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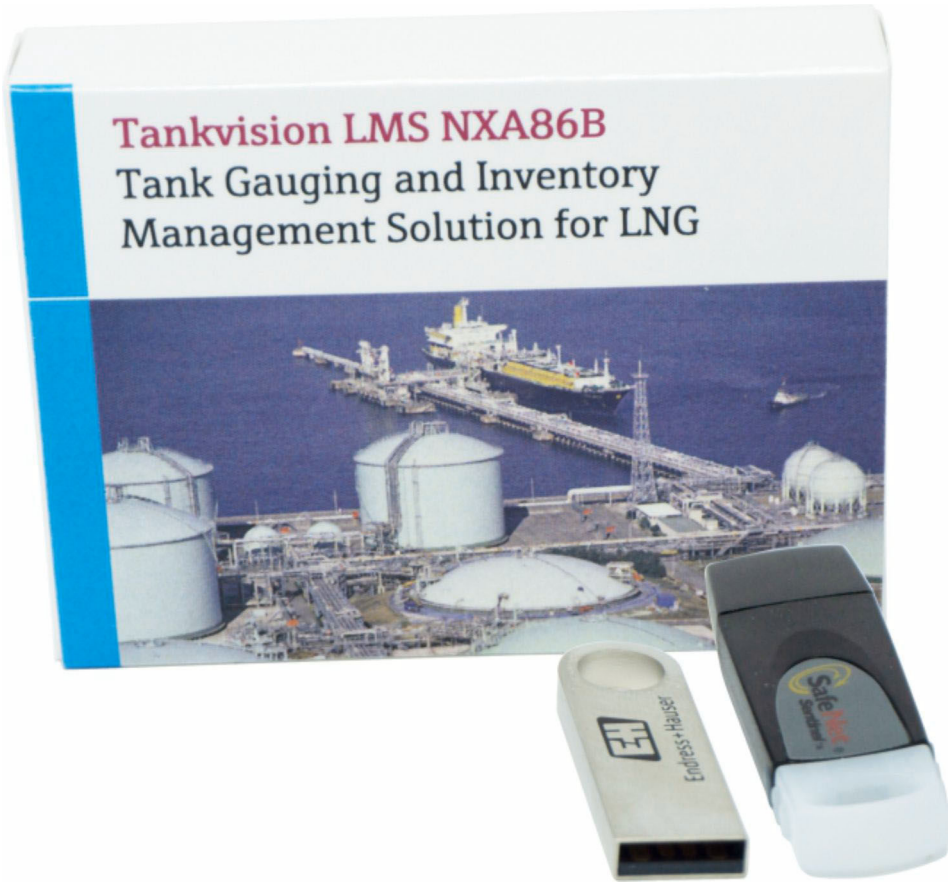
2024-04-03

Valid as of version
18.3.3

Operating Instructions
Tankvision LMS NXA86B

Rollover Prediction in LNG storage tanks



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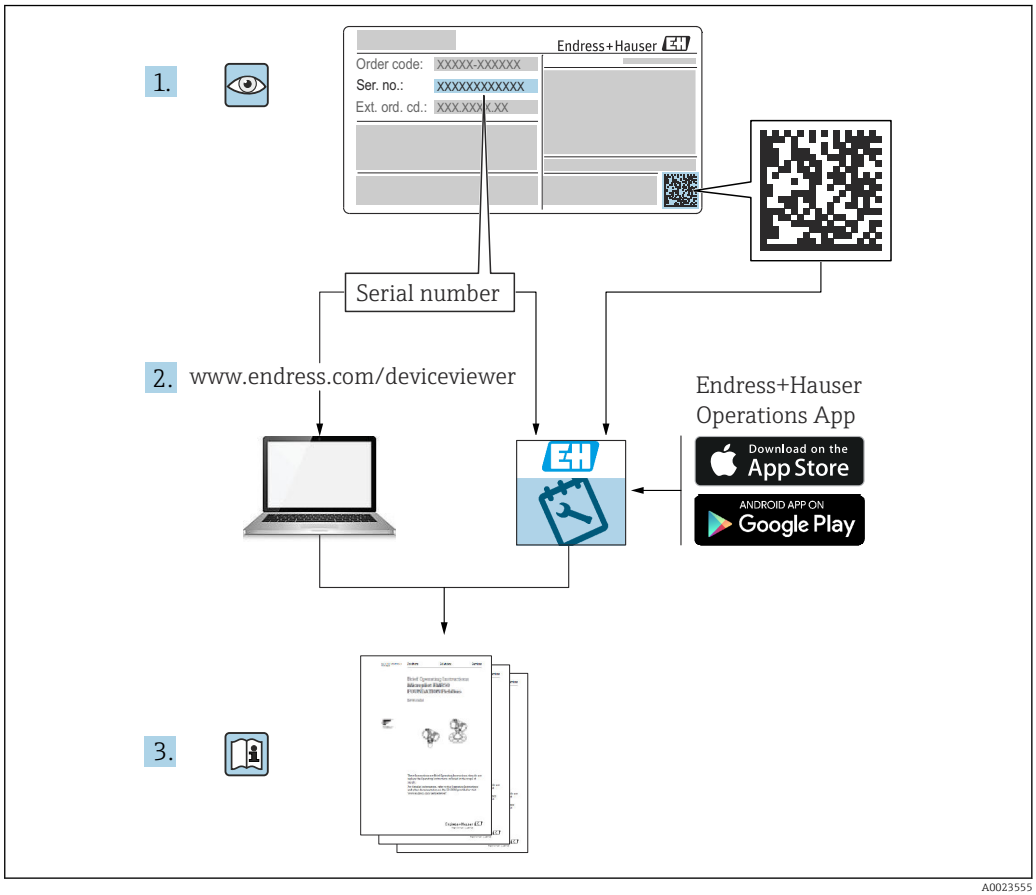
People for Process Automation

- Make sure the document is stored in a safe place such that it is always available when working on or with the device.
- To avoid danger to individuals or the facility, read the "Basic safety instructions" section carefully, as well as all other safety instructions in the document that are specific to working procedures.
- The manufacturer reserves the right to modify technical data without prior notice. Your Endress+Hauser sales organization will supply you with current information and updates to this manual.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Change history

BA01702G/01.17
- Valid for software version: 18.0.2 and 18.0.3
- Initial version

BA01702G/02.18
- Valid for software version: 18.1.1
- Changes to the previous version:
  Compatibility with Windows 10 and Windows Server 2016

BA01702G/03.22
- Valid for software version: 18.3.2
- Changes to the previous version:
  Chapters added:
  Viewing results
  Scheduling rollover predictions

BA01702G/04.24
- Valid for software version: 18.3.3
- Changes to the previous version:
  Compatibility with Windows 11 and Windows Server 2022. Minor changes to existing functionality.

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1 About this document

1.1 Document function

This manual should support during the installation of Tankvision LMS NXA86B.

Beside basic PC operating knowledge no special training is needed to perform the Tank Gauging System operations. Nevertheless it is recommended receiving a training on the system by Endress+Hauser.

1.2 Symbols

1.2.1 Safety symbols

⚠ DANGER
This symbol alerts you to a dangerous situation. Failure to avoid this situation will result in serious or fatal injury.

⚠ WARNING
This symbol alerts you to a potentially dangerous situation. Failure to avoid this situation can result in serious or fatal injury.

⚠ CAUTION
This symbol alerts you to a potentially dangerous situation. Failure to avoid this situation can result in minor or medium injury.

NOTICE
This symbol alerts you to a potentially harmful situation. Failure to avoid this situation can result in damage to the product or something in its vicinity.

1.2.2 Symbols for certain types of information and graphics

Tip
Indicates additional information

Reference to documentation

Reference to graphic

▶
Notice or individual step to be observed

1., 2., 3.
Series of steps

Result of a step

1, 2, 3, ...
Item numbers

A, B, C, ...
Views

1.3 Documentation

For an overview of the scope of the associated Technical Documentation, refer to the following:
- *Device Viewer* (www.endress.com/deviceviewer): Enter the serial number from the nameplate
- *Endress+Hauser Operations app*: Enter serial number from nameplate or scan matrix code on nameplate.

1.4 Registered trademarks

1.4.1 Microsoft®, Windows®

Microsoft and Windows are registered trademarks of the Microsoft Corporation

1.4.2 Modbus™

Modbus is a registered trademark of Schneider Electric USA, Inc.

1.4.3 Java®

Java is a registered trademark of Sun Microsystems, Inc.

1.4.4 Mozilla® Firefox®

Mozilla and Firefox are registered trademarks of the Mozilla Foundation

1.4.5 Android®

Android, Google Play and the Google Play logo are registered trademarks of Google Inc.

1.4.6 iPhone®, iPad®

iPhone and iPad are trademarks of Apple® Inc., registered in the U.S. and other countries.

2 Basic safety instructions

2.1 Requirements for the personnel

The personnel for installation, commissioning, diagnostics and maintenance must fulfill the following requirements:

- Trained, qualified specialists must have a relevant qualification for this specific function and task.
- Are authorized by the plant owner/operator.
- Are familiar with federal/national regulations.
- Before starting work, read and understand the instructions in the manual and supplementary documentation as well as the certificates (depending on the application).
- Follow instructions and comply with basic conditions.

The operating personnel must fulfill the following requirements:

- Are instructed and authorized according to the requirements of the task by the facility's owner-operator.
- Follow the instructions in this manual.

2.2 Intended use

2.2.1 Intended use of Tankvision LMS NXA86B software

Tankvision LMS is a total LNG Tank Storage and Management solution for Peak Shaving, Receiving and Production LNG facilities. The LMS system has been designed to interface to all instruments commonly found on LNG storage tanks, and to collect and present the instrument data through a range of intuitive graphical user interfaces. A typical LNG Tank will have a wide range of measurement instruments to measure Liquid Level, Liquid Density, Liquid and Vapour Temperature, Liquid and Vapour Pressure, Skin Temperature and much more.

Typically each tank would be fitted with an LTD gauge, two further level gauges configured as a Primary and Secondary, and an Alarm Gauge. The LTD gauge is a servo operated unit mounted on the tank roof. The purpose of the LTD gauge is to take accurate profiles of temperature and density throughout the liquid, and whilst not profiling provide continuous liquid level, temperature and density measurement. The Primary and Secondary gauges can be either servo and or radar operated units also mounted on the tank roof. The purpose of these gauges is to provide continuous liquid level measurement, and average liquid temperature measurement. They provide redundancy on the measurement of level and temperature. The average liquid temperature is derived from a multi point temperature sensor device. The alarm gauge is often a servo or radar based gauge configured to provide volt free contact alarm status to an independent system.

An LMS system can operate in a simple standalone configuration or as a fully redundant system where security and integrity are of paramount importance. The LMS system has a flexible and scalable architecture allowing it to be tailored to a number of different applications easily.

2.3 IT security

Our warranty is valid only if the product is installed and used as described in the Operating Instructions. The product is equipped with security mechanisms to protect it against any inadvertent changes to the settings.

IT security measures, which provide additional protection for the product and associated data transfer, must be implemented by the operators themselves in line with their security standards.

3 Incoming acceptance and product identification

3.1 Incoming acceptance

On receipt of the delivery:

1. Check the packaging for damage.
   ↳ Report all damage immediately to the manufacturer.
   Do not install damaged components.
2. Check the scope of delivery using the delivery note.
3. Compare the data on the nameplate with the order specifications on the delivery note.
4. Check the technical documentation and all other necessary documents, e.g. certificates, to ensure they are complete.

If one of the conditions is not satisfied, contact the manufacturer.

3.2 Product identification

The following options are available for identification of the software:

- Nameplate specifications
- Order code with breakdown of the software features on the delivery note
- Enter serial numbers from nameplates in *Device Viewer* (www.endress.com/deviceviewer): All information about the software is displayed.

For an overview of the technical documentation provided, enter the serial number from the nameplate in the *Device Viewer* (www.endress.com/deviceviewer).

3.2.1 Nameplate

The information that is required by law and is relevant to the product is shown on the nameplate, e.g.:

- Manufacturer identification
- Product name
- Order code
- Extended order code
- Serial number
- Barcode

3.2.2 Manufacturer address

Endress+Hauser SE+Co. KG
Hauptstraße 1
79689 Maulburg, Germany

Place of manufacture: See nameplate.

