Paper 3.2

Ineos' Experience in Pipeline Leak Detection Using Flow and Pressure Measurements

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1   INTRODUCTION

Pipeline leak detection was not a welcome subject for most pipeline operating companies because of its poor performance track record and high support cost. With the availability of modern instrumentation system and improved leak detection technology, significant benefits of leak detection systems have now been recognised by the pipeline industry ([1], [2], [3], [4], [5]).

Over the past six years, Ineos (previously BP Chemical) have gained a lot of experience in a statistical leak detection system ([6], [7]). This system works with conventional flow and pressure measurements used for pipeline operation and control. Without any additional hardware, such measurements are used for pipeline integrity monitoring. This paper addresses the application of conventional instruments to the following five pipelines:

- A 12", 152.8 KM long high pressure ethylene pipeline
- A 10", 38.1 KM long ethane pipeline
- A 6", 85 KM long liquid propylene network
- A 12", 93 KM long multi-product pipeline and
- A 20", 93 KM long crude oil pipeline.

The leak detection applications to the above pipelines have been carried out between 2000 and 2006. The flow meters used include orifice, turbine, ultrasonic and coriolis types. In the following section, the details of each application are presented, followed by the summary and conclusions in section 3.

2   CASE STUDIES

2.1   Teesside to Saltend Ethylene Pipeline (TSEP)

The Teesside to Saltend Ethylene Pipeline was built between 1999 and 2000 in the North East of England. It has a total length of 152.8 KM and a diameter of 12" with varying wall thicknesses. As shown in Figure 1, two redundant flow meters are installed at the inlet of the pipeline (Newton Bewley) and they are both of the coriolis type. Originally there were two outlets at Saltend: VAM and ETAC. Coriolis flow meters are used to measure gaseous ethylene for both of them after the pressure reduction station. In 2004 a new outlet was installed at EVOH and another coriolis meter was used to measure ethylene under supercritical conditions.

In addition to the above flow measurements, pressure instruments are available at the inlet of the pipeline and both upstream and downstream of each block valve. Although a pressure measurement is available at the outlet, it is not used in the leak detection system as the pressure readings are downstream of the pressure reduction station and are not representative of the pipeline pressure.
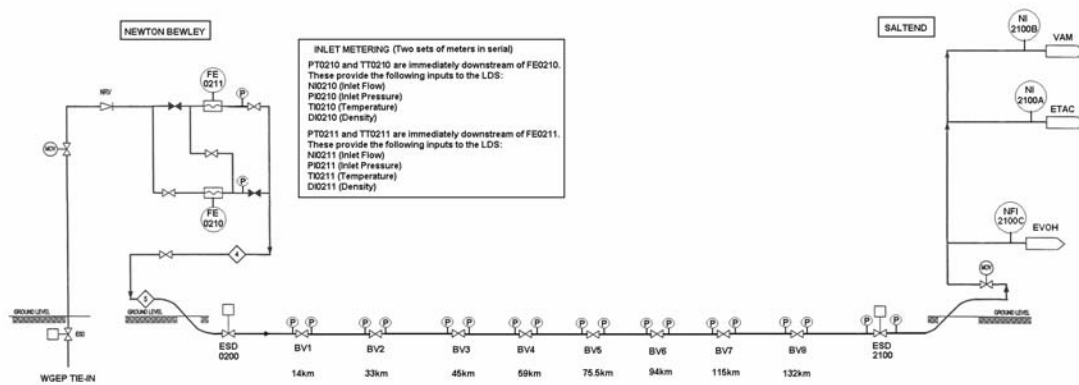
Fig. 1 - The Schematic Diagram of TSEP

As shown in Figure 2, a SCADA system is responsible for making the above field data available to the LDS PC. All pipeline instrumentation is connected to Remote Terminal Units (RTUs). Each RTU transmits its field data to the master SCADA server for transmission to the LDS. Physically the link between the SCADA and the LDS PC is set up as a network connection. Network redundancy is provided by means of a second network interface card in the LDS PC. The network uses TCPIP. Communication is by means of text files transferred between the SCADA server and the LDS PC.

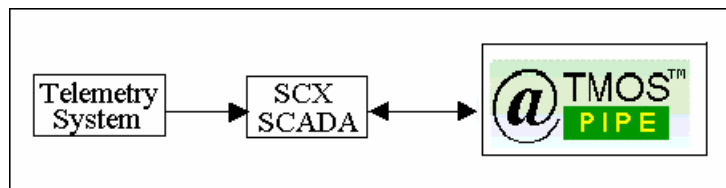The SCADA server and LDS are both configured to read and write their data every ten seconds.

Fig. 2 - Interface between the SCADA and LDS Systems for TSEP

The pipeline travels along a varying terrain with a maximum elevation difference of 132 metres. Figure 3 shows the elevation profile of the pipeline.
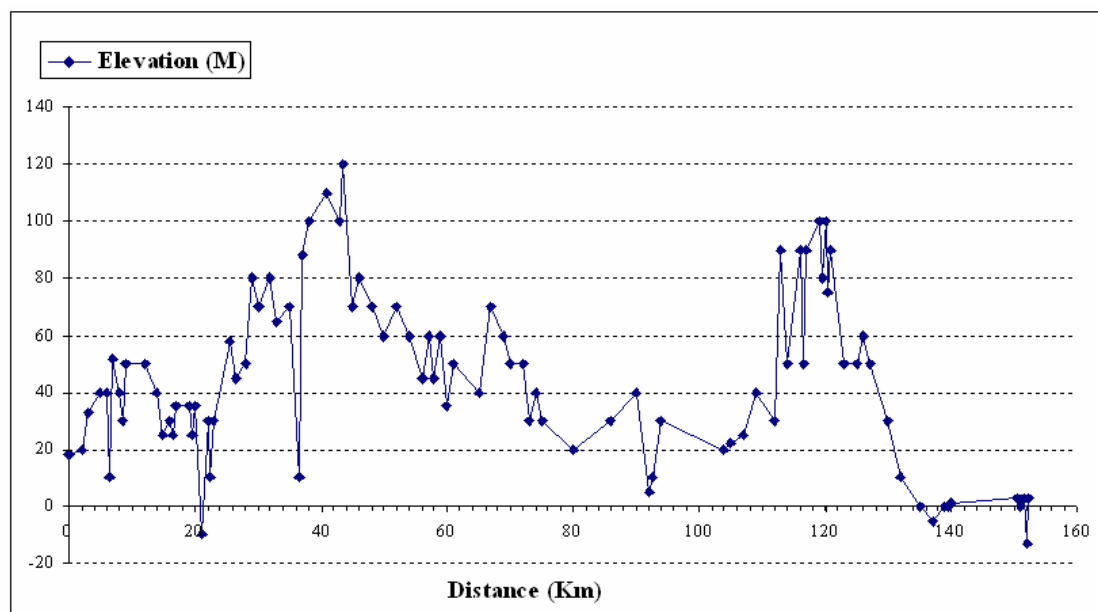

Fig. 3 - Elevation Profile of TSEP

The leak detection system was configured in 1999 based on the pipeline design data. After the pipeline and the instrumentation system were commissioned in October 2000, the LDS was tuned and commissioned using actual operational data. Table 1 lists the performance of the LDS under three operating scenarios: steady-state, small transient and large transient (NetOpstatus is equal to 0, 1 and 2 respectively).

