Pipeline Management System

Product Description

TRADEMARKS

Edition 2001 – Revision 0

NOTICE

Table Of Contents

1. Introduction

The Pipeline Management System (PLMS) Product Description Manual provides an overview of the pipeline management, leak detection system developed by Synergy Systems & Solutions. PLMS merges volume balance techniques, which have been employed for decades in pipeline gain/loss calculations, and the real time transient modelling. This combination offers the pipeline operator an ideal tool that is both easy to understand and capable of accurately modelling and tracking the transients in the pipeline. The leak detection system uses the latest techniques that utilize the known sources of input error, such as instrumentation specifications, to assure the proper tuning of the pipeline system. Leak detection system also has the flexibility to handle the loss of many sensor measurements, and can also efficiently handle the change in states of the equipments like the pump stations, valves etc. at the runtime.

PLMS provides the operator with a computer modelled profile of the whole pipeline network, that helps him in tracking the flow of the batches along the pipeline. It also provides the ope`rator with alarms in case of leaks, along with the location of the leak and its size.

PLMS can also be used as simulation tool for carrying out experiments on a virtual pipeline network, which can be used for analysis of better utilization of the pipeline.

The salient features of PLMS are:

- Configuration Editor
- Pipeline Parameter Tuning
- Pipeline Hydraulic Profile Generation for the whole network
- Handles multiple pipeline networks
- Flexibility of boundary conditions.
- Steady State Calculations
- Transient State Calculations
- Mass Balance Leak Detection
- Pressure/Flow Deviation Leak Detection
- Leak Size
- Leak Location
- Leak Initiation Time
- Environmental Consequences & Safety Consequence Factor Calculations
- Threshold Calculations
- Instrument Tuning
- Batch Tracking
- Expected Time Of Arrival (ETA) Of Batch
- Batch Queuing At Delivery
- Over/Under Pressure Protection
- Interface With Any SCADA Server via OPC
- Interface With SIRIUS

PLMS is based on the concepts of **Computer Modelling**. Computer Modelling is a powerful tool that is well adapted to everyday usage in almost every field of the modern world. Engineers, Economists, Scientists, and Mathematicians analyse the working of complex interactive systems using this technique. This technique is well implemented and has been used in a wide range of industries such as Process Control Facilities, Power Plants, Manufacturing, Medical, Industrial and Military. The basic idea behind this technique is to break down the whole network into logical interconnected components whose interaction can be calculated using the standard equations of Mathematics and Physics.

A Pipeline System can be divided into its simplest components such as pipes, pumps, regulators, valves etc. and standard equations of Fluid Mechanics can be used to calculate the behaviour of Flow, Pressure, Temperature and Density through each of the component. If the Flow, Pressure, Temperature and Density of a fluid are known at the one end of a pipe, we are able to calculate the change in these values by the time the fluid reaches the other end. To carry out these calculations, the physical properties of pipe (Length, Diameter, Roughness, Elevation etc.) are required. Also required are the physical data of all the instruments and equipment on the way.

The pipeline itself is the only component of a significant length, in which the fluid flows in space and time. For applying a proper mathematical model for calculations, the pipeline is imagined to be consisting of small parts (called knots) and the calculations are done for each knot. Similarly for solving each knot in time, a time step is chosen. Smaller the size of knot and time step, more accurate are the results.

PLMS, when started, solves the pipeline for **steady-state conditions**, i.e., assuming that the flow parameters at any point on the pipeline do not change with time. This is a necessary first step towards applying the **transient solution**. The steady state values of the initial time (say, **N**th time step) and the boundary conditions measured at the next (**N+1** th) time-step are sufficient to calculate the flow parameters at the next (N+1 th) time step.

The transient solution is based on the theory that any sudden change in flow conditions (e.g., start of a pump) causes a wave to travel in the pipeline which travels at certain speed. The wave is also reflected back when it strikes the end of a pipe. The wave travelling in the pipeline affects the measurements taken at the boundaries of the pipeline. Transient model thrives to calculate the flow parameters accurately after taking into account the effect of whese waves on flow parameters at each knot.

