Symbols and Numbers
Mathematical Software GbR
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Courses of Instruction: Controlling and Monitoring of Pipelines

Pipeline facilities comprise a relatively small amount of different elements like pipes, valves or pumps, but because of the enormous extension of some hundred kilometers fluid behavior in pipelines is beyond our horizon of experience. In order to operate this equipment safely, to understand messages of the control system and to react properly in critical situations, a training is needed and a broad background knowledge is required.

Symbols and Numbers has arranged courses of instruction, which are addressed to the operating staff of pipeline facilities, and in a more detailed form to the supervisory staff.
They may be also interesting to suppliers of process control systems, who are not too familiar with hydraulics and monitoring of pipelines and purchase additional equipment from third party contractors.

These instruction courses are based on a more than 5 years experience in development, configuration, test and training on control systems of pipelines.

All treated physical phenomena will be demonstrated and visualized with a pipeline process simulator. Appropriate reactions in critical situations can be trained at an exemplary pipeline.

The instruction courses are mainly designed for in-house training which enables the concerns of a specific pipeline to be considered intensively.

Instruction courses are offered about the following topics:

(1)	Hydraulic Profile	1 day
(2)	Physical Basics of Pipe Flows (including hydraulic profile)	2 days
(3)	Elementary Control Operations	1 day
(4)	Safety Facilities and Mastery of Critical Situations	1 day
(5)	Leak Detection	2 days
(6)	Fatigue of Materials and Prognosis of Life Time	1 day
(7)	Optimal Driving Strategies	1 day

The second course includes the first one. All the other courses are independent and do not build on others. For in-house training a specific program can be arranged.
The times given are recommended minimum times and are intended for seminar attendees who already have basic skills in pipeline operations. For others about twice the time is recommended to get familiar with the subject.

(1) *Hydraulic Profile*

The hydraulic profile shows the course of pressure resp. pressure head as well as flow, temperature and other physical data along the complete pipeline.

It is continuously updated and displays how the hydraulic state is developing. For example it can be observed how a pressure wave is propagating through the pipeline and it can be estimated just by viewing at which time and how powerful it will reach certain critical points.

The hydraulic profile constitutes the central basis for manipulations by the operator. The hydraulic profile allows him to interpret the state of the pipeline quickly and safe and to derive appropriate actions and reactions.

The hydraulic profile does not only show measured data, but presents information provided by a simultaneously running online simulation which calculates the hydraulic state between the measuring stations by applying physical laws.

The training course demonstrates how the displayed curves are generated, what they tell us and what we learn from them.

- *Physical Properties of Crude Oils*
  (compressibility and viscosity)
- *Relationship between pressure and pressure head*
  (Influence of gravity, pressure curve at zero flow)
- *Physical properties of the pipeline*
  (strength, MAOP line and cross-sectional area)
- *Pipe friction impact on pressure curve*
  (flow resistance, energy loss, steady state pressure profile)
- *Temperature profile*
  (heat transport, friction heat, environmental heat loss)
- *Density and Flow*
  (conversion of standard values and operational values , determination of flow line)
- *Viscosity calculation*
  (dependency on temperature)
- *Transient flow*
  (emergence, propagation and reflection of pressure waves)
- *Slackline flow*
  (liquid flashing into gas phase, cavitation at low pressure)

(2) *Physical Basics of Pipe Flows*

Without the knowledge of the physical basics an interpretation of the hydraulic profile remains incomplete. Particularly the supervising staff should be able to analyze abnormal situations. For this the knowledge about the mathematical models of pipe and fluid behaviour is needed, on which the calculation of the hydraulic profile is based on.

The topics resemble those of course (1) but are treated much more in detail and in the physical context.

