A Comparison between

commercial Pipeline Fluid-dynamic Codes

OLGA vs. LEDAFLOW

Presentation Content

- Scope
- Analyzed Pipeline System and Basic Data
- Steady State Simulation – Results and Summary
- Transient Simulation – Results and Summary
- Summary of Main Findings
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Scope

Scope

- The Scope of work is a fluid-dynamic comparison to confront and contrast OLGA (developed by Schlumberger) and Leda Flow (developed by Kongsberg) by simulating deep water Flowline connected via offshore platform to a subsea pipeline. Comparison was performed by selecting pre-defined process variables (such as pressure, temperature, velocity, hold up, etc).

- The aim of the study was to emphasise the reliability of results obtained when using either of two software; i.e. how different the results would be if the simulations were parting from identical input file and would the potential deviations have any impact on the project outcome.

- The steady state analysis was performed using four different fluids, three different flowline and trunkline diameters for three different receiving pressures at the arrival onshore terminal.

- The sensitivity analysis was the base for the transient analyses, namely shut down (and subsequent cool down), depressurization, ramp up, turn down and pigging.

- This work has been jointly performed by **Saipem** (Olga cases' simulation and data processing) and **Streamline** (LedaFlow cases' simulation and data processing).

Analyzed Pipeline System
And Basic Data

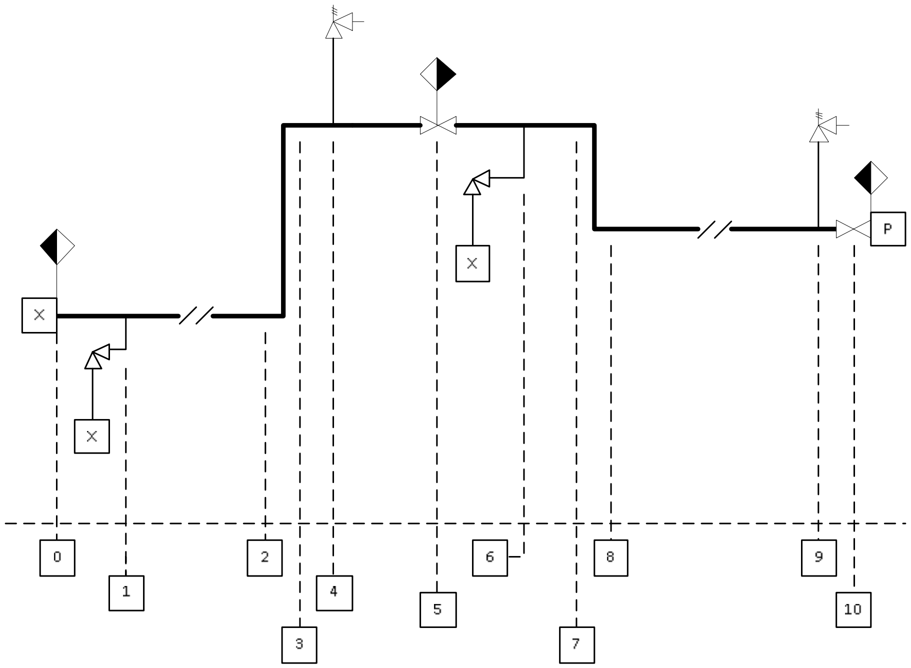
Basic Data – Production HC Fluids

Fluid	TAG	EoS	Critical Point	Cricondembar	Cricondentherm	Water dew point @70bar
			[°C / bara]	[bara]	[°C]	[°C]
Dry Gas	GD	PRp	-80 / 48.7	48.7	-79.0	n/a
Light Condensate	GCL	SRKp	n/a	221.0	+79.0	n/a
Multiphase	GCW	SRKp	306 / 305	313.0	+465.0	+225.0
Oil	MO	SRKp	569 / 80	87.0	+646.0	n/a

Fluid	Molar Composition (%)			Spec. Gravity		Viscosity [cP]		
	Gas	Oil	Water	Gas	Oil	Gas	Oil	Water
GD	100	0.0	0.0	0.689	-	0.010	-	-
GCL	99.9	0.1	0.0	0.767	0.883	0.011	2.2	-
GCW	41.4	24.2	34.4	0.958	0.827	0.010	3.6	1.1
MO	14.7	85.3	0.0	1.540	0.939	0.009	213	-

Fluid Property files (i.e. the fluid property tables) have been prepared using PVTsim thermodynamic package for each fluid. The PVT tables were an input to both the fluid-dynamic simulators.

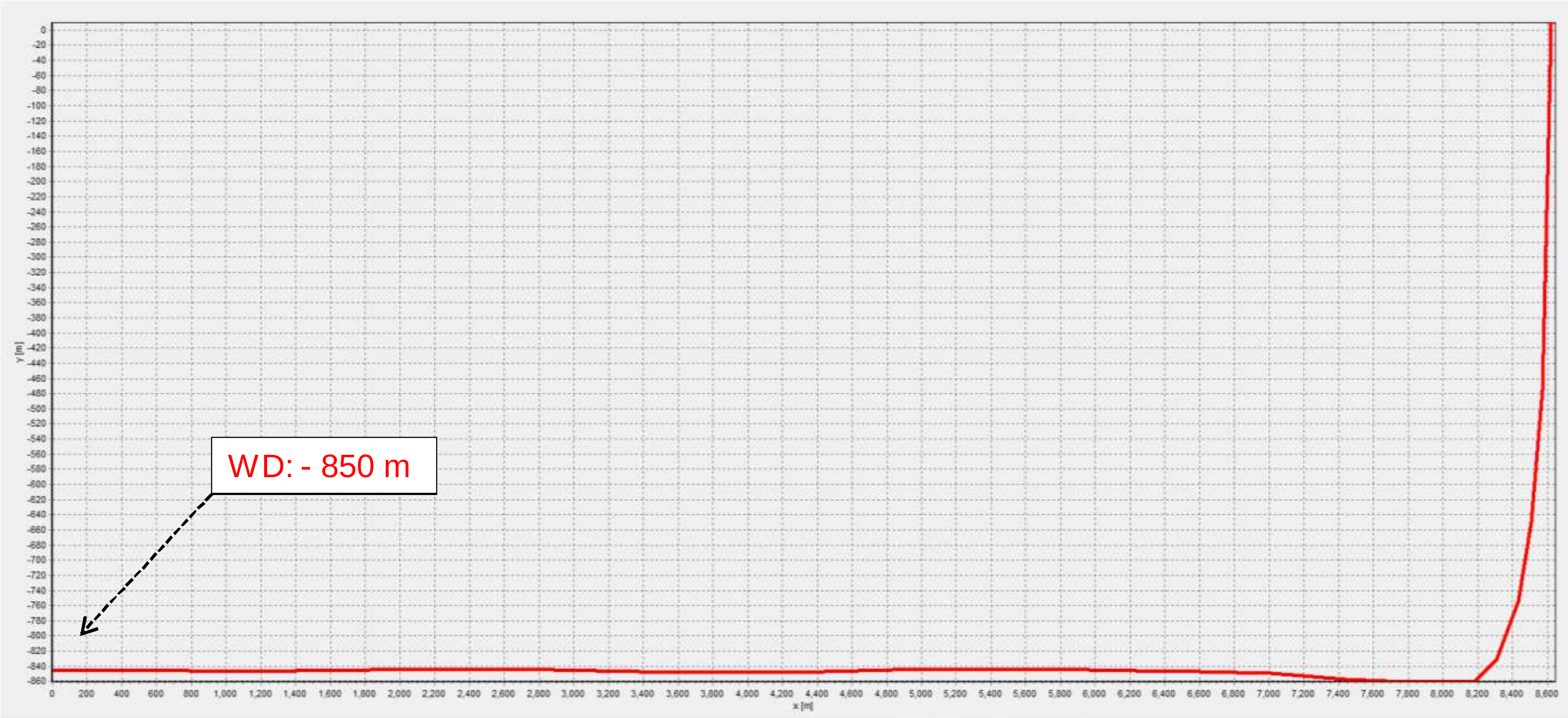
Basic Data – Used Subsea Pipeline Simulation Scheme



Material	Capacity [J/kg-K]	Conductivity [W/m-K]	Density [kg/m3]
Carbon Steel	460	50	7850
Concrete	880	2.1	3040
PE3L	1300	0.4	900
Soil	3000	2.5	2100
Contratherm™	2200	0.186	850

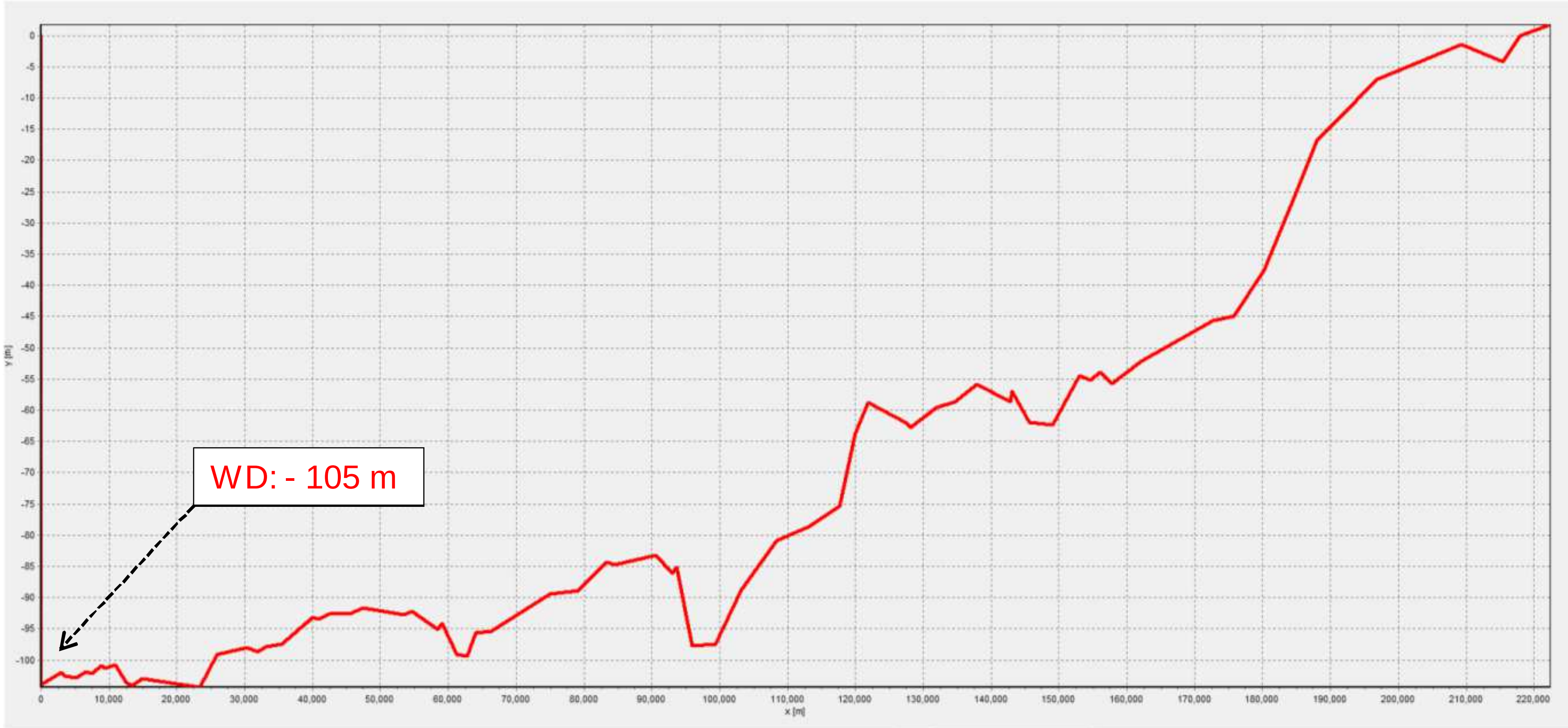
Point ID.	Item	Line	Pipe	Section	Section Boundary	KP
0	Closed Inlet Node	Flowline	-	-	-	0
1	Source	Flowline	PIPE-01	1	-	37.7184
2	Riser Inlet	Flowline	PIPE-23	-	1	
3	Riser Outlet	Flowline	PIPE-28	-	1	
4	Leak	Flowline	PIPE-29	3	-	9279.98
5	Valve / Merge Node	Flowline	PIPE-29	-	4	9284.87
6	Source	Trunkline	PIPE-01	1	-	2.54344
7	Riser Inlet	Trunkline	PIPE-02	-	1	
8	Riser Outlet	Trunkline	PIPE-04	-	1	
9	Leak	Trunkline	PIPE-74	2	-	222476
10	Valve / Pressure Node	Trunkline	PIPE-74	-	3	222480

Basic Data – Flowline Characteristics



Position		Insulation	Concrete	Burial Condition		Ambient	OHTC
From KP	To KP	Type	Type	Type	Depth [m]	Type	[W/m2-K]
0.000	9.250	C55-850	-	Exposed	-	Water	3.4
9.250	9.285	C55-850	-	Exposed	-	**Air**	3.4

Basic Data – Trunkline Characteristics



Position		Insulation		Concrete		Burial Condition		Ambient	OHTC
From KP	To KP	Type	WT [mm]	Type	WT [mm]	Type	Depth [m]	Type	[W/m2-K]
0.000	0.020	3L-PE	3.5	-		Exposed	-	Air	117.1
0.020	209.330	3L-PE	3.5	**Yes**	**40**	Exposed	-	**Water**	39.6
209.330	218.092	3L-PE	3.5	-	-	**Buried**	**1.0**	Water	4.0
218.092	222.460	3L-PE	3.5	-	-	Buried	**2.0**	Water	3.1
222.460	222.480	3L-PE	3.5	-	-	**Exposed**	-	**Air**	117.1

Basic Data – Pipeline Size, Flowrate, Arrival Pressure

The following nominal diameters of flowline and trunkline were considered:

- **8” / 24”**
- **10” / 32”**
- **12” / 36”**

Line	ND [inch]	OD [mm]	ID [mm]	WT [mm]
Flowline	8	203.2	177.8	12.70
	10	254.0	222.3	15.88
	12	304.8	266.7	19.05
Trunkline	24	609.6	574.6	17.48
	32	812.8	766.2	23.31
	36	914.4	862.0	26.22

Fluid	Flowline Injection Point			Trunkline Injection Point		
	Mass Rate [kg/s]	T [°C]	P [bara]	Mass Rate [kg/s]	T [°C]	P [bara]
GD	35	80	400	85	60	200
GCL	15	120	350	95	65	250
GCW	70	80	400	175	60	300
MO	50	65	300	250	60	200

	Trunkline Arrival Point [bara]
Onshore Arrival Pressure	40
	60
	80

Basic Data – Creation of simulation cases

- Starting from the data reported in the previous slide, 36 simulation cases were created:
  - Three couples of different diameters for flowline and trunkline were selected, namely 8" & 24", 10" & 32" and 12" & 36";
  - Three different arrival pressures were imposed at the Onshore Terminal, namely 40 bara, 60 bara and 80 bara;
  - Four fluids were defined for the scope of the study;
  - Total number of simulation cases equal to 36 (nine cases for each fluid).

