Liquid and Gas Pipelines

PSIpipelines Software for Pipeline Operators

PSI

Contents

The Application Suite

PSIpipelines incorporates a complete range of powerful real-time applications to assist operators in monitoring their liquid and gas pipelines. The suite includes the following software applications:

Hydraulic Simulation
- Real-Time Transient Modelling
- Look-Ahead
- What-If

Leak Detection and Location
- RTTM-Model Compensated Mass Balance
- Compensated Mass Balance
- Shut-In
- Pressure Gradient Evaluation
- Negative Pressure Wave

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- Instrumentation Analyzer
- Slack Line Control
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- Commodities
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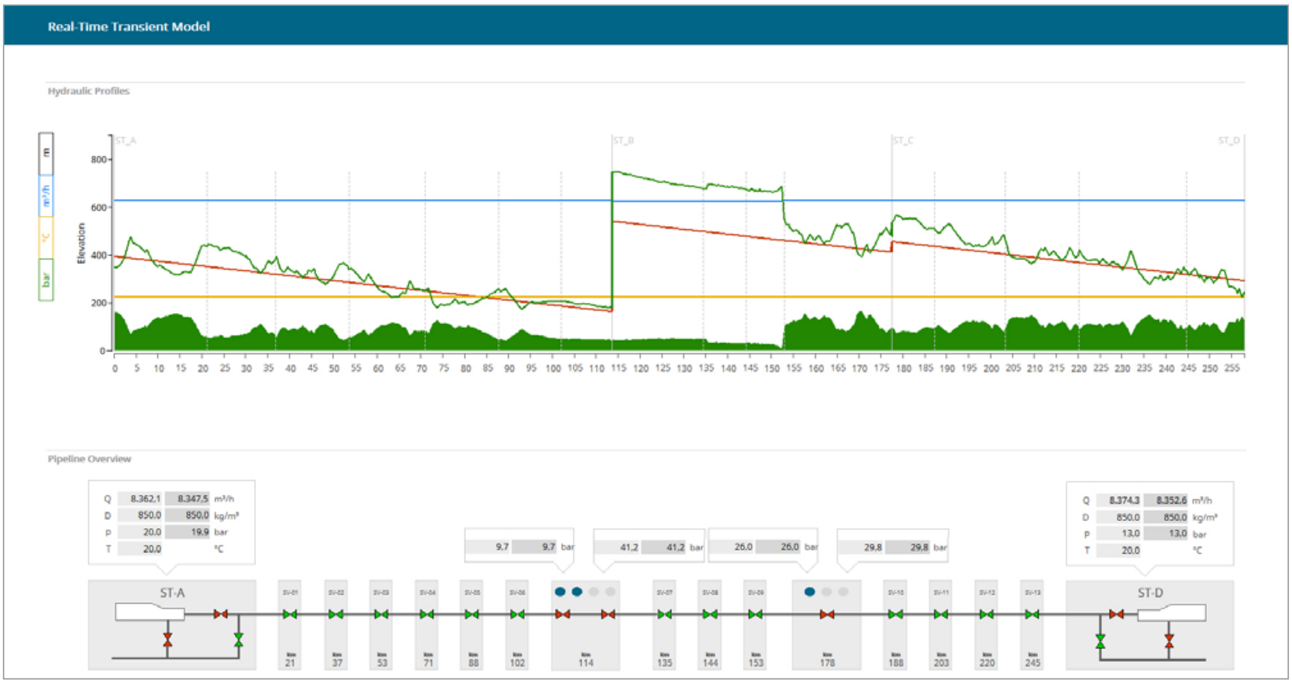


Benefits

PSIpipelines applications add value to other mission critical systems like SCADA. They enhance situational awareness and provide a greater use of important information for safe and cost-efficient operations.

Improved Operations

+ Holistic view of pipelines, commodities, stations, instrumentation and equipment
+ Enhanced monitoring and control
+ Complete set of information
+ High performance visualizations to provide a high degree of situational awareness

Effective Prevention

+ Early detection of deviating conditions
+ Asset damage prevention
+ Material fatigue prediction
+ Quick identification of measurement drifts

Increased Safety

+ Reliable and comprehensive information in unmetered areas
+ Early prediction of critical situations
+ Assessment of consequences of operator-initiated actions
+ Analysis of effects of changed settings

Reduced Risks and Costs

+ High performance leak detection methods
+ Fast leak detection and accurate leak location
+ Reduction of impacts on production, transportation and environment
+ Cost reduction

Reduced Power Consumption

+ Continuous efficiency calculation
+ Identification of optimal pigging frequency
+ Determination of optimal settings
+ Supervision of energy consumption

Accurate Delivery

+ On-time delivery of commodities
+ Reduction of transmix volumes
+ Reduction of product contamination
+ Cost savings

PSIpipelines

Made for the Industry

PSIpipelines is made for upstream, midstream and downstream pipeline operations. The applications are designed for any complexity, from single pipeline to large pipeline systems. Today, the software supports the transportation of more than 30 different liquids and gases.

UPSTREAM

Flowlines and Trunklines

Liquids & Gases

MIDSTREAM

Transportation Pipelines

Liquids & Gases

DOWNSTREAM

Transportation Pipelines

Liquids & Gases

30+ Liquids and Gases

Oil & Gas	Refined Products	Chemical Products	Other
Sour Gas	Gasoline	Ethylene	Water
Sales Gas	Jet A1	Propylene	Hydrogen
Sour Crude Oil	Diesel	Butadiene	Carbon Dioxide
Sweet Crude Oil	Heating Oil	Styrene	Brine
Gas Condensate	Heavy Fuel Oil	2-Ethylhexanol	
Natural Gas Liquids	Naphtha		

Hydraulic Simulation

PSIpipelines provides the following simulation applications: Real-Time Transient Modelling, Look-Ahead Simulation and What-If Simulation.

Real-Time Transient Modelling

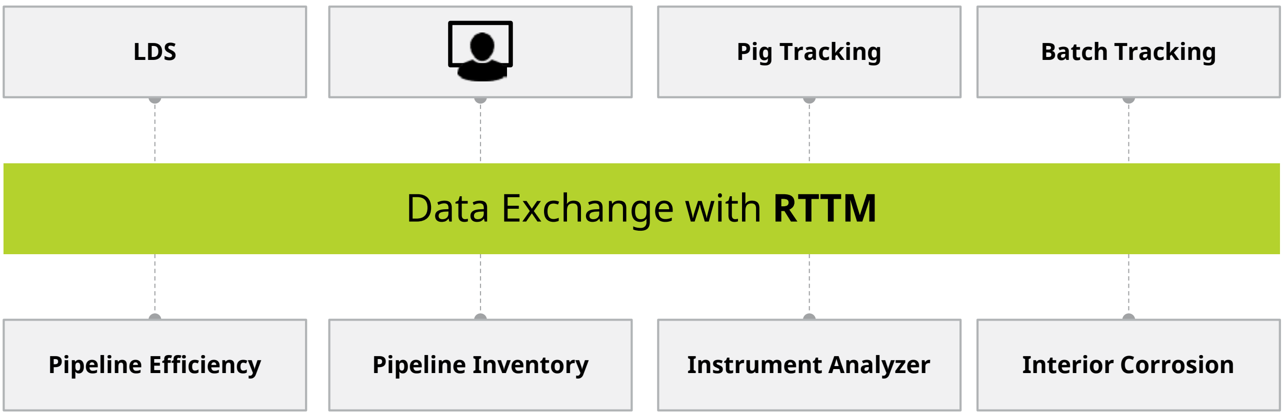
The Real-Time Transient Modelling (RTTM) application is a tool that provides reliable and comprehensive information about the actual but invisible physical processes inside a pipeline.