3.2.3 Order code and product version

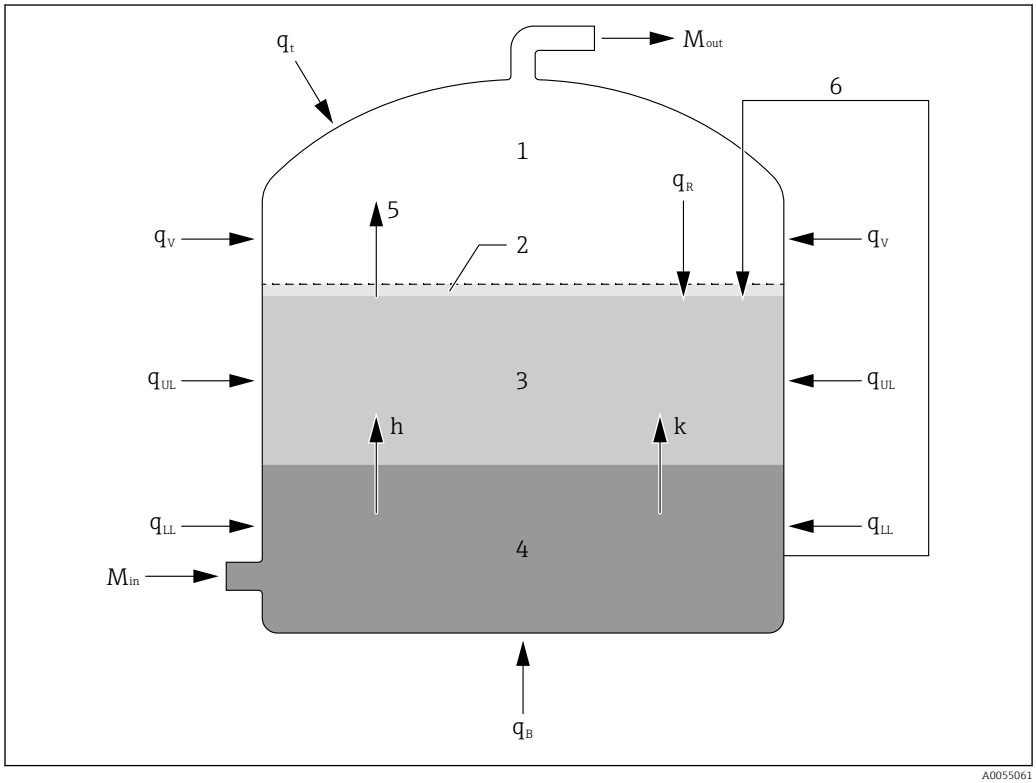
To find out the version of your software, enter the order code indicated on the nameplate in the search screen at the following address:
www.products.endress.com/order-ident

4 Rollover Prediction

The rollover prediction algorithms are based upon a lumped parameter model using energy and material balance equations. The model also takes into account boil-off using thermodynamic principles.

The model allows the user to visualise the evolution of temperature, density, layer thickness of the stratified layers within a tank from an initial condition for temperature, layer depth and composition. The change in boil-off rate and vapour pressure can also be visualised with time.

The illustration below summarises the various parameters that are considered within the model.



1 *Rollover prediction parameters*

1 *Vapour*
2 *Film*
3 *Upper layer*
4 *Lower layer*
5 *Boil-off, molar vapourisation rate from vapourising film*
6 *External recirculation*
h, k *Heat and mass transfer coefficients across the interface, respectively*
M_{in} *Molar flow rate into LNG tank*
M_{out} *Molar flow rate out of LNG tank*
q_B *Heat leak rate into bottom of LNG tank*
q_{LL} *Heat leak rate into lower layer from side wall of LNG tank*
q_R *Rate of heat transfer from vapour space to vapourising film*
q_t *Heat leak rate into vapour from dome of LNG tank*
q_{UL} *Heat leak rate into upper layer from side wall of LNG tank*
q_V *Heat leak rate into vapour from side wall of LNG tank*

Heat and mass transfer between the stratified layers are incorporated in the model using heat and mass transfer coeffcients. Heat and mass transfer coeffcients can be fed in by the user or calculated from a built-in empirical correlation assuming turbulent conditions inside the individual layers. In addition the model offers a novel approach where heat and mass transfer coeffcients can be calculated from the real time LTD profiles using the inverse methodology.

4.1 Inverse methodology

The novelty of the model comes from its ability to estimate heat and mass transfer coefficients from the real time level-temperature-density (LTD) profiles using the inverse method.

The governing equations of the lumped parameter model are first solved for the initial set of heat and mass transfer coefficients to estimate the change in density of the stratified layers over a specific time. LTD profiles taken over the same period provide the actual change in density of stratified layers in the tank. In the inverse method, the lumped parameter model is iteratively solved by performing a directed search and by varying a set of heat and mass transfer coefficients until the estimated density change matches with the actual density change (obtained from LTD profiles) providing a unique set of heat and mass transfer coefficients.

4.2 Preferential boil-off

LNG is mainly comprised of methane, ethane, propane, and butane with traces of nitrogen. The boiling points of these species vary considerably with nitrogen boiling preferentially followed by lighter hydrocarbons. The lumped parameter model incorporates preferential boil-off of more volatile species using Vapour Liquid Equilibrium. The saturation pressure of individual species is obtained from Antoine equation, which estimates the highest saturation pressure for nitrogen followed by methane, ethane, propane and butane.

4.3 Flash Calculations

Flash calculations are particularly relevant when the tank is filled from the top and during any external recirculation operation. Flash calculations are performed for the abovementioned operations if tank pressure is greater than the dew point pressure and smaller than the bubble point pressure. The phase fraction of a particular filling rate or recirculation rate going into the vapour space is estimated based upon the composition and temperature of the LNG fed or recirculated and the tank pressure.

4.4 Assumptions

The prediction model is based upon the following assumptions:
- The tank is initially stratified and the compositions of at least one liquid layer is known.
- An LTD profile exists for the tank. For the inverse mode, two profiles are required (alternatively profiles can be entered manually).
- The heat leakage rates remain constant for the duration of the calculation.

4.5 Input Parameters

The following list identifies the inputs required to the model. When the model is ran with an LNG Tank Management System most of the data is already available within that system.

Where data items are not available they can either be entered manually, read from the DCS or any other devices capable of providing the data:
- Tank pressure
- Vapour temperature
- Tank strapping table
- Time for running the prediction (maximum duration)
- Time step for generating the outputs

- Compositions of stratified liquid layers and vapour space in the tank (the model may estimate the missing compositions from the LTD data). Where pre-defined compositions are available in Tankvision LMS, the composition which most closely matches the temperature and density of the layer can be automatically selected.
- Rates and durations for filling, emptying and recirculation, as well as composition in case of filling the tank
- Heat leakage rates into the tank, or the following in order to calculate them; average temperatures inside and outside of the tank, number of insulating layers, thickness of insulating layers and thermal conductivity of insulating materials
- Physical properties such as thermal conductivity, thermal diffusivity and kinematic viscosity if known (otherwise the model may calculate them)
- Vent pressure and design pressure for alarm annunciation
- The user needs to specify the mode of heat and mass transfer coefficients calculation: manual, empirical or inverse mode
- The user needs to specify either automatic, manually picked or manually entered mode of profile selection
- A proportionality constant, in case of using empirical mode to estimate heat transfer coefficient
- Heat and mass transfer coefficients in case of using manual mode
- Level, temperature and density of each layer in case of manually entered profile

4.6 Model Features

The simulation can be performed for any profile available in the profile history by using the manual profile selection. Automatic profile selection uses the last profile available in the profile history for empirical and manual modes and the last two profiles for the inverse mode. Alternatively the required inputs characterizing layers may be filled in by the user in "manually entered" mode.

The model can incorporate various tank operations such as tank filling (top or bottom), tank emptying (top or bottom) and external recirculation.

The model recommends top or bottom filling depending on the density of the new LNG and the density of the LNG already in the tank.

4.7 Model Predictions

The model will determine the time until rollover as the period it takes for the density equalisation. The user will be guided to save the output data obtained from the model predictions, which can later be used to compare and contrast the predictions for various operations.

The following parameters are also calculated for each prediction:
- Time to rollover
- The normal boil-off rate
- The peak boil-off rate
- The maximum vapour pressure
- The product lost until roll-over event
- Heat transfer coefficient
- Mass transfer coefficient

4.8 Displayed warnings

The model will display the following warnings depending upon the calculated data:

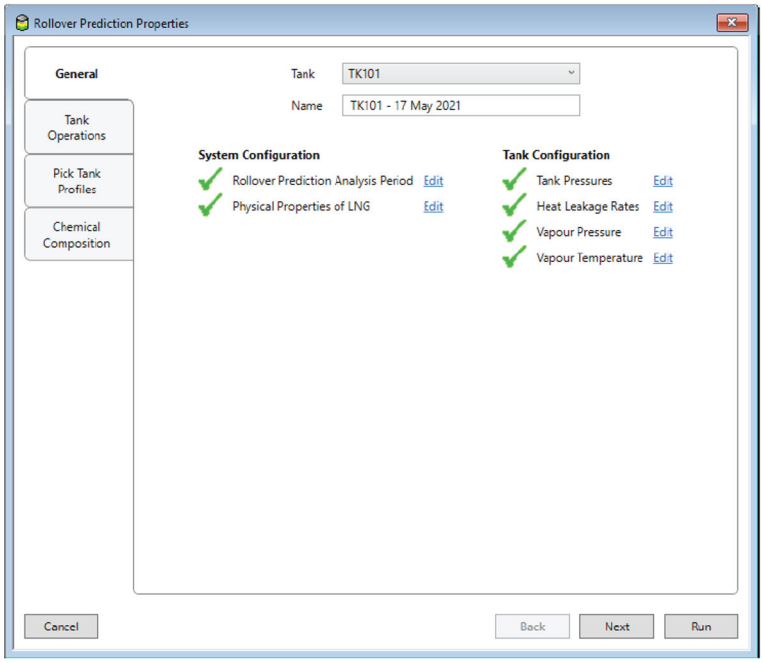
- Occurrence of rollover within the prediction time
- Warning: Risk of venting to atmosphere.
  If the predicted vapour pressure exceeds the specified vent pressure, the model will annunciate this alarm.
- Warning: Risk of tank damage.
  If the predicted vapour pressure exceeds the specified design pressure, the model will annunciate this alarm.

5 Rollover Prediction Software

The rollover predictions are subject to tank pressure and vapour temperature which can be specified manually by selecting Configuration menu on LNG tank management GUI screen and then by selecting the Manual Data option. Select the appropriate tank and gauge, tick the checkbox and set the vapour pressure and temperature fields to appropriate values. Generally, LNG is stored just above atmospheric pressure. The densitometer gauge device is used in order to retrieve all the profile data. Tank diameter and tank height are calculated from the Tank Capacity Tables.

5.1 Setting up a simulation

To launch the rollover prediction module first open Tankvision LMS and then click on the rollover prediction button ( ) on Tankvision LMS GUI to open rollover prediction software. This will invoke a blank window with menu on the top. From the menu bar select **Prediction → New**. This will invoke a pop-up window as shown below.

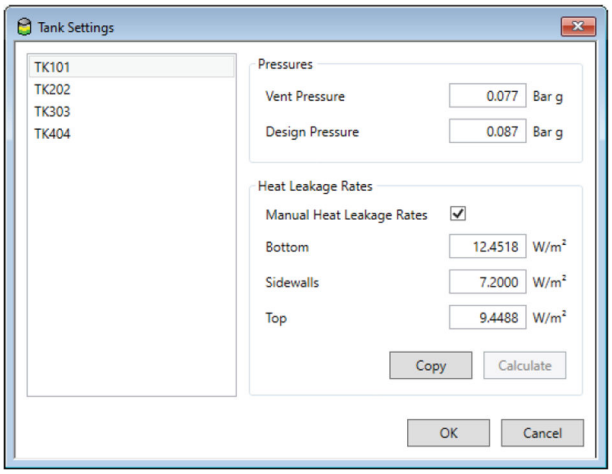


2 *Rollover Prediction Properties*

5.1.1 General

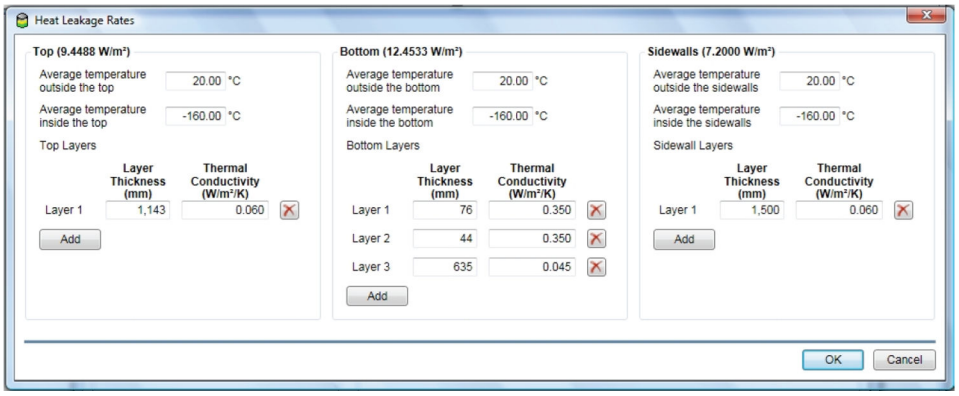
Select a tank from the drop down list and edit the automatically generated prediction name if desired.

Tank Pressures and **Heat Leakage Rates** can be configured by clicking the **Edit** link at the side of the relevant item. This opens a configuration screen as shown.