- Steady state analysis was performed for all the 36 cases.
- Transient analysis was performed only for several cases, using the results of steady state analysis as its starting point.

- In order to obtain plausible results, it was decided to generate identical input model for both software. Input model was first created by OLGA (version 6), and then converted to LedaFlow input file (version 1.3).

Steady State Analysis

Sum up & Results

Steady State Analysis - Legend

1: Case **GC-L_RP60_D8&24** is to be interpreted in the following way:

- **GC-L** stands for the fluid, in this case **Light Gas Condensate**.
- **RP60** stands for the Onshore Receiving Pressure, in this case equal to **60 bara**.
- **D8&24** stands for a Flowline having the diameter of 8” ND and a Trunkline having the diameter of 24” ND.

2: The deviation , expressed in **percentage** and used to compare the Steady State results, has been calculated using the following equation:

$$dev[\%] = \frac{x_i\,LEDA - x_i\,OLGA}{x_i\,OLGA}\%$$

3. The Flow Regime is identified according to codes given in the following Table:

Physical Flow Regime	
Value	**Description**
0 - 1	Stratified flow
2	Annular flow
3	Slug flow
4	Bubble flow

Single Phase Gas Flow (GD) - Steady State Sum up

Compared Variables (Flowline and Trunkline):

1. Inlet and Outlet Pressure; Pressure Drop (DP).
2. Inlet and Outlet Temperature.
3. Gas Mass Content.

Remarks:

- All cases have reached the steady state condition.
- For single phase (gas phase) simulations: no significant differences are reported for the analyzed variables.

Single Phase Gas Flow (GD) - Steady State Results

GD	FLOWLINE					
Case	Pressure			Temperature		Mass Fluid Content
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas
GD_RP40_D8&24	-0.09%	-0.17%	0.06%	-0.04%	-0.03%	0.12%
GD_RP40_D10&32	-0.08%	-0.29%	0.37%	-0.05%	-0.08%	0.14%
GD_RP40_D12&36	0.00%	-0.38%	1.24%	0.00%	-0.29%	0.23%
GD_RP60_D8&24	-0.08%	-0.14%	0.04%	-0.04%	-0.03%	0.14%
GD_RP60_D10&32	-0.07%	-0.21%	0.31%	-0.04%	-0.09%	0.18%
GD_RP60_D12&36	0.00%	-0.24%	1.06%	0.00%	-0.20%	0.24%
GD_RP80_D8&24	-0.07%	-0.12%	0.03%	-0.03%	-0.02%	0.15%
GD_RP80_D10&32	-0.05%	-0.15%	0.27%	-0.03%	-0.08%	0.22%
GD_RP80_D12&36	0.00%	-0.15%	0.91%	0.00%	-0.14%	0.25%

GD	TRUNKLINE					
Case	Pressure			Temperature		Mass Fluid Content
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas
GD_RP40_D8&24	0.00%	-0.04%	0.02%	-0.08%	-2.98%	-0.05%
GD_RP40_D10&32	0.01%	-0.06%	0.11%	-0.01%	-0.98%	-0.02%
GD_RP40_D12&36	0.02%	-0.07%	0.22%	0.04%	-0.76%	-0.02%
GD_RP60_D8&24	0.01%	-0.02%	0.03%	-0.08%	-1.92%	-0.04%
GD_RP60_D10&32	0.01%	-0.02%	0.11%	-0.05%	-0.73%	-0.03%
GD_RP60_D12&36	0.01%	-0.03%	0.21%	-0.04%	-0.60%	-0.03%
GD_RP80_D8&24	0.01%	-0.01%	0.03%	-0.09%	-1.35%	-0.04%
GD_RP80_D10&32	0.01%	-0.01%	0.10%	-0.08%	-0.60%	-0.04%
GD_RP80_D12&36	0.01%	-0.02%	0.20%	-0.08%	-0.52%	-0.03%

Single Phase Oil Flow (MO) - Steady State Sum up

Compared Variables (Flowline and Trunkline):

1. Inlet and Outlet Pressure; Pressure Drop (DP).
2. Inlet and Outlet Temperature.
3. Liquid Mass Content.

Remarks:

- All cases have reached the steady state condition.
- For single phase (liquid phase) simulations: no significant differences are reported for the analyzed variables.

Single Phase Oil Flow (MO) - Steady State Results

MO	FLOWLINE					
Case	Pressure			Temperature		Mass Fluid Content
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Oil
MO_RP40_D8&24	-0.04%	-0.07%	-0.01%	0.01%	-0.04%	0.27%
MO_RP40_D10&32	0.02%	0.02%	0.01%	0.00%	-0.05%	0.31%
MO_RP40_D12&36	0.06%	0.12%	0.02%	-0.01%	-0.03%	0.27%
MO_RP60_D8&24	-0.04%	-0.06%	-0.01%	0.01%	-0.04%	0.27%
MO_RP60_D10&32	0.01%	0.02%	0.01%	0.00%	-0.05%	0.31%
MO_RP60_D12&36	0.05%	0.09%	0.02%	-0.01%	-0.06%	0.27%
MO_RP80_D8&24	-0.04%	-0.06%	-0.01%	0.01%	-0.03%	0.27%
MO_RP80_D10&32	0.01%	0.01%	0.01%	0.00%	-0.02%	0.31%
MO_RP80_D12&36	0.04%	0.06%	0.02%	0.00%	0.03%	0.27%

MO	TRUNKLINE					
Case	Pressure			Temperature		Mass Fluid Content
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Oil
MO_RP40_D8&24	-0.04%	-0.01%	-0.05%	-0.05%	0.00%	-0.003%
MO_RP40_D10&32	0.04%	0.01%	0.10%	-0.07%	-0.16%	-0.002%
MO_RP40_D12&36	0.08%	0.01%	0.25%	-0.07%	-0.21%	-0.002%
MO_RP60_D8&24	-0.03%	-0.01%	-0.05%	-0.05%	0.00%	-0.003%
MO_RP60_D10&32	0.03%	0.01%	0.09%	-0.06%	-0.15%	-0.002%
MO_RP60_D12&36	0.06%	0.01%	0.26%	-0.07%	-0.19%	-0.001%
MO_RP80_D8&24	-0.04%	0.00%	-0.06%	-0.05%	0.00%	-0.003%
MO_RP80_D10&32	0.02%	0.01%	0.07%	-0.06%	-0.18%	-0.002%
MO_RP80_D12&36	0.04%	0.01%	0.23%	-0.06%	-0.21%	-0.001%

Light Gas Condensate (GC-L) - Steady State Sum up

Compared Variables (for both Flowline and Trunkline):

1. Inlet and Outlet Pressure; Pressure Drop (DP).
2. Inlet and Outlet Temperature.
3. Gas and Liquid Mass Content.
4. Gas and Liquid Velocities.
5. Flow Regime.

Remarks:

- Four cases (out of nine) have not reached the steady-state condition (Unstable cases for at least one software are shown in the following table **in red**).
- No significant differences for **Pressure, Temperature, Gas Content, Gas Velocity.** Minor differences are noted when comparing **DP**.

Light Gas Condensate (GC-L) - Steady State Results

GC-L	FLOWLINE						
Case	Pressure			Temperature		Mass Fluid Content	
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas	Oil
GC-L_RP40_D8&24	0.37%	1.33%	-4.31%	0.11%	-0.36%	1.00%	-48.75%
GC-L_RP40_D10&32	-0.51%	0.51%	-5.64%	-0.16%	0.39%	0.20%	-40.57%
GC-L_RP40_D12&36	2.03%	0.20%	12.90%	-0.06%	-0.72%	1.99%	42.60%
GC-L_RP60_D8&24	**0.32%**	**1.00%**	**-3.37%**	**0.10%**	**-0.12%**	**0.82%**	**-50.19%**
GC-L_RP60_D10&32	-0.55%	0.25%	-5.53%	-0.18%	0.29%	0.08%	-42.09%
GC-L_RP60_D12&36	2.12%	0.02%	16.65%	0.03%	-0.72%	1.70%	62.38%
GC-L_RP80_D8&24	0.18%	0.60%	-2.32%	0.05%	0.02%	0.57%	-52.43%
GC-L_RP80_D10&32	0.48%	0.05%	3.54%	-0.33%	-0.13%	0.61%	40.45%
GC-L_RP80_D12&36	2.47%	-0.07%	21.85%	0.19%	-0.88%	1.63%	86.02%

GC-L	TRUNKLINE						
Case	Pressure			Temperature		Mass Fluid Content	
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas	Oil
GC-L_RP40_D8&24	1.35%	-0.02%	2.34%	1.71%	-1.45%	1.57%	-22.29%
GC-L_RP40_D10&32	0.56%	-0.03%	1.86%	9.22%	-0.51%	0.48%	-11.25%
GC-L_RP40_D12&36	0.27%	-0.04%	1.41%	15.68%	-0.42%	0.17%	-1.39%
GC-L_RP60_D8&24	**1.01%**	**-0.01%**	**2.41%**	**1.13%**	**-1.08%**	**1.17%**	**-19.80%**
GC-L_RP60_D10&32	0.25%	-0.01%	1.47%	3.57%	-0.42%	0.18%	-3.53%
GC-L_RP60_D12&36	0.06%	-0.02%	0.66%	4.62%	-0.36%	-0.07%	8.91%
GC-L_RP80_D8&24	0.61%	0.01%	1.96%	0.56%	-0.78%	0.68%	-16.53%
GC-L_RP80_D10&32	0.05%	-0.01%	0.54%	1.09%	-0.36%	-0.05%	5.23%
GC-L_RP80_D12&36	-0.09%	-0.01%	-1.22%	1.00%	-0.34%	-0.05%	-4.38%

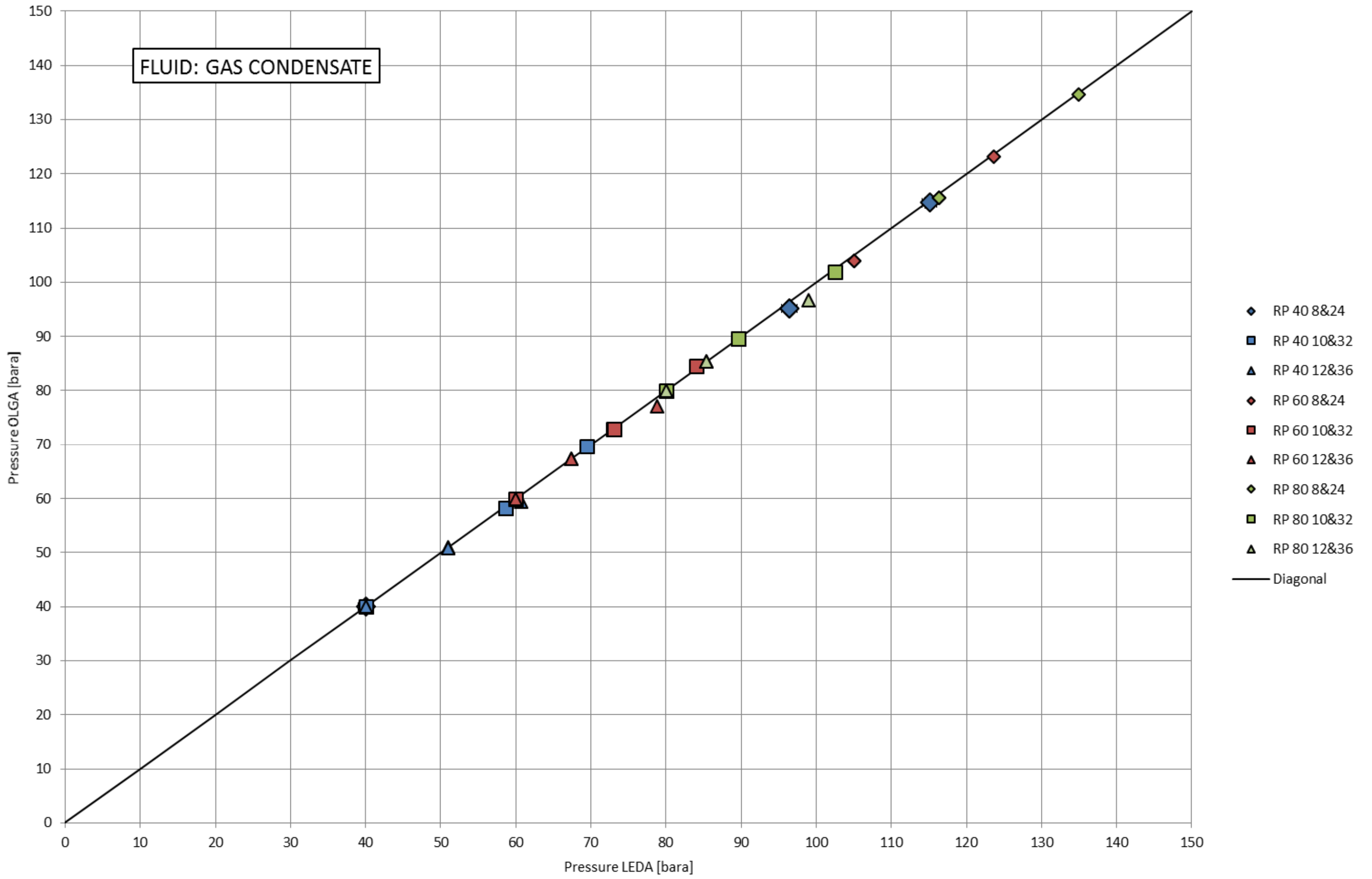
- Unstable cases for at least one software are shown **in red**.