At the basic level, the computations above require *equation of motion* and *equation of continuity.* All the equations related to the computations are specified later in this document. The computations become more accurate when we take into account the changes in fluid density, and amount of heat loss due to temperature difference between the pipeline and the surrounding air/soil. These are goverened by the *equation of state* and *energy balance equation* respectively. Rather these effects are so important that errors remain very significant without use of these two equations. The calculation results are further improved when the elastic behaviour of pipeline material is taken into account and its change area is also calculated in time. PLMS uses all of these five equations in solving the transients.

The transient values calculated by the model above are used for variety of purposes like leak detection and batch tracking etc.

Since occurance of leak is equivalent of creating another boundary which is not knon to the model, therefore the calculations done by the model start to differ from the measurements taken, and that is how leak is detected.

Any attempt to detect leak at early stages after a fresh startup (cold start) of PLMS would tend to give incorrect results because the intial condition was assumed to be steady-state but in real-life that is seldom the case. Therefore the calculation model needs certain cold start period during which the transient values are calculated at each progressive time-step but no attempt is made to detect the leak. After cold start period is over, the effect of the initial steady-state assumption in the calculations is sufficiently subdued and therefore the calculations start to reliably depict the real pipeline conditions. Therefore leak detection software starts to work only after cold start period is over.

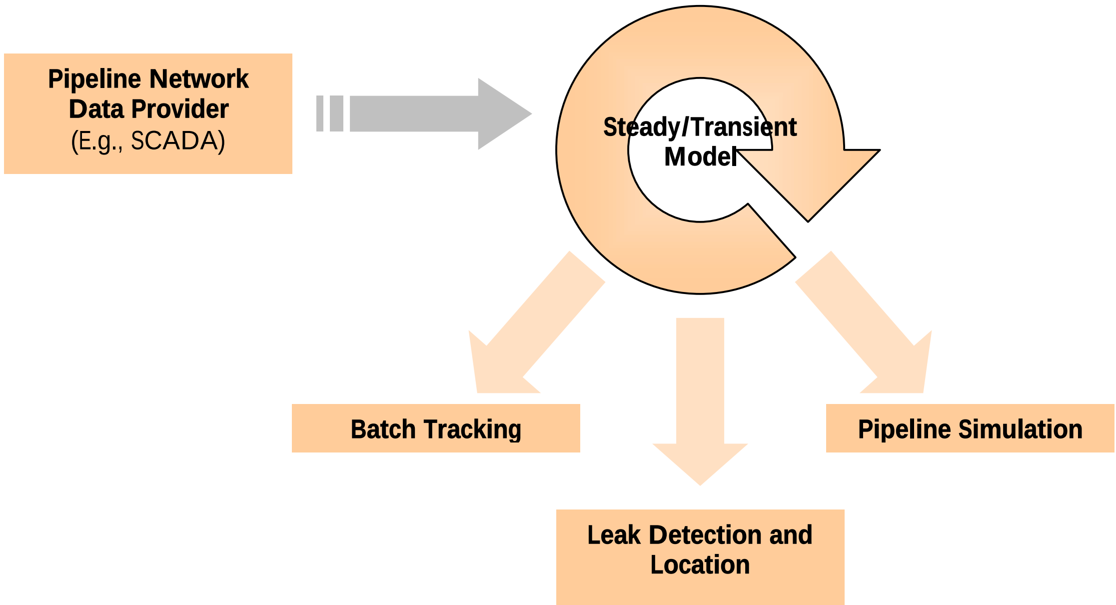
Batch tracking is basically done by tracking the movement of known mass of the product in the pipeline. The time when a batch is introduced into the pipeline goes as input to the system. Then depending upon the flow rate and density of the product at various knots, the movement of the product in the pipeline accurately calculated.

PLMS is an expert system, that uses the concepts of Device Simulation and Decision-Making in order to emulate the conditions as close as possible to those in real-life.