Table 1 Leak Detection Time in Minutes for Steady-State, Small Transient and Large Transient Operations for the Ethylene Pipeline

	Steady State			Small Transient			Large Transient		
Lambda	Leak Size (t/h)	Leak Size (%)	Detection Time_0	Leak Size (t/h)	Leak Size (%)	Detection Time_1	Leak Size (t/h)	Leak Size (%)	Detection Time_2
1	0.75	3	825	1.5	6	464	4	16	242
2	1.5	6	172	4	16	60	8	32	60
3	2	8	145	8	32	12	12	48	27
4	2.5	10	93	10	40	10	18	72	17
5	3	12	43	12	48	6	25	100	9
6	5	20	20	14	56	4	30	120	5
7	15	60	2	18	72	3	45	180	2

The pipeline is designed for transportation of high density ethylene between Teesside and Saltend. The flow-rate in the pipeline varies between 10 and 25 ton/h with a pressure drop of less than two bars over the entire pipeline. Such a low pressure drop over the 152.8 KM long pipeline makes it more challenging for any LDS to work effectively. A large change in the flow-rate corresponds to very small pressure variations. As an example, Figure 4 shows the trends of flow, pressure and the corresponding statistical leak detection variables for a 24 hour period. When the inlet flow increases from 14.2 to 19.8 ton/h (39%) around 3 AM, the inlet pressure increases from 68.5 to 69 barg which is only 0.7%. The LDS has to be tuned to be very sensitive to pressure/inventory variations for this pipeline. To avoid false alarms under such extreme low capacity operating conditions, the detection time for the small leaks is much longer than most other pipelines. As shown in Figure 4, the LDS increases the NetOpstatus from 0 (steady-state operation) to 2 (large transient operation) when the large change in the inlet flow occurs. The statistical variables Lambda1 and Lambda2 remained around -7 (less than 1% probability of having a leak) throughout the 24 hour period including the transient.
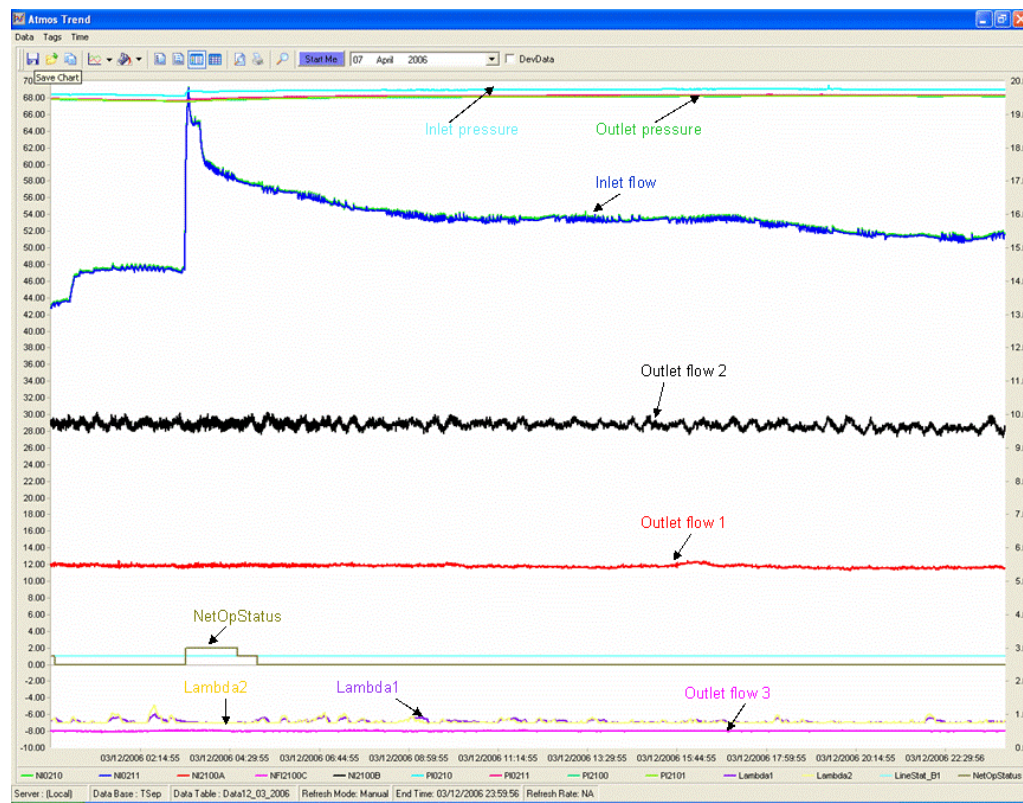

Fig. 4 – Trends of Pressure, LineStat_B1, NetOpStatus, Lambda1 and Lambda2 as Shown on the Left Axis and Flow as Shown on the Right Axis, for the 12th March 2006.

Although no real leak occurred on the pipeline to test the above performance figures in anger, the responses of Lambda's under changing operating conditions including telecommunication and interface failures have proven the effectiveness of the statistical leak detection system.

In the fourth quarter of 2004, the SCADA system was upgraded together with the replacement of RTUs (Remote Terminal Units). To maximise the availability of the LDS during the upgrade and switch over, an additional LDS PC was supplied with the interface with the new SCADA system installed and tested. The project team planned the upgrade carefully so that the inlet and outlet flow and pressure data remained available to the existing LDS until the final switchover to the new SCADA system. As more pressure data from the remote RTUs were switched over to the new SCADA system, the existing LDS was desensitised gradually. However it continued to detect leaks until the flow meter readings were switched over to the new SCADA system, then the new LDS took over the responsibility of integrity monitoring.

The SCADA upgrade was combined with the addition of the new outlet at EVOH. As shown in Figure 5 the total downtime of the LDS was less than 6 hours during which none of the LDS PC had sufficient data to run. No leak alarm was generated by either LDS PC during the SCADA upgrade and switchover.
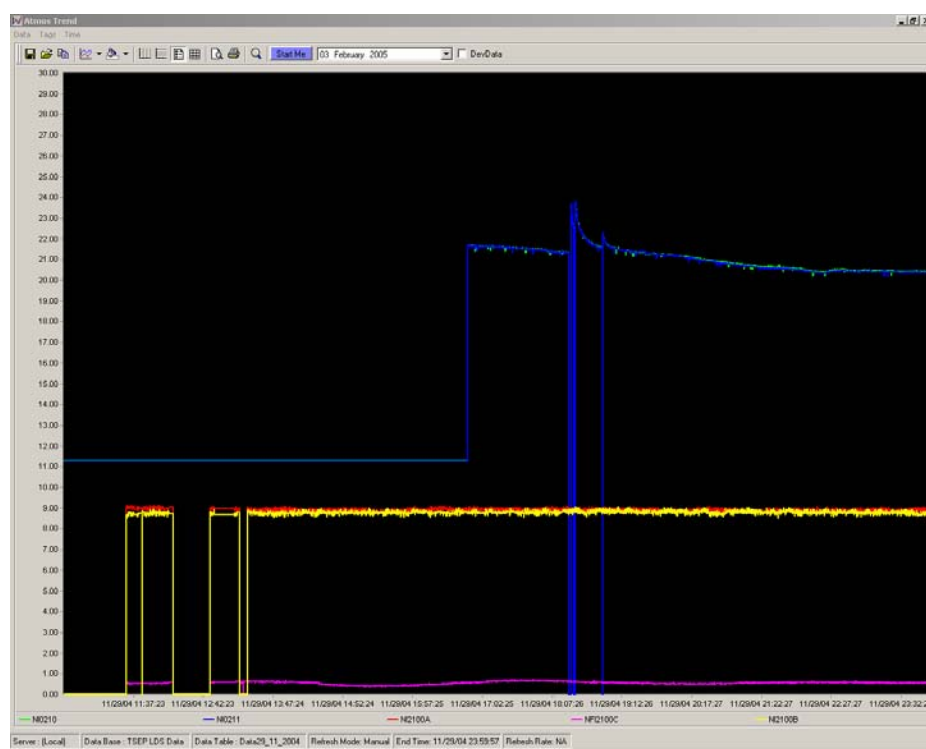

Fig.5 – Both Inlet and Outlet Flow Data Switched Over to the New SCADA System on the 29th Nov 2004 when the New LDS PC Took Over Pipeline Integrity Monitoring

Over the past six years since the LDS was installed, the flow and pressure meters have remained reliable and accurate. When the pipeline was pigged in the autumn of 2005, a temporary pressure reduction station was installed at Newton Bewley in order to increase the fluid velocity by transporting the ethylene in a gaseous phase. The field instruments worked under this unusual operating condition, which made it possible for the LDS to continue the monitoring of the pipeline integrity throughout the pigging period. To assist the tracking of pigs, an additional pig tracking module was installed on the LDS PC in August 2005.