The results are used by operators to
- have information in unmetered areas,
- identify changing conditions,
- make correct decisions,
- observe the consequences of initiated actions.

The results are used by other PSIpipelines applications to
- calculate very precise mass balances,
- avoid leak detection and location errors,
- determine exact tracking positions and arrival times,
- advise on energy consumption,
- advise on segments affected by corrosion,
- identify malfunctioning instrumentation.

The accurate determination of flow dynamics requires extensive knowledge of the conditions at any time at any point of a pipeline. This objective is only achieved by PSIpipelines RTTM. SCADA and other technologies are not able to provide accurate information about flow, pressure, temperature, density and many other physical states at any point of a pipeline. It is PSI's modelling principle and technology that makes the difference in terms of reliability, sensitivity, accuracy and robustness.

The main objectives of the RTTM are to
- minimize the effect of missing, inaccurate or skewed data,
- correctly determine the actual physical state along a pipeline based on discrete input values,
- provide a complete set of plausible data for each point of a pipeline (transient and steady-state conditions).

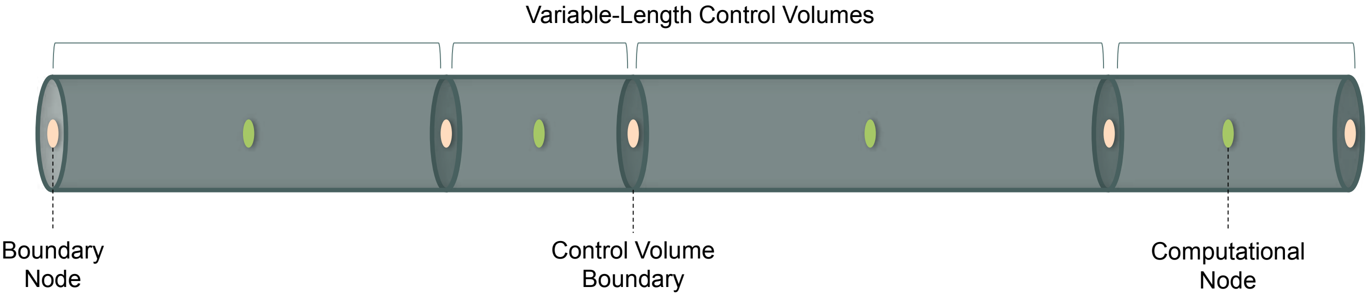


Method

Operating and environmental conditions, pumps, valves, tanks, scraper facilities, instrumentation, communication networks, data acquisition units as well as the fluid properties are always unique for each pipeline. In some scientific papers one method is preferred over other methods. Individual findings often depend on several assumptions or on tests in specific environments. The challenges are more complex and nuanced than they may appear.

This makes it very difficult or almost impossible to compare computational techniques.
The PSIpipelines RTTM is based on the Finite Volume Method (FVM) that has been successfully deployed over the past 30 years in many onshore and offshore pipeline projects for the transportation of crude oil, sour gas, sales gas, condensate, refined products and chemical products.
The actual physical state of a pipeline can only be determined if the conservation equations for mass, energy and momentum, in combination with state and model equations, are solved to calculate the specific correlation between pressure, temperature, density and velocity. Complex partial differential equations must be discretized and transformed into a set of algebraic equations. Today, the Finite Volume Method is the most effective method for computational fluid dynamics.

FVM discretizes a pipeline system into multiple control volumes and allows accurate and robust solutions even for complex geometries. Pumps, valves, compressors and other equipment are seamlessly integrated in the model. The minimum length of a control volume is 10 metres. The specific length also depends on other factors such as pipeline elevation points. Simulation accuracy is always a trade-off between discretization level and calculation time.



Slack line conditions and dual-phase simulation

Slack line flow occurs when the pressure in a liquid pipeline falls below the vapour pressure of the product. This results in a void that is filled with hydrocarbon vapour of lower density than the liquid. The PSIpipelines RTTM provides a Volume of Fluid (VOF) method to precisely determine the moment of phase transition. In addition to the conservation equations of mass, momentum and energy the VOF method includes the equations of convective transport of fluid volume fractions.

The VOF solution offers many advantages:

- Consistent calculation method for all segments of a pipeline
- Precise calculation of mass for sections with slack line conditions
- Hydraulic simulation of sections with slack line conditions does not require extra instrumentation
- The method is also suitable for pipelines that operate in batch mode.

Simulation cycle time

The RTTM receives measured values from field instruments (e.g. flow, pressure, temperature, density) via a data acquisition system. The model is updated on a fixed cycle after data pre-processing and validation. Typical cycle times are 1 to 5 seconds.

Cycle times are typically determined by flow meter sample rates. The internal processing cycle of the RTTM is less than 100 milliseconds. The fast processing speed is important to precisely simulate wave propagations through pipelines during transient operations.

Operational conditions

Based on a complete and accurate mathematical representation the RTTM simulates the pipeline state under steady, transient and stand-still conditions and provides accurate information to the operator as well as to associated applications.

Robustness

The RTTM is very robust in handling incomplete or inconsistent data and ensures that poor data from the telemetry system will never cause instability or shut-down of the complete system. It contains auto-tuning and self-adaption functions to improve results during pipeline operation.

Significant Factors

The RTTM calculations include regular solving of hydraulic, thermodynamic and state equations that take a number of parameters into account:

Instrumentation (accuracy, repeatability, location, availability)

- Flow
- Pressure
- Density
- Temperature
- Soil temperature
- Scraper signals

Facilities

- Pumps
- Turbines
- Valves
- Control valves
- Scraper launchers and receivers
- Relieve tanks

Pipeline construction

- Laying (buried, above ground)
- Slope

Pipeline material and geometry

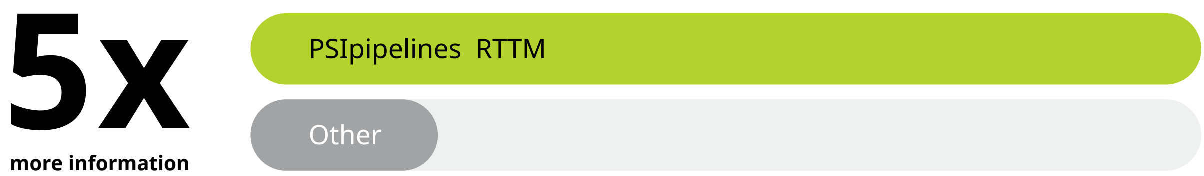
- Elasticity
- Thermal capacity
- Thermal conductivity
- Roughness
- Diameter
- Wall thickness
- Length