3 Tank Settings

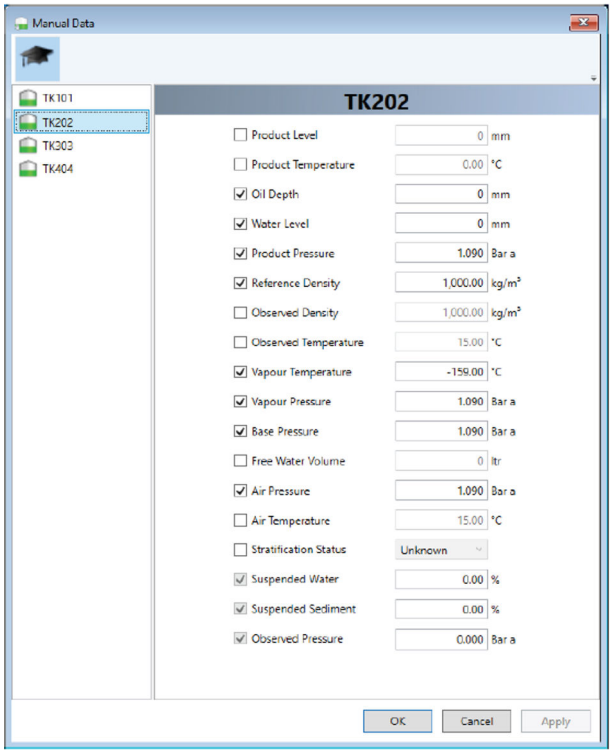
Here you can tick the **Manual Heat Leakage Rates** box and enter the **Bottom**, **Sidewalls** and **Top** leakage values. To copy the heat leakage rates from another tank, click the **Copy** button and then choose the source tank from the list. Alternatively they can be calculated. In order to do this leave the **Manual Heat Leakage Rates** option unchecked and click the **Calculate** button. This will display the screen shown.



4 Calculate heat leakage rates

In case of calculating heat leakage rates, the user needs to specify the average temperature outside and inside the tank at the top, bottom and sidewalls of the tank, the number of insulating layers and the thickness and thermal conductivity of each of them (see "Appendix" for specific values).

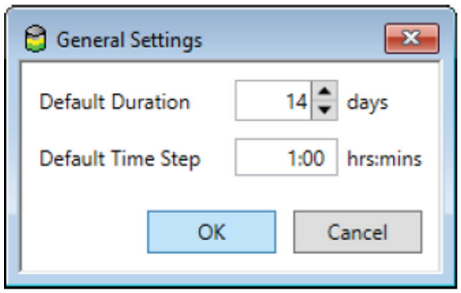
Vapour Pressure and **Vapour Temperature** settings can be configured by clicking the **Edit** link at the side of the relevant item. This opens the **Manual Data** input screen as shown in the following figure. To see extended items click on the mortarboard icon at the top left of the window.



5 Manual Data

The duration of the simulation to be run must be configured (maximum 99 days) as well as the time steps at which you want the outputs to be displayed. To do this click the **Edit** link at the side of the **Rollover Prediction Analysis Period** item.

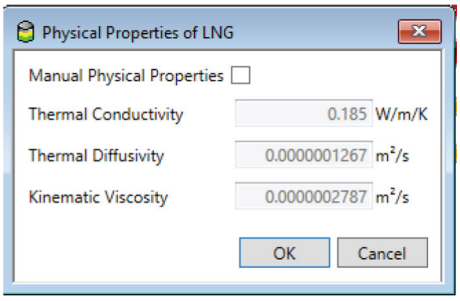
This opens a window as shown in the following figure.



6 Analysis Period Configuration

The physical properties of LNG such as thermal conductivity, thermal diffusivity and kinematic viscosity can be specified in the **Physical properties of LNG** screen. To do this click the **Edit** link at the side of the **Physical Properties of LNG** item.

This will open a configuration window as shown in the following figure.

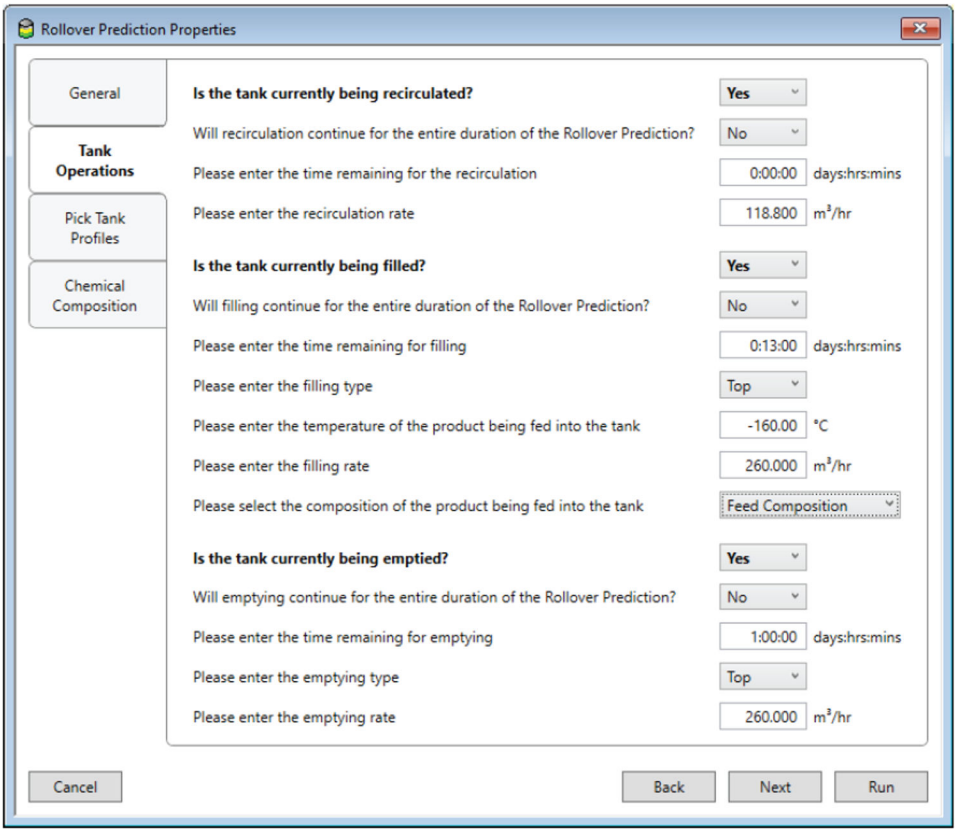


7 *Physical properties of LNG*

By leaving the tick box empty the user may leave this data to be calculated by the model from the LNG properties such as temperature and density.

5.1.2 Tank Operations

To specify various tank operations such as tank filling, tank emptying and external recirculation, select **Tank Operations** from the tabs on left hand side. This will display the screen shown below.



8 *Tank Operations*

Select the appropriate option to turn the External Recirculation on or off. Recirculation rate, at which LNG is taken out from the bottom of the tank and filled in from the top along with the duration of the process, needs to be specified if the external recirculation is selected.

Select the appropriate option to determine if the tank is currently being filled.

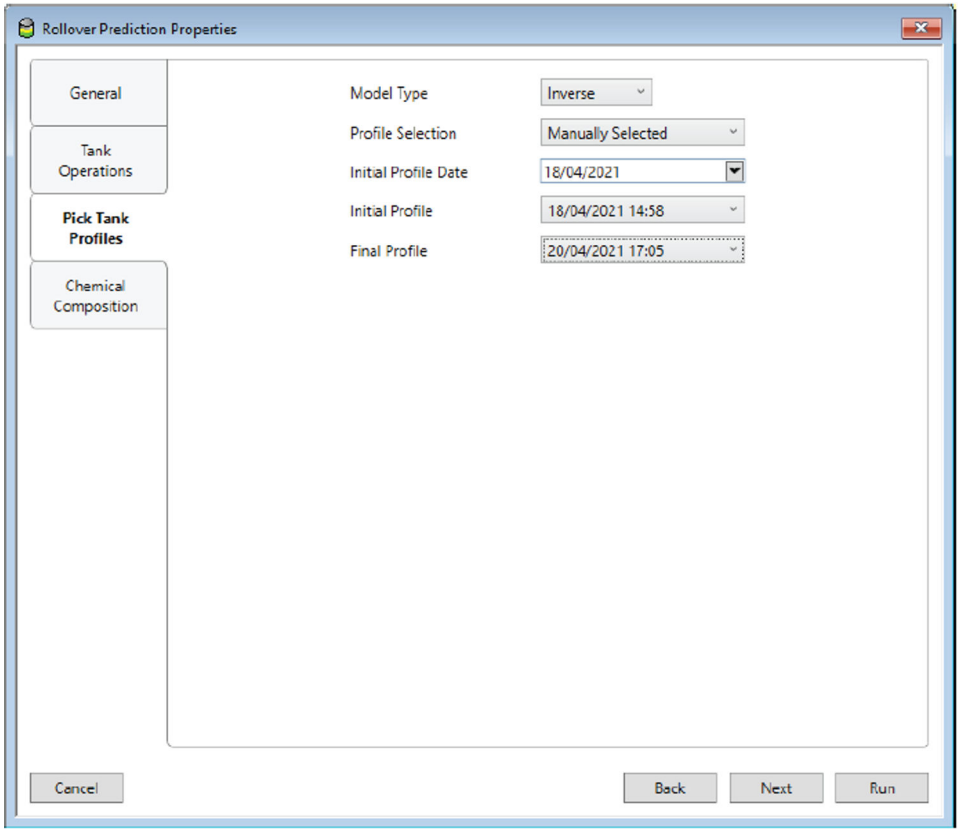
If it is specified that the filling will not continue throughout the entire duration of the prediction then the **time remaining for filling** must be specified.

Other items that must be configured for filling are:
- **Filling type** - **Top** or **Bottom**
- **Temperature of the product being fed into the tank**
- **The filling rate**
- **The composition of the product being fed into the tank**

Select the appropriate option to manage the configuration of any emptying process which is currently ongoing.

Similar to the filling configuration, the duration, type and rate of the emptying must be configured.

5.1.3 Pick Tank Profiles



9 *Pick Tank Profiles*

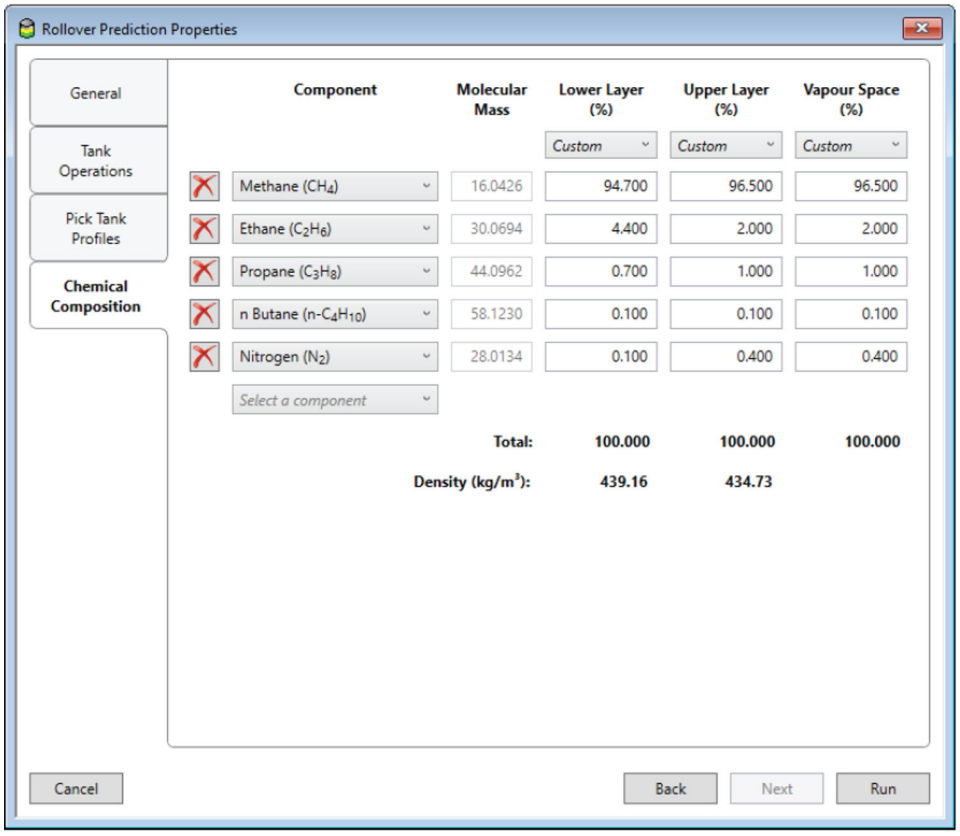
The model provides two methods of calculating heat and mass transfer coefficients, which are used to estimate heat and mass transfer rates between the stratified layers of the tank, namely the manual and inverse modes. This can be selected by changing the **Model Type** option.

For the Manual mode, heat and mass transfer coefficients need to be specified manually. The inverse mode uses two real time LTD profiles in order to estimate heat and mass transfer coefficients from the change in density of the stratified layers of the two profiles.

Both modes can be used with any of the stratified profiles available in the profile history, or LTD data provided by the user. The profiles can be either selected automatically or manually by the user. In absence of an LTD profile a single set of data characterizing levels, temperatures and densities of both liquid layers can be manually entered. For an automatic profile selection, the last profile available in profile history is used for both the manual and the empirical modes and the last two profiles, separated by at least 6 hours, are used for the inverse mode. Under the Manual Profile Selection, the exact day, month, year and time in hours and minutes need to be specified from the dropdown boxes as that of the profile to be used to run the model.

5.1.4 Chemical Composition

To specify the composition for both liquid layers and the vapour space, select **Chemical Composition** from the tab on left hand side. This will display the screen shown below.



10 *Chemical Composition*

The composition of each of the **Lower Layer**, **Upper Layer** and **Vapour Space** should be entered.

There are four ways of doing this which can be selected from the drop down list under the layer name:

- **Estimated (Vapour Space Only)**
  The composition is to be estimated by the model.
- **Automatic**
  The pre-defined composition which closest matches the temperature and density of the model will be used.
- **Name**
  The pre-defined composition set with the selected name is to be used.
- **Custom**
  The details of the components to be used are specified. When **Custom** is selected, the various components of LNG can be selected from a drop down list of species. The molecular mass of the selected species will be automatically displayed. When a component is selected in the last row, a new component will automatically be added. Components can be removed by clicking the **X** sign on the left-hand end of the row.