While the field instruments worked well after the initial commissioning, there had been reliability issues regarding the interface between the SCADA and LDS systems. This was largely caused by the simultaneous access of both systems to the same text file. Ineos plans to upgrade the interface to OPC in order to eliminate this problem.

2.2 Mossmorran to Grangemouth Ethane Pipeline (MGEP)

The Mossmorran to Grangemouth Ethane Pipeline is located in Scotland. It had been in operation for many years prior to the installation of ATMOS Pipe leak detection system in 2001. The cross country pipeline goes under the Firth of Forth and is 38.1 KM long with a diameter of 10". As shown in Figure 6, two duplicate flow meters are installed in series at both the inlet (Mossmorran) and outlet (Grangemouth) of the pipeline. They are all of the orifice type. Flow computers are used to provide mass flow readings based on the flow, pressure, temperature and density measurements at both the inlet and outlet.
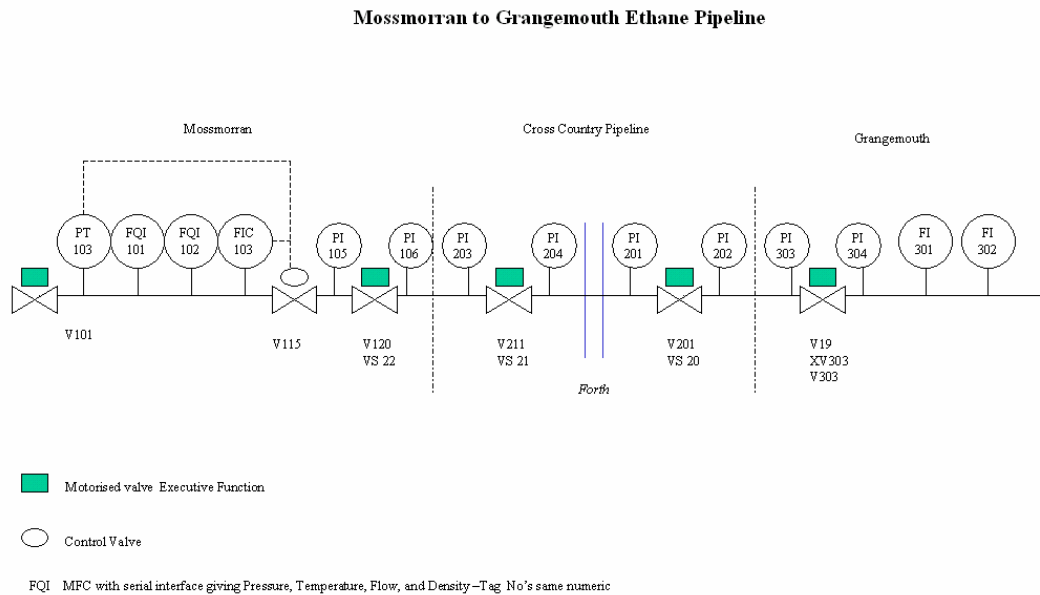

Fig.6 – Schematic Diagram of MGEP

Similar to TSEP, pressure instruments are available both upstream and downstream of each block valve. The leak detection system is running in the same PC as TSEP and it shares the same SCADA interface.

The throughput in the pipeline has been reduced over the years from 15 to 4 ton/h. Such a low throughput makes it difficult for the LDS to perform optimally for several reasons:

- Continuous transient operating conditions with large flow fluctuations.
- Small pressure drop over the pipeline determines that the LDS has to be very sensitive to pressure/inventory changes, the continuous packing and unpacking of the pipeline under normal operating conditions increases the leak detection time.
- Flow meter accuracy is compromised due to reduced flow-rates, though re-sized orifice plates have helped.

No instrument upgrade or alteration was carried out prior to the installation of LDS. Instead actual operational data was used to tune the leak detection system so that it would detect the leaks within the shortest time possible without false alarms. Table 2 lists the performance of the LDS under three operating scenarios: steady-state, small transient and large transient (NetOpstatus is equal to 0, 1 and 2 respectively).
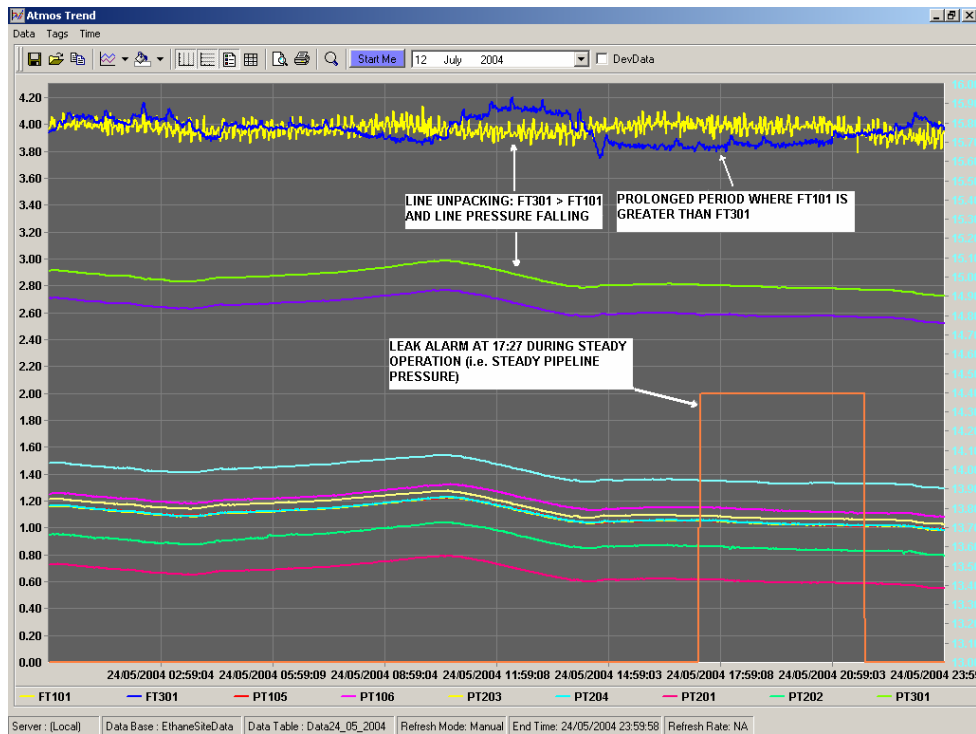
Fig. 7 – Trends of Flow, Pressure and Leak Alarm over a 24 hour Period on 24th May 2004

Table 2 Leak Detection Time in Minutes for Steady-State, Small Transient and Large Transient Operations for the Ethane Pipeline

	Steady State			Small Transient			Large Transient		
Lambda	Leak Size (t/h)	Leak Size (%)	Detection Time_0	Leak Size (t/h)	Leak Size (%)	Detection Time_1	Leak Size (t/h)	Leak Size (%)	Detection Time_2
1	0.15	1	69	0.25	2	74	0.4	2.7	97
2	0.3	2	43	0.4	3	48	0.5	3.3	77
3	0.5	3	31	0.6	4	16	0.6	4	86
4	1	7	8	1	7	15	1.2	8	54
5	2	13	3	2	13	6	3	20	26
6	3	20	2	3	20	4	6	40	10
7	5	33	2	5	33	4	10	67	10

The reliability of the overall instrumentation system on the ethane line is lower than on TSEP. There were a few instances of pressure and density meter faults over the past five years. Figure 7 gives an example of inconsistent readings in the flow and pressure data that caused a leak alarm on the 24th May 2004. As shown in Figure 7, while the inlet flow (FT101) reads higher than outlet flow (FT301) between 14:59 and 20:59 hours, the pipeline pressure is decreasing.   Such changes in the flow and pressure are typical of a pipeline leak, consequently a leak alarm is generated. Investigation of the instrumentation system indicated that the reduced density readings at the outlet were contributing to the lower mass flow readings. Figure 8 shows outlet flow and density trends on the 24th May 2004. The density continues to decrease when the pipeline pressure increases after 14:59 hours.