Light Gas Condensate (GC-L) - Steady State Results

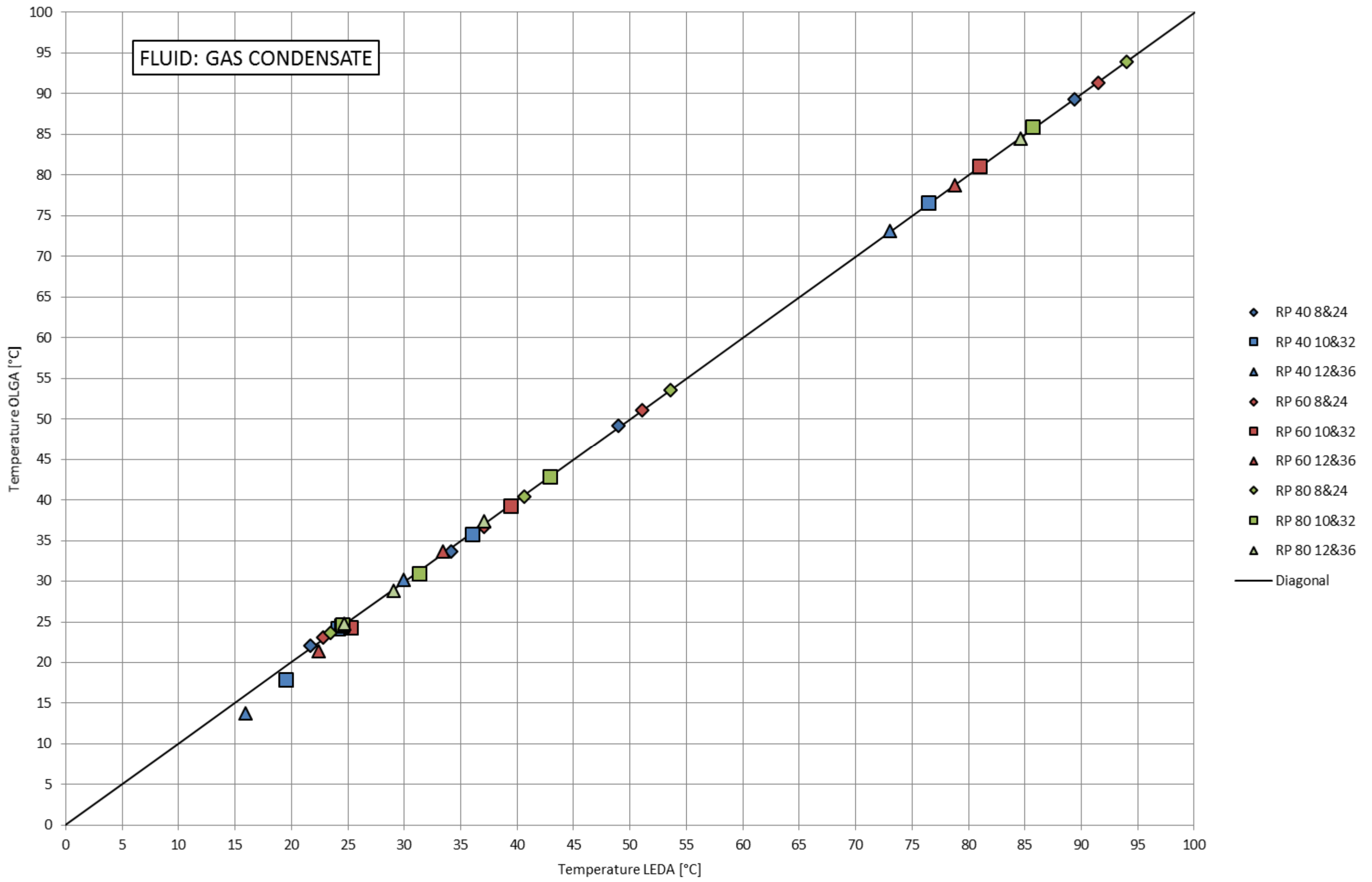
The following readings have been taken at the most significant points of the pipeline:

- Temperature and Pressure – at four significant points:
  - Flowline Inlet
  - Flowline Arrival
  - Trunkline Inlet
  - Trunkline Arrival
- Velocity – at two significant points:
  - Flowline Arrival
  - Trunkline Arrival
- Accumulated Liquid (Oil and Water) has been recorded along both the Flowline and Trunkline.

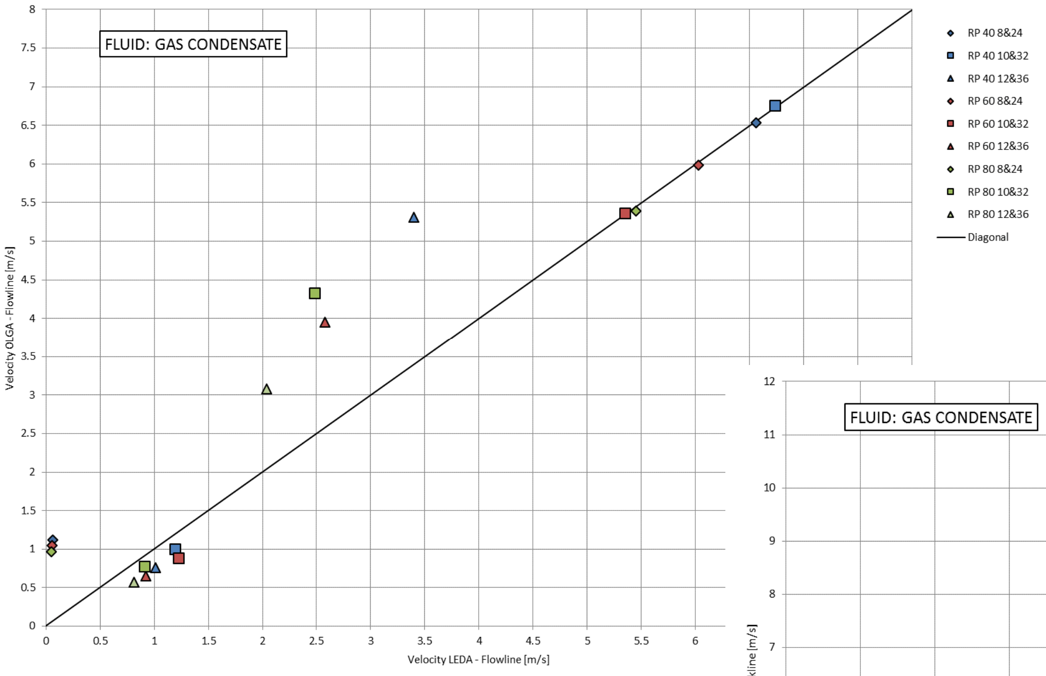
Light Gas Condensate (GC-L) - Steady State Results

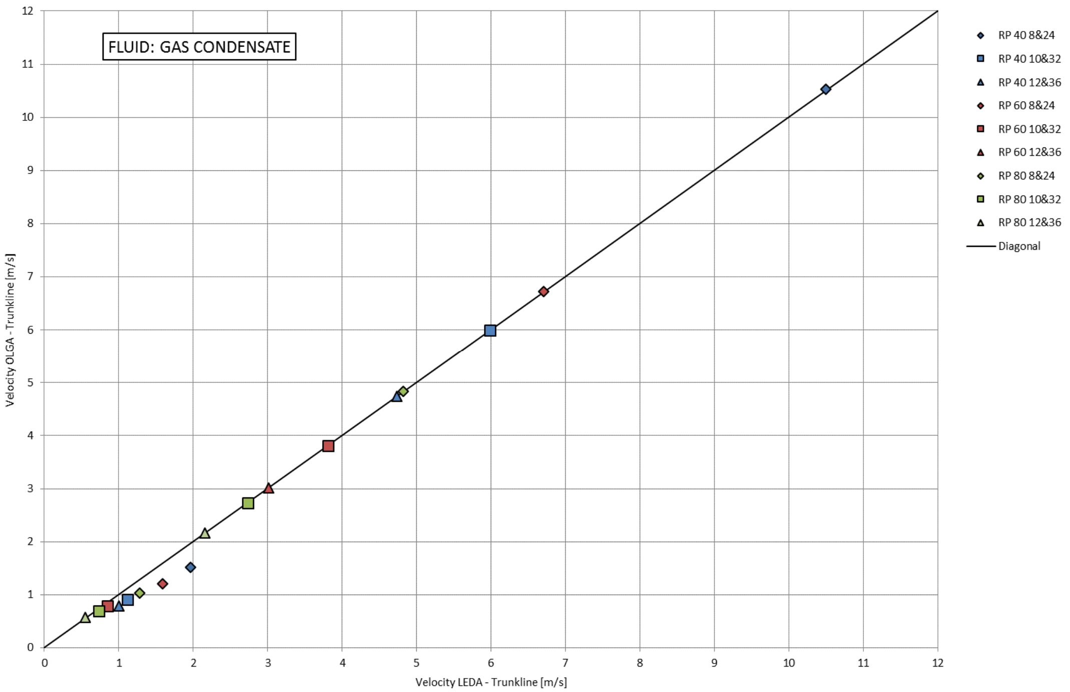


Light Gas Condensate (GC-L) –Steady State Results

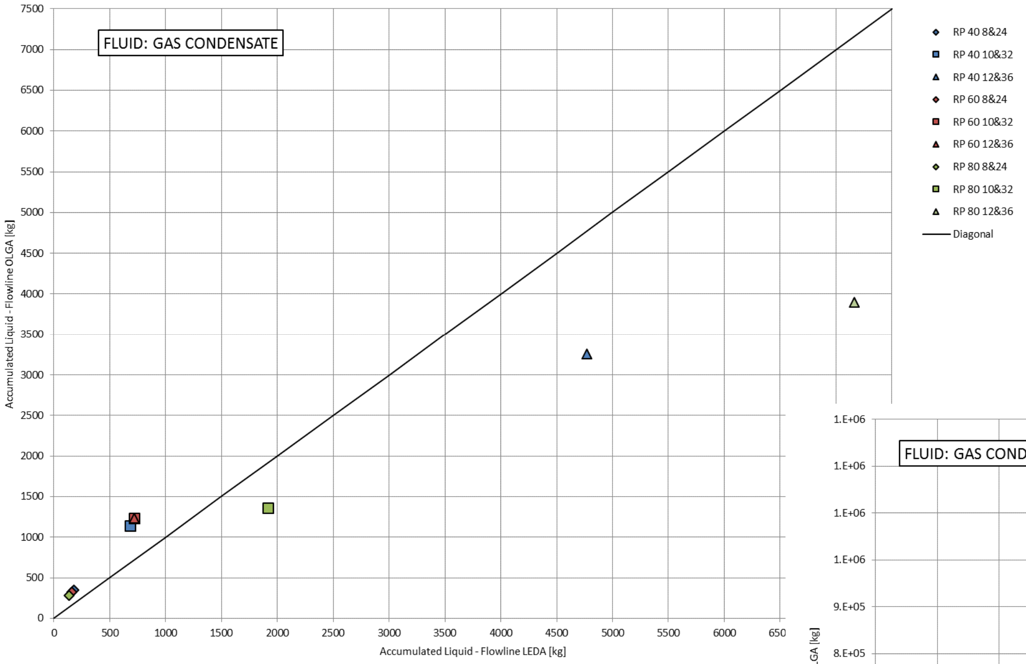


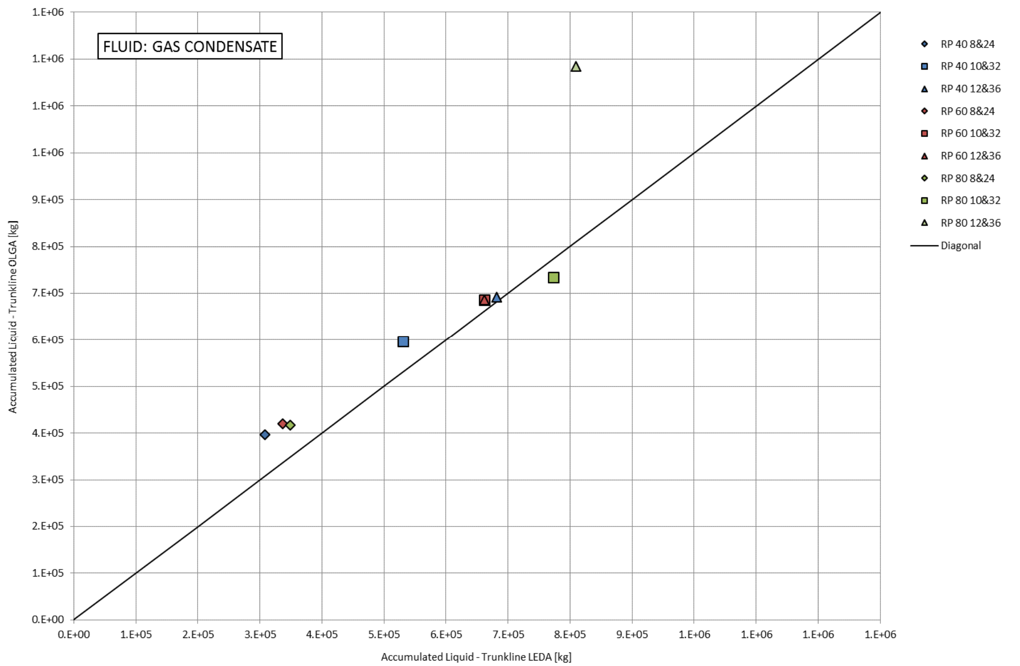
Light Gas Condensate (GC-L) –Steady State Results





Light Gas Condensate (GC-L) –Steady State Results





Multiphase Flow (GC-W) - Steady State Sum up

Compared Variables (for both Flowline and Trunkline):

1. Inlet and Outlet Pressure; Pressure Drop (DP).
2. Inlet and Outlet Temperature.
3. Oil, Gas and Water Mass Content.
4. Oil and Water Velocities.
5. Flow Regime.