- *Introduction: Displaying the hydraulic profile*
  - physical state along the pipeline
  - purpose and benefit
  - interaction between online simulation and hydraulic profile
- *Physical Properties of Crude Oils and Oil Products*
  - state description by pressure and temperature
  - compressibility under pressure
  - volume expansion by temperature increase
  - standard density and operational density
  - viscosity and its dependency on temperature
- *Physical properties of the pipe*
  - Strength and MAOP (maximum allowed operational pressure)
  - Change of cross-sectional area by pressure and temperature
- *Pressure and Pressure Head*
  - pressure profile at zero flow
  - gravity and air pressure
  - influence of elevation profile, density and temperature
  - MAOH line (maximum allowed operational pressure head)
  - calibration of pressure meters
- *Pipe friction*
  - Friction loss and friction number of pipe
  - smooth and rough pipes
  - internal friction and pipe roughness
  - pipe bends and cross section changes
  - pressure and energy loss
- *Physical Laws for steady state pipe flows*
  - pressure and flow profile
- *Units for Quantity and Flow*
  - quantity units: operational volume, standard volume, mass
  - flow units: operational flow, standard flow, mass flow
  - unit conversion

- *Flow Curve*
  - determination of flow curve
  - calibration of flow line
  - adaptation of pipe friction resp. pipe roughness
- *Batch and Pig Tracking*
  - velocity of batches and pigs
  - estimation of arrival times
- *Pressure Wave Propagation*
  - emergence of pressure waves
  - physical laws for transient pipe flows
  - propagation of pressure waves
  - reflections
  - pressure profile at transient flow
- *Pumps*
  - pump and system characteristics: delivery height and flow
  - energy consumption and efficiency
  - start and stop behaviour
- *Valves*
  - valve characteristics: pressure loss and flow
  - flow resistance
  - energy loss
- *Temperature Model*
  - temperature transport by liquid movement
  - frictional heat and heat of compression
  - environmental temperature exchange
  - temperature measurement and model calculation
  - adaption of heat exchange parameters
- *Slackline*
  - liquid flashing into gas phase at low pressure
  - cavitation: danger for pipeline and pumps
  - slackline flow

(3) *Elementary Control Operations*

As simple as some control operations may appear, like starting a pump, the associated processes turn out to be rather complex. Knowing the effects of a control operation is decisive for responsible and precise acting.

Accordingly, the consequences of every-day operations are treated exactly and detailed. Thereby an understanding will be developed to react quickly and adequate in critical situations without the single operations adding up in a bad result.

The following elementary operations are covered:

- *Turning On and Off a Pump*
  - effects of suction and discharge pressure
  - differences between booster and main pumps
  - serial and parallel operation
  - line pump stations
  - induced pressure waves
  - suction side stream stall
  - start and stop sequences
- *Opening and Closing Line Block Valves*
  - flow resistance of a partially open valve
  - pressure waves caused by opening and closing
  - upstream sided stall when closing
  - reflexions at a closed valve
- *Adjusting Control Valves*
  - setting a set point (usually pressure or flow)
  - impact of restrictions on controller (e.g. minimum or maximum pressure)
  - characteristics of control valves
  - controlling the valve position
  - speed of controlling
  - control oscillations
- *Shut-down and Start-up of the Pipeline*
  - restrictions for the idle state
  - preconditions for starting pumps
  - optimal times for operating pumps and valves
  - avoiding stress when closing and opening valves
- *Flow Path Switching*
  - switching in the storage tank farm
  - switching to branches
  - identifying the optimal switching times
  - blending fluid from two tanks

(4) *Safety Facilities and Mastery of Critical Situations*

The prevention of injuries to persons, substantial material damages and environmental damages precede all other considerations how to operate a pipeline. Therefore numerous safety features should be engineered and installed to avoid these kinds of damages.

Under normal operating conditions interventions of safety facilities should be avoided, because they heavily strain the equipment, cause time delays and costs, and additionally generate investigations.

A detailed knowledge about the functioning of the safety facilities and about safe driving strategies, which do not reach border situations, should belong to the repertoire of every well-skilled operator.

During this instruction course critical situations will be analyzed and procedures are worked out to master them. It goes without saying that conditions of a specific pipeline can be discussed.

The following examples of safety facilities will be treated:

- *Pressure Limitations*
  by pump shut-downs, relief tanks equipped with safety valves or rapture disks
- *Minimum Pressure resp. Minimum Flow Monitoring*
  for safe starting and stopping pumps supported by suction pressure control, blocking of further pump starts and shut-downs if necessary
- *Pressure Gradient Monitoring*
  in case of pump break downs in line pumping stations
- *Suction Pressure Monitoring and Closing Sequences*
  for a safe closing of line valves
- *Mutual Blockings (Interlocks)*
  to avoid undesirable states
- *Emergency Shut Down (ESD)*
  for extremely critical situations, e.g. pipeline devices can not be observed or controlled in the control center

(5) *Leak Detection*

In Germany and in some neighboring countries oil pipelines are only allowed to be operated if sufficient provisions have been made to detect leaks and to limit the consequences of leakages. There exists a bunch of different methods, which as a whole set up a so-called leak detecting system (LDS).

