standard Density / Specific gravity / API gravity (Selection depending on the customer)

The above-mentioned parameters show only current values.

For the creation of the oil table, additional information must be logged over a longer period of time. This task is fulfilled by the internal data logger of the FST030 transmitter.

The following parameters (Modbus registers) must be logged:

- Sound velocity — Modbus register 3006
- Medium temperature — Modbus register 3042
- **Liquident** — **Modbus register 3058**

For a later possible diagnosis, the following data should be logged as well:

- Liquid identifier — Modbus register 3150
- Kinematic viscosity — Modbus register 3046
- Standard kinematic viscosity — Modbus register 3054
- Density — Modbus register 3040
- Specific gravity — Modbus register 3064
- API gravity — Modbus register 3060
- Standard Density — Modbus register 3056
- Standard Specific gravity — Modbus register 3066
- Standard API gravity — Modbus register 3062

In this example the data logger shows following information:

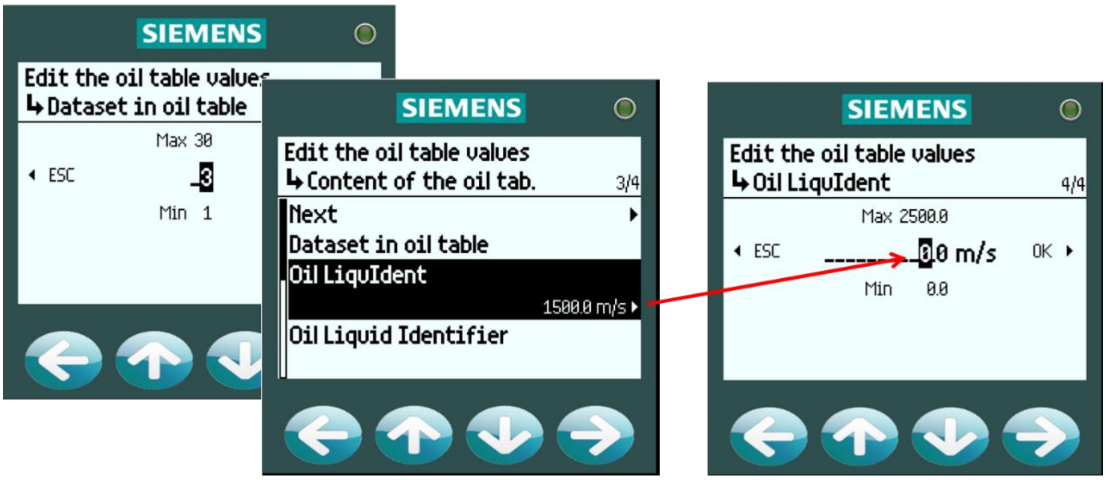
Date	*Time*	*Vs*	*Temp.*	*Liquident*
03.12.2019	*15:45:52*	*1250 m/s*	*30°C*	*1310 m/s*
03.12.2019	*20:01:30*	*1338 m/s*	*35°C*	*1418 m/s*

According to the customer, crude oil 1 ran through the pipeline between 2 pm and 5 pm.
From 5 pm, crude oil 2 has run through the pipeline.

With the above-mentioned information as well as the data from the data sheet of the oil, it is now possible to create a new oil table.

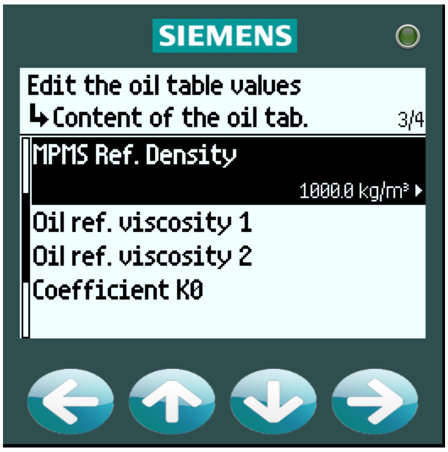
The Liquident 1 must be set to 1310 m/s and Liquident 2 must be set to 1418 m/s.

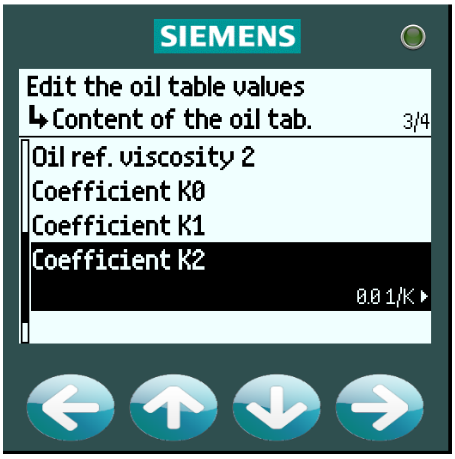
Since only the first two Liquidents are required, the remaining Liquidents should be deactivated by setting the third Liquident to 0 m/s.
This will force the lookup function to ignore all rows after that point.