Since the changes in flow and pressure on the 24 May 2004 as shown in Figure 7 are typical of a leak, it serves as an indirect test of the LDS.

When the SCADA system was upgraded in 2004, the same switchover procedure as TSEP was applied to minimize the downtime of the LDS. Figure 9 shows that the inlet flow meter readings start updating using the new SCADA system on the 13th December 2004 and the new LDS PC has been monitoring the pipeline integrity since then.
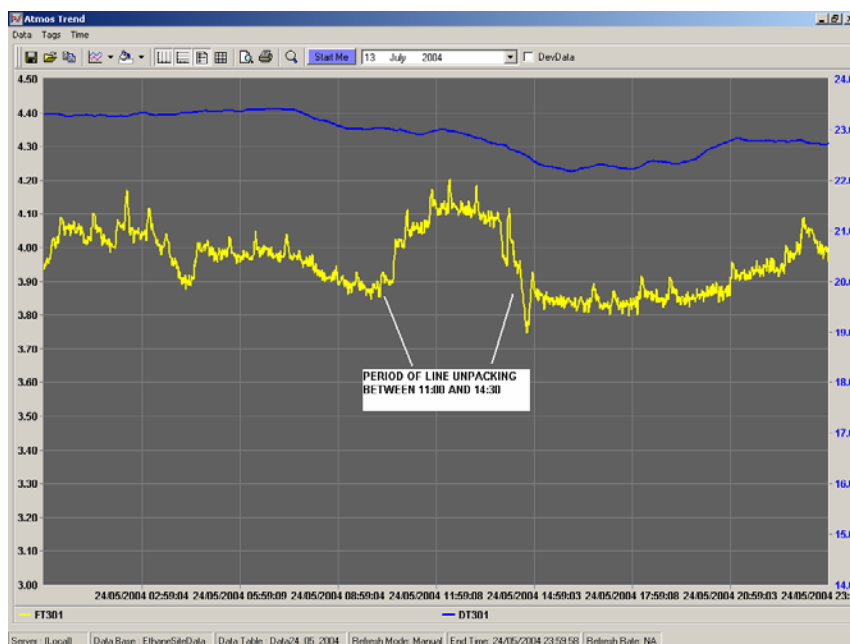
Fig. 8 – Trends of Outlet Flow (Left Axis) and Density (Right Axis)

The flow trends shown in Figure 9 are typical of the ethane pipeline operations:

- The inlet and outlet flow are rarely equal to each other
- The outlet flow changes continuously
- The pipeline is packing or unpacking most of the time.

Such transient operations do not cause false alarms in the leak detection system as long as the instrumentation system works reliably.
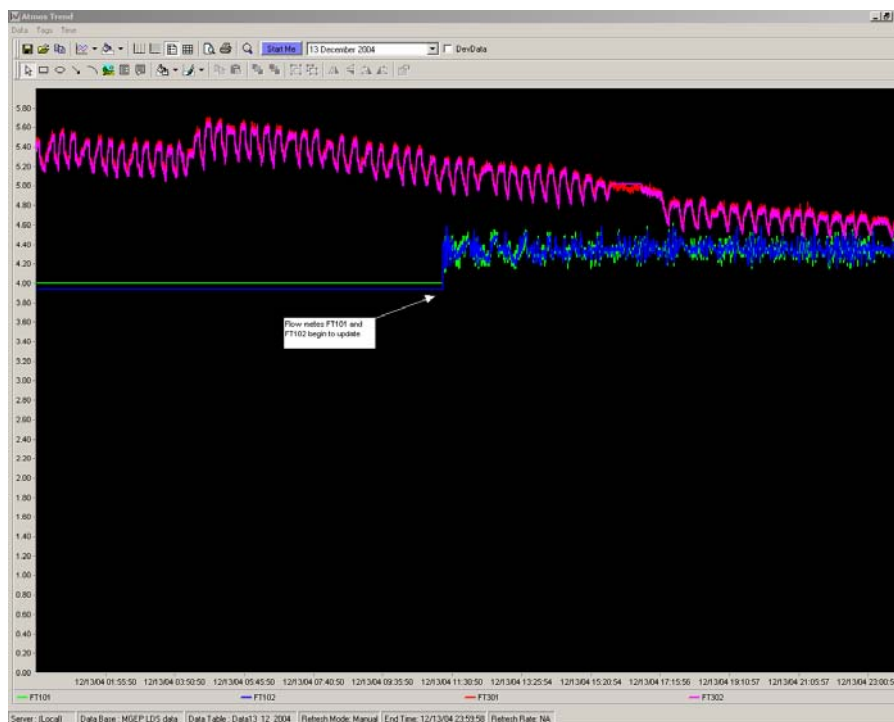

Fig. 9 – Both Inlet and Outlet Flow Data Switched Over to the New SCADA System on the 13th Dec 2004 when the New LDS PC Took Over Pipeline Integrity Monitoring

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2.3 Antwerp to Geel Propylene Pipeline

The Antwerp to Geel propylene pipeline is located in Belgium. It is 6" in diameter, 77 KM long. The pipeline runs from the Shell, Dow and BASF facilities in Antwerp to the BP facility in Geel. In addition, there is an 8.2 KM long branch pipeline to the AGT facility, along with a takeoff to the Solvay facility. A schematic representation of the pipeline is given in Figure 10. Note that bi-directional flow is possible at both Shell and AGT facility. To maintain a minimum delivery pressure of 18 barg, a boosting pump station is available at Oil Tanking.
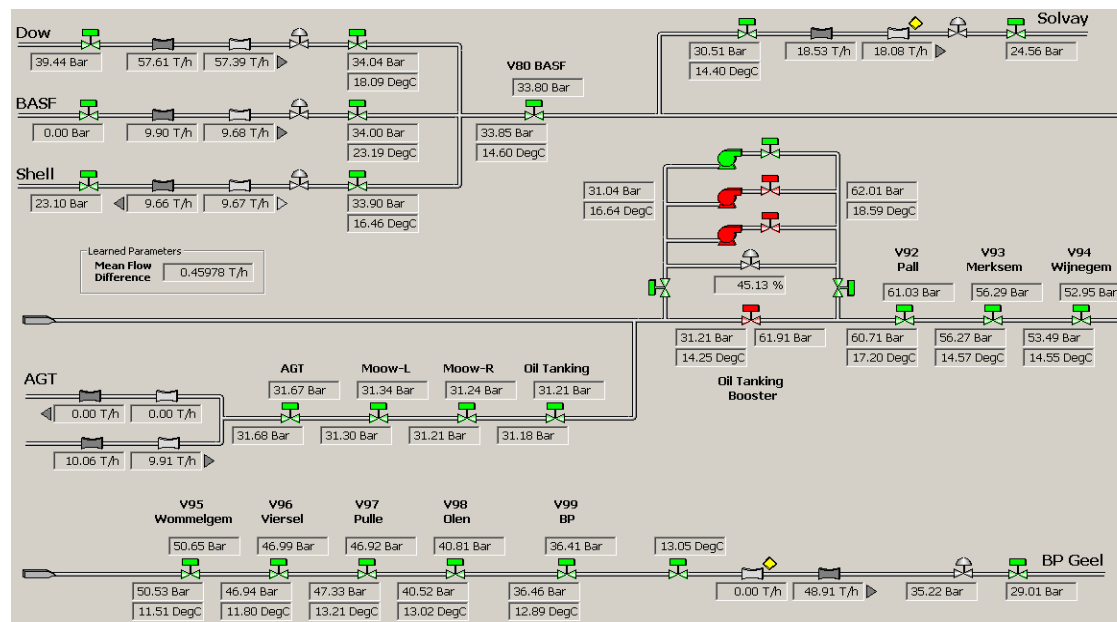
Fig.10 – Schematic Diagram of the Antwerp to Geel Propylene Pipeline

The Pipeline Control System consists of dual redundant Modicon TSX Momentum PLCs which collect flow, pressure and temperature measurements at the inlets and outlets of the Pipeline. Additional pressure readings are also available from either side of most of the valve stations along the length of the main and branch pipelines. The PLCs collect field data approximately every 2 seconds.