PLMS uses the continuous system technique to simulate the pipeline system.

1.1. PLMS Architecture

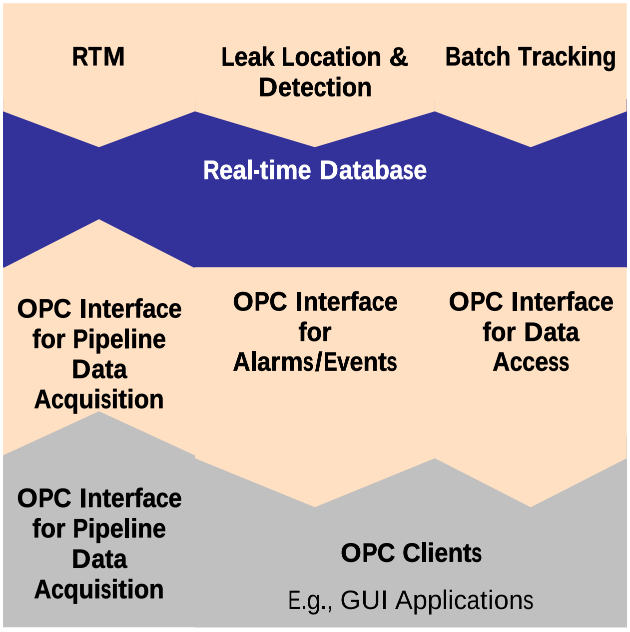
PLMS acquires the values required for generating the pipeline profile from an external application, which could be a SCADA server, a simulator, or such similar application, which can provide value like instrument readings, equipment status, etc. PLMS then uses this data to apply it in the Real-Time Model (RTM) for generating the profile of the pipelines along the network. This data is used for pipeline applications, like, batch tracking, leak detection and location, and for purposes like pipeline network analysis for better utilization, etc.



PLMS initially starts in steady state mode, where changes in flow, pressure, temperature, etc. with respect to time is assumed to be zero or negligible. This allows the system to provide an initial profile of the network, based on which the transient model can work. With each cycle, the changes made to the pipeline profile are notified to the pipeline applications, based on which they work.

1.2. Interfacing with SCADA and other applications

The Pipeline Management System uses an open architecture, that enables it to be integrated with any other external application that provides it with the data for real-time modelling of the pipeline network. PLMS uses the OLE for Process Control (OPC) link for receiving values from an OPC server. Any SCADA application that can act as an OPC Server can be linked with PLMS, for supplying real-time data to PLMS. PLMS also has an OPC Alarm/Event server, that can be linked with OPC clients to access the alarms, events generated by PLMS. Also, for integration with other clients (typically, graphical user interfaces), PLMS provides a OPC Data Access server, using which clients can get the data for the pipeline profiles created by PLMS real-time model.



2. Pipeline Network Configuration

The **Configuration Editor** is a utility developed to assist the user to configure the pipeline network. This utility can be executed on the user demand and the user can add, modify or delete the various components of a pipeline network, as well as modify the physical characteristics the network, like:

- Pipeline Parameters
- Connection Structure
- Liquid Characteristics
- Specification Of Instruments
- Specification Of Equipment

This utility supports creation of new pipeline networks and modification of the existing networks. The utility has a user-friendly interface that is easy to work with. Using the editor the user can specify all the configurable data required for the working of PLMS. Examples of data that can be configured via the editor are:

- Physical data associated with the network

  These include the physical structure of the pipeline such as the pipeline length, the pipe diameter, elevation, connections, pipe legs, pipe wall thickness, pipe young modulus etc.

- Constant data associated with the network

  These include the data that remains valid for the entire pipeline network and remains constant forever such as leak detection enable/disable, cold start length, SCADA cycle etc.

- Definition of Instruments

  These include the data about the instruments such as the additive constants, multiplier constants, span, accuracy etc.

- Fluid type data

  These include the data about the different fluids and the properties associated with the fluid.