Fluid properties

- Density
- Viscosity
- Composition
- Thermal capacity
- Thermal conductivity

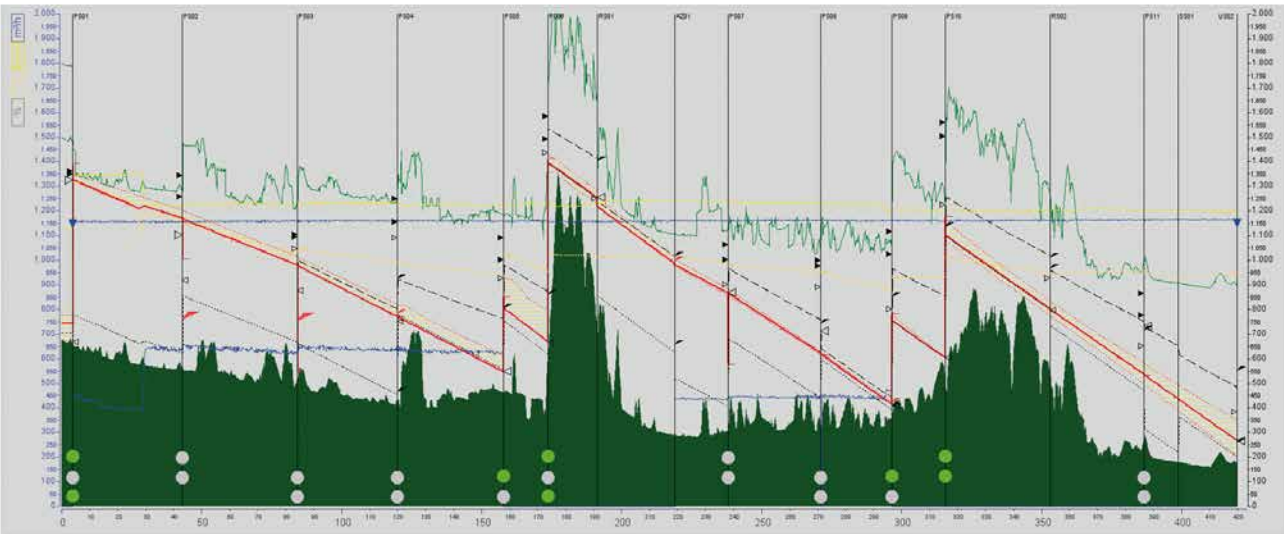
Hydraulic profiles

The RTTM calculates more than 60 high-resolution profiles per simulation cycle. Some profiles contain data for LDS and other applications. Other profiles are plotted on computer screens to identify pressure excursions, density changes, liquid dropout or drifts of instrument performance.



The following list provides some profile examples

- Pipeline elevation
- Pressure
- Maximum operating pressure
- Maximum allowable operating pressure
- Pressure at optimum operation
- Minimum pressure before vaporization
- Maximum pressure at pressure surge
- Stationary pressure
- Smoothed pressure
- Operating volumetric flow
- Stationary volumetric flow
- Gas fraction volume
- Liquid fraction volume
- Drag Reducing Agent fraction
- Standard density
- Operating density
- Density at maximum pressure
- Temperature
- Flow velocity
- Sonic speed
- Viscosity



Look-Ahead Simulation

The Look-Ahead Simulation application is a tool that identifies in advance any negative drift to undesirable hydraulic conditions. It is used to prevent assets from damage.
The prediction period is only limited by computing power, but from the operators point of view the typical period is 30 minutes to 24 hours.
Even during steady-state operations the hydraulic conditions may change, e. g. due to consecutive batches of different density. The application detects the process element that is going to reach a certain threshold and calculates the exact time at which the event will occur. The operator can thus accordingly adjust pump switches or modify set points. The resulting simulation values for flow, pressure, density, etc. are recorded in the database.
The Look-Ahead Simulation is based on the RTTM hydraulic data model and runs on a cyclical basis. Cycle times can be individually configured. The simulation can be started either manually by the operator or it runs permanently in the background.

What-If Simulation

The What-If Simulation application is a tool that determines in advance the consequences of operator-initiated actions. It is used to

- prevent critical events
- find optimal settings for future operations
- analyze the impacts of changes in demands and supplies of commodities
- check the effects of changes on operational facilities (instrumentation, valves, pumps, etc.)

Different scenarios can be configured, saved and used to determine cost-effective pump combinations, transport volumes, optimal control parameters or maximum pressures. Pump switch settings, modified set points, flow path variations and the corresponding time at which a change takes effect can be predefined in control schedules. Based on these control schedules the application calculates the corresponding process values.
The What-If Simulation is based on the RTTM hydraulic data model.

Leak Detection and Location

PSIpipelines provides the following LDS applications:
- RTTM-Model Compensated Mass Balance
- Compensated Mass Balance
- Shut-In
- Pressure Gradient Evaluation
- Negative Pressure Wave

The nature of LDS

LDS is a tool to reliably detect a leak as fast as possible and to locate a leak as accurate as possible. Its purpose is to alarm on incidents. In general, LDS is not a tool to prevent leaks but to reduce damages and costs caused by leaks. Other PSIpipelines applications do support preventative measures. It is the responsibility of every pipeline operating company to establish an incident response plan and to advise their operators and emergency teams accordingly.

Internal and External LDS

PSIpipelines LDS applications are internal-based detection methods that monitor the conditions inside a pipeline to detect commodity loss. These methods are commonly known as computational pipeline monitoring (see API 1130 "Computational Pipeline Monitoring for Liquids").
External-based detection methods use technologies to detect the presence of commodity outside a pipeline. The drawbacks of external-based systems are the total costs for equipment, software, field-work and tuning. Although these technologies may work well under certain conditions to detect small spills and to locate commodity releases with a high degree of accuracy, external systems are not able to identify the root causes of leaks. They remain to be an expensive alarming system for incidents.
Pipeline companies should take care when making investment decisions. The expenses for pipeline integrity and incident prevention are smaller than the costs for production stoppages, environmental recovery and pipeline repair.
In general, PSIpipelines can run in parallel with external-based technologies and exchange data via standard industry protocols.

Standard Compliance

PSIpipelines LDS is approved by the independent experts of TÜV and fully complies with industry and international standards:
- TRFL (Technical Guideline on Pipelines)
- API 1130 Computational Monitoring for Liquids
- Saudi Aramco Engineering Standard SAES-Z-003
- Transneft OTT-13.320.00-KTH-051-12
- IEC EN 61508 (SIL 1)

Selection of LDS Methods

Each LDS method has strengths and weaknesses. The MCMB method provides excellent sensitivity under all operating conditions. The time to detect a large leak is much shorter than for a small leak. The NPW method can detect leaks very fast and provides excellent capabilities to locate a leak but it requires good pressure sensors and high sample rates. NPW performs reliably on liquid pipelines with a low degree of transients.

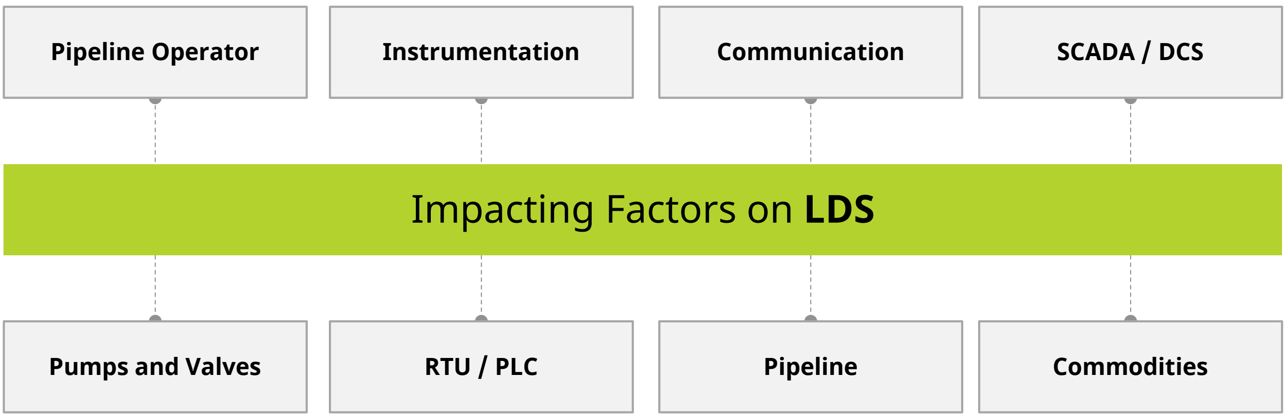
The RTTM is of particular importance and the core of all parts of a true hybrid leak detection system. This component is the essential and reliable data source for the operator, each LDS method and other applications of the PSIpipelines software package. The permanent availability and the high quality of specific data at every point in a pipeline is the definitive basis to maximize the capability to detect and locate a leak under all typical operating conditions.

Interrelation between LDS and Instrumentation

Software-based leak detection systems utilize existing flow, pressure and temperature instrumentation to monitor pipeline operations. Unfortunately, in many cases, the instrumentation, data acquisition system and communication network are designed and installed not having leak detection and location in mind.

All too often the LDS is expected to overcome these deficiencies without any loss of performance. Regardless of the selected methodology, it should be accepted that poor instrumentation and other deficiencies will impact the overall performance of leak detection systems in terms of detectable leak size, accuracy of leak location, number of false alarms, leak detection availability and time to detect leaks.

Accurate, repeatable, available, correctly positioned and well-maintained instrumentation in combination with appropriate data acquisition and telemetry systems are the basis to achieve maximum leak detection performance. However, instrumentation and data acquisition devices can only be installed at certain locations. Thus it is necessary to determine the hydraulic behaviour in unmetered areas at every point in a pipeline. Furthermore, a data set may include measurements made across a wide geographic area and it cannot be assumed that all values in the data set are taken precisely at the same instant of time.



RTTM-Model Compensated Mass Balance

Model Compensated Mass Balance (MCMB) is the most powerful and most accurate balancing method to detect pipeline leaks. Unlike uncompensated mass balance, the MCMB takes changes in pipeline inventory into account. The calculation of inventory requires product density as a parameter. Density and pipe geometry may vary along a pipeline.

That's why it is necessary to integrate a density profile which in turn depends on pressure and temperature. The profiles are provided by the RTTM in order to correctly determine the pipeline inventory for steady-state and transient conditions. Finally, the MCMB compares mass changes based on measured data against mass changes based on model data.

The MCMB uses the following data for calculations:

- Flow meter readings at pipeline inlets and outlets
- Pipeline geometrical data
- Topological data
- RTTM calculated pressure, temperature and density profiles
- Fluid compressibility
- Inventory

The MCMB supports three time frames (balance periods) in order to properly detect small and large leaks and to eliminate random errors. The definition of time frames is always a trade-off between achievable sensitivity and reaction time. Each time frame can be individually configured. The final time frames are usually set during the commissioning stage when the actual instrumentation accuracies and sampling rates are determined. The MCMB can be configured for each pipeline section with individual time frames.

A leak alarm is issued when a mass balance falls below a threshold.

Warning and alarm thresholds can be set for each time frame.

Compensated Mass Balance

The basis of pipeline inventory calculation is the significant difference between Compensated Mass Balance (CMB) and MCMB. Density is calculated as a function of temperature and pressure where available readings from pressure and temperature measurements are utilized. For every segment between two adjacent meters an average density is calculated. A mathematical function approximates a profile between two metered points. The total pipeline inventory is the sum of all segment inventories.

The CMB supports three time frames (balance periods) in order to properly detect small and large leaks and to eliminate random errors. The definition of time frames is always a trade-off between achievable sensitivity and reaction time. Each time frame can be individually configured. The final time frames are usually set during the commissioning stage when the actual instrumentation accuracies and sampling rates are determined. The CMB can be configured for each pipeline section with individual time frames.

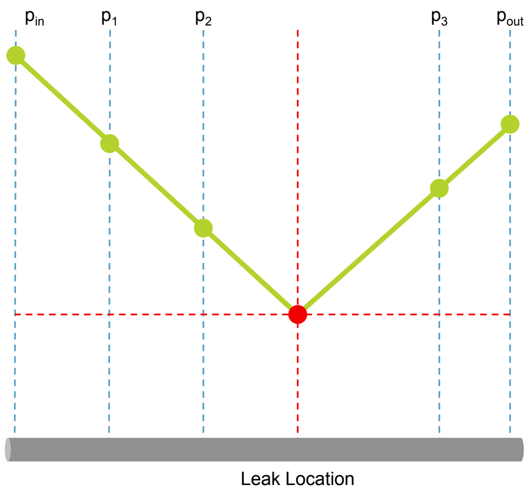
A leak alarm is issued when a mass balance falls below a threshold. Warning and alarm thresholds can be set for each time frame.

Shut-In

Shut-In leak detection is primarily based on the same principles as MCMB. The significant difference is that the flow of shut-in segments/pipelines is zero and not used to determine a mass balance. Hence metering inaccuracies become irrelevant and the sensitivity of leak detection increases. The calculation of pipeline inventory is carried out on a cyclical basis using pressure and temperature profiles.

Pressure Gradient Evaluation

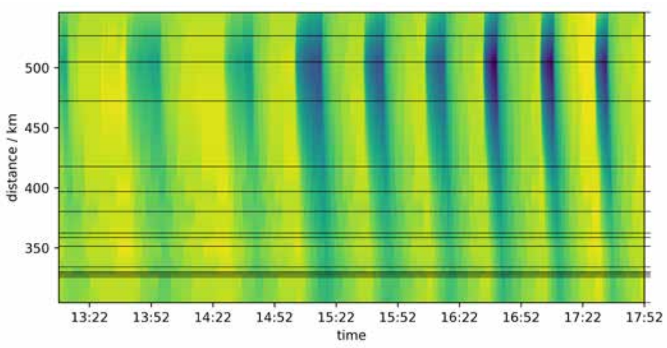
Leak locations are determined by the model-based pressure gradient intersection method. The gradient intersection method is primarily based on the fact that the pressure profile along a pipeline will significantly change when a leak occurs. In these cases, the LDS calculates in combination with the RTTM the intersection point of the differential pressure profiles upstream and downstream of the leak. The system uses a multi-step approach to achieve maximum location accuracy by reducing the impacts of pressure fluctuations. The model-based pressure gradient intersection method utilizes the profiles of the RTTM to compensate transients.



Negative Pressure Wave

The NPW method is based on the analysis of pressure signals. When a leak occurs, it causes a negative pressure wave propagating in both directions, upstream and downstream of a leak's location. The wave induces pressure drops at measurement points. These events, including time series before and after an event, are recorded and pre-processed by RTUs or special processing units before being transmitted to the PSIpipelines LDS for analysis of data and wave front propagation. The RTU buffer should be able to store pressure measurements for a period of at least 10 seconds (3 seconds before and 7 seconds after detection time at measurement points).

Another important requirement is precise time stamping and synchronization of instrumentation and telemetry components. Pressure sensors and processing units must have fast response times and sample rates respectively. A sample rate should not exceed 50 milliseconds. Otherwise, if a leak event is not immediately recorded, it disappears without the opportunity to detect it again.



Location accuracy is directly proportional to the sample rate. If an RTU is able to support sample rates of 10 milliseconds, it is possible to install 2 pressure sensors with a maximum distance of 15 metres. This configuration is helpful in identifying the direction of wave propagation. It is thus possible to distinct the source of a pressure drop either inside or outside the supervised pipeline segment. The magnitude of pressure change must be detectable at pressure sensors. If the accuracy of pressure measurement is 0.01 bar, then the resulting NPW accuracy is approximately 0.02 bar, assuming two sensors, upstream and downstream. However, years of field experience under real operating conditions confirm that the cost-benefit ratio does not significantly increase with instrumentation accuracy of better than 0.05 bar. To take advantage of highly accurate instrumentation, sensor and background noise must be suspended and the pipeline must constantly operate in steady-state mode. The impact of a leak can be significant in relation to sensor accuracy but it is small compared to operational changes.

The dissipation in pressure change is a function of distance and fluid compressibility. The performance of any negative pressure wave method will decline with increasing distance between pressure measurements and increasing fluid compressibility. This is, in particular, relevant for gas pipelines where damping is 1000 times greater than in liquid pipelines. If, for example, a distance of 20 km between two pressure sensors is sufficient for liquid pipelines, the maximum distance would be 20 metres for gas pipelines. This means this method is not suitable for gas pipelines. Leak signals in liquid pipelines attenuate to undetectable values at a point between 30 and 60 km.

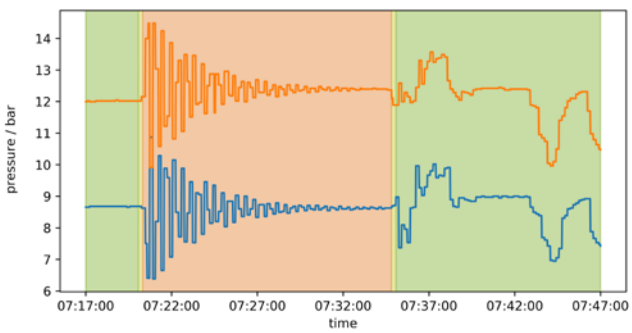
The intensity p of a pressure wave drops exponentially from its initial intensity p_0.

$$p = p_0 e^{-\alpha x}$$

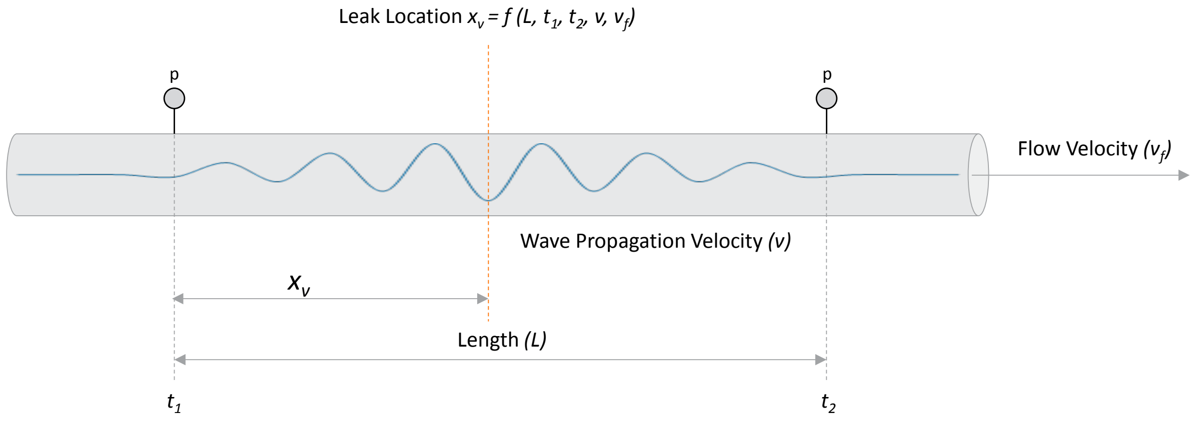
x denotes the distance from the leak location in km and α is the attenuation factor that is determined based on commodity and pipeline properties.

The attenuation factor depends on

- sonic speed
- pipeline inner diameter
- product dynamic viscosity
- product density



The location of a leak is determined based on the pressure wave propagation velocity in the fluid, the pipeline or segment length and arrival times of the pressure drop at sensors. It takes into account that a wave first appears at measuring points closest to a leak and with certain delay at distant points. If pressure measurements are blocked or are unavailable, the system automatically adjusts the sections of adjacent measurement points.
The location accuracy depends on the sampling rate of pressure meters and the sonic speed in the pipeline section. Sonic speed is an altering variable and depends on fluid composition, temperature and pressure. For precise velocity calculations, the RTTM takes into account traveling pressure waves issued by pump or valve operations.



The direct link between NPW and RTTM allows the use of the following hydraulic profile data in order to achieve accurate results:

- Density
- Temperature
- Pressure
- Pipeline diameter
- Pipeline wall thickness
- Sediments / waxing
- Batch interface

NPW takes the pipeline inventory into account. This is particularly important in case of batch operations. When systems do not consider pipeline inventory this inevitably leads to significant leak location errors.

Section length:	20 km	Outer diameter:	530 mm
Density:	850 kg/m³	Wall thickness:	8 mm
Temperature:	15 °C	Sonic Speed:	1,081.1 m/s

Parameter	Change in Value	Impact on sonic speed (m/s)	Impact on leak location error (m)
Outer diameter	+ 10 mm	1,078.1	55.15
Density	+ 10 kg/m³	1,086.3	96.55
Temperature	+ 1 °C	1,075.3	106.95
Wall thickness	+ 1 mm	1,099.0	331.50

Tracking

PSIpipelines provides a comprehensive tracking system. Data is permanently exchanged between the RTTM and the tracking system to ensure very precise calculation results. The tracking applications utilize velocity profiles from the RTTM. The batch tracking application provides density data to the RTTM during the movement of different products.

PSIpipelines provides tracking applications for:

- Pigging Devices and Batch Separation Spheres
- Batches
- Precision Batch Cutting
- Drag Reducing Agents

Pigging Devices and Spheres Tracking

The Pigging Device and Sphere Tracking application helps to precisely track the movement of pigging devices or spheres and to predict arrival times to the next block valve and/or receiving facility. Furthermore, it helps to prevent asset damage. This application can track different types (also numerous simultaneously) of scrapers, pipeline inspection gauges and batch separation spheres within a pipeline and provides detailed information including

- Start time
- Estimated arrival time (at receiver station, next station, next pig signal)
- Position
- Velocity (based on RTTM velocity profile)
- Slippage factor
- Launcher and receiver station

The application uses passage signals to automatically adjust slippage and position. In combination with the PSIpipelines Valve Anti-Collision Advisor the system generates warnings before approaching valve stations in order to avoid potential damage caused by valve closures. Pigs/scrapers and spheres are tracked down the line according to the current flow velocity corrected by the slippage factor. PSIpipelines has been designed to avoid false leak alarms during transmission and receiving operations.

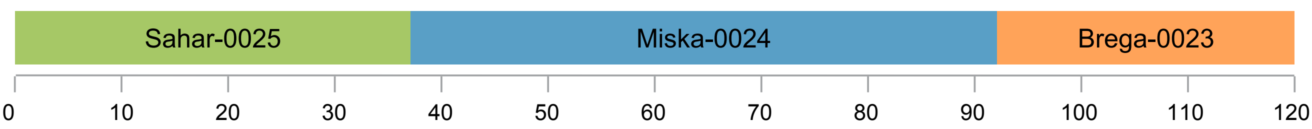
The application provides the following functions:

- Start
- Move
- Delete
- Information
- Data historian

Batch Tracking

The Batch Tracking application helps to monitor the transportation of different types of liquids in the same pipeline. It is used to set up optimal batch sizes and configurations taking equipment availability and downtime into account and to take advantage of variable energy costs for pump power.

Batch tracking is based on accepted nomination quantities and schedules provided by other systems.



Different products are moved through the same pipeline in batches. Once the batches arrive at their respective destinations they are diverted into other lines or tanks. The Batch Tracking application is able to track different types of batches within a pipeline and provides detailed information including

- Start time
- Estimated arrival time
- Planned and actual volume
- Storage tanks at inlet and outlet
- Transmix (interface) volume
- Position
- Liquids and their volumes
- Velocity
- Density and viscosity
- Pipeline branch

A batch moves according to the velocity of the fluid. The system utilizes the data from flow meters. Batch positions are cyclically updated.

The application provides the following functions:

- Start
- Insert
- Move batch head
- Delete
- Batch information
- Data historian

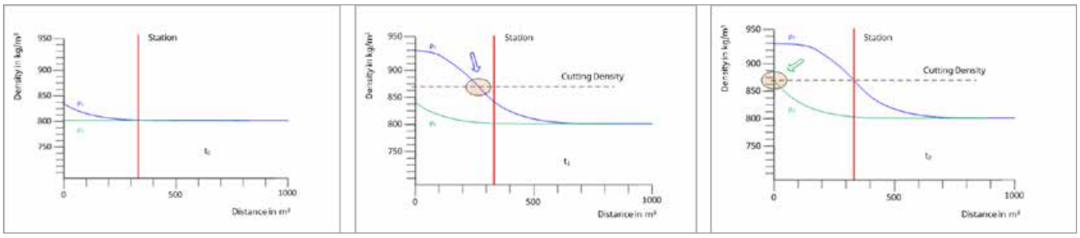
Precision Batch Cutting

The Precision Batch Cutting (PBC) application helps to significantly reduce transmix volumes and product contamination. The corresponding savings are an important revenue generator for pipeline companies. PBC allows more product volumes to get to the customer and a greater control of product quality.

Batch cutting is the process of identifying changes between batches and redirecting the flow from one location to another by opening and closing valves.

Using the Precision Batch Cutting application, operators can precisely track density changes to obtain the optimal time of batch cutting. Some mixing of product occurs at the interface of adjacent product grade batches. This volume can sometimes be mixed into one or both of the adjacent batches and still meet product specifications. When products are of significantly different grade, the product interface (transmix) must be diverted to dedicated tanks to avoid contamination.

Pipeline operators need time to evaluate the optimal batch cut. Precise batch cutting is carried out with preview stations. These stations are located upstream from a delivery station and have real-time precision instrumentation like densitometers or colorimeters. The distance between preview and delivery stations may vary. Typically the preview station is located between 15 minutes and one hour upstream as measured by maximum flow rate.



Drag Reducing Agents

The DRA Tracking application helps to determine the effectiveness of these additives and hence to save money.

Drag Reducing Agents reduce the decrease of pressure caused by friction within the flow of a pipeline. Using DRA enables operators to increase pipeline flow capacity, reduce energy consumption, optimize efficiency and reduce line pressure.

The effectiveness of DRA injection is continuously analyzed and plotted like hydraulic profiles. With drag reduction, there are many factors which play a role in how well the drag is reduced.

The following factors are considered:

- Temperature
- Injected volume
- Viscosity
- Distance
- Velocity
- Elapsed time

The relationships of these factors are modeled using various pre-defined mathematical functions. The parameters of these functions can be modified to achieve best possible results.

+ PSIpipelines

Monitoring and Integrity

PSIpipelines provides the following pipeline monitoring and integrity applications:

- Pipeline Stress Monitor
- Pipeline Efficiency
- Pipeline Inventory
- Instrumentation Analyzer
- Slack Line Control
- Interior Corrosion
- Pumps

Pipeline Stress Monitor

The Pipeline Stress Monitor application helps to maintain pipeline safety and to extend the life time of the pipeline's infrastructure. The total life time of a pipeline segment is limited and depends on operational procedures. In order to predict material fatigue, it is important to monitor the stress that is caused by varying pipeline pressures. If most pump operations are performed during steady state with only a few interruptions, the impact on the total lifetime is much less than during transient conditions.

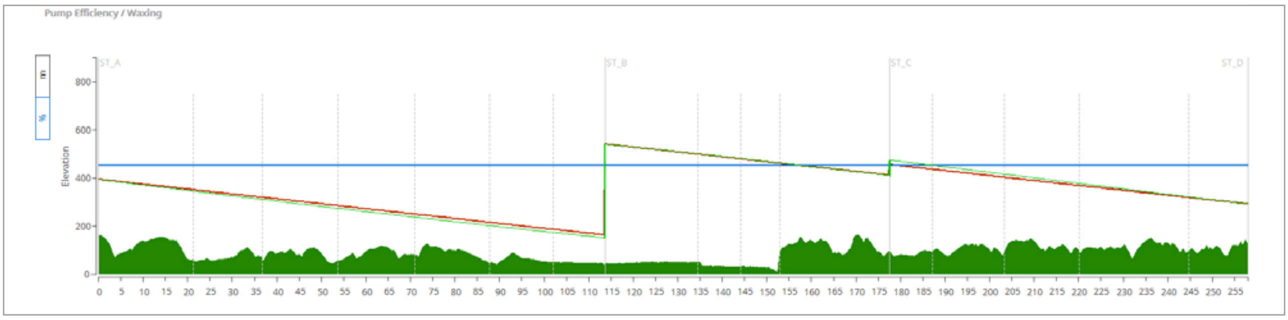
Based on actual pressure values for monitored pipeline segments, which are stored continuously in the database, the Pipeline Stress application permanently analyses pressure trend curves, determines maximum and minimum possible thresholds and calculates the impacts of pressure changes. When a pipeline approaches the end of its life, operating companies are advised to inspect the condition of the pipeline. The application executes calculations in accordance to TÜV AD S1 and S2 Code of Practice.

Pipeline Efficiency

The Pipeline Efficiency application helps to ensure flow assurance, to identify optimal pigging frequency and to reduce pumping energy.
Required throughput must be obtained at the lowest operating cost. Deposits like wax

- accumulate at pipe walls over time
- cause drastic reduction of efficiency
- increase the pumping power costs due to the decreasing inner diameter of a pipeline
- reduce the flow rate and can cause a total flow blockage
- encourage corrosion growth
- potentially prevent corrosion inhibitors from being properly applied

The Pipeline Efficiency application indicates pressure deviations from optimal operation and notifies the operator in advance to initiate cleaning scraper runs when the calculated efficiency falls below a certain level. Efficiency values are recorded to to identify how quickly deposits affect a pipeline and to adjust the pigging frequency. Pumping energy consumption can be compared for maximum and minimum efficiency. The application utilizes pressure and flow profiles of the RTTM.

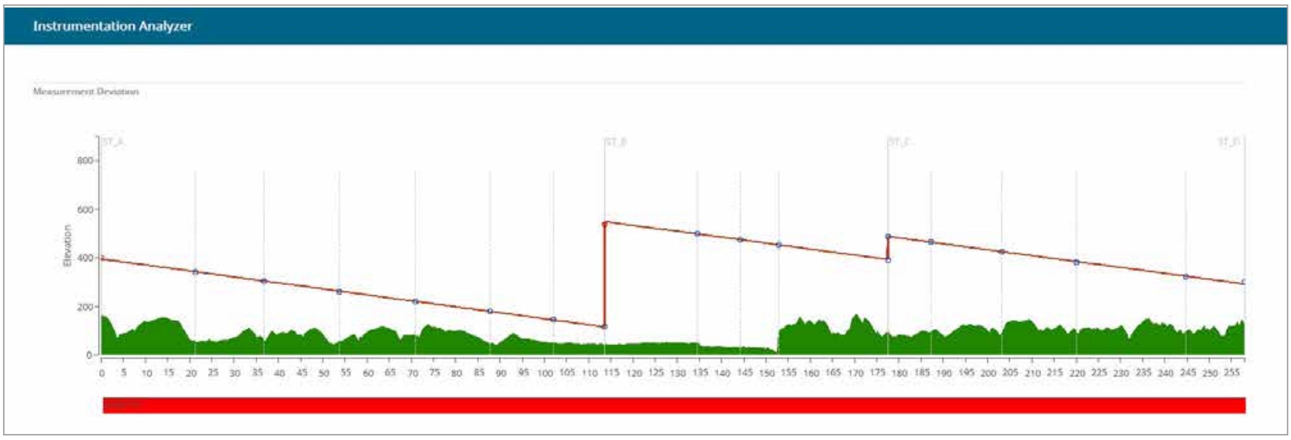


Pipeline Inventory

The Pipeline Inventory application helps to determine the exact quantity of commodity in a pipeline.
Over the course of a day, the contents of the pipeline may change due to temperature and pressure variations. The Pipeline Inventory application utilizes the inventory data of the RTTM and stores the data in the real-time database. Quantities are determined for each pipeline segment and also for every product in multi-product pipelines. This information can be used for hourly/daily reports.

Instrumentation Analyzer

The Instrumentation Analyzer helps to improve instrumentation maintenance and to quickly detect failures.
Measurement errors are systematic and random, but still affect the results and system performance if not considered accordingly. Systematic errors are typically constant or proportional to the true value. If the cause of the systematic error can be identified, then it usually can be eliminated. Systematic errors are caused by imperfect calibration of measurement instruments or interference of the environment with the measurement process. Random errors are always present in a measurement. They are caused by inherently unpredictable fluctuations in the readings of an instrument. Random errors show up as different results for the same repeated measurement. They can be estimated by comparing multiple measurements and can be reduced by averaging multiple measurements.
The Instrumentation Analyzer continuously compares and analyses in real-time the readings from field instrumentation with the calculated values of the RTTM to detect drift or instrument malfunction.



Slack Line Monitoring and Control

The Slack Line Monitoring and Control application helps to identify in advance undesired slack line conditions. It is also used to set the optimal operating pressure at critical points along a pipeline in order to reduce pump power consumption and to save costs.
The basic principle is a closed-loop control system to automatically keep a pressure at a defined value. A pressure set-point needs to be assigned and a PID controller is used to optimise the control response (i.e. pump speed or valve position).
At critical points where instrumentation is not available (e.g. highest points of elevations) the corresponding values will be provided by the RTTM.

Interior Corrosion

The Interior Corrosion application helps to prevent potential corrosion damage that possibly could lead to pipeline leaks. Liquids and gases may contain considerable amounts of acid-forming components. The primary factor that affects internal corrosion in pipelines is flow rate. Internal corrosion can occur if the flow conditions in the pipeline allow these components to accumulate and settle on the pipe floor for extended periods of time. Pipelines with slow flow (below critical velocity) tend to be more susceptible to corrosion than those with high flow (above critical velocity). The critical velocity for entrainment depends upon physical properties of the transported commodity and the throughput.
The RTTM provides a precise velocity profile that clearly indicates the flow velocity at every point in a pipeline. This profile can be combined with a wall thickness profile for the specific time period to identify susceptible locations. The wall thickness profile is based on the results of intelligent pigging. When data records of multiple profile pairs are combined, operators can determine corrosion rates and trends to promptly predict the remaining period of pipeline lifetime.

Pumps

The Pump application helps to monitor the performance capabilities of pumps because energy conumption is the single largest operating expense for many pipelines.

Pump characteristic curves are used to represent pump performance in regard to:
- Pumping head and volume flow rate
- Efficiency and volume flow rate

The application allows the selection of:
- One pump
- All pumps of a station
- All pumps of a pipeline segment

In addition to pump curves and actual operating points, the following data is provided:
- Volume flow
- Pumping head
- Power consumption
- Revolution speed
- Liquid density
- Volume flow at optimal operating point
- Pumping head at optimal operating point
- Efficiency at optimal operating point
- Pump model

Pipeline Management

PSIpipelines provides the following management applications:
- Commodities
- Batches
- Pigging Devices
- Tanks
- Pumps

Commodity Management

The Commodity Management application is used to manage liquids and gases and their respective physical properties in a central database.

The master data is used by the following applications:
- RTTM
- Batch Tracking
- Tank Management

For each commodity the following properties can be set or modified:
- Composition
- Density
- Viscosity
- Sonic speed
- Compressibility
- Thermal expansion

Properties for single commodities or mixtures can additionally be determined with REFPROP, the NIST Reference Fluid Thermodynamic and Transport Properties Database.

Batch Management

The Batch Management application is used for batch operation scheduling in accordance to actual transport conditions.
Operation schedules are defined using accepted nomination quantities and movement orders that are provided by other systems.

A schedule is an ordered list which can be edited and modified by operators. It contains the essential data for every batch including:
- Scheduled time
- Batch volume
- Destination
- Tanks at inlet and outlet
- Liquid
- Blending data

Pigging Devices Management

The Pig/Scraper Management application is used to manage different types of pigs and scrapers. Operators can edit and modify the following master data:
- Type
- Diameter
- Initial slippage factor

Tank Management

The Tank Management application is used to manage storage and relief tanks and tank farms. Data records include static and operational data:

- Tank type
- Diameter
- Height
- Volume
- Calibration data
- Level
- Temperature
- Liquid properties
- Status
- Filling and discharging

Operational data is automatically ingested and can also be modified by the operator. Precise tank volumes are determined with pre-measurements prior to filling or discharging as well as re-measurements after filling or discharging.

Pump Management

The Pump Management application is used to manage pump models and to assign the corresponding model data to pumps. A pump model is a complete data set of hydraulic and energy properties of a pump unit.

Operators can edit and modify the following master data:

- Type of control
- Impeller diameter
- Revolution speed
- Volume flow
- Pumping head
- Efficiency

System Tools

Human-Machine Interface

The human-machine interface is the collection of graphic displays, keyboards and other technologies used by operators to monitor and interact with pipeline monitoring applications. PSIpipelines supports the implementation of a consistent, effective and high performance HMI where operational values are shown in an informational context and not simply as raw numbers scattered around the screen.

Historical Data and Trending

PSIpipelines has an integrated, ultra-fast historical database. It provides complete tabular and graphical capabilities to perform continuous data analysis over the timeline, either event by event or in time steps. The historical data playback function supports operators analyze pipeline scenarios, determine significant events to source problems and effects they may cause as well as identify malfunctioning instrumentation.

Data Pre-Processing and Validation

The main purpose of data pre-processing and validation is to ensure that the RTTM operates at optimum performance. PSIpipelines provides comprehensive data pre-processing and validation functions including plausibility checks to avoid any RTTM model instability and inaccurate real-time simulations. Different strategies at different levels can be configured to enable the system to substitute implausible or invalid values with acceptable values to the greatest possible extent.

Alarm and Event Logging

Alarm or event messages are logged whenever an event occurs. Different filter criteria can be applied to focus on crucial information. Priorities and acknowledgement strategies can be defined per user. Messages contain at least the type of event, date and time of entry, date and time of origin, tag object, event text and priority.

Access Control and User Authentication

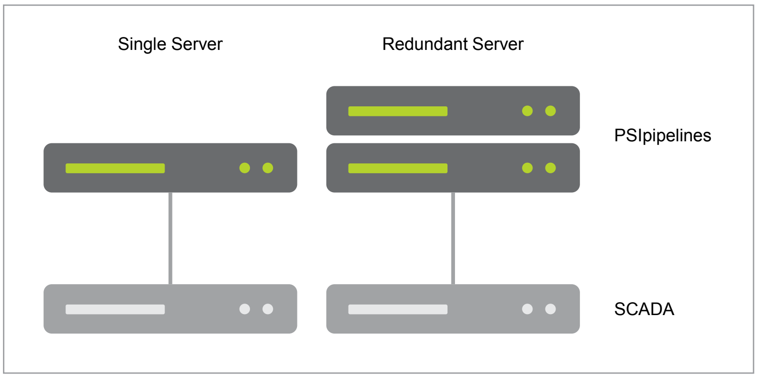
The system provides multi-level, multi-role access control and user authentication. Security level, access level, passwords, permissions for process displays, applications and system functions can be individually set and managed for every operator, operator group or work shift. The assigned authorizations are activated after system login and deactivated after log-off.

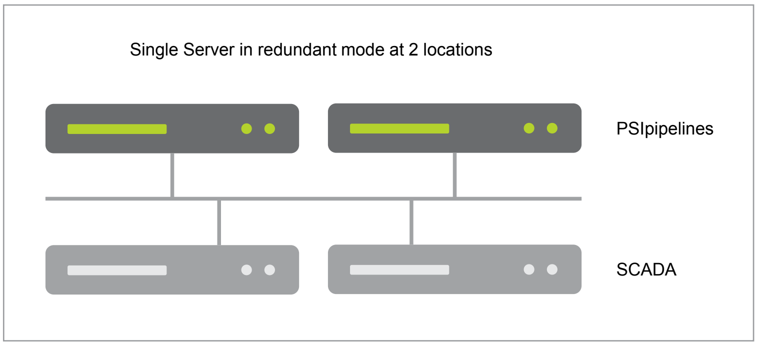
System Integration

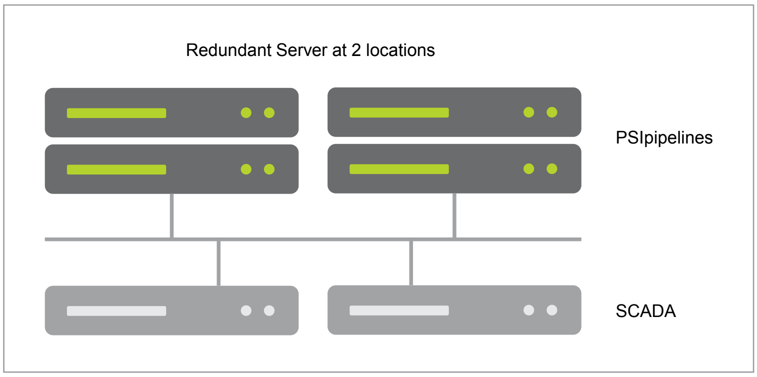
Scalable System Architecture

PSIpipelines applications run on Windows and Linux platforms. The following configuration modes are currently supported:
- Stand-alone system
- Redundant system at one site
- Redundant systems at multiple sites

Redundant configurations run in hot-standby mode with automatic failover. Applications can run on one computer or across two or more computers to optimize resource use and to avoid processing overload.
The scalable architecture allows a pipeline model and application system to incrementally grow while preserving the initial configuration and investment.







System Integration

PSIpipelines currently supports the following industry standard protocols:
- OPC
- Modbus TCP
- IEC 60870-5-104

PSIpipelines can be integrated with any SCADA or DCS via OPC. In this case SCADA/DCS provides OPC server and OPC client capabilities to send data to PSIpipelines and to receive data from PSIpipelines.
PSIpipelines can be directly connected to any RTU or PLC that supports the above-mentioned protocols.
The PSIpipelines HMI either runs on dedicated computer screens or is integrated into SCADA HMI via Remote Desktop Protocol.

Abbreviations

API	American Petroleum Institute
CFD	Computational Fluid Dynamics
CMB	Compensated Mass Balance
CPM	Computational Pipeline Monitoring
DRA	Drag Reducing Agent
DCS	Distributed Control System
FVM	Finite Volume Method
HMI	Human Machine Interface
LDS	Leak Detection System
MCMB	Model Compensated Mass Balance
NIST	National Institute of Standards and Technology
NPW	Negative Pressure Wave
PBC	Precision Batch Cutting
PID	Proportional Integral Derivative
REFPROP	Reference Fluid Thermodynamic and Transport Properties Database
RTTM	Real-Time Transient Model
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SIL	Safety Integrity Level
TRFL	Technische Regel für Rohrfernleitungen
TÜV	Technischer Überwachungsverein
VOF	Volume of Fluid

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