All the flow meters are of coriolis type and mass flow readings are used for the leak detection system. As redundant meters are provided at each inlet and outlet, the "pay" meter readings are normally used by the LDS unless a maintenance flag is set (Figure 11). Figure 11 shows that it is possible for operators to put a pay meter in maintenance mode so that the LDS will use the flow readings from the "check" meter.

The LDS PC interfaces with the PLCs by means of OPC over a Local Area Network (LAN). Kepware OPC software installed on the LDS PC provides the OPC interface between the LDS and the PLCs. Figure 12 shows the layout of the instrumentation system.

When a leak is detected, a flag is written in the primary PLC. This flag is then read by the Honeywell DCS at the facility. The DCS presents the alarm to the operators for further actions.

Remote login to the LDS is provided by the RAS service so that maintenance and support are carried out effectively from the UK. This remote access has proven to be very useful when a new takeoff was included in the pipeline network in April 2006. After the configuration changes, the LDS was upgraded to include the new outlet within ten minutes without the need to travel to site.
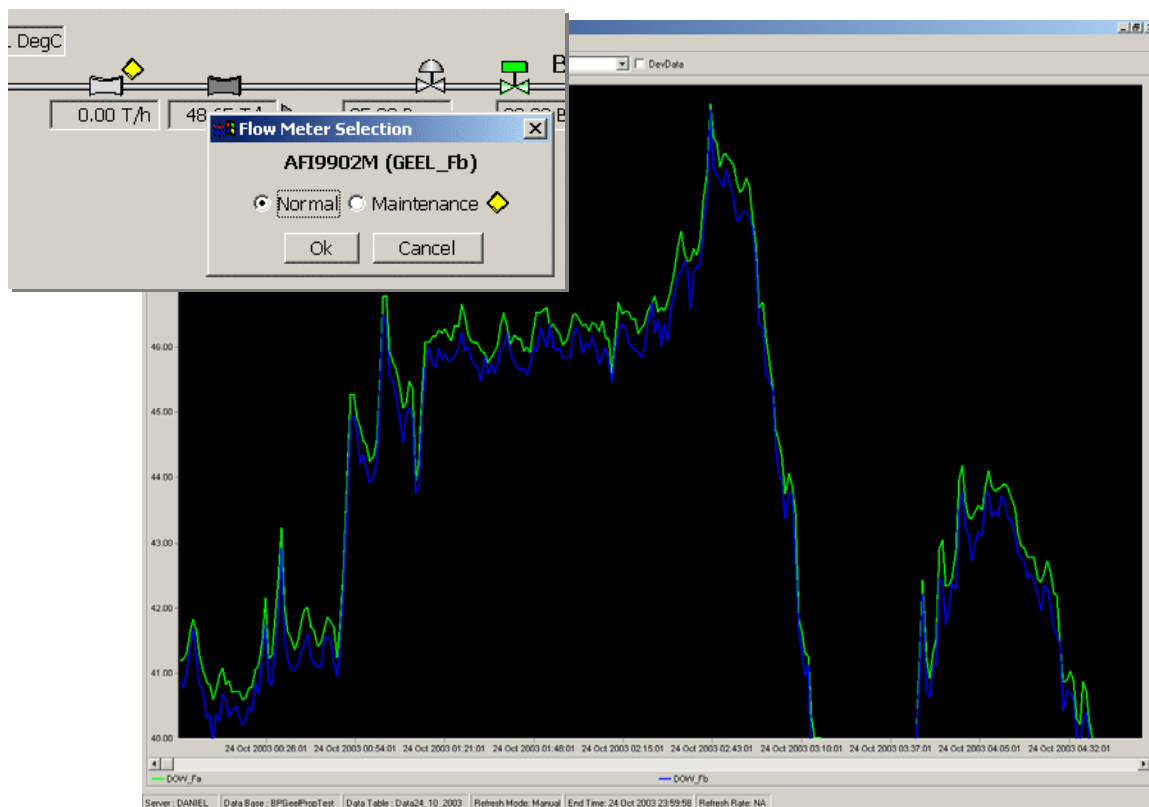
Fig.11 – Flow Readings Given by Pay and Check Meters at Dow and the Availability of Maintenance Flag to the LDS
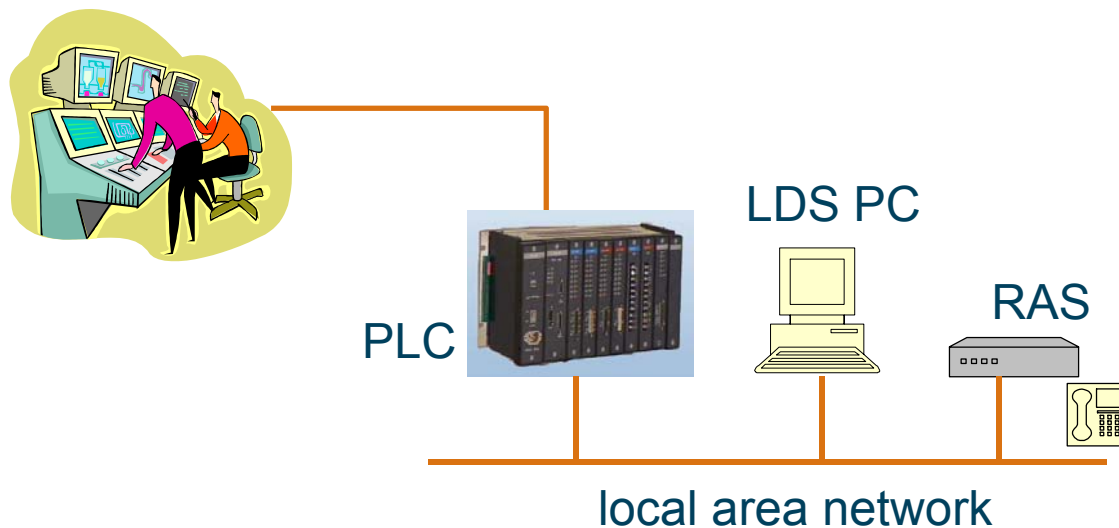

Fig.12 – The Interface between the LDS and the Site Instrumentation System

The implementation of the LDS on this propylene pipeline is one of the most successful projects in terms of project execution and system performance. From project initiation to final acceptance, the project took only three months:

- Purchase order received in August 2003
- LDS PC installed on site for data collection in Sept 2003
- FAT in Oct 2003 followed by immediate site installation