The Configuration Editor can be executed without affecting the running modules. This allows modifying the network configuration while the rest of the system operating. After the modifications are made, it is recommended to start the Pipeline Management System in Cold Start State.

3. The Real - Time Model (RTM)

Supervisory Control and Data Acquisition (SCADA) systems are used to provide much of the Real Time Data, which are required to operate a pipeline with safety and efficiency. These systems provide the instantaneous information on various quantities at specific data points along the pipeline network. These specific points are not permanent, as the pipeline system is a dynamic system, which changes with time. These data points are important but they cannot really predict the entire picture of what is happening at any particular point in the system. They cannot even predict how the rest of the pipeline system will be affected, if there is a change at one location in the pipeline.

PLMS therefore, supports a real-time model pipeline simulation model based on hydraulics. PLMS uses the static pipeline configuration data and the online real-time data acquired by SCADA, to accurately create the computer model of the pipeline. Then using these data, it performs the calculations and portrays the resultant information to the pipeline operator.

PLMS is applicable to liquid pipelines and the liquid classes include Crude Oil, Kerosene, Benzene, Diesel and other specialty fluids. PLMS can model a wide variety of pipeline systems types, including transportation and distribution Systems.

The application modules are defined to do the following tasks:

- Configure the Pipeline
- Tune the Modelling Parameters
- Detect and Locate Leaks
- Track the Batches
- Estimate Batch Expected Time of Arrival
- System Wide Displays
- Generate Alarms

4. The Mathematical Model

The following sets of equation are used by the RTM to simulate the pipeline conditions at each location on the pipeline network.

4.1. Equation Of Motion

$$\frac{\partial P}{\rho\ \partial x} + V\frac{\partial V}{\partial x} - \frac{fV^2}{2D} - g\sin\theta = 0$$

where,

P = Pressure

ρ = Density of the fluid

V = Flow velocity

f = Friction Factor

D = Diameter of the pipeline

gSinθ = Elevation of the pipeline

4.2. Equation Of Continuity

$$V\frac{\partial P}{\partial x} + \rho a^2\frac{\partial V}{\partial x} = 0$$

where,

P = Pressure

ρ = Density of the fluid

V = Flow velocity

a = Wave velocity

4.3. Energy Balance Equation

$$\frac{\partial T}{\partial t} = -\frac{\partial(\rho VAT)}{\rho A\partial x} - \frac{T\left\{\frac{\partial P}{\partial T}\right\}_{\rho}}{\rho Ac_v}\frac{\partial(\rho VA)}{\rho\,\partial x} + \frac{fV^3}{2Dc_v} - \frac{4U_w(T-T_g)}{D\rho c_v} - \frac{Vg\sin\theta}{c_v}$$

where,

ρ – *density of the fluid*

T_t – *change in temperature with time*

T_x – *change in temperature with distance*

P_x – *change in pressure with distance*

T_g – *ground temperature*

U_w – *ground heat flow coefficient*

c_v – *heat capacity of the fluid*

$\left\{\frac{\partial P}{\partial T}\right\}_\rho$ – *is the change in pressure with temperature at constant* ρ

In the above equation of energy balance, the term U_w is known as the overall heat transfer coefficient, which tells how much heat is transferred to the sink(ground). The heat transfer will change the temperature of the pipe (or the fluid).

Temperature of the fluid will change as it flows through the pipe because of the temperature difference between the fluid and the temperature of the soil (ground). The energy equation will therefore be used in the steady state to account for the change in temperature along the pipe length.