6 Run & Post-processing

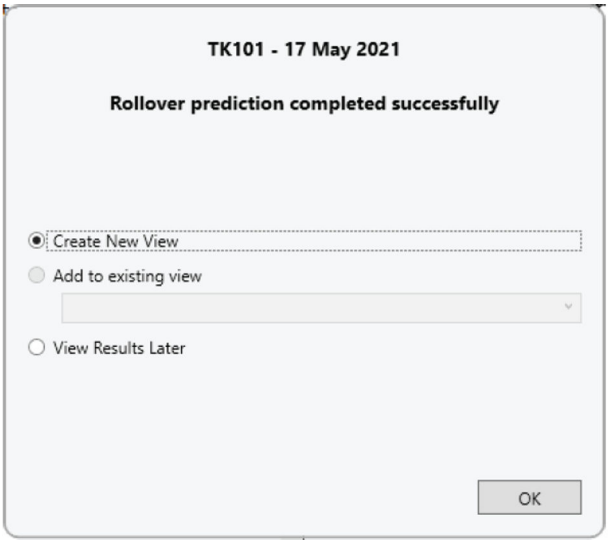
Once the model is set up, click the **OK** button on the bottom of the window. This will launch the simulation. The execution of the model should normally take around 5 minutes depending on the mode of heat and mass transfer coefficients calculation you have chosen and the set duration.

Whilst the model is running the screen shown below will be displayed.

11 *Prediction running*

To cancel the current model run, click **Cancel** button. To hide the screen, click the **Close** button. Whilst the model is still running an icon will be displayed in the Windows notification tray.

After the calculations are complete, a screen similar to the one shown below will appear.



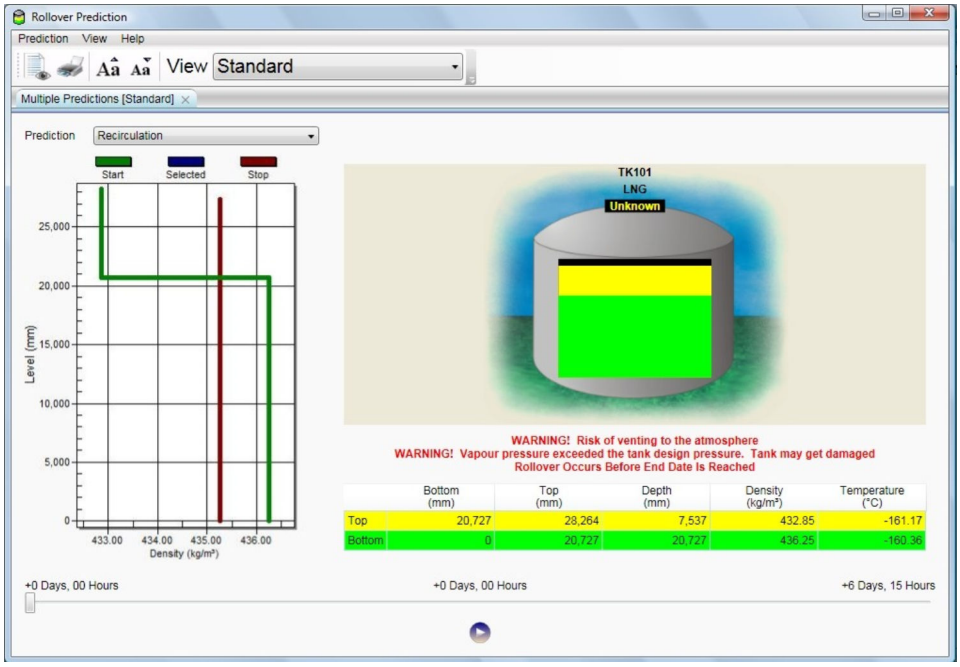
12 *Rollover calculations complete*

If the model has failed to run successfully, details of the error will be displayed.

If the model has completed successfully there are three options:

- **Create New View**
  Show the results in a new pane in the main window.
- **Add to existing view**
  If there are already results open in the main window, an existing set of results can be selected to which the new model run results can be added for comparison.
- **View Results Later**
  Do not display the results. The results will still be saved for later viewing

When the new view option is selected, the results are shown in a new pane in the main window as show below:



13 *Rollover results*

If the model predicts the possible occurrence of rollover before the end date, a warning message will be displayed below the tank image.

Similarly, if the estimated vapour pressure exceeds the preset values of the vent pressure and the tank design pressure, warnings indicating the risk of venting to atmosphere and the risk of tank damage will be triggered.

The graph on left of the **Rollover Prediction** screen shows a plot of liquid level against density. The green solid line represents the initial condition, while the red one the predicted end profile. The time slider allows the user to view the predicted change in the profile either as a movie (after clicking play button) or by manually setting the time slider to a given point in time (displayed above the slider).

The table at the bottom of the screen indicates the top and bottom positions of the upper and lower layer, along with layers' depths, densities and temperatures. As the time slider is moved, the numerical data is updated in the table to reflect the predicted conditions at that time.

As density equalization is the criterion for the occurrence of rollover, the rollover prediction model terminates once the uniform density of the stratified layers is reached displaying the message "Rollover Occurs Before End Date Is Reached" on the screen. If rollover does not occur until the specified end date, the software displays the message "End Date Reached".

If tank emptying operation is ticked on and density equalization occurs before end date is reached, the software displays the message "Rollover Occurs Before Tank Is Emptied" on the screen. If tank emptying operation is ticked, as soon as the depth of either lower or

upper layer becomes smaller than 0.1 m, the rollover prediction model is terminated displaying the message "Tank Emptied Safely" on the screen.

A unique feature of the rollover prediction model is its ability to infer heat and mass transfer coefficients from the real time LTD profiles. The inverse method uses the two LTD profiles which are at least 6 hours apart (for a considerable change in temperature and density). The inverse method then estimates the heat and mass transfer coefficients that match the calculated density change with the corresponding value obtained from the LTD profiles over the same period of time. The heat and mass transfer coefficients, estimated using the inverse method, are displayed in the summary screen. The same heat and mass transfer coefficients values, as those predicted, are used for rollover prediction when the Inverse mode is selected by the user.

Using options from the toolbar you can view a printed version of the current window, print it, increase or decrease font size and view different results, respectively.

6.1 Viewing Predictions

In order to view different screens with predictions of the simulation use the drop-down **View** list on the right of the toolbar.

The options given are as follows:
- **Standard** (one displayed by default, after finished simulation)
- **Convergence Graph**
- **Summary**
- **Boil-off Rate Graph**
- **Density Graph**
- **Layer Thickness Graph**
- **Temperature Graph**
- **Composition Graph**
- **Calorific Value Graph**
- **Output data**
- **Composition Output Data**
- **Document view**

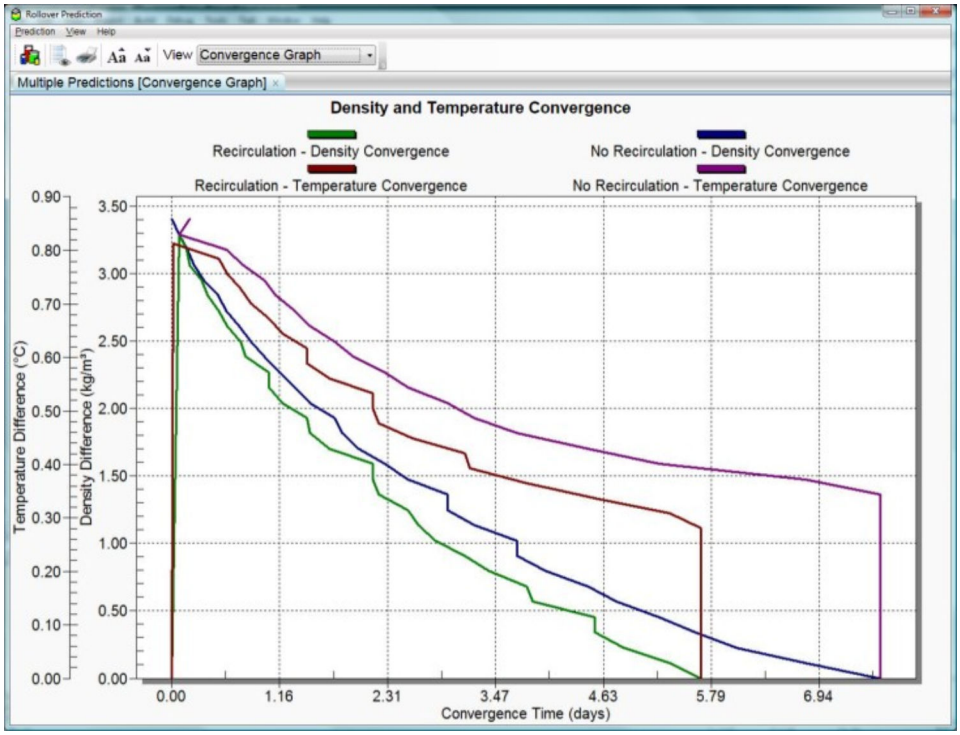
Using the **Add** and **Remove** options from the **Prediction** menu you can load multiple predictions. In the **Standard** view, in order to switch between different predictions use the **Prediction** drop-down list above the density profile (available only in the multiple predictions mode). Same list is provided in all table displays.

For all the graphical displays, multiple predictions are plotted on the same chart to provide better means of comparing them. You can also check settings of each simulation using the **Properties** option from **Prediction** menu. For every new simulation you run a new tab will be displayed on the top of the screen.

Here, we illustrate the model predictions for the scenario with external recirculation and without external recirculation.

6.2 Density and Temperature Convergence

On selecting **Convergence Graph** from the drop-down menu list, the screen shown below will appear.



14 Convergence Graph

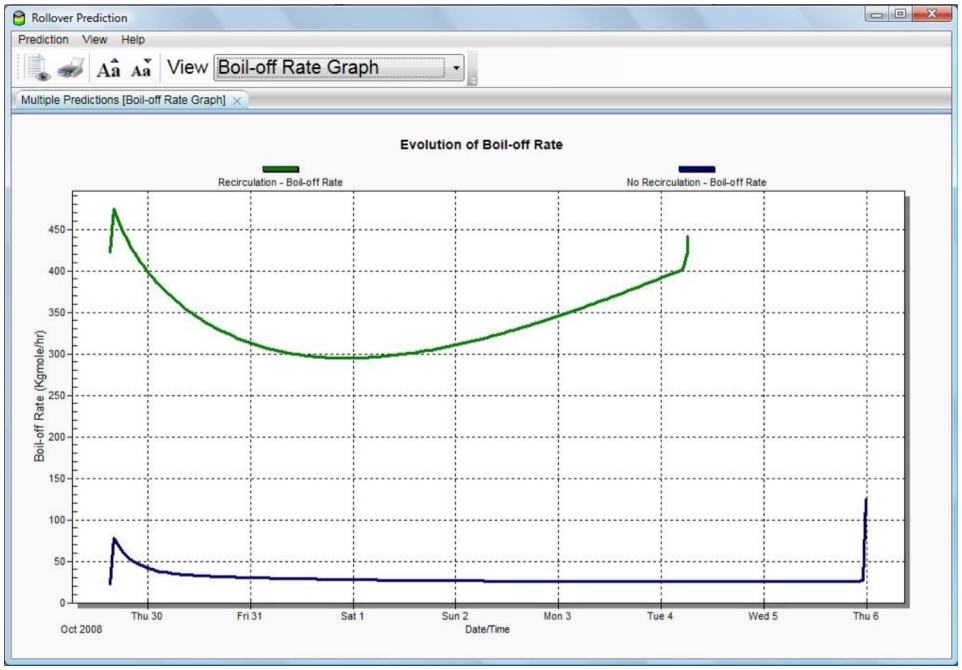
Two Vertical axes are Temperature and Density Gradients respectively and the Horizontal axis is Convergence Time.

As explained previously – the criterion for rollover occurrence is the density equalization. In addition – the graphs are plotted only until the density convergence is reached.

This illustration confirms the existence of a temperature gradient just before the rollover, in accordance with the Temperature Evolution profile.

6.3 Evolution of Boil-off Rate

On selecting **Boil-off Rate Graph** from the drop-down menu list, the screen shown below will appear.



15 Boil-off Rate Graph

The boil-off rate is plotted against time for the two operations – with recirculation and without recirculation.

It should be noted that the boil-off rate shown in the above figure is the total boil-off rate which also takes into account the liquid escaped into the vapour space due to flashing. It can be seen that the boil-off rate with recirculation is considerably higher than that without recirculation, which is due to the fact that a significant amount of liquid is flashed into the vapour space while recirculation is on. It can also be seen that recirculation promotes the mixing between the stratified layers which triggers the rollover event quicker than without recirculation. Thus, although boil-off rate is higher with recirculation on, due to higher flash, the tank becomes homogeneous quicker than without recirculation.