In cases where many types of crude oil will flow in the pipeline but data is only available for a few types, it is recommended to start the oil table with the available Liquidents that have the lowest and highest viscosities. The flowmeter will interpolate between the two points.
From then on, the oil table should be updated with Liquidents between the two points whenever possible in order to improve the accuracy of the oil table.

The standard density specified on the data sheet must be adjusted for both Liquidents as well as the coefficient K0, K1 and K2.
The coefficient K0, K1 and K2 for crude oil can be found in table 4-2 on page 15.





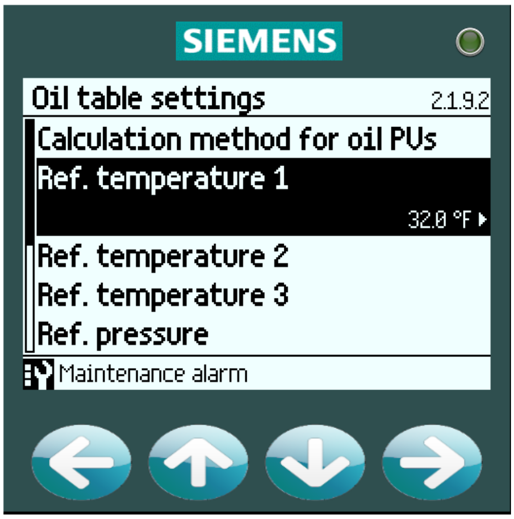
In some rare cases, the coefficient K0, K1 and K2 must be optimized.

An incorrect coefficient setting will cause a density error, which becomes greater the farther away the current temperature is from the standard temperature.

The calculation of the coefficient K0, K1 and K2 is very complex and depends on many factors.

The easiest approch is to set K1 and K2 to 0, then adjust K0 until the measured density values matches the real density values of the application.
Please contact technical support if a calculation for the coefficient K0, K1 and K2 is required.

For the viscosity calculation, temperature 1 must be set to 20°C (68°F) and temperature 2 to 40°C (104°F).



The corresponding viscosity 1 and 2 must be adjusted for both Liquidents.

Since only one viscosity is available for crude oil 2, the standard calculation method of the FST030 cannot be performed to determine the characteristic curve of the viscosity.
However, it is possible the calculate the second viscosity for any temperature with the following equation:

Viscosity equation related to Celsius:

$$Viscosity\ 2 = e^{-0.0287x(Temp.\ 2 - Temp.\ 1)x\ 1.8 + ln\ (Viscosity\ 1)}$$

Viscosity equation related to Fahrenheit:

$$Viscosity\ 2 = e^{-0.0287x(Temp.\ 2 - Temp.\ 1) + ln\ (Viscosity\ 1)}$$

$$Viscosity\ 2 = e^{-0.0287x(40°C - 20°C)x\ 1.8 + ln\ (21\ cSt)}$$

$$Viscosity\ 2 = 7.5\ cSt$$

Overview of the created oil table:

	Crude oil 1	Crude oil 2
Dataset in oil table	1	2
Oil Liquident	1310 m/s	1418 m/s
Oil Liquident Identifier	1	2
MPMS Ref. Density	744 kg/m^3	888 kg/m^3
Oil ref. viscosity 1	10.5 cSt	21 cSt
Oil ref. viscosity 2	3.8 cSt	7.5 cSt
Coefficient K0	613.9723	613.9723
Coefficient K1	0.0	0.0
Coefficient K2	0.0	0.0

If the Liquident values cannot be clearly defined or are not reproducible over the entire range due to an unreliable temperature measurement, Liquident ranges can be created.

In addition to the two existing Liquident entries, a duplicate for each Liquident can be created that express the exact same density and viscosity values. Only the Liquident values are different.
This ensures that the correct density and viscosity values are taken from the oil table.

The table below shows how this can be realized.

	Crude oil 1.1	Crude oil 1.2	Crude oil 2.1	Crude oil 2.2
Dataset in oil table	1	2	3	4
Oil Liquident	**1310 m/s**	**1417 m/s**	**1418 m/s**	**1500 m/s**
Oil Liquident Identifier	1	2	3	4
MPMS Ref. Density	744 kg/m3	744 kg/m3	888 kg/m3	888 kg/m3
Oil ref. viscosity 1	10.5 cSt	10.5 cSt	21 cSt	21 cSt
Oil ref. viscosity 2	3.8 cSt	3.8 cSt	7.5 cSt	7.5 cSt
Coefficient K0	6.139.723	6.139.723	6.139.723	6.139.723
Coefficient K1	0.0	0.0	0.0	0.0
Coefficient K2	0.0	0.0	0.0	0.0

For further questions please contact our technical support via Support Request at
[Siemens Industry Online Support]