Each method has its advantages and disadvantages and is best suited for certain conditions. Only the combination of well-selected methods guarantees safety. Some methods only work with steady-state conditions, some are able to detect creeping leaks at zero flow conditions and only few also work with transient conditions. For each pipeline and its special conditions and depending on the requirements set by the authorities, a good mix of methods needs to be designed.

It is not the aim of the instruction course to end up with an optimal combination for a certain pipeline. This would be a task of its own. It is the aim to learn how the different methods work, under which conditions they work, which alarm thresholds can be reached and what the operator needs to know.

Due to the fact that each leak detection method requires certain conditions, a method may - once in a while - erroneously raise false alarms. In such a case it is advantageous to know how to make sure that a leak has been occurred.

The following methods are treated in the course:

To detect leaks under all operating conditions (steady-state, transient, zero-flow):

- *Line Balance Method*
  - mass balance equation
  - flow metering requirements
  - line pack correction (according to pressure and temperature)
  - recognition of the current operating condition
  - achievable accuracy and reaction time depending on operating conditions
  - check for proper operation

To detect leaks under steady state conditions:

- *Pressure Drop Method*
  - recognition and display of pressure drops
  - interpretation by operators
- *Wave Propagation Method*
  - leak location derived from run time differences of pressure waves
  - pattern recognition of pressure waves
  - requirements to time stamp accuracy
  - suppressing artifacts like reflexions
  - masking of explainable pressure waves (e.g. by control operations)
  - achievable accuracy and reaction time
  - check for proper operation

- *Gradient Intersection Method*
  - pressure gradient measurement
  - pressure gradient calculation based on flow measurement
  - leak detection by comparing calculated and measured gradient
  - leak location by intersecting measured gradients
  - requirements to apply the method
  - achievable accuracy and reaction time
  - check for proper operation

To detect creeping leaks under zero flow condition:

- *Pressure-Temperature Method*
  - pressure-temperature relationship in a closed container
  - sectioning the pipeline
  - procedure to be performed
  - requirements for temperature measurements
  - modeling temperature changes in a pipe
  - waiting time and achievable accuracy
- *Pressure-Difference Method*
  - sectioning the pipeline
  - starting conditions and procedure to be performed
  - requirements for best results
  - waiting time and achievable accuracy

(6) *Fatigue of Materials and Prognosis of Life Time*

Continuous variation of the inside pressure causes stress and fatigue of the pipeline material. This can be a possible cause for a leak. In Germany the supervisory authorities request that pressure variations must be recorded in such a way that the remaining life time of the pipeline can be determined from these data.

If the factors are known which have an impact on the material fatigue, the remaining life time resp. the inspection intervals can be prolonged by an appropriate and conservative driving strategy.

The course of instruction deals with these topics:

- material stress and stress limits
- dynamic fatigue tests and endurance curve
- fatigue wear by a load spectrum
- fatigue endurance limit and fatigue strength
- norms and technical regulations
- weighting and counting of load cycles
- selection of representative measuring points
- reduction of pressure data
- weighting load cycles by span method (TUEV Sued) and class passing method (TUEV Rheinland)
- estimation of remaining fatigue life time

(7) *Optimal Driving Strategies*

A driving strategy which needs a minimum of energy and produces a minimum of stress does not necessarily lead to an optimum in an economic sense.

In fact there are varying cost factors like day and night-time produced electricity, requests of customers for rapid delivering, restrictions because of low temperatures and many more factors, which need to be considered. In this respect every pipeline has its own requirements.

Therefore this course is not focused on knowledge transfer rather than on working out driving strategies to reach an optimum in an engineering as well as an economic sense. The criteria of an optimum, the requirements and the factors which influence the system will be gathered and intensively discussed.

The effectiveness of the discussed solutions will be better understood by accompanying simulation studies.