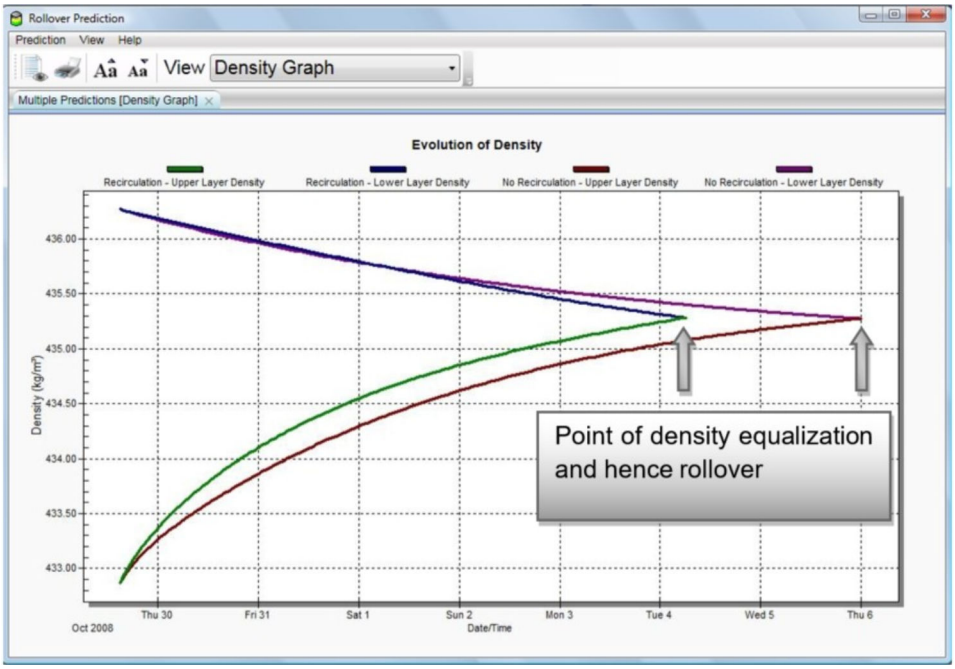
For both the model predictions considered here, the boil-off rate is higher in the initial stages, which is attributed to higher nitrogen concentration in the upper layer. For the model predictions with recirculation on, the amount of liquid flashed into the vapour space overshadows the change in boil-off rate at the time of rollover. However, the change in boiloff rate at the time of rollover is more apparent in model predictions without recirculation.

The temperature gradient between the stratified layers of LNG is one of the most significant parameters which control the change in boil-off rate. The higher temperature gradient between the stratified layers just before rollover triggers the sharper increase in the boil-off rate at the time of rollover.

The boil-off rate is also sensitive to tank pressure. The higher the tank pressure, the smaller the boil-off rate.

6.4 Evolution of Density of Stratified Layers

On selecting **Density Graph** from the drop-down menu list, the evolution of density will appear as shown below.



16 *Evolution of Density*

The density of the two stratified layers is plotted against time for the two operations – with recirculation and without recirculation.

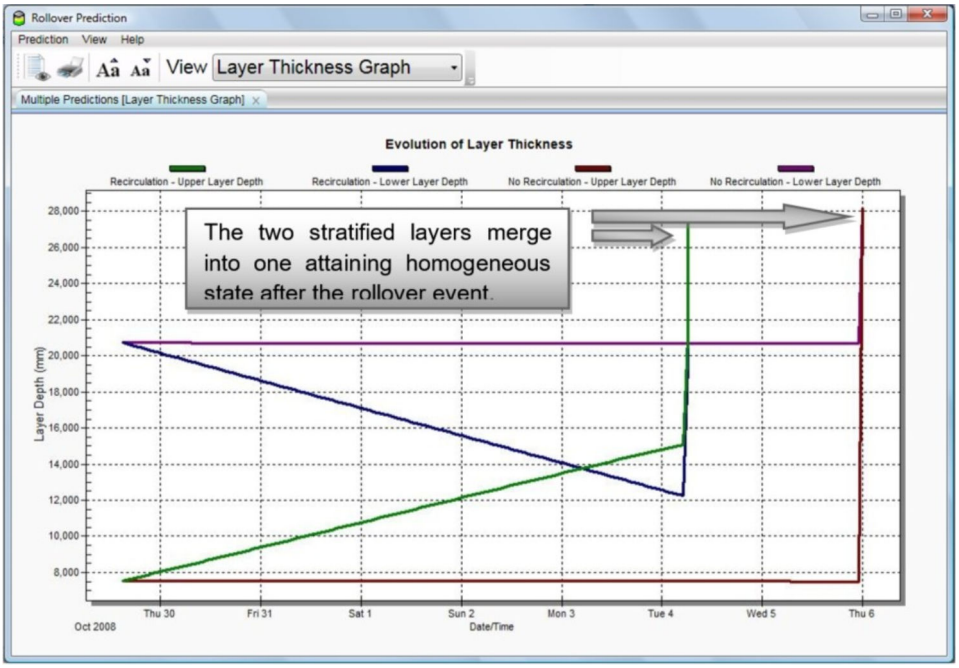
For both predictions, density of the lower layer decreases continuously with time and density of the upper layer increases with time. The rate of change in density of the stratified layers is different. The change in density is attributed to the change in temperature and the change in composition of LNG in the stratified layers.

The point of density equalization is the criterion for rollover, as the stratification no longer exists after the rollover event due to the LNG in the lower layer mixing with that in the upper layer.

It can be seen that by performing external recirculation, rollover occurs quicker than without external recirculation.

6.5 Evolution of Layer Thickness

On selecting **Layer Thickness Graph** from the drop-down menu list, the screen shown below will appear.



17 *Evolution of Layer Thickness*

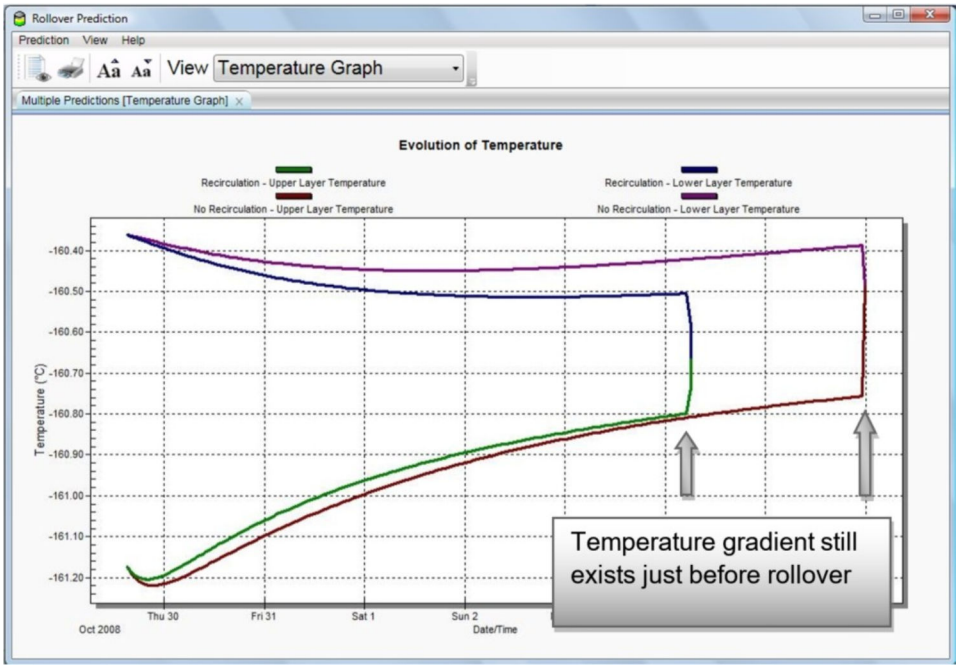
Layer thickness of the two stratified layers is plotted against time for the two operations – with recirculation and without recirculation.

While recirculation operation is on LNG is taken out from the lower layer and fed back to the top layer and hence thickness of the lower layer decreases with time while that of the upper layer increases. With no recirculation, the layer thickness of both stratified layers remains almost the same until the occurrence of rollover.

As the two stratified layers merge into one attaining the homogeneous state after the rollover event, the effective layer thickness of LNG after the rollover is equal to summation of layer thickness of the two stratified layers just before the rollover.

6.6 Evolution of Temperature of Stratified Layers

On selecting **Temperature Graph** from the drop-down list, the plot of evolution of temperature will appear as shown below.



18 *Evolution of Temperature*

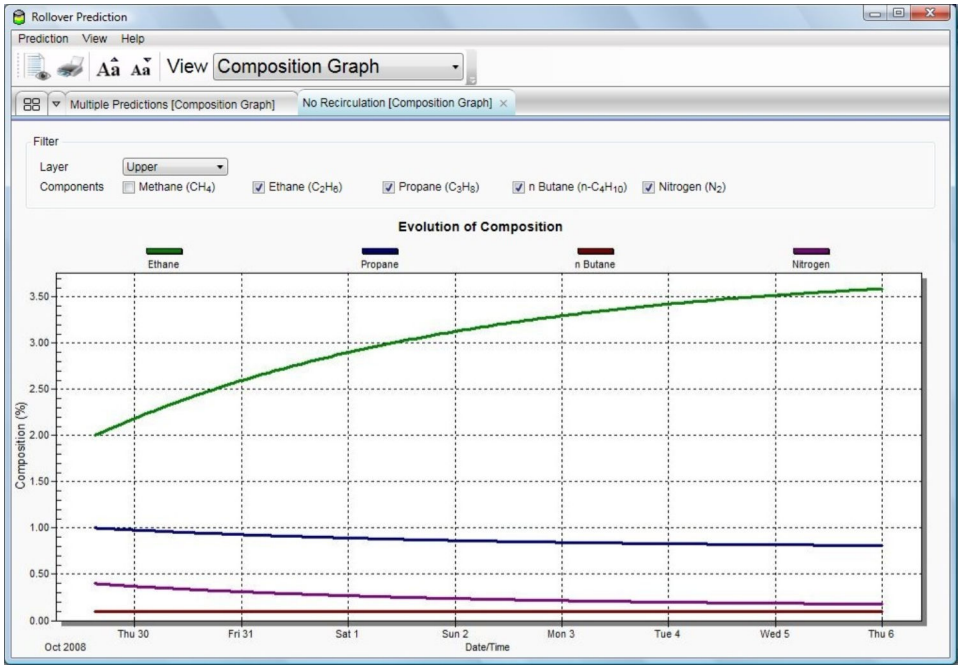
The temperature of the two stratified layers is plotted against time for the two operations – with recirculation and without recirculation.

For both the predictions, the rate of the change in temperature of the stratified layers is not exactly the same as the rate of the change in density of the stratified layers. This reiterates the fact that the change in density is not only due to the change in temperature, but also due to change in the composition of LNG in the stratified layers.

The temperature gradient between the stratified layers controls the severity of the change in the boil-off rate at the time of rollover and is addressed in the next section.

6.7 Evolution of Composition

On selecting **Composition Graph** from the drop-down menu, the screen shown below will appear.



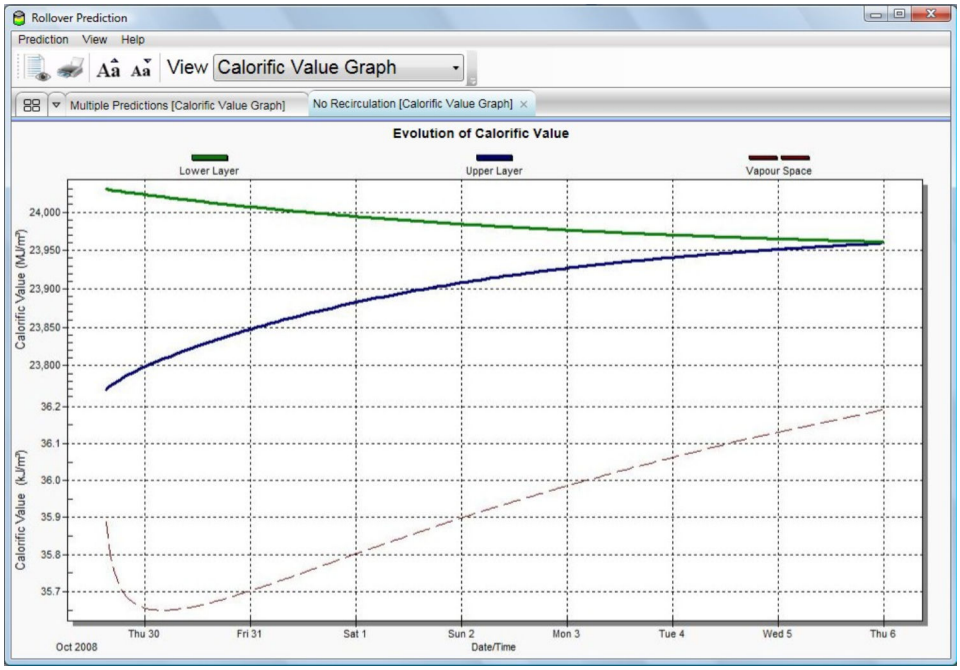
19 Evolution of Composition

The composition in mole percentage is plotted against time. It is possible to switch between the compositions of the stratified layers and the vapour space.

For the sake of better clarity methane was excluded from the chart, since its composition is of higher order of magnitude then the other components. However it can be easily plotted by ticking the appropriate box.

6.8 Evolution of Calorific Value

On selecting **Calorific Value Graph** from the drop-down menu, the screen shown below will appear.



20 Evolution of Calorific Value

The Calorific Value of the stratified layers (solid line) and the vapour space (dashed line) is plotted against time. Two different scales are used on the Calorific Value axis, as there is a significant difference in the order of magnitude of liquid and gaseous phase of natural gas. Same as previously you can plot a couple of scenarios on one graph.