Remarks:

- Four cases (out of nine) have not reached the steady state condition (Unstable cases for at least one software are shown in the following table **in red**).
- No significant differences for **Pressure, Temperature, Gas Content, Gas Velocity, Oil Volume Fraction.** Minor differences are noted when comparing **DP.**

Multiphase Flow (GC-W) - Steady State Results

GC-W	FLOWLINE							
Case	Pressure			Temperature		Mass Fluid Content		
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas	Oil	Water
GCW-M_RP40_D8&24	-1.24%	0.65%	-3.04%	-0.28%	0.10%	0.96%	-1.86%	18.80%
GCW-M_RP40_D10&32	-1.70%	-1.44%	-1.99%	-0.19%	-0.13%	-2.88%	-0.53%	21.49%
GCW-M_RP40_D12&36	-0.07%	-2.76%	3.80%	-0.04%	-0.32%	-1.94%	-0.05%	18.44%
GCW-M_RP60_D8&24	**0.44%**	**2.56%**	**-1.89%**	**-0.25%**	**0.13%**	**-1.62%**	**-1.01%**	**21.96%**
GCW-M_RP60_D10&32	-0.59%	-1.03%	0.04%	-0.23%	-0.13%	-5.65%	1.24%	15.91%
GCW-M_RP60_D12&36	-0.06%	-1.95%	3.16%	-0.35%	-0.17%	-7.46%	0.91%	34.73%
GCW-M_RP80_D8&24	0.77%	2.24%	-1.10%	-0.23%	0.14%	-3.61%	-1.06%	23.83%
GCW-M_RP80_D10&32	-0.50%	-1.28%	0.82%	-0.37%	0.03%	-10.13%	1.18%	26.70%
GCW-M_RP80_D12&36	-0.19%	-1.52%	2.45%	-0.25%	-0.21%	-11.53%	1.17%	37.60%

GC-W	TRUNKLINE							
Case	Pressure			Temperature		Mass Fluid Content		
	Inlet	Outlet	Pressure Drop	Inlet	Outlet	Gas	Oil	Water
GCW-M_RP40_D8&24	0.78%	-0.02%	1.47%	-0.72%	-0.05%	-5.25%	-0.98%	23.29%
GCW-M_RP40_D10&32	-1.25%	-0.03%	-4.11%	-2.16%	-0.26%	-5.78%	3.55%	-0.01%
GCW-M_RP40_D12&36	-2.54%	0.03%	-9.99%	-1.98%	-0.29%	-5.95%	5.49%	-8.62%
GCW-M_RP60_D8&24	**2.67%**	**-0.01%**	**6.82%**	**-0.81%**	**-0.20%**	**-8.00%**	**-0.12%**	**31.08%**
GCW-M_RP60_D10&32	-0.92%	-0.01%	-4.44%	-2.47%	-0.25%	-8.53%	3.62%	3.30%
GCW-M_RP60_D12&36	-1.81%	-0.01%	-10.08%	-3.18%	-0.32%	-8.44%	6.33%	-10.01%
GCW-M_RP80_D8&24	2.33%	0.01%	7.76%	-0.76%	-0.14%	-13.59%	0.56%	33.67%
GCW-M_RP80_D10&32	-1.20%	-0.01%	-7.85%	-2.15%	-0.23%	-14.10%	4.33%	4.73%
GCW-M_RP80_D12&36	-1.44%	-0.01%	-10.62%	-4.37%	-0.32%	-10.42%	5.81%	-8.55%

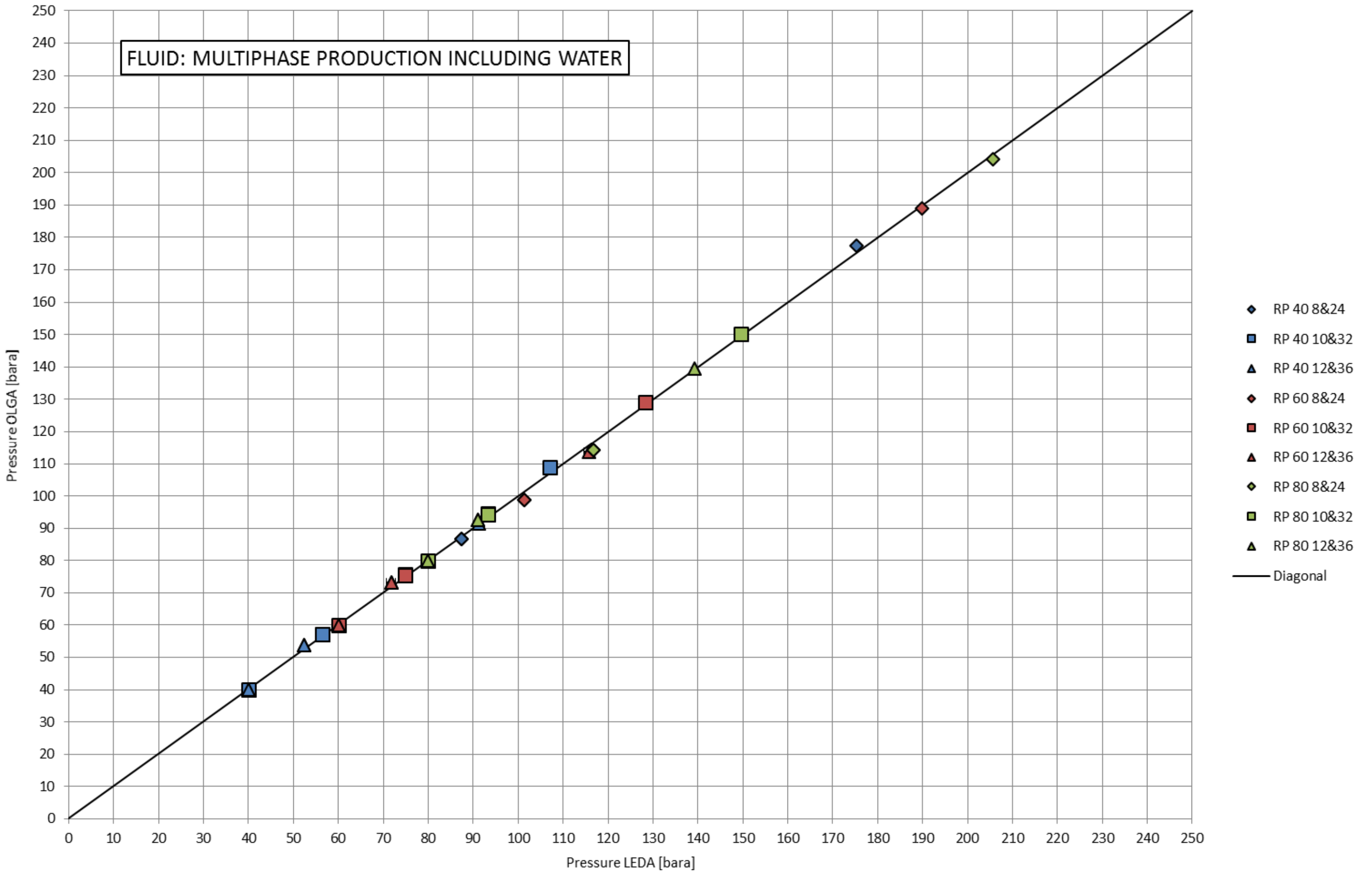
- Unstable cases for at least one software are shown **in red**.

Multiphase Flow (GC-W) - Steady State Results

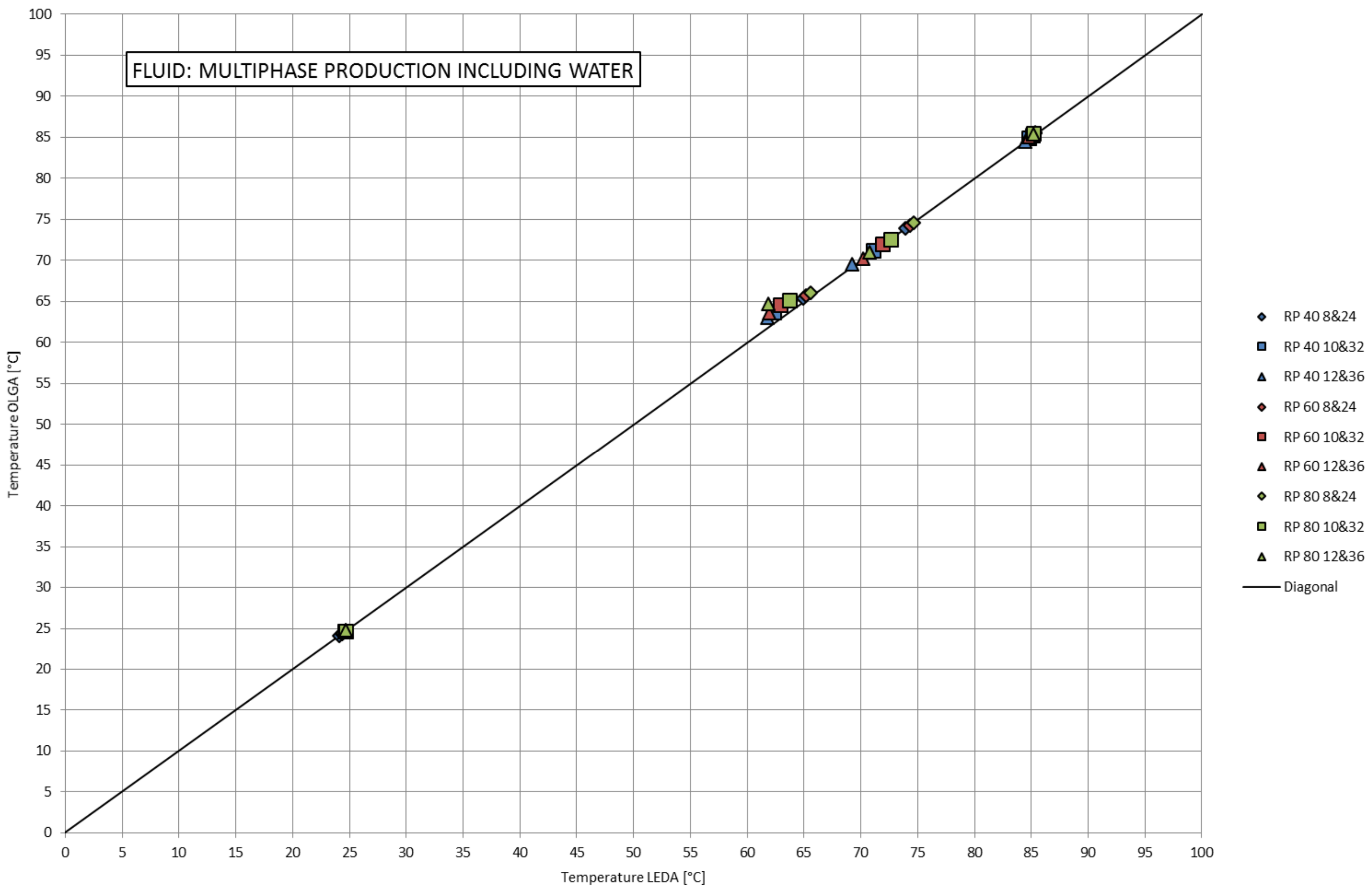
The following readings have been taken at the most significant points of the pipeline:

- Temperature and Pressure – at four significant points:
  - Flowline Inlet
  - Flowline Arrival
  - Trunkline Inlet
  - Trunkline Arrival
- Velocity – at two significant points:
  - Flowline Arrival
  - Trunkline Arrival
- Accumulated Liquid (Oil and Water) has been recorded along both the Flowline and Trunkline.