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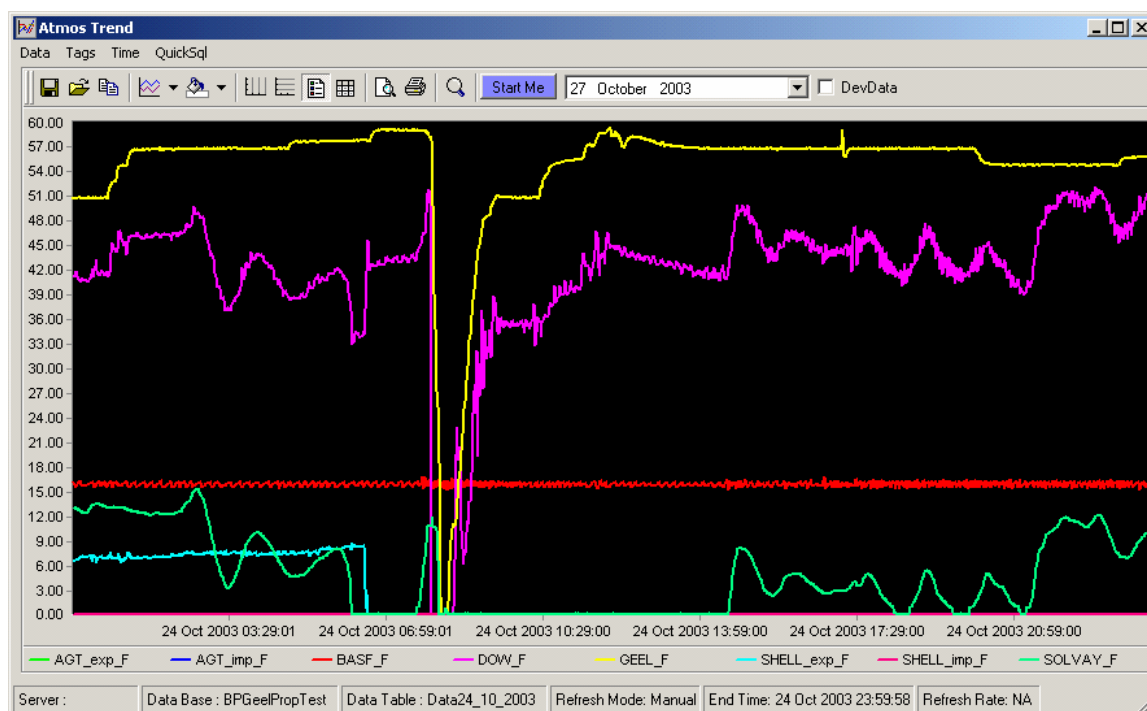- Final acceptance after Site Acceptance Test in Nov 2003.

Fig.13 – An Example of Flow Readings over a 24 hour Period

The complex layout of the pipeline network determines that the operational conditions could vary significantly. Transients are introduced by changes in the supply and delivery locations. Figure 13 gives an example of typical operations of the pipeline. The LDS has been tuned to such operational data prior to the FAT. Table 3 lists the performance of the LDS under three operating scenarios: steady-state, small transient and large transient (NetOpstatus is equal to 0, 1 and 2 respectively). Note that the leak size detectable remains the same for all operating scenarios but the detection time is increased for transient operations.

Table 3 Leak Detection Time in Minutes for Steady-State, Small Transient and Large Transient Operations for the Propylene Pipeline

	Steady State		Small Transient		Large Transient	
Lambda	Leak Size (%)	Detect Time_0	Leak Size (%)	Detect Time_1	Leak Size (%)	Detect Time_2
1	0.75	60	0.75	480	0.75	2400
2	1.5	30	1.5	240	1.5	1200
3	3.75	20	3.75	80	3.75	320
4	7.5	10	7.5	40	7.5	80
5	15	5	15	20	15	40
6	30	4	30	16	30	32
7	37.5	3	37.5	12	37.5	24

A few "leaks" were detected by the LDS in April 2006 when a new client Gamatex was included on the AGT branch line upstream of the Oil Tanking Booster Station. When Gamatex started to take 4 t/h propylene out of the pipeline, the LDS alarmed within 10 minutes with the exact leak size and location estimates. However after the system was upgraded with the corresponding flow and pressure meter at the takeoff point, no further leak alarm has been generated.

Over the last three years, the LDS has been operating reliably. It has detected all the "leaks" when unaccounted propylene is taken out of the pipeline network. On average only one false alarm is generated over a 12 month period. Figure 14 gives an example of potential leak alarms due to scheduled maintenance of pressure transmitters. Since sudden pressure drop is introduced by maintenance and calibration of the pressure transmitters, the LDS may generate a leak alarm unless the maintenance flag is set to inform the LDS of the planned activities.

One practical constraint on the propylene pipeline is that the instruments located at the clients' facility are out of the control of Ineos. Sometimes when a flow meter fault is identified by the LDS, it may take a few days before maintenance work can be carried out to fix the fault.
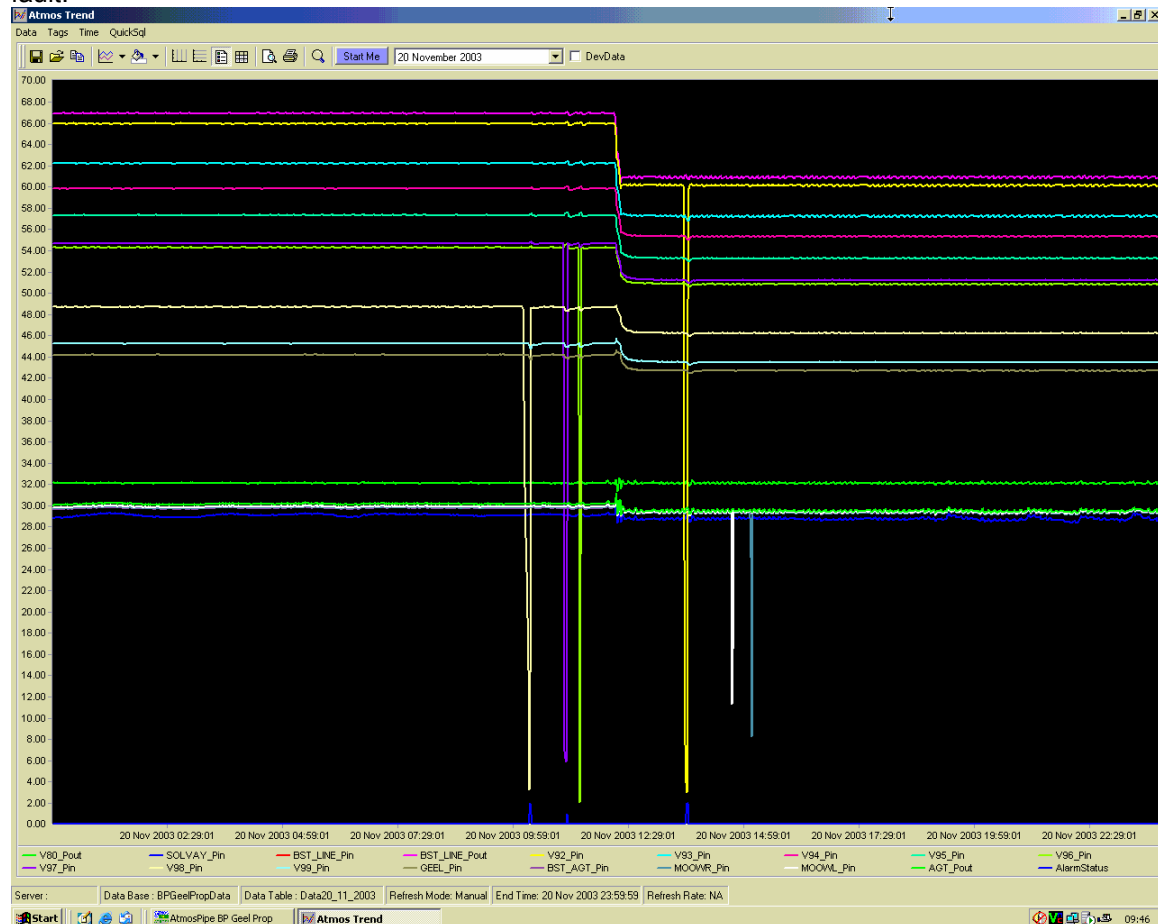