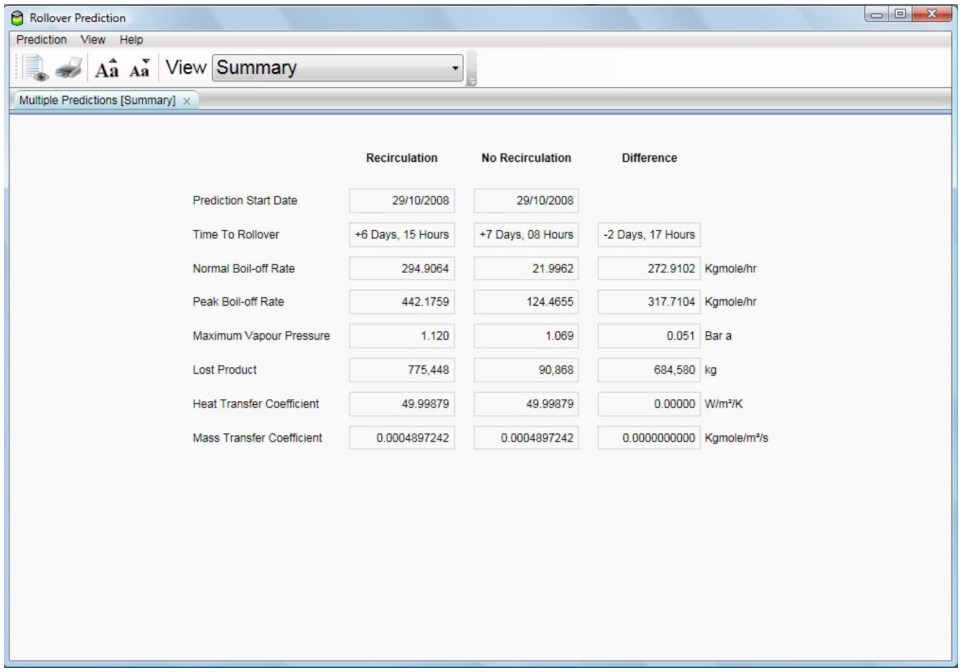
6.9 Predictions summary

The output data from each prediction is saved to a file. On the **Summary** screen from the drop-down list up to two predictions can be visualised simultaneously allowing the user to compare and contrast the model predictions for two different operating conditions.

The following parameters are also calculated for each prediction:

- **Time To Rollover**
- The **Normal Boil-off Rate**
- The **Peak Boil-off Rate**
- The **Maximum Vapour Pressure**
- The product lost until roll-over event
- **Heat Transfer Coefficient** and **Mass Transfer Coefficient** used in the model

The above information will be displayed on the **Summary** screen as shown below.



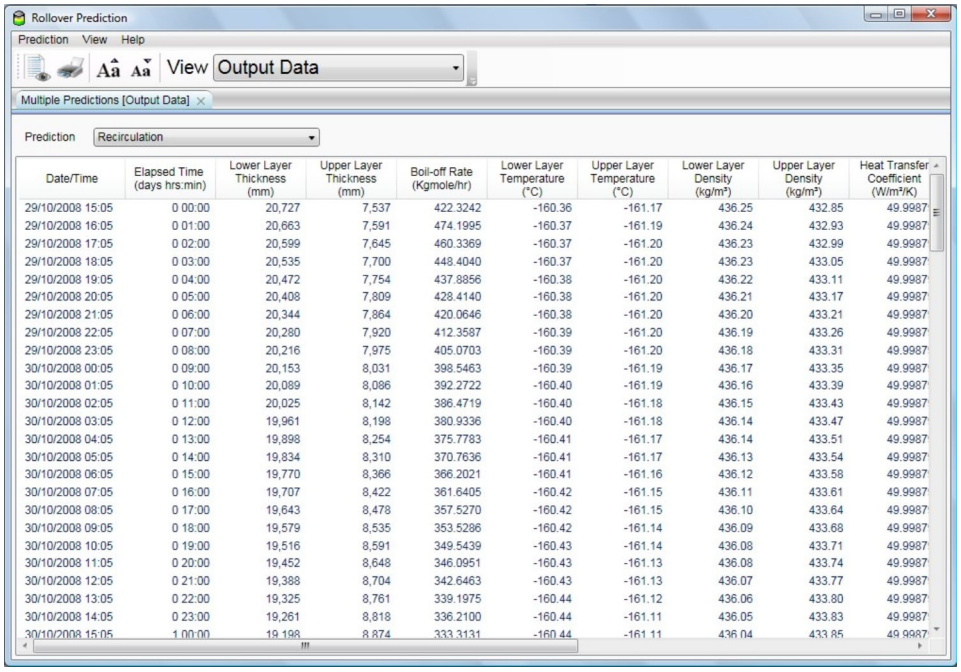
21 Summary

You can see in the figure above that the **Peak Boil-Off Rate** and the amount of **Lost Product** is considerably higher when the tank is recirculated.

In order to view the output data in a tabular form choose **Output Data** from the drop-down list. In case of multiple predictions you can switch between different tables.

The parameters given in each column are as follows:
- **Date/Time**
- **Elapsed time**
- **Lower layer thickness**
- **Upper layer thickness**
- **Boil-off rate**
- **Lower layer temperature**
- **Upper layer temperature**
- **Lower layer density**
- **Upper layer density**
- **Heat transfer coefficient**
- **Mass transfer coefficient**
- **Mass lost**
- **Excess vent-out**
- **Lower layer CV**
- **Upper layer CV**
- **Vapour space CV**

The above parameters are displayed below.



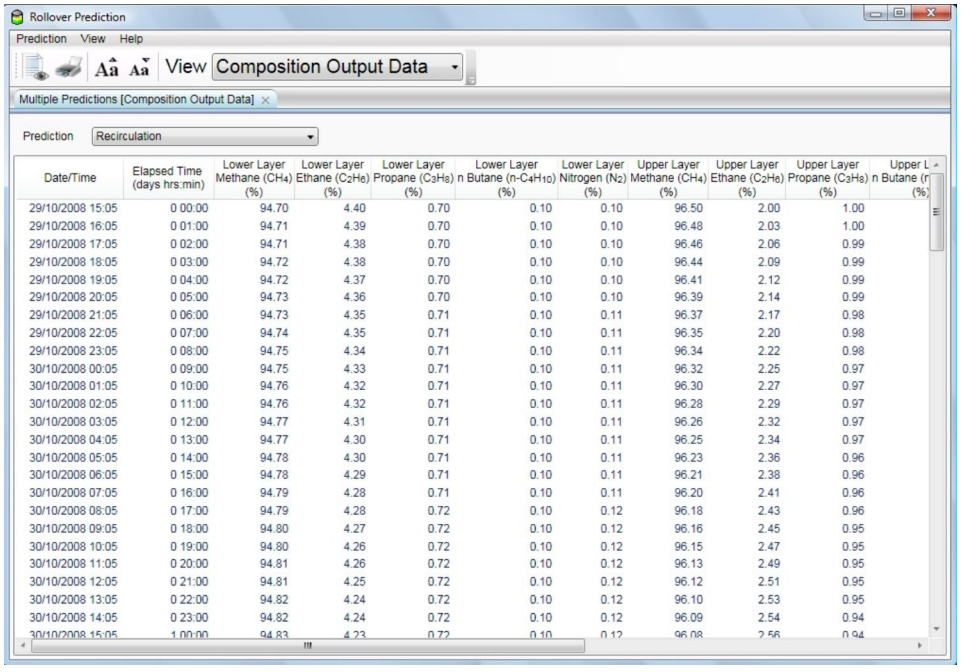
Date/Time	Elapsed Time (days hrs:min)	Lower Layer Thickness (mm)	Upper Layer Thickness (mm)	Boil-off Rate (Kgmole/hr)	Lower Layer Temperature (°C)	Upper Layer Temperature (°C)	Lower Layer Density (kg/m³)	Upper Layer Density (kg/m³)	Heat Transfer Coefficient (W/m²/K)
29/10/2008 15:05	0 00:00	20,727	7,537	422.3242	-160.36	-161.17	436.25	432.85	49.9987
29/10/2008 16:05	0 01:00	20,663	7,591	474.1995	-160.37	-161.19	436.24	432.93	49.9987
29/10/2008 17:05	0 02:00	20,599	7,645	460.3369	-160.37	-161.20	436.23	432.99	49.9987
29/10/2008 18:05	0 03:00	20,535	7,700	448.4040	-160.37	-161.20	436.23	433.05	49.9987
29/10/2008 19:05	0 04:00	20,472	7,754	437.8856	-160.38	-161.20	436.22	433.11	49.9987
29/10/2008 20:05	0 05:00	20,408	7,809	428.4140	-160.38	-161.20	436.21	433.17	49.9987
29/10/2008 21:05	0 06:00	20,344	7,864	420.0646	-160.38	-161.20	436.20	433.21	49.9987
29/10/2008 22:05	0 07:00	20,280	7,920	412.3587	-160.39	-161.20	436.19	433.26	49.9987
29/10/2008 23:05	0 08:00	20,216	7,975	405.0703	-160.39	-161.20	436.18	433.31	49.9987
30/10/2008 00:05	0 09:00	20,153	8,031	398.5463	-160.39	-161.19	436.17	433.35	49.9987
30/10/2008 01:05	0 10:00	20,089	8,086	392.2722	-160.40	-161.19	436.16	433.39	49.9987
30/10/2008 02:05	0 11:00	20,025	8,142	386.4719	-160.40	-161.18	436.15	433.43	49.9987
30/10/2008 03:05	0 12:00	19,961	8,198	380.9336	-160.40	-161.18	436.14	433.47	49.9987
30/10/2008 04:05	0 13:00	19,898	8,254	375.7783	-160.41	-161.17	436.14	433.51	49.9987
30/10/2008 05:05	0 14:00	19,834	8,310	370.7636	-160.41	-161.17	436.13	433.54	49.9987
30/10/2008 06:05	0 15:00	19,770	8,366	366.2021	-160.41	-161.16	436.12	433.58	49.9987
30/10/2008 07:05	0 16:00	19,707	8,422	361.6405	-160.42	-161.15	436.11	433.61	49.9987
30/10/2008 08:05	0 17:00	19,643	8,478	357.5270	-160.42	-161.15	436.10	433.64	49.9987
30/10/2008 09:05	0 18:00	19,579	8,535	353.5286	-160.42	-161.14	436.09	433.68	49.9987
30/10/2008 10:05	0 19:00	19,516	8,591	349.5439	-160.43	-161.14	436.08	433.71	49.9987
30/10/2008 11:05	0 20:00	19,452	8,648	346.0951	-160.43	-161.13	436.08	433.74	49.9987
30/10/2008 12:05	0 21:00	19,388	8,704	342.6463	-160.43	-161.13	436.07	433.77	49.9987
30/10/2008 13:05	0 22:00	19,325	8,761	339.1975	-160.44	-161.12	436.06	433.80	49.9987
30/10/2008 14:05	0 23:00	19,261	8,818	336.2100	-160.44	-161.11	436.05	433.83	49.9987
30/10/2008 15:05	1 00:00	19,198	8,874	333.3131	-160.44	-161.11	436.04	433.85	49.9987

22 *Output Data*

Same applies to the **Composition Output Data** screen. The change in composition until rollover can be viewed in a tabular form with the same options of switching between different tables as before.

The parameters given in each column are as follows:
- **Date/Time**
- **Elapsed time**
- Mole percentage of the given components in the **Lower Layer**
- Mole percentage of the given components in the **Upper Layer**
- Mole percentage of the given components in the **Vapour Space**

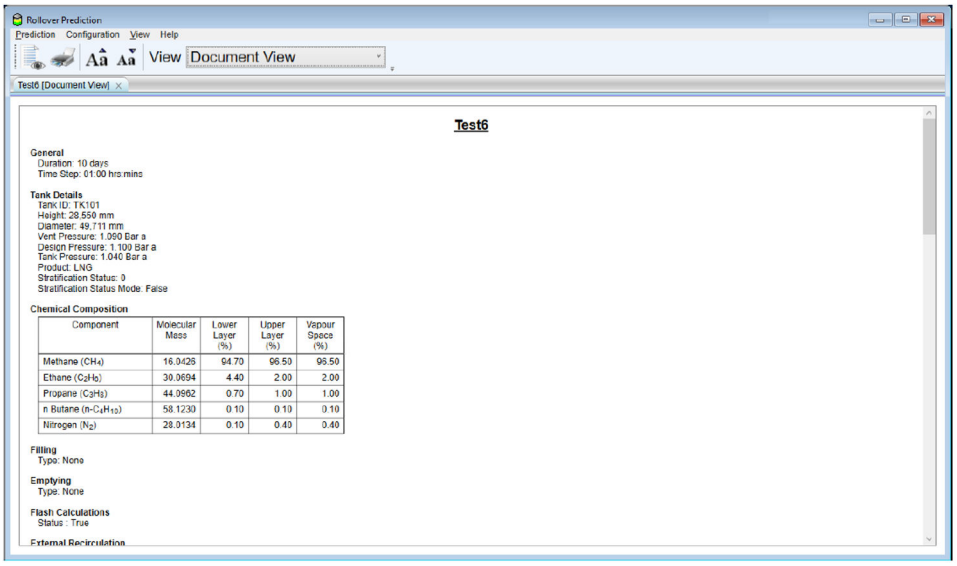
The above parameters are displayed on the screen shown below.