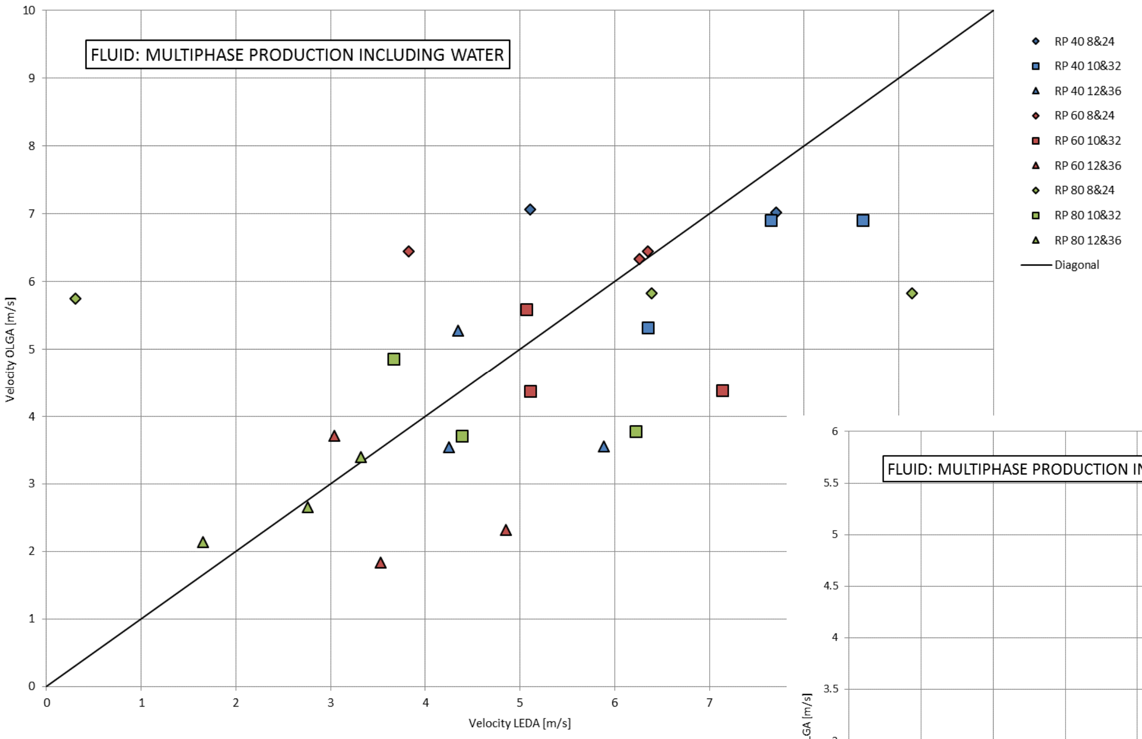
Multiphase Flow (GC-W) - Steady State Results

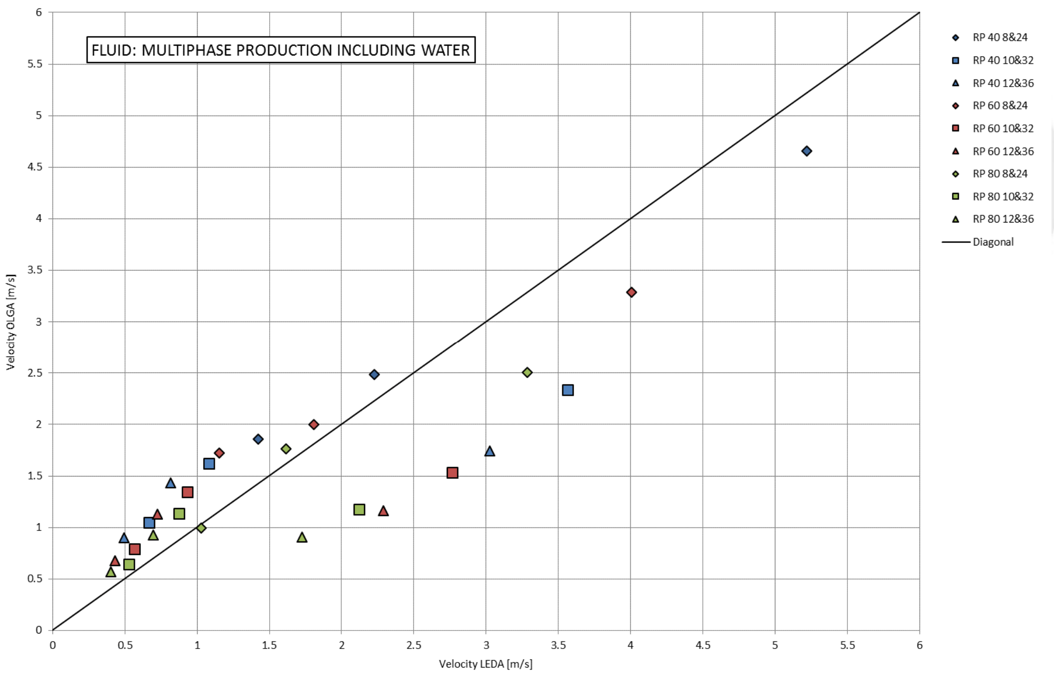


Multiphase Flow (GC-W) - Steady State Results

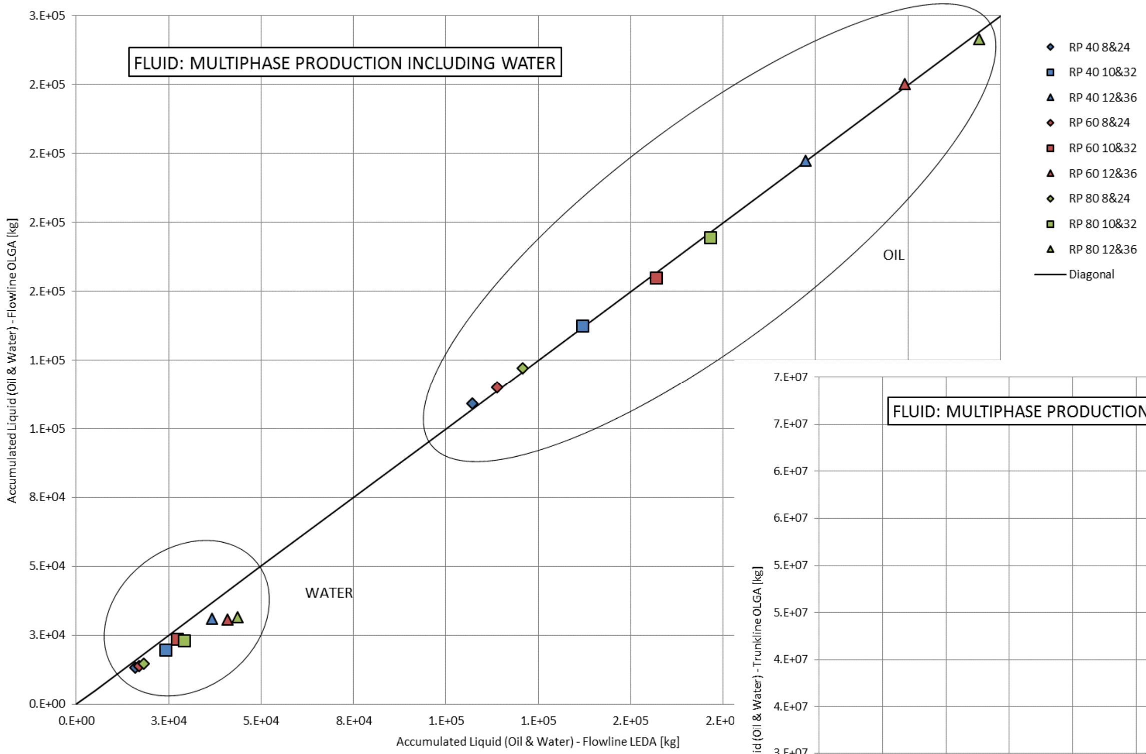


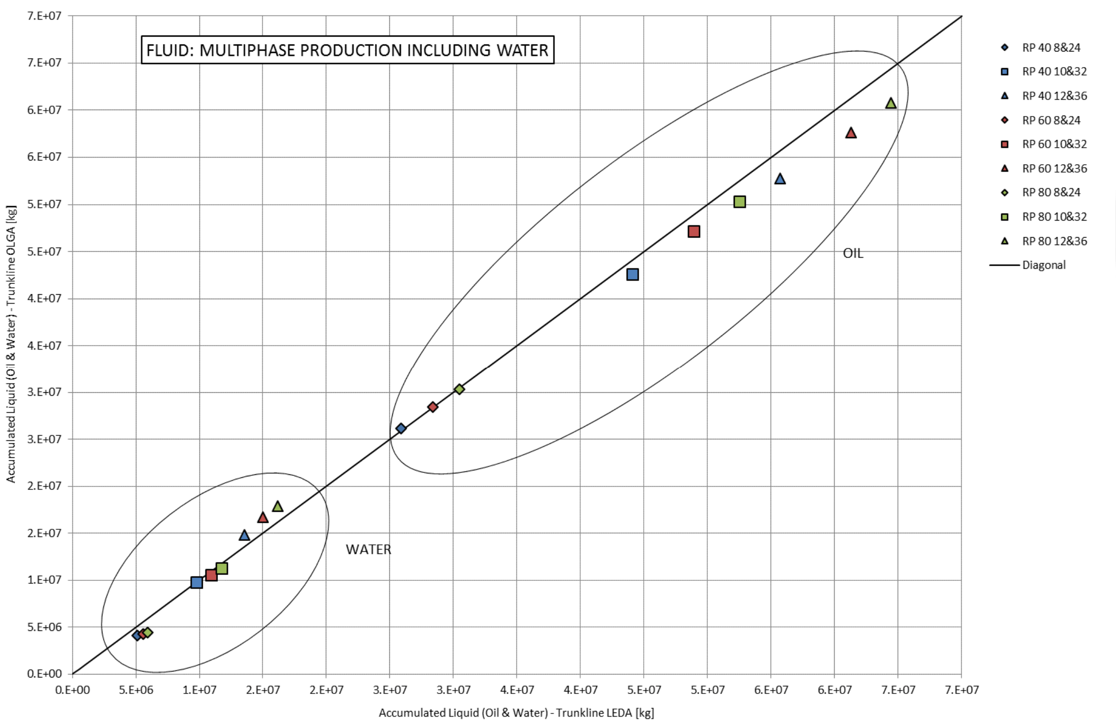
Multiphase Flow (GC-W) - Steady State Results





Multiphase Flow (GC-W) - Steady State Results





STREAMLINE PIPELINE ENGINEERING

Transient Analysis

Sum up & Results

Transient Analysis – Analyzed Cases

TRANSIENT	DRY GAS	GAS CONDENSATE LIGHT
Shut-down and **Depressurization** (Blow-down)	Flowline: 8” Trunkline: 24” Receiving Pressure: 60 barg	Flowline: 10” Trunkline: 32” Receiving Pressure: 40 barg

Shut-down

Initial Condition:	Relevant Steady State.
Valves closure speed:	1 inch/second.
Simulation end:	Liquid content stabilization along both lines.

Depressurization (Blow-down)

Initial Condition:	Shut-down condition estimated by LEDA has been used as initial condition for both codes.
Leak opening speed:	1 min
Leak diameter:	1” (25.4 mm) for flowline; 4” (101.6 mm) for trunkline.
Leak discharge coefficient:	0.84.
Simulation end:	Pressure equalization with the ambient.

F/L (8inch) and T/L (24inch)

Shut-down Simulation

Dry Gas

Compared Variables (for both Flowline and Trunkline):

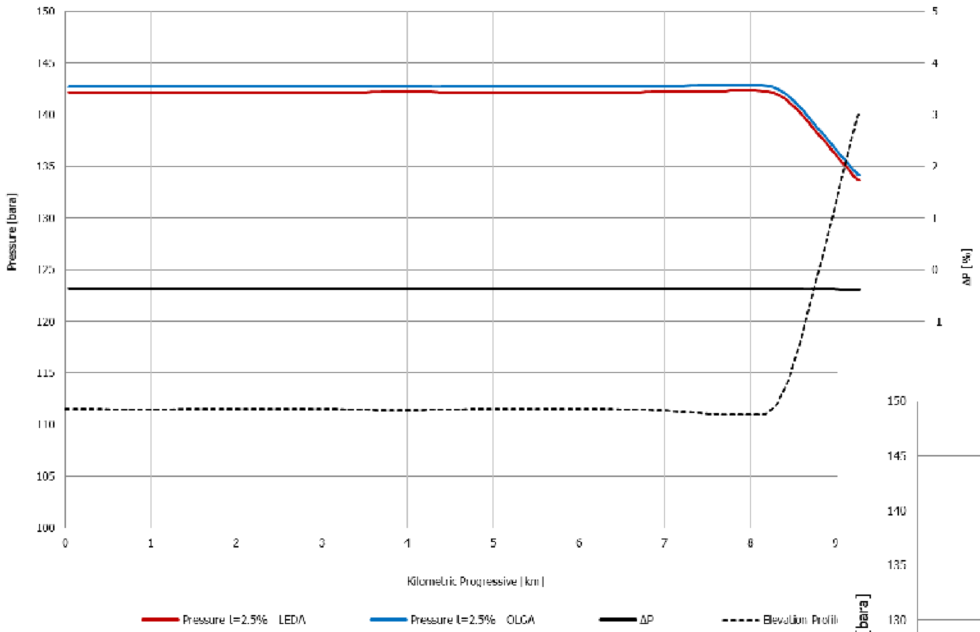
1. Pressure along the pipelines at the beginning of transient analysis (at the instant corresponding to 2.5% of the total time required to reach steady state condition~~s~~) and at the final instant of the shut-down i.e. when steady state condition has been achieved (t=100%).
2. Temperature along the pipelines during the shut-down (2.5% and 10% of the total time required to reach steady state condition).
3. The deviation for both pressure and temperature, expressed in **percentage and** calculated using the following equation:

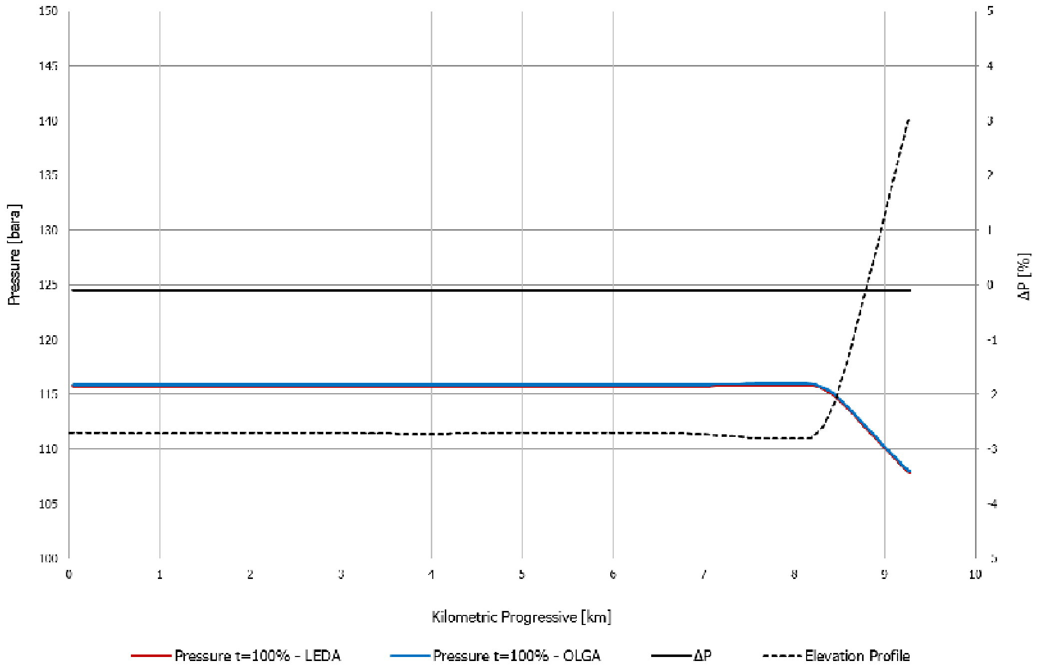
$$dev[\%] = \frac{x_i\ LEDA - x_i\ OLGA}{x_i\ OLGA}\ \%$$

Remarks:

- No significant differences were noted for **Pressure** and **Temperature** along both Flowline and Trunkline**.**

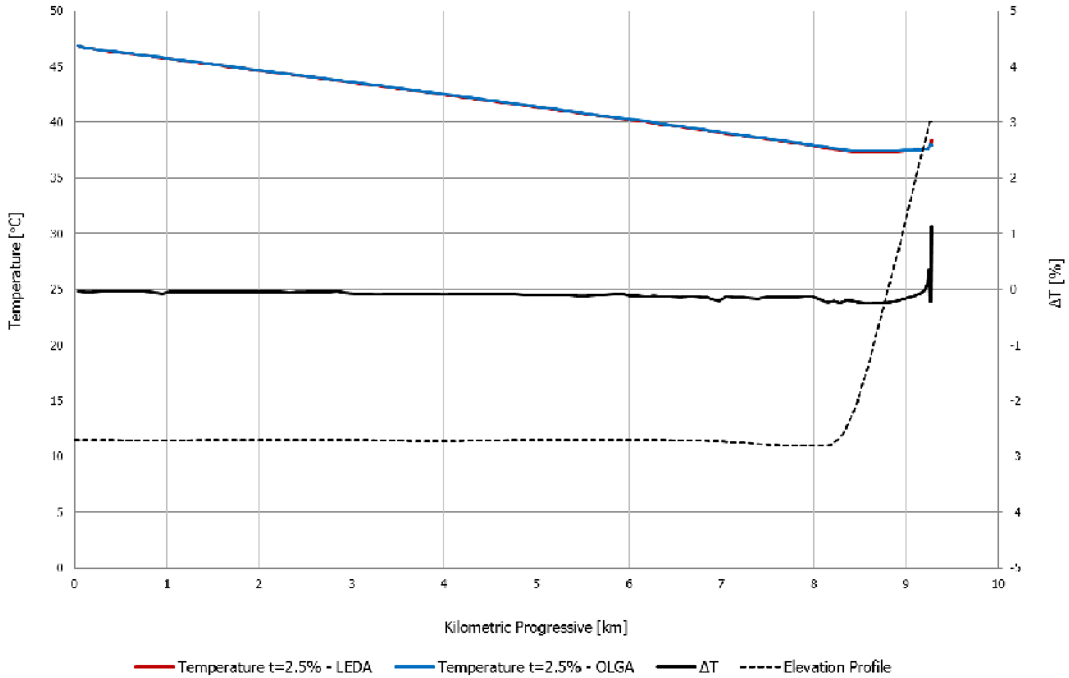
Flowline Shut-down – Dry Gas - COMPARISON

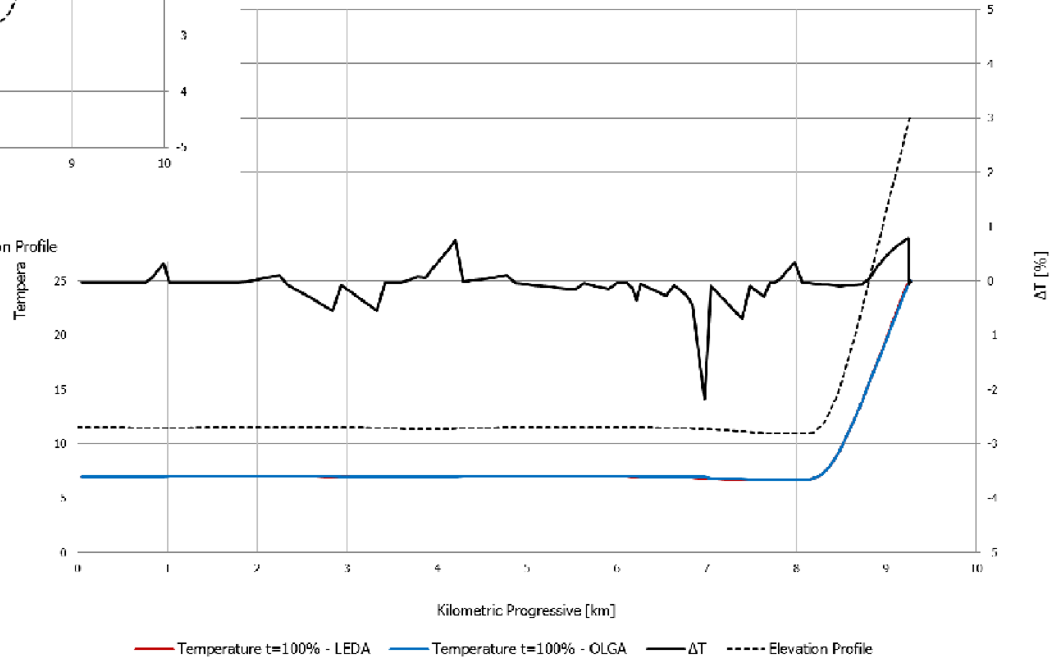




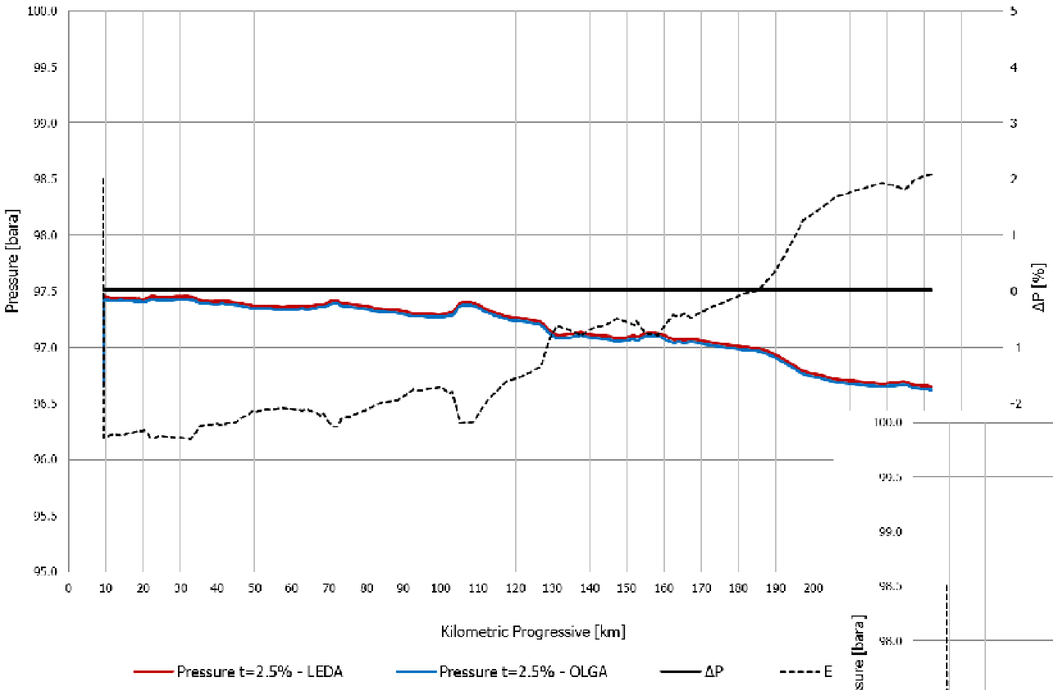
STREAMLINE PIPELINE ENGINEERING

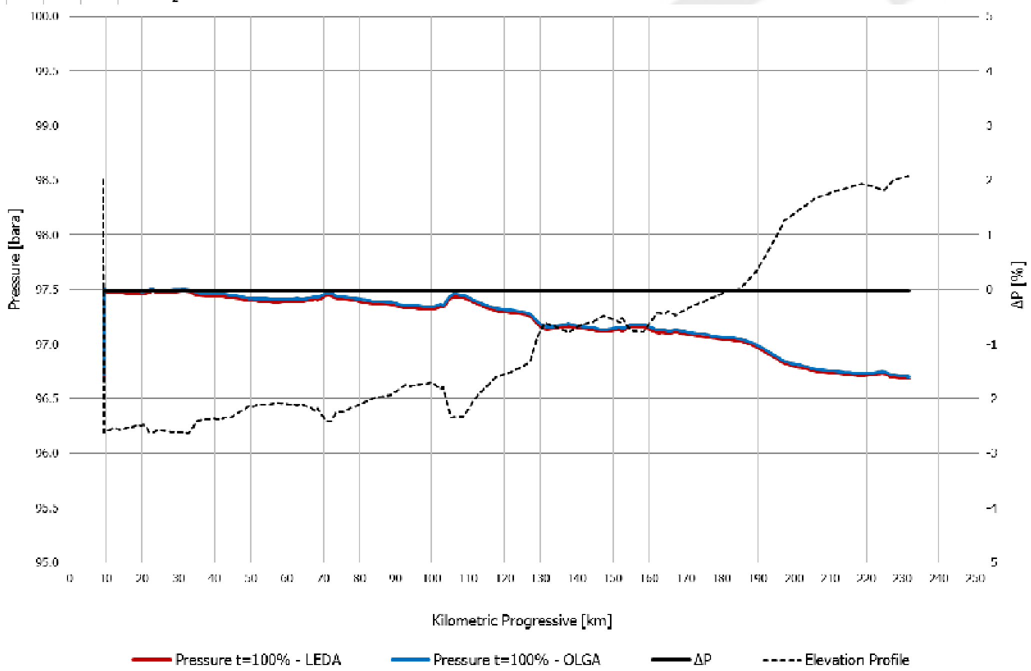
Flowline Shut-down – Dry Gas - COMPARISON



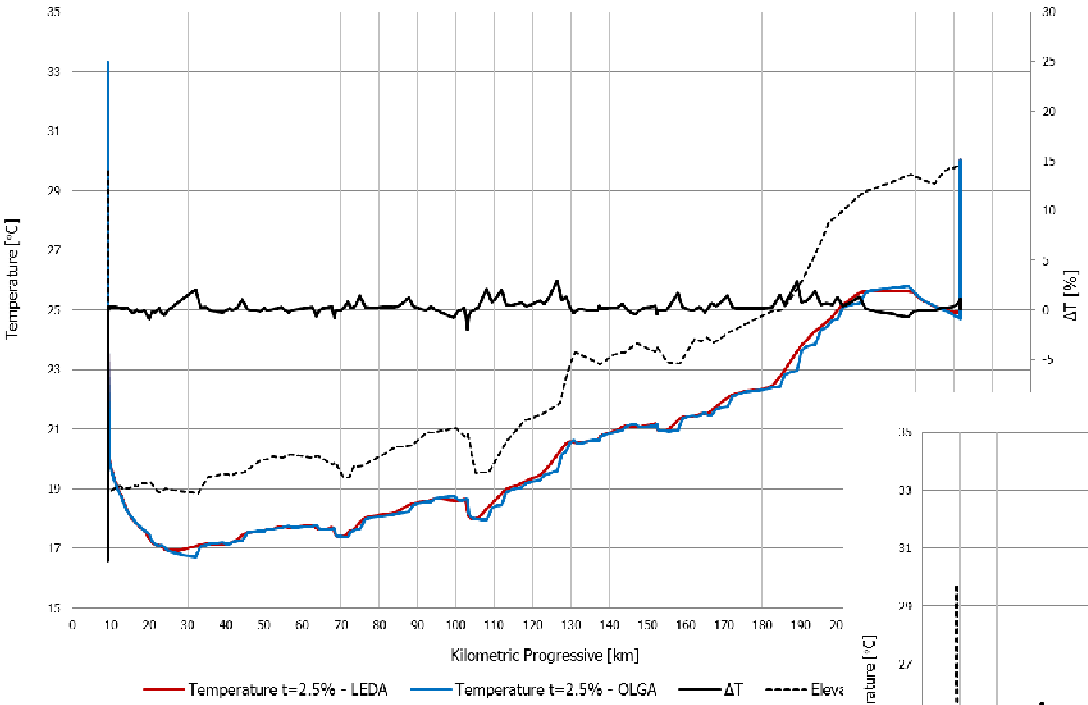


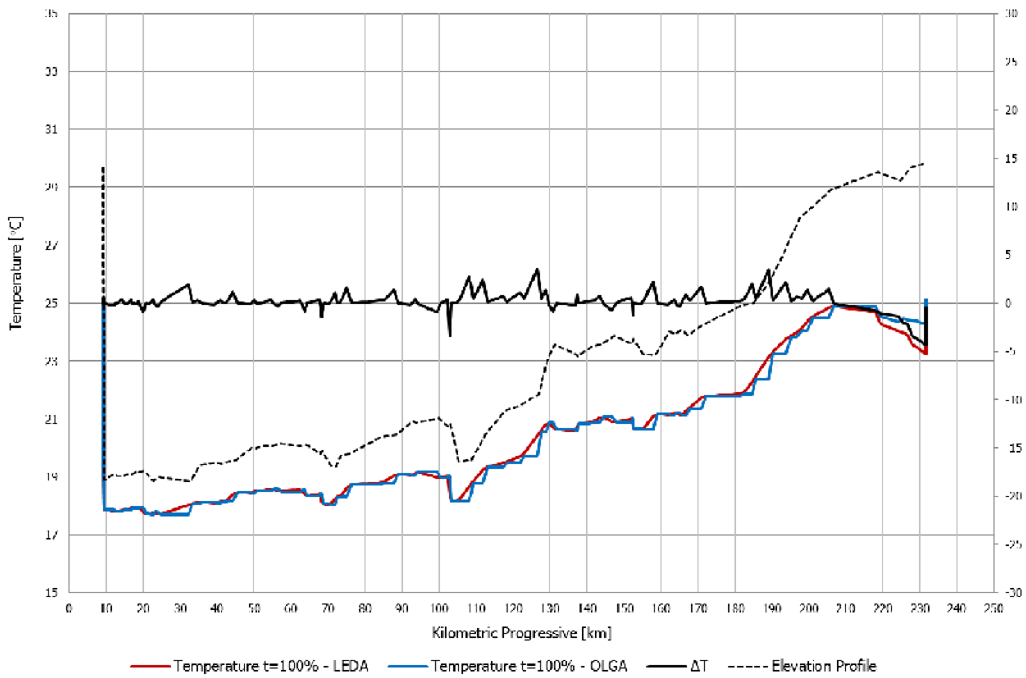
Trunkline Shut-down – Dry Gas - COMPARISON





Trunkline Shut-down – Dry Gas - COMPARISON





Flowline (8inch)

Depressurization Simulation

Dry Gas

Flowline Depressurization (B/D) – Dry Gas: Sum up

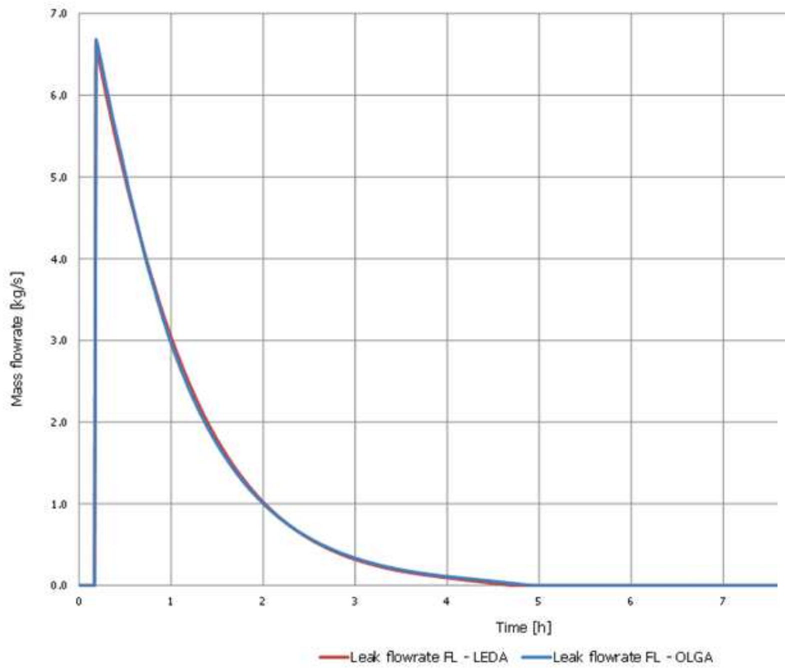
Compared variables are:

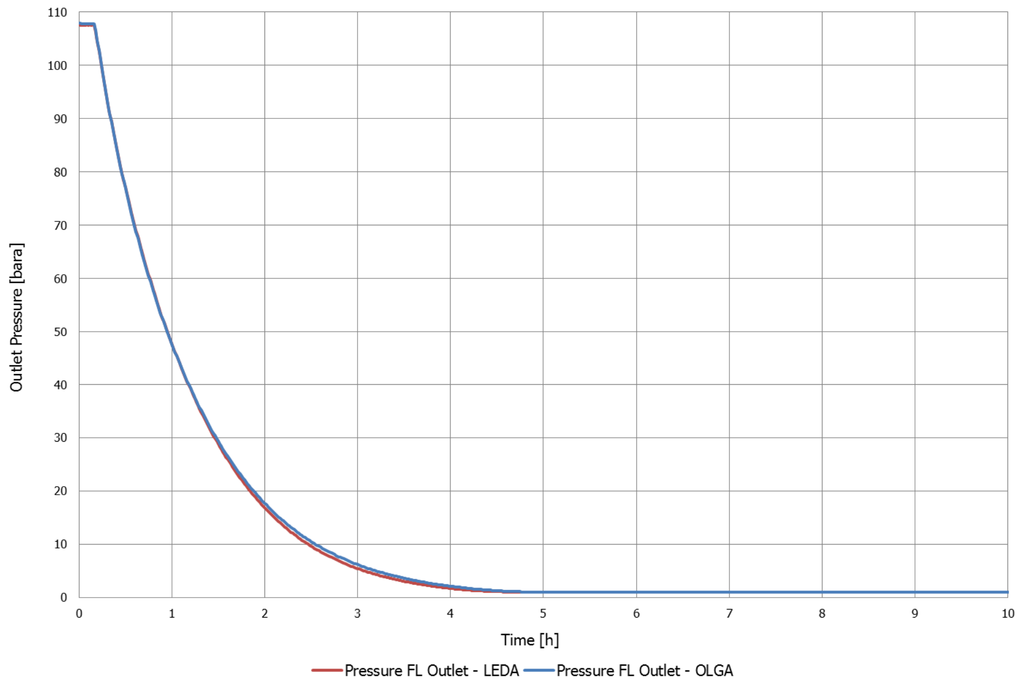
1. Leak Flowrate vs. time at the Flowline discharge (Outlet).
2. Pressure vs. time at the Flowline discharge (Outlet).
3. Temperature vs. time at the Flowline far end (Inlet).
4. Temperature vs. time at the Flowline discharge end (Outlet).

Remarks:

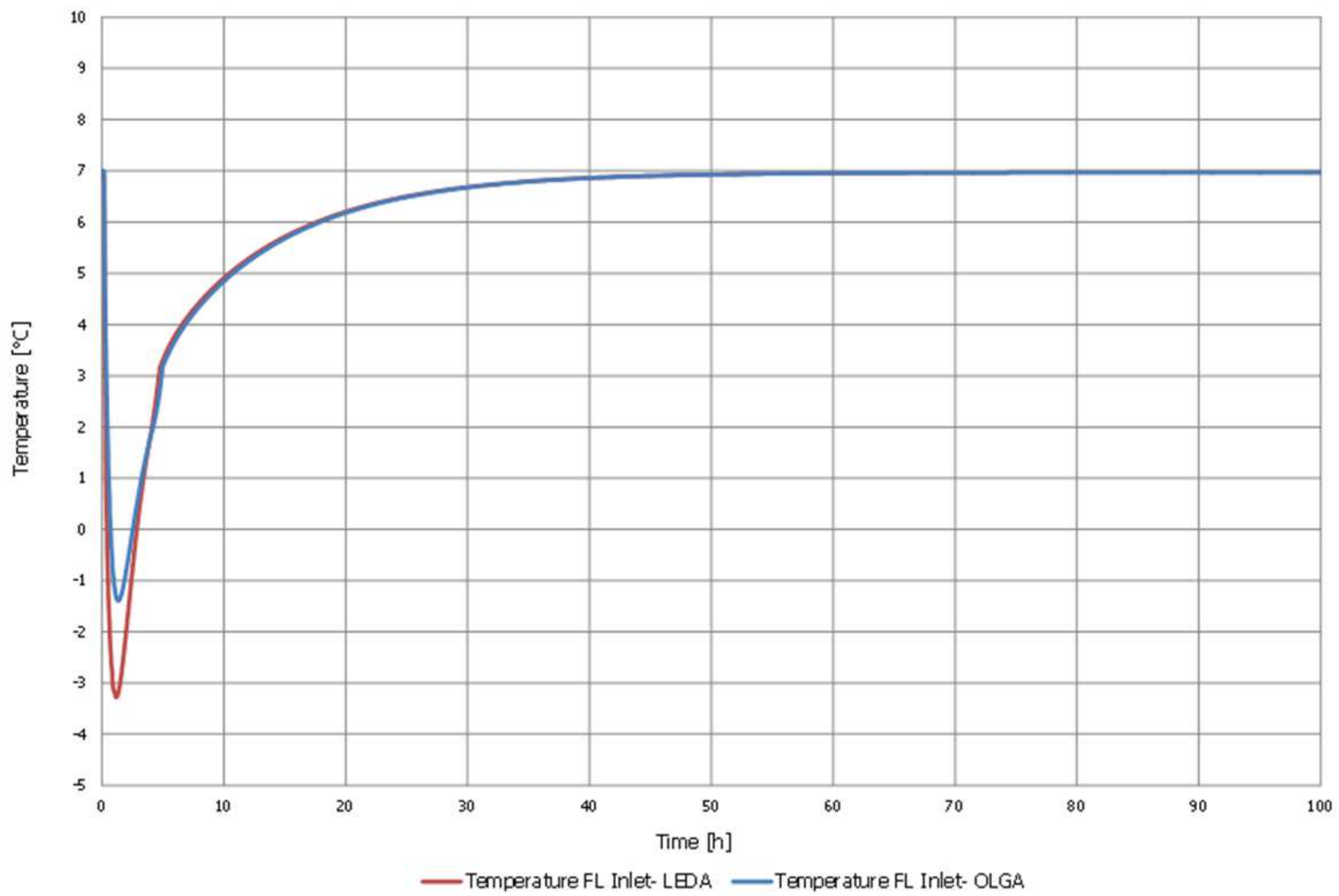
- No significant differences were noted for **Leak Flowrate** and **Pressure**.
- Different behavior is noted for **Temperature at the flowline far end**: LEDA indicates a cooling effect (represented by low temperature), which is not reported by OLGA.
- No significant differences were noted **at the pipeline discharge**.

Flowline Depressurization (B/D) – Dry Gas: COMPARISON

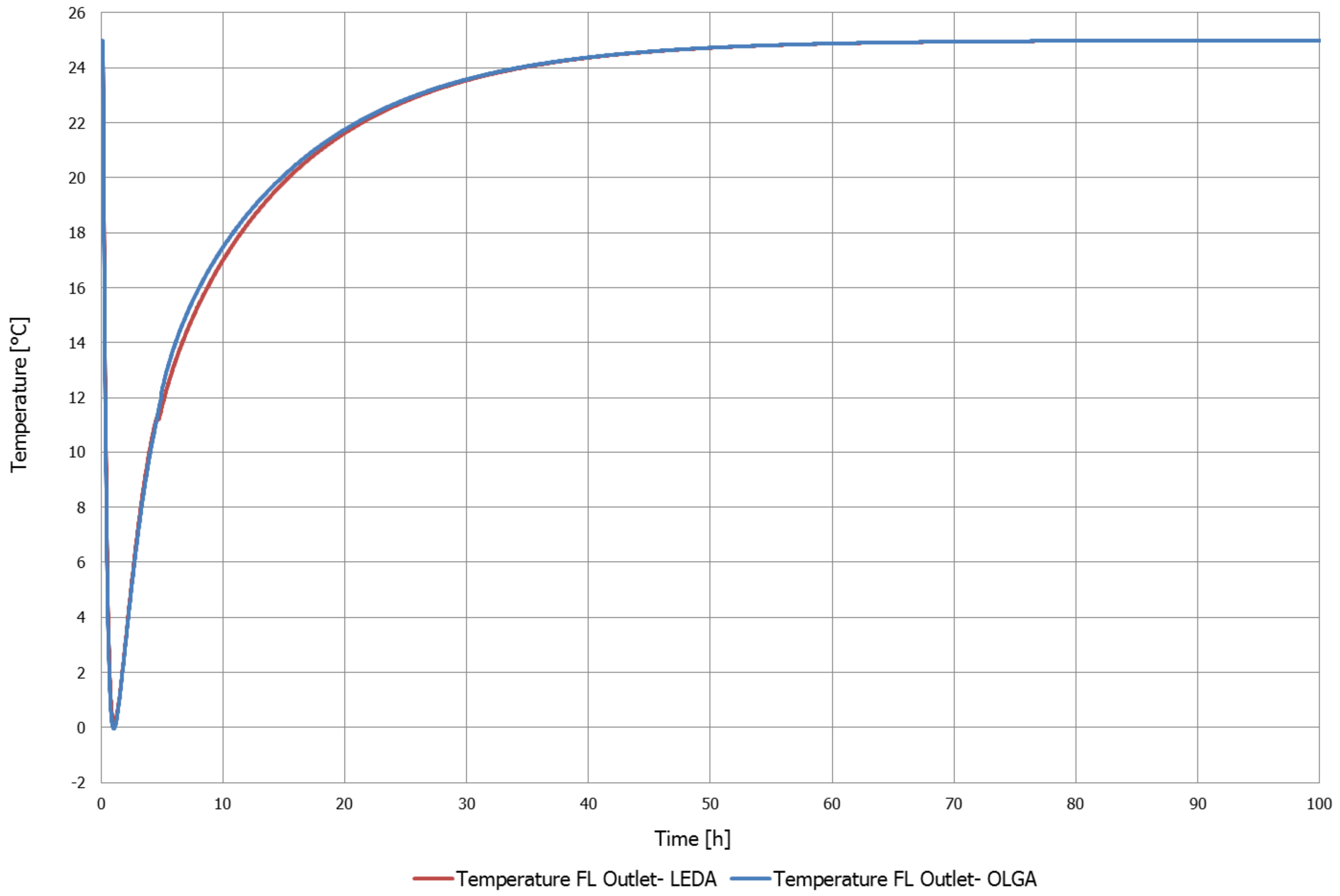




Flowline Depressurization (B/D) – Dry Gas: COMPARISON



Flowline Depressurization (B/D) – Dry Gas: COMPARISON



Trunkline (24inch)

Depressurization Simulation

Dry Gas

Trunkline Depressurization (B/D) of Dry Gas: Sum up

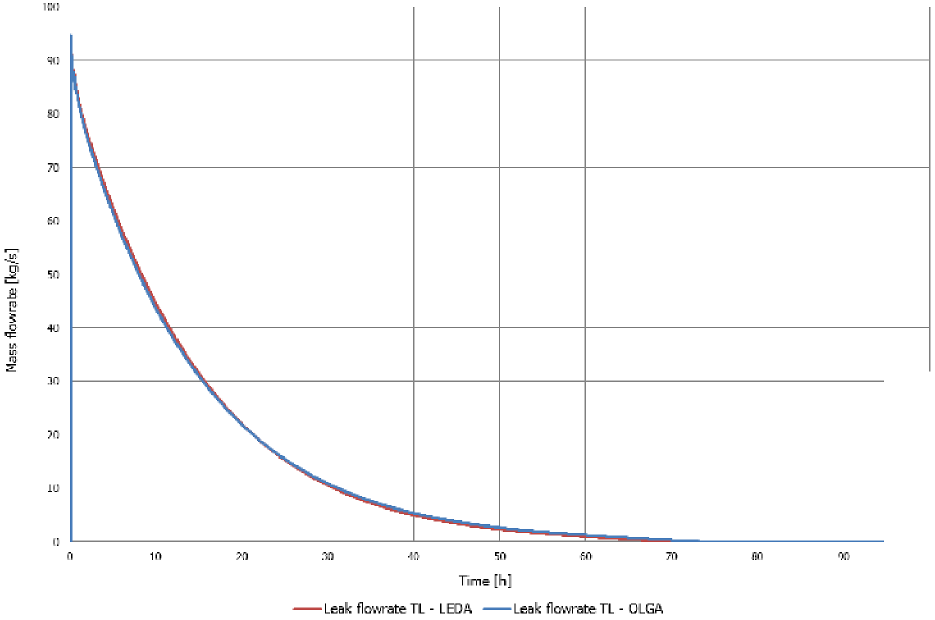
Compared Variables:

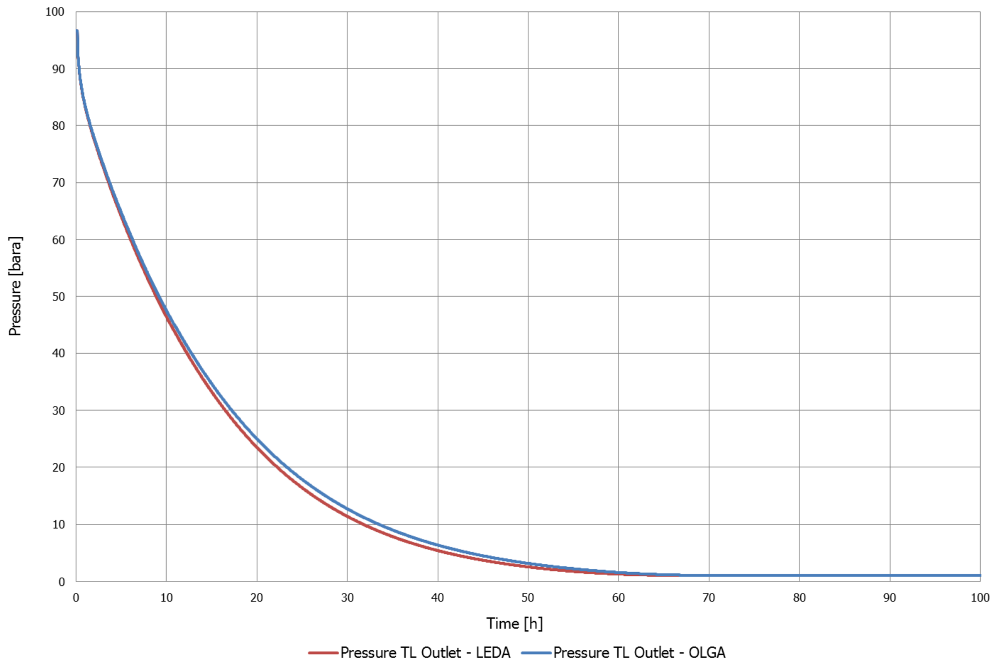
1. Leak Flowrate vs. time at the Trunkline discharge (Outlet).
2. Pressure vs. time at the Trunkline discharge (Outlet).
3. Temperature vs. time at the Trunkline far end (Inlet).
4. Temperature vs. time at the Trunkline discharge end (Outlet).
5. Temperature vs. Trunkline profile when Pressure equalization with the ambient was completed.

Remarks:

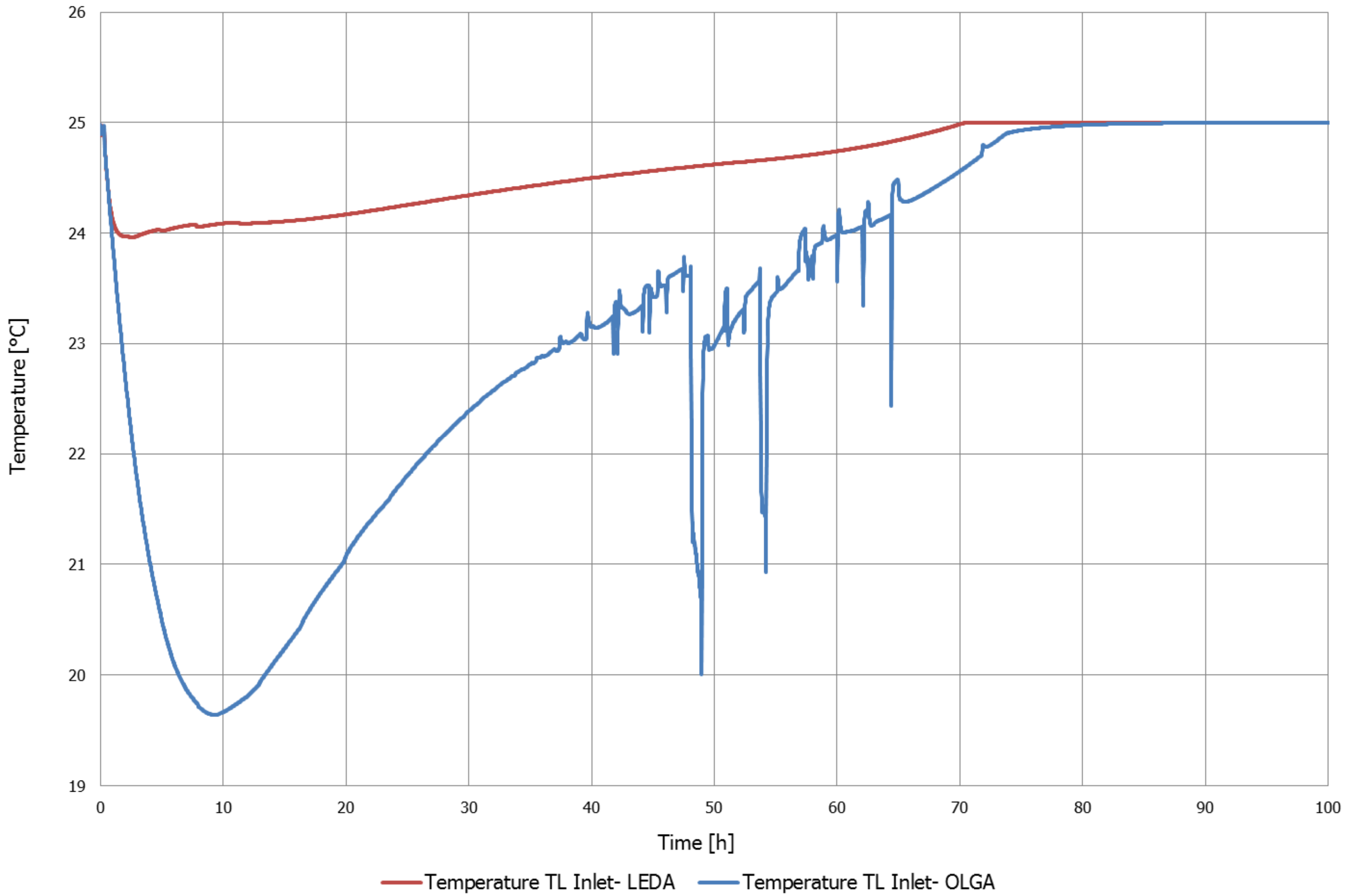
- No significant differences were noted for **Leak Flowrate** and **Pressure**.
- Different behavior is noted for **Temperature both at Trunkline discharge** and **far end extreme**: OLGA indicates a wider temperature variations with respect to LEDA.

Trunkline Depressurization (B/D) – Dry Gas: COMPARISON

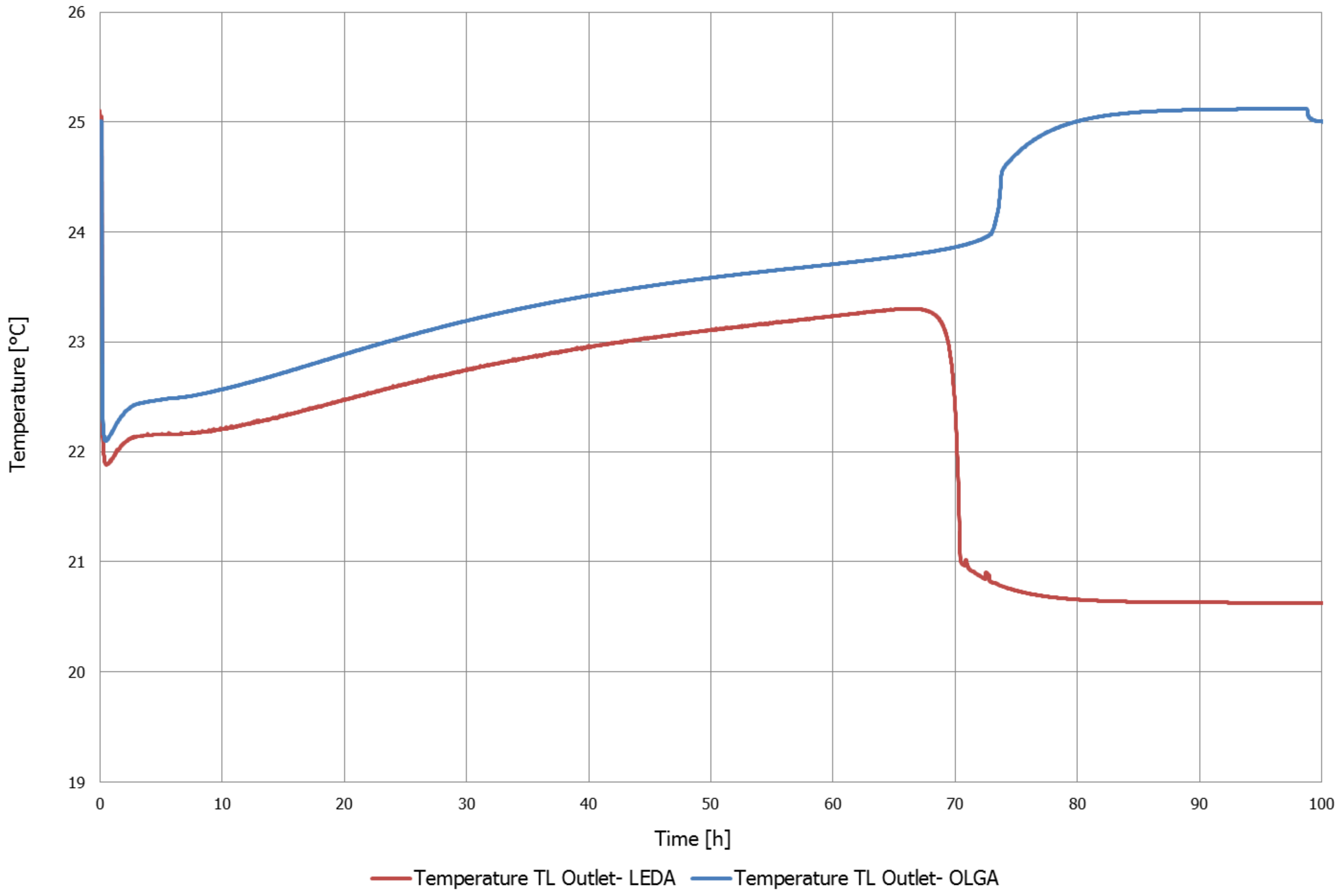