4.4. Equation Of State

The equation of state represents the density of the fluid at a particular point. Equation of state will be solved separately and not along with the motion and continuity equation so as to reduce the complexity of the matrix. These can be solved separately at each iteration and then these values can be substituted for the next iteration.

$$\rho_x = \rho_s \exp((P_x - P_s)/K - \alpha\,(T_x - T_s))$$

where,

ρ_s – *is the density of the fluid in standard conditions*

ρ_x – *is the density at pressure* P_x *and temperatur e* T_x

P_s – *standard pressure*

P_x – *pressure*

T_s – *standard temperature*

T_x – *current temperature*

K – *bulk modulus of the fluid*

α – *coefficient of thermal expansion of the fluid*

4.5. Change In Area

The area can also be treated same like the density (equation of state) and solved separately.

$$A = A_s\left(1 + \frac{PD}{EW} - \alpha(T - T_s)\right)$$

where,

A is the area

A_S *– is the area under standard conditions*

P *– is the pressure*

D *– is the internal diameter of the pipe*

E *is the Young's Modulus of pipe material*

W *– is the thickness of pipe wall*

α *– is the coefficient of thermal expansion*

T *– temperature of the pipe*

T_S *– standard temperature*

5. Numerical Analysis

5.1. Steady State Model

During steady state of the pipeline management system, the parameters are calculated using the initial data, which is acquired from the SCADA database. The RTM retrieves the initial data from SCADA server. This initial data is the measured data that is supplied by the instruments given. The data is then substituted in the mathematical model which is **solved simultaneously using a fast-converging implicit iterative procedure**. After completion of steady state, the RTM has the parameters for all the points in the pipeline network. After all the parameters have been calculated in the steady model, the RTM is now ready to change its state from the steady to the transient state.

5.2. Transient State Model

The Transient Model sets up an array of **Finite Difference Equations** and uses an **implicit method** to solve the mathematical model simultaneously at each time step. It then uses the measured values of parameter of the current time step and the profiles from the previous time step. All the **Instrument Analysis, Equipment Analysis, Pressure/ Flow Deviation Leak Detection** are done in this model.

The real-time transient model continuously models the actual real-time conditions in the pipeline system. The model is continuously synchronized to real-time measured data from the available from SCADA.

Each scan, the SCADA system sends measured data to the real-time model. The measured data include flow rates or volumes, pressures, temperatures, batch, and measurement and valve status at various locations along the pipeline. Then the model simulates the current pipeline states in real-time.

The transient model computes the pressure, temperature, flow and density of the fluid in each component for the entire pipeline system. The model takes into account product compressibility, changes in elevation, pipe wall expansion, frictional heating, ground heat transfer, station control, and valve operations, so that an accurate representation of the pipeline system is maintained.

The model can solve simple and complex networks that include loops, block valves, junctions, pump stations and control valves.

5.3. Ground Heat Flow Model

This model is used to calculate the total heat that is transferred between the ground and the pipeline. In this model the ground is considered to consist of concentric cylindrical shells around the pipe whose thickness is already configured in the pipeline configuration. During the operation, the RTM will know the ambient temperature. Since at each knot the RTM have already calculated the temperature, the RTM will use the **fast converging implicit iterative technique** to calculate the transfer of heat between the pipe and the ground. During this operation, the RTM will also calculate the temperature at the intermediate shells hypothetically created by it.

5.4. Pipeline Parameter Tuning

This module is internal process of the Pipeline Management System, which the RTM uses to improve the simulation accuracy of the each pipeline operation characteristics. The basic approach behind is, the RTM calculates the general parameters in the pipeline and when the real time data is available compares these values with those calculated. If the calculated values do not agree with the latter, the RTM adjusts the tuning parameters automatically on order to decrease the variations/ discrepancies.

The model is automatically tuned so that the calculated values agree with the measured quantities. If the data and the model are correct, the tuned quantities will not change in response to transient model. An incorrect model, or a model tuned to bad data will develop the errors in response to the flow changes.

Parameter tuning tunes the **Pipeline Roughness**, **Temperature**, and **Imbalances** for each leg in the pipeline network. The **Calibration Tolerances** or **Limits** can be set for each tuning correction factor. If the Correction Factor exceeds the present limit, the tuning stops and an alarm is generated by the system.

The Pipe Roughness Tuning determines the **Friction Factor**, which is a relation between the Calculated Flow and the Pressure Drop. For a larger calculated flow, the roughness is increased and for a larger measured flow, the roughness is decreased. The Roughness Tuning is done on regular intervals, which may vary from 50 minutes to 3 hours. Roughness tuning is inhibited for low flows, as the roughness does not affect the flow significantly.