Date/Time	Elapsed Time (days hrs:min)	Lower Layer Methane (CH_4) (%)	Lower Layer Ethane (C_2H_6) (%)	Lower Layer Propane (C_3H_8) (%)	Lower Layer n Butane (n-C_4H_{10}) (%)	Lower Layer Nitrogen (N_2) (%)	Upper Layer Methane (CH_4) (%)	Upper Layer Ethane (C_2H_6) (%)	Upper Layer Propane (C_3H_8) (%)	Upper L n Butane (r (%)
29/10/2008 15:05	0 00:00	94.70	4.40	0.70	0.10	0.10	96.50	2.00	1.00	
29/10/2008 16:05	0 01:00	94.71	4.39	0.70	0.10	0.10	96.48	2.03	1.00	
29/10/2008 17:05	0 02:00	94.71	4.38	0.70	0.10	0.10	96.46	2.06	0.99	
29/10/2008 18:05	0 03:00	94.72	4.38	0.70	0.10	0.10	96.44	2.09	0.99	
29/10/2008 19:05	0 04:00	94.72	4.37	0.70	0.10	0.10	96.41	2.12	0.99	
29/10/2008 20:05	0 05:00	94.73	4.36	0.70	0.10	0.10	96.39	2.14	0.99	
29/10/2008 21:05	0 06:00	94.73	4.35	0.71	0.10	0.11	96.37	2.17	0.98	
29/10/2008 22:05	0 07:00	94.74	4.35	0.71	0.10	0.11	96.35	2.20	0.98	
29/10/2008 23:05	0 08:00	94.75	4.34	0.71	0.10	0.11	96.34	2.22	0.98	
30/10/2008 00:05	0 09:00	94.75	4.33	0.71	0.10	0.11	96.32	2.25	0.97	
30/10/2008 01:05	0 10:00	94.76	4.32	0.71	0.10	0.11	96.30	2.27	0.97	
30/10/2008 02:05	0 11:00	94.76	4.32	0.71	0.10	0.11	96.28	2.29	0.97	
30/10/2008 03:05	0 12:00	94.77	4.31	0.71	0.10	0.11	96.26	2.32	0.97	
30/10/2008 04:05	0 13:00	94.77	4.30	0.71	0.10	0.11	96.25	2.34	0.97	
30/10/2008 05:05	0 14:00	94.78	4.30	0.71	0.10	0.11	96.23	2.36	0.96	
30/10/2008 06:05	0 15:00	94.78	4.29	0.71	0.10	0.11	96.21	2.38	0.96	
30/10/2008 07:05	0 16:00	94.79	4.28	0.71	0.10	0.11	96.20	2.41	0.96	
30/10/2008 08:05	0 17:00	94.79	4.28	0.72	0.10	0.12	96.18	2.43	0.96	
30/10/2008 09:05	0 18:00	94.80	4.27	0.72	0.10	0.12	96.16	2.45	0.95	
30/10/2008 10:05	0 19:00	94.80	4.26	0.72	0.10	0.12	96.15	2.47	0.95	
30/10/2008 11:05	0 20:00	94.81	4.26	0.72	0.10	0.12	96.13	2.49	0.95	
30/10/2008 12:05	0 21:00	94.81	4.25	0.72	0.10	0.12	96.12	2.51	0.95	
30/10/2008 13:05	0 22:00	94.82	4.24	0.72	0.10	0.12	96.10	2.53	0.95	
30/10/2008 14:05	0 23:00	94.82	4.24	0.72	0.10	0.12	96.09	2.54	0.94	
30/10/2008 15:05	1 00:00	94.83	4.23	0.72	0.10	0.12	96.08	2.56	0.94	

23 *Composition Output Data*

The input parameters for each prediction are displayed in a combined form in the **Document View** shown below.



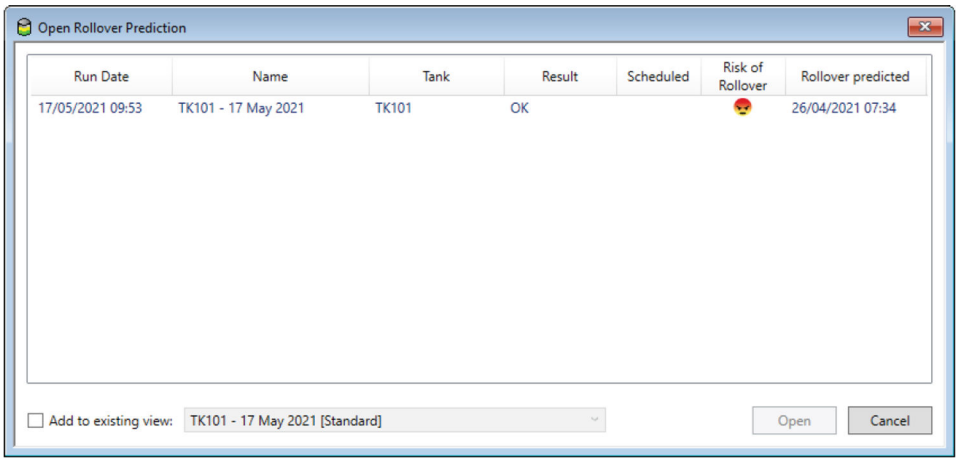
24 Document View

7 Viewing results

Whenever a Rollover Prediction is run, the results are stored in the Tankvision LMS database to allow for future analysis of the results.

7.1 Open existing results

To open results of a previous model run, select **Open** from the **Prediction** menu on the main window. A screen will be displayed showing previous results:



25 *Open Rollover Prediction*

To view the results, select the required results and then click the **Open** button. To add the results to a set of results that are already open, tick the **Add to existing view** option and select the existing results to which the results are to be added for comparison before clicking the **Open** button.

7.2 Import results

If the rollover prediction functionality has been used in earlier versions of Tankvision LMS, it is possible to import the legacy data. This is done by selecting **Import** from the **Prediction** menu on the main window and then selecting the .rpd file to be imported.

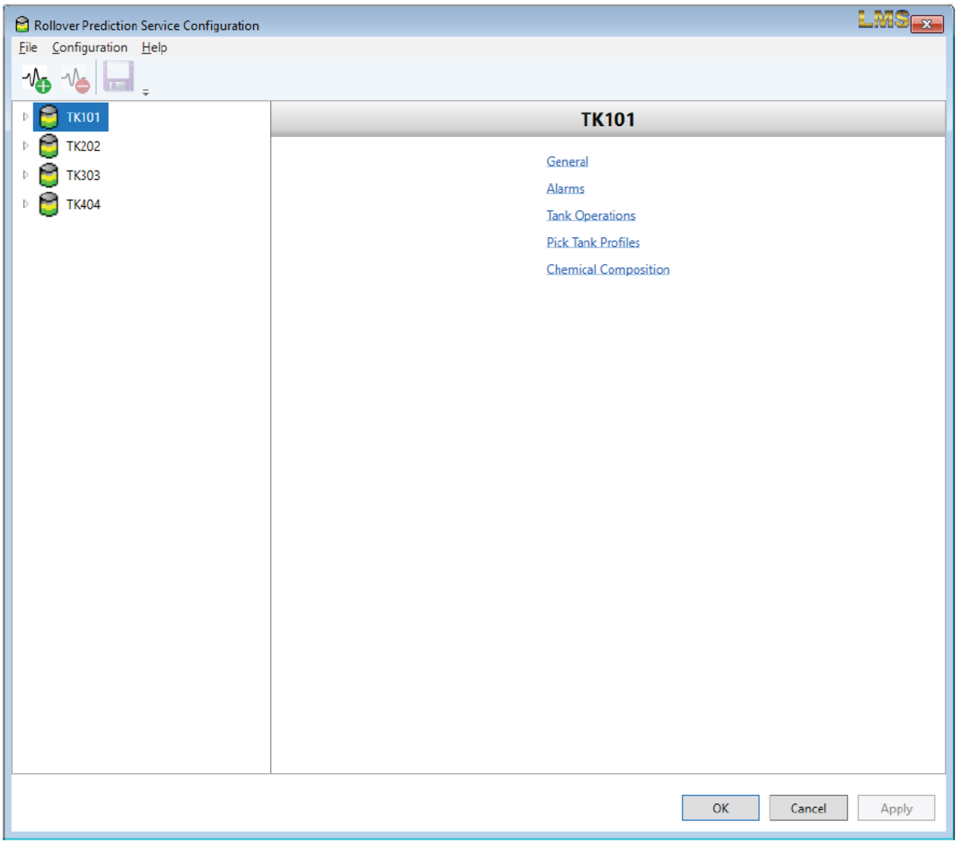
7.3 Re-running predictions

It is possible to run the rollover prediction model again for a given set of results. This allows the input parameters to be tweaked to run what-if-scenarios.

To re-run a rollover prediction, open or import the previous results. Then choose **Configure** from the **Prediction** menu on the main window. The same screen as that used for creating a new model run will be displayed, but in this case it will be populated with the input parameters from the selected model run.

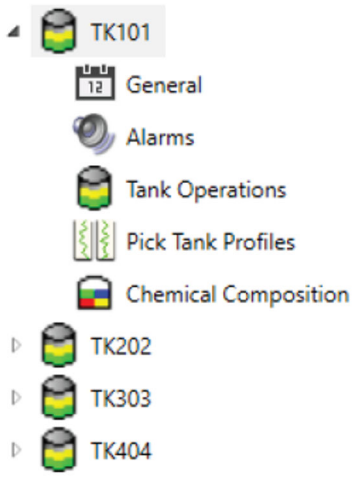
8 Scheduling rollover predictions

Rollover predictions can be scheduled to be run either on a timed basis or when a profile is taken. This functionality is governed by a separate license option and will only be available if licensed. To configure the schedule when rollover predictions are to be automatically run, click on the **Schedule** option from the **Prediction** menu on the main **Rollover Prediction** window. The following screen will be displayed:



26 *Schedule Rollover Predictions*

Each tank that can be configured for scheduled rollover predictions is listed on the left hand side of the screen. The different parts of the configuration for each tank can be shown in the list by 'expanding' the tank either by double-clicking on the tank name or by clicking on the arrow to the left of the tank name:

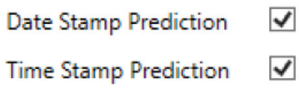


27 *Tank Schedule Details*

8.1 Configuration

8.1.1 General

The **General** settings are used to define the name of the rollover prediction that will be generated. This will always include the name of the tank. In addition, the date/time the prediction was run can also be used:

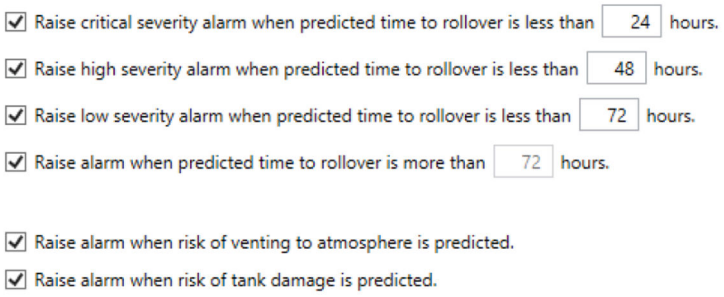


28 *General settings*

If neither date nor time stamps are used, then each time the prediction is run only the name of the tank will be used. This will cause the previous results to be overwritten.

8.1.2 Alarms

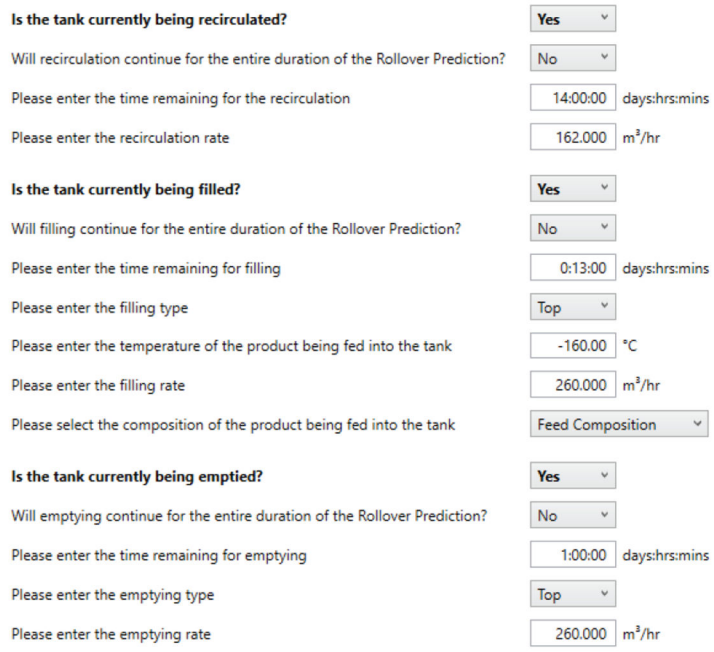
A set of **Alarms** can be configured that may be raised depending on the results of running a scheduled rollover prediction:



29 *Alarm configuration*

8.1.3 Tank Operations

The **Tank Operations** that are taking place at the time the rollover prediction is to be run should also be configured:



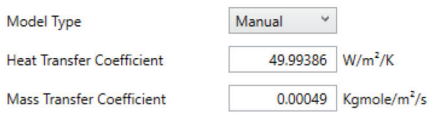
30 Tank Operations

These parameters are the same as used when doing an ad-hoc rollover prediction, see "Tank Operations" in section "Setting up a simulation".