Fig.14 – Sudden Pressure Drop Introduced by Calibration of Pressure Transmitters

2.4   Grangemouth to Finnart Multi-product and Crude Oil Pipelines

There are two 93 KM long pipelines between Grangemouth (Kinneil) and Finnart. The 12" multi-product pipeline carries various petrochemical products including aviation fuel, diesel, kerosene and low sulphur diesel and petrol. The 20" pipeline is bidirectional and carries crude oil. Figure 15 and 16 give the schematic diagram of these two pipelines respectively.
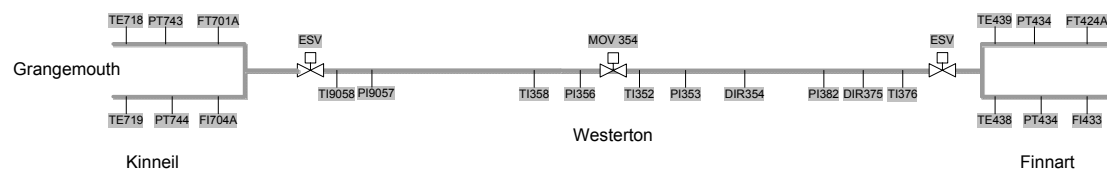

Fig.15 - Schematic Diagram of Grangemouth to Finnart Multi-product Pipeline

As shown in Figure 15, at both the inlet and outlet of the multi-product pipeline, two parallel turbine flow meters are available to measure the total flow, one in service and one as a standby. A bi-directional ball prover is installed at each location. Pressure and temperature measurements are available at the inlet, outlet and one intermediate valve station. For batch tracking, density meters are installed at the outlet and one intermediate valve station.

For the crude oil pipeline, there was no existing flow measurement; tank level measurements at each end have been employed to monitor and define transfers. To provide flow measurement and accommodate bi-directional and pigging requirements it was decided to install clamp on ultrasonic flow meters in suitable locations at each end of the pipeline. Pressure, temperature, density, viscosity and valve status are also available at the inlet and outlet of the pipeline (Figure 16). Viscosity measurement is required to compensate the ultrasonic flow meter for the wide range of viscosity of the various crude oils; density is also derived from the coriolis meter employed in viscosity determination.
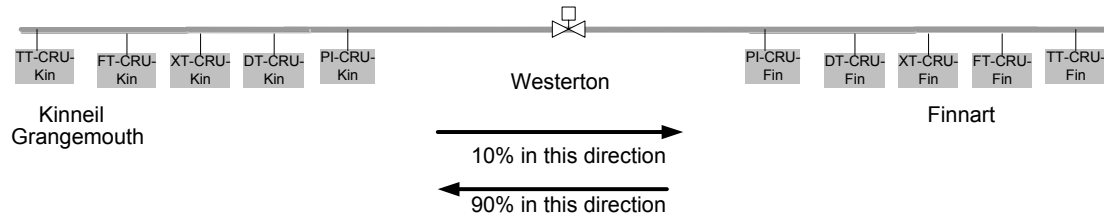

Fig.16 - Schematic Diagram of Grangemouth to Finnart Crude Oil Pipeline

A SCADA system is used to make pipeline data (flow, pressure, temperature, density, viscosity and MOV status) available to the LDS via the OPC protocol over a dual redundant LAN. Dual LAN redundancy is handled by way of NIC (Network Interface Cards) teaming, and presents a single IP address to the operating system.

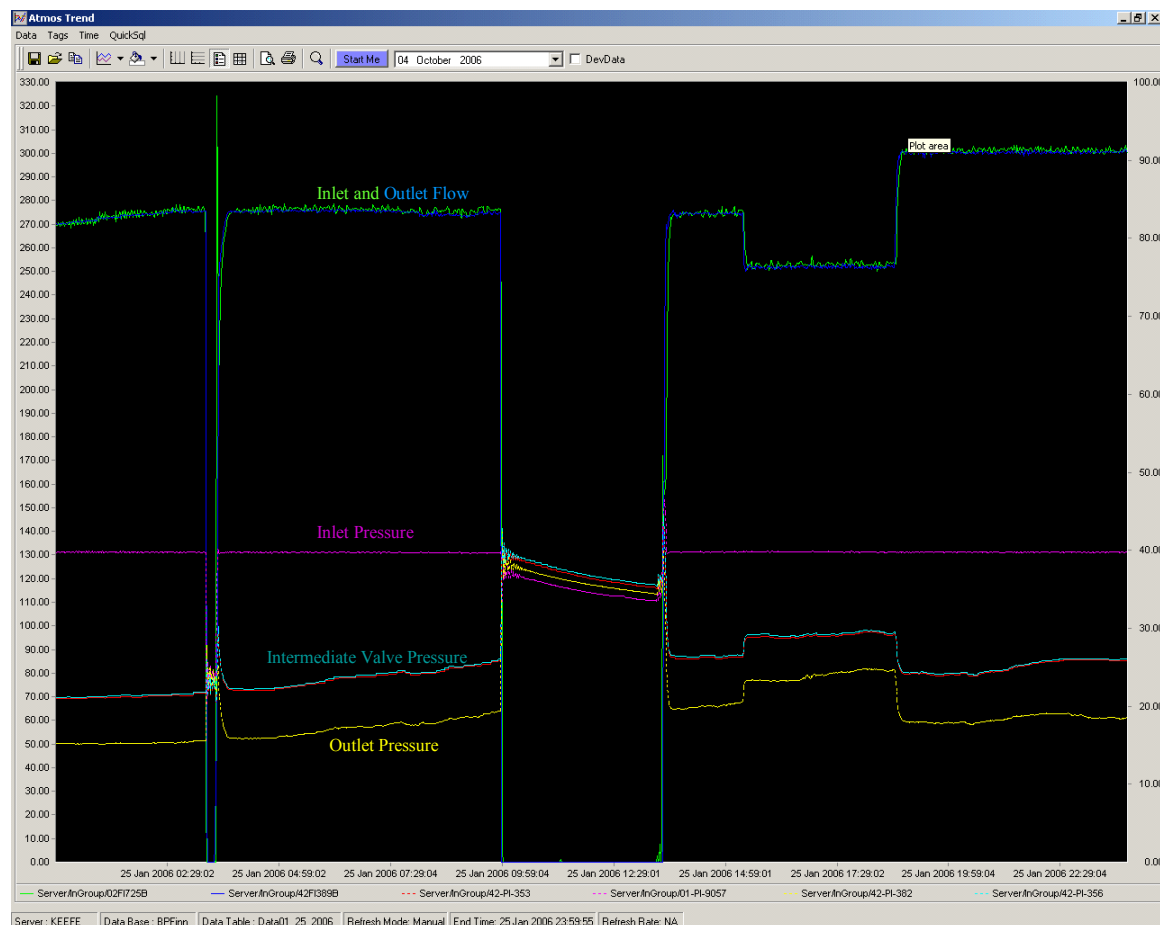The scan rate at which the SCADA updates all reported values is set to 5 seconds.

Fig.17 – An Example of Flow and Pressure Trends Over a 24 Hour Period with Batch Stop/Start and Shut-in Data

The batch tracking system for both pipelines was installed on site in January 2006 after the SCADA upgrade. The LDS for the multi-product pipeline was installed in February 2006. However the implementation of the LDS on the crude oil pipeline is postponed awaiting the site installation of the clamp on ultrasonic flow meters, density and viscosity systems at both ends of the pipeline.

Both the multi-product and crude oil pipelines are run in batches. The pipelines are under shut-in conditions between each batch transfer. Figure 17, Figure 18 and Figure 19 show some examples of typical operations of the product pipeline over three consecutive days (25, 26 and 27th January 2006).

The LDS has been tuned to such operational data prior to the FAT. Table 4 lists the performance of the LDS under three operating scenarios: steady-state, small transient and large transient (NetOpstatus is equal to 0, 1 and 2 respectively).