Temperature Tuning is the approach to automatically adjust the thermal parameters for pipe legs in the pipeline network in order to eliminate the discrepancies between the measured and calculated temperatures. **Thermal Conductivity** and **Ground Temperature** play a big role in the calculations of temperature for **Buried Pipe Legs** and **Submerged Pipe Legs**.

6. Application Software

6.1. Profile Generation

The RTM using the above set of hydraulic equation generates a profile at each individual knots. These profiles will be used by the various applications like for leak detection and location, batch tracking.

6.2. Leak Detection

The PLMS provides the options of Leak Detection for the pipelines modelled by it. The leak Detection Module works using the profiles generated during normal transient and the validated SCADA values to identify, size and locate the leaks. For the model to perform these tasks three different Leak Detection techniques are implemented. This helps in analysing the data and increasing the leak detection sensitivity and meanwhile *minimizing False Alarm Generation*.

The leak detection module uses three different techniques:

- Mass Balance Technique
- Pressure Deviation Technique, and
- Flow Deviation Technique.

6.2.1. Mass Balance Technique

This technique uses law of conservation of mass.

Mass entered into the system = Mass inside the system + Mass leaving the system

The above law of conservation of mass is used by the RTM by using the density and the flow rate at the supply and the delivery to calculate the total mass entering and leaving the system. Since, some mass of the fluid is still inside the system the RTM will use the calculated density and flow at each point, to know the total mass that is inside the system. Since, the density and the flow rate calculated by the RTM have already been compensated by the ***line packing effect***, the RTM is able to conserve the total mass.

6.2.2. Pressure/Flow Deviation Technique

Once the RTM has calculated the Pressure and Flow rates at each point, these calculated readings will be compared with the corresponding measured readings. This comparison is possible only at the points where the pressure and flow instruments are available and which are not being used the RTM for simulation. The RTM uses **voting algorithms** to minimize false alarms caused by the sudden transients. The pressure deviation technique will compare the calculated pressure with the measured pressure of the instruments which are not used by the RTM for simulations. Similarly, for the flow deviation calculated flow is compared with measured flow.

6.2.3. Location, Size and Time of Leak

The leak location module uses a technique called, '**Method of characteristics using the spatial direction**' which is able to locate the leak within a respectable time and with minimum error. The same method is also able to calculate the size and the time of the leak. Since this technique uses the measured reading at the supply and delivery it is considered to be the best technique for leak location.

It also calculates the **Environmental Consequences** because of leak, depending upon the following parameters:

- Potential Leak Mass
- Persistent/ Seepage Factor
- Climate Correction Factor
- Clean-up and/or other costs

It also calculates the **Safety Consequences Factors** of a leak with regard to safety, which are governed by the following parameters:

- Leak Rate
- Ignition Factor
- Fluid Hazard Factor
- Population Density Factor
- Pipe Section Length

6.3. Instrument Tuning

This model works as a part of PLMS. It is inhibited during Steady State and Cold Start State. This model detects the malfunctioning of the instruments on the basis of evaluation of the data received through SCADA system. The analysis is done for the pipeline instrumentation only.

The model uses the data from the instruments through the SCADA system and the profiles at the current time step. The basic approach is that the calculated values and the instrument configuration data are both used to find the discrepancy between the measured and the calculated values. If the error comes out to be more than the defined limit, the model generates an alarm stating this.

This model allows the user to enter the maximum allowable **Least Count** or **Accuracy** as percentage of the instrument's range. It checks each pipeline instrument for a violation of the **Maximum Allowable Error**.

6.4. Batch Tracking

The **Batch-Tracking model** is an optional addition to the PLMS, which executes as part of the PLMS. This software tracks the points moving with the fluid throughout the Pipeline System. It uses the current flow rates to determine the movement of each batch in the pipeline, tracking the batches from the start to the finishing point of the pipeline.