8.1.4 Pick Tank Profiles

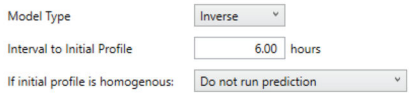
The profile(s) to be used by the model when running the rollover prediction must also be supplied. The main difference to running an ad-hoc rollover prediction is that the **latest** profile is **always** used.

If the **Manual** model is selected, values must also be entered for the **Heat Transfer Coefficient** and the **Mass Transfer Coefficient**.



31 Scheduled Manual Model

If the **Inverse** model is selected, details must also be given of how to determine the **Initial Profile**.



32 Scheduled Inverse Model

8.1.5 Chemical Composition

To specify the composition for each of the liquid layers and the vapour space, select **Chemical Composition** for the tank.

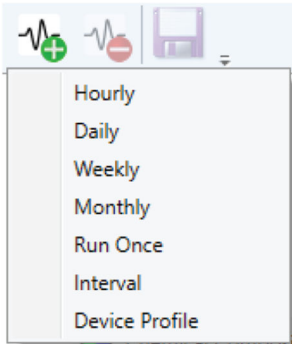
This allows entry of the chemical composition in the same way as when doing an ad-hoc rollover prediction, see "Chemical Composition" in section "Setting up a simulation".

	Component	Molecular Mass	Lower Layer (%)	Upper Layer (%)	Vapour Space (%)
			Custom	Custom	Custom
✕	Methane (CH_4)	16.0426	94.700	96.500	96.500
✕	Ethane (C_2H_6)	30.0694	4.400	2.000	2.000
✕	Propane (C_3H_8)	44.0962	0.700	1.000	1.000
✕	n Butane (n-C_4H_{10})	58.1230	0.100	0.100	0.100
✕	Nitrogen (N_2)	28.0134	0.100	0.400	0.400
	Select a component				
		Total:	100.000	100.000	100.000

33 *Scheduled Chemical Composition Parameters*

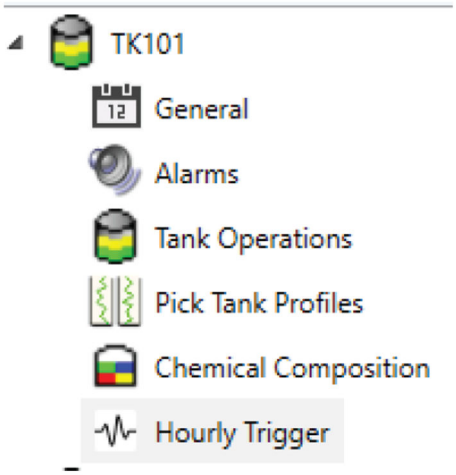
8.2 Triggers

To add a trigger for a tank, select the tank and then click the add trigger ( ) button. A list of available triggers will be displayed:



34 *Select Trigger*

Select the desired trigger type and it will be added to the tank entry:



35 *Rollover Prediction Trigger*

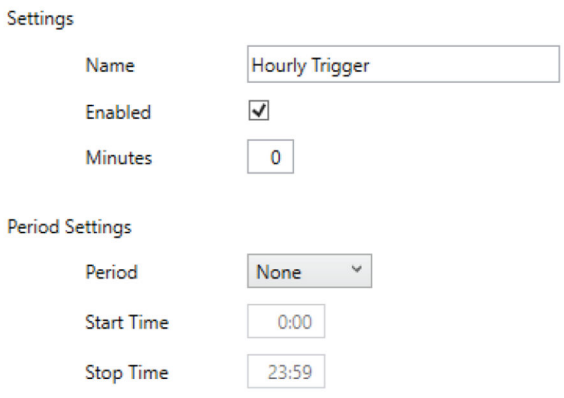
8.2.1 Common trigger parameters

For any kind of trigger there are some common parameters. These are:

- **Name**
  The name of the trigger.
- **Enabled**
  Allows the trigger to be temporarily disabled without having to delete it and recreate it when it is required again.
- **Period Settings**
  Allows the trigger to be active for a limited period of time. There are three possible types of period:
  - **None**
    Disables periodic triggering. The trigger will always be active (unless explicitly disabled by unticking **Enabled**).
  - **Daily**
    The trigger will only be active between the entered **Start Time** and **Stop Time** each day.
  - **Dates**
    The trigger will only be active between the entered **Start Date/Time** and **Stop Date/Time**.

8.2.2 Hourly trigger

The hourly trigger is used to trigger a rollover prediction once an hour:

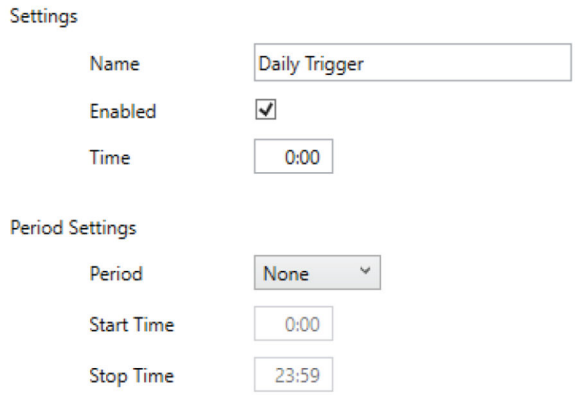


36 *Hourly Trigger Parameters*

In addition to the common parameters, an hourly trigger also has:
Minutes
Specifies the number of minutes past the hour when the rollover prediction is to be run.

8.2.3 Daily trigger

The daily trigger is used to trigger a rollover prediction once a day:

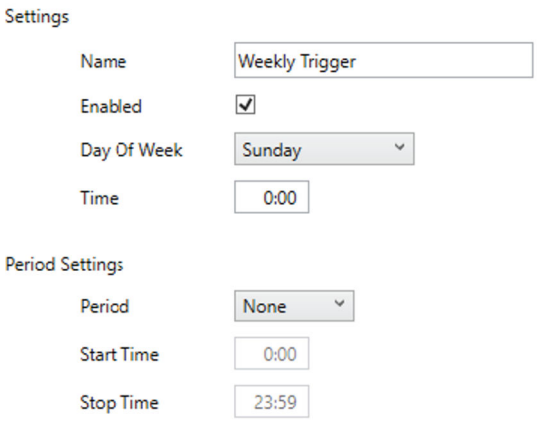


37 *Daily Trigger Parameters*

In addition to the common parameters, a daily trigger also has:
Time
Specifies the time of day when the rollover prediction is to be run.

8.2.4 Weekly trigger

The weekly trigger is used to trigger a rollover prediction once a week:

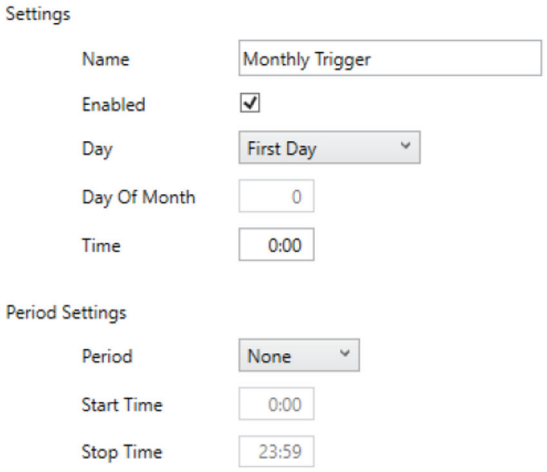


38 *Weekly Trigger Parameters*

In addition to the common parameters, a weekly trigger also has:
- **Day Of Week**
  Specifies the day of the week on which the rollover prediction is to be run.
- **Time**
  Specifies the time of day when the rollover prediction is to be run.

8.2.5 Monthly trigger

The monthly trigger is used to trigger a rollover prediction once a month:



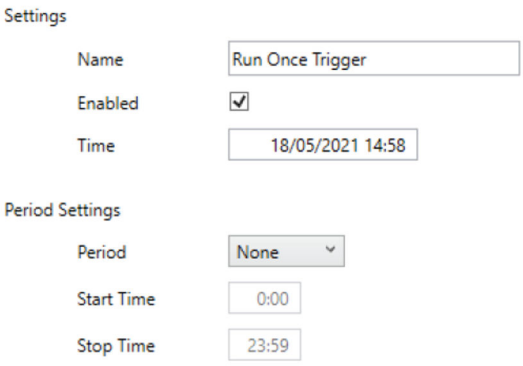
39 Monthly Trigger Parameters

In addition to the common parameters, a monthly trigger also has:

- **Day**
  The day of the month on which the rollover prediction is to be run:
  - **First Day**
    Specifies that the rollover prediction is to be run on the first day of the month.
  - **Last Day**
    Specifies that the rollover prediction is to be run on the last day of the month.
  - **Specific Day**
    Specifies that the rollover prediction is to be run on a specific day in the month. The actual day is specified by the **Day Of Month** parameter.
- **Day Of Month**
  Specifies the day of the month on which the rollover prediction is to be run when **Specific Day** has been selected.
  Note! Care must be taken in specifying the day. For example, selecting 29 will mean that the rollover prediction is not run in February except in a leap year.
- **Time**
  Specifies the time of day when the rollover prediction is to be run.

8.2.6 Run once trigger

The run one trigger is used to trigger a rollover prediction exactly once:

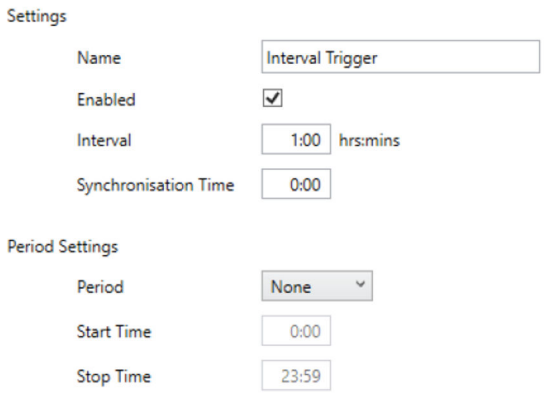


40 Run Once Trigger Parameters

In addition to the common parameters, a run once trigger also has:
Time
The date and time at which the rollover prediction is to be run.

8.2.7 Interval trigger

The interval trigger is used to trigger a rollover prediction on a regular basis:

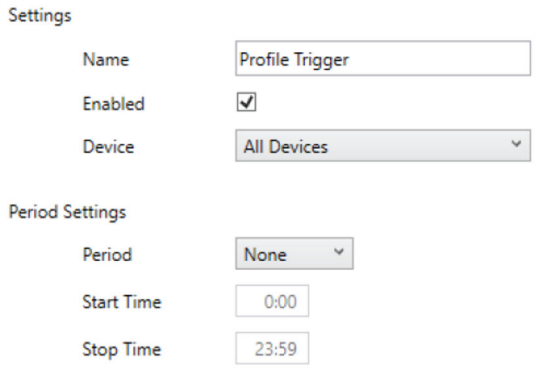


41 *Interval Trigger Parameters*

In addition to the common parameters, an interval trigger also has:
- **Interval**
  The interval at which rollover predictions are to be run.
- **Synchronisation Time**
  A specific time of day at which the rollover prediction is to be run. Intervals will be taken backwards and forwards from this time to determine when the rollover predictions are to be run.

8.2.8 Profile trigger

The profile trigger is used to trigger a rollover prediction when a profile is completed by a device:



42 *Profile Trigger Parameters*

In addition to the common parameters, a profile trigger also has:
Device
The device whose profile completion will trigger a rollover prediction. Any device connected to the tank which can take a profile will be listed. To trigger a rollover prediction when any device on a tank completes a profile select **All Devices**.

9 Appendix

9.1 Thermal conductivity values

9.1.1 Concrete thermal conductivity

Temperature (°C)	Conductivity (W/m·°C)
60	1.77
25	2.00
-160	3.20
-180	3.33

9.1.2 HLB 800 Foamglass®thermal conductivity

Temperature (°C)	Conductivity (W/m·°C)
60 [1)]	0.0430
10	0.0430
0	0.0415
-20	0.0385
-40	0.0358
-80	0.0314
-120	0.0281
-160	0.0252
-170	0.0244

1) assume the same values at 10 °C

9.1.3 Perlite thermal conductivity

Temperature (°C)	Conductivity (W/m·°C)
60 [1)]	0.0430
10	0.0410
0	0.0410
-20	0.0390
-40	0.0355
-80	0.0325
-120	0.0261
-160	0.0218
-170	0.0142

1) assume the same values at 10 °C

9.1.4 Fibreglass insulation thermal conductivity

Temperature (°C)	Conductivity (W/m·°C)
60 [1)]	0.0360
10	0.0360
0	0.0341
-20	0.0308
-40	0.0278
-80	0.0223
-120	0.0181
-160	0.0141
-170	0.0130

1) assume the same values at 10 °C

9.1.5 9 % Nickel steel thermal conductivity

Temperature (°C)	Conductivity (W/m·°C)
38.0	30.0
26.7	28.0
-40.0	26.0
-100.0	23.0
-170.0	16.5

9.1.6 Miscellaneous materials thermal conductivity

Material	Conductivity (W/m·°C)
Carbon steel liner	41.0
Sand layers	0.60
Rock	2.0 (average)

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