Table 4 Leak Detection Time in Minutes for Steady-State, Small Transient and Large Transient Operations for the Multi-product Pipeline

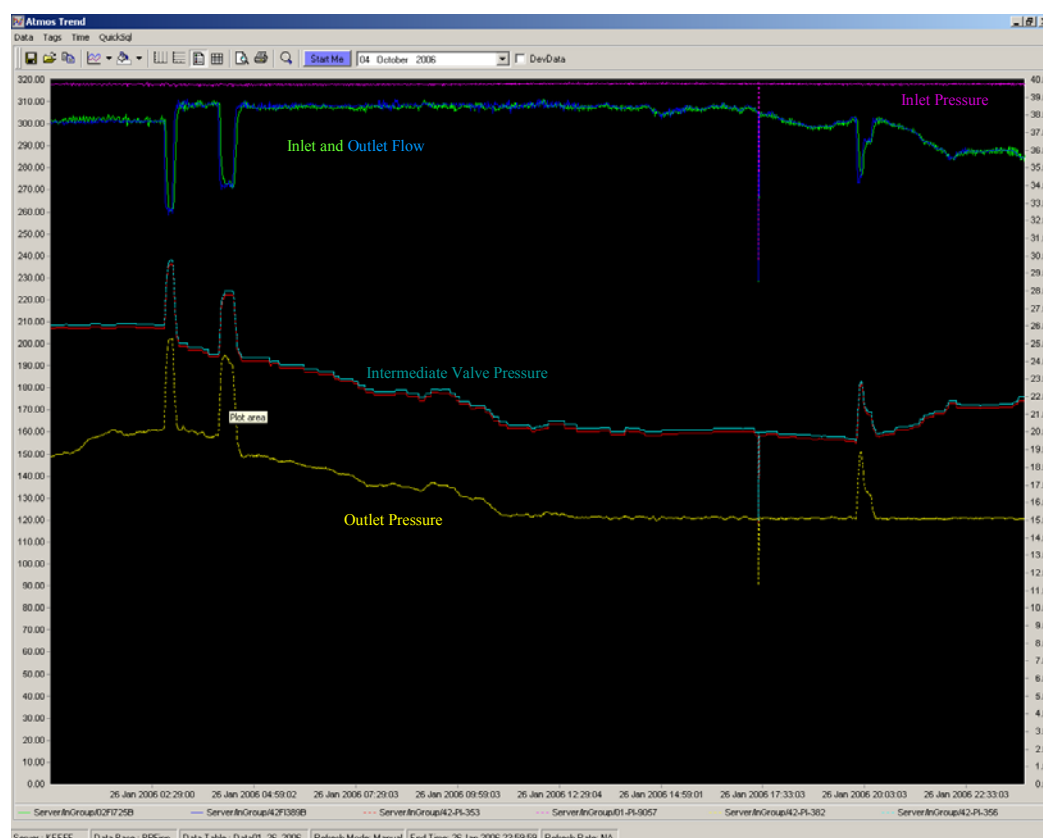|	Steady State		Small Transient		Large Transient	
Lambda	Leak Size (%)	Detect Time_0	Leak Size (%)	Detect Time_1	Leak Size (%)	Detect Time_2
1	1	40	1	60	2	83
2	2	18	2	27	3	39
3	5	8	5	12	5.5	18
4	10	4	10	6	10.5	9
5	20	2	20	3	20	5
6	30	1.7	30	2.55	30	4
7	50	1	50	1.5	50	2.5

Fig.18 – An Example of Flow and Pressure Trends Over a 24 Hour Period with Continuous Operational Change
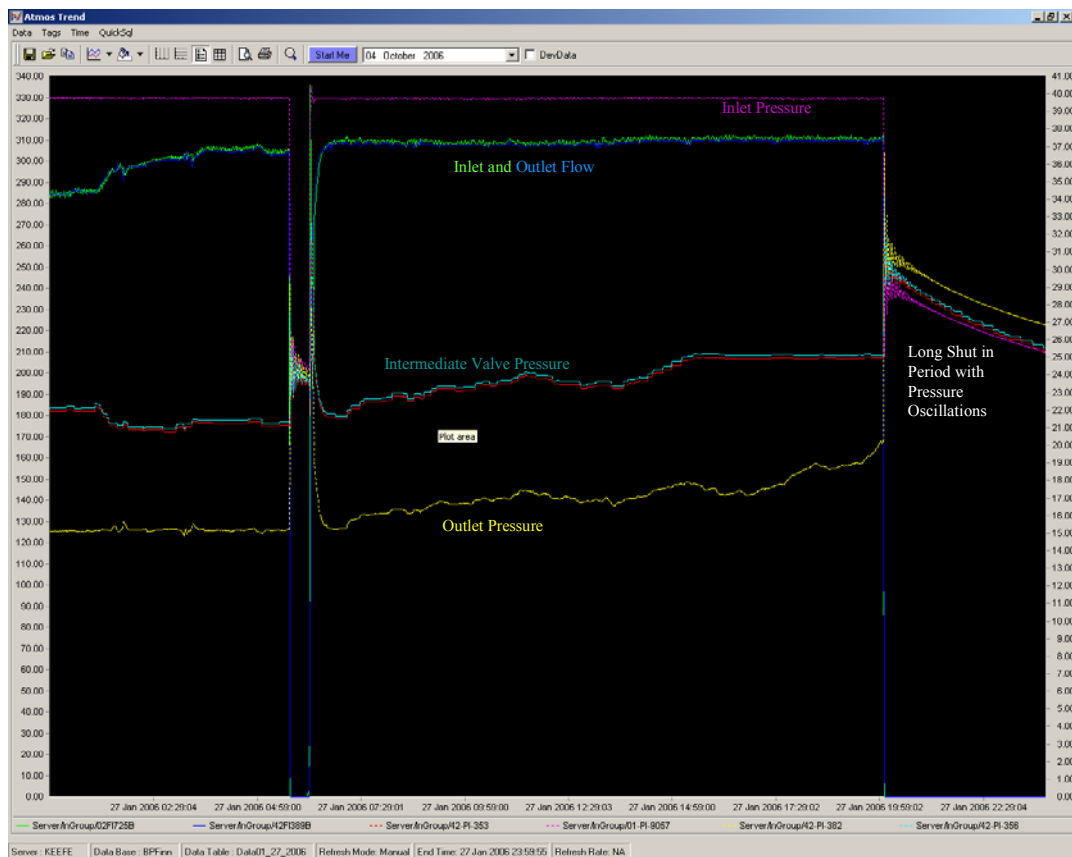
Fig.19 – An Example of Flow and Pressure Trends Over a 24 Hour Period with Long Shut-in Period with Pressure Oscillations

3   SUMMARY AND CONCLUSIONS

This paper has addressed the application of conventional flow and pressure measurements to real-time leak detection.   Five case studies are presented covering supercritical and gaseous ethylene, ethane, liquid propylene, multi-product and crude oil pipelines with varying dimensions and complexities.   With the exception of TSEP, all the other applications are retrofit to the existing pipeline and instrumentation systems.   No special instrument or hardware has been required for the implementation of the LDS. All of the applications involve the interface of the LDS with the site SCADA or PLC systems.   The scan interval varies between 2 and 10 seconds.

As shown in Table 5, the coriolis flow meters have proven to be reliable for a wide range of fluid type and operating conditions. The operational experience on liquid propylene and both gaseous and supercritical ethylene has been successful. To maintain the accuracy of turbine flow meters for different products, online provers are required to recalibrate the meter curves. The performance of the clamp on ultrasonic flow meter is yet to be assessed after the commissioning of the new instrumentation.   Due to the poor track record of clamp on ultrasonic flow meters, special care has been taken to install the meters with external protection and additional viscosity meters.

Table 5 Summary of Flow Meters and Observations for LDS

Pipeline	Flow Meter Type	Observations for LDS
TSEP	Coriolis	Reliable flow measurements
MGEP	Orifice	Reliable flow meters but mass flow readings are adversely affected by density and temperature measurements
Liquid Propylene	Coriolis	Reliable flow measurements
Multi-product	Turbine	Reliable with on-line provers
Crude Oil	Clamp-on Ultrasonic	Performance of ultrasonic meters to be confirmed

4 ACKNOWLEDGEMENT

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