Its main function is to keep the liquid property data up to date for use. The data is automatically acquired from SCADA system via densitometers or by manual entry by the operator. Based upon the input data it automatically adjusts the location of batch for accurate Batch Tracking. The functionality includes providing the data for batch through the SCADA system, including Batch Position, Volume, API Gravity and other relevant information. The operator has got the privilege to tell the forthcoming batches to the application. User can give any number of the batches that will be introduced in the future.

It uses the configuration data, Initial Batch Fill, Schedule of Batches at each Supply, and measured flows and model calculated flows to produce a current state representation of the batch in each of the pipelines.

The batch tracking uses the following techniques for the better accuracy:

- Volume Tracking,
- Mass Tracking, and
- Interface Tracking.

This model does the following:

- Helps the user to specify the Initial Line Fill to start the Batch-Tracking Model.
- Calculates the Batch Position within the pipeline sections.
- Tracking of Batches within the Pipeline Sections.
- Expected Time of Arrival of Batch.
- Batch Queuing at Delivery.

6.4.1. Estimated Time of Arrival

ETA or the Estimated Time of Arrival is the expected time in which any batch will reach a particular node. ETA for a batch is calculated for each node from which the batch is expected to pass. Once the batches interface position in known, it is traced through the pipeline and all the nodes that are intersected are updated in the database. The user has given the privilege to know the ETA time of any batch at any node.

6.5. Over/ Under Pressure Protection

This model has an ability to check the **Over Pressure** and **Under Pressure** situations in the pipeline network by comparing Pressure Profiles generated by the Transient Model against the Pressure Limits specified in the configuration. This model works for each pipe leg/ section. In case there is need to generate an alarm because of the Pressure Protection for each pipe leg/ section.

This model allows the user to:

- Provide the Over Pressure and Under Pressure Limits for each pipe segment/ leg.
- Checks each model point for a violation of Over Operating Pressure and Under Operating Pressure.
- Checks each model point for a violation of Over Allowable Pressure and Under Allowable Pressure.
- Generates Alarm if such condition is violated.

7. Instrumentation Required

A minimum instrumentation is required by the **Real Time Model** (RTM) to carry out its calculations.

7.1. Type of Instrumentation

The instrumentation required at various locations are given below:

7.1.1. Boundary

It is important to define boundaries for solving the pipeline equations. At a boundary,either P or V can be provided as a boundary condition for solving the transient and steady state(i.e., equation of motion and equation of continuity). Out of the two, the one which is unused in these calculations is used for finding descripencies for leak detection purpose.

7.1.2. Supply Node

At Supply, we necessarily need Pressure, Flow, Temerature & Density . Out of these, P,V,T are normally measured readings. Density is also required at supply node because a starting density value is required to solve the hydraulic equations. In case a pipeline has many batches, then we must know which batches are at intermediate locations in the piepline (and therefore also the density for each of these batches).

Temperature is always used for solving the energy equation which provides temperatures along the whole of pipeline.

7.1.3. Delivery Node

Only Pressure & Flow are required at the delivery. One of the reading will be used for the calculation and other for leak detection purposes.

7.1.4. Pump Station

Pressure at both the ends of the pump station and flow meter at any on of the end. Turbine meter will also be required if pump is using the oil from the pipeline for its fuelling.

7.1.5. Block Valve

If pipe shutin is to be handled then we need atleast one Pressure reading within the shutin area. That Pressure reading can come from either the Pressure measurement at exit of the valve at upstream end of the pipe leg, or from the entry of the valve at the downstream end.

7.2. Instrument Specifications

7.2.1. Pressure Instruments

Accuracy	0.1 %
Repeatability	0.1 %

7.2.2. Flow Instruments

Accuracy	0.15 %
Repeatability	0.1 %

7.2.3. Temperature Instruments

Accuracy	0.15 %
Repeatability	0.1 %

Surface-mounted RTD type temperature transmitters shall be used for ground temperature measurement.

7.2.4. Density Instruments

Accuracy	0.5 %
Repeatability	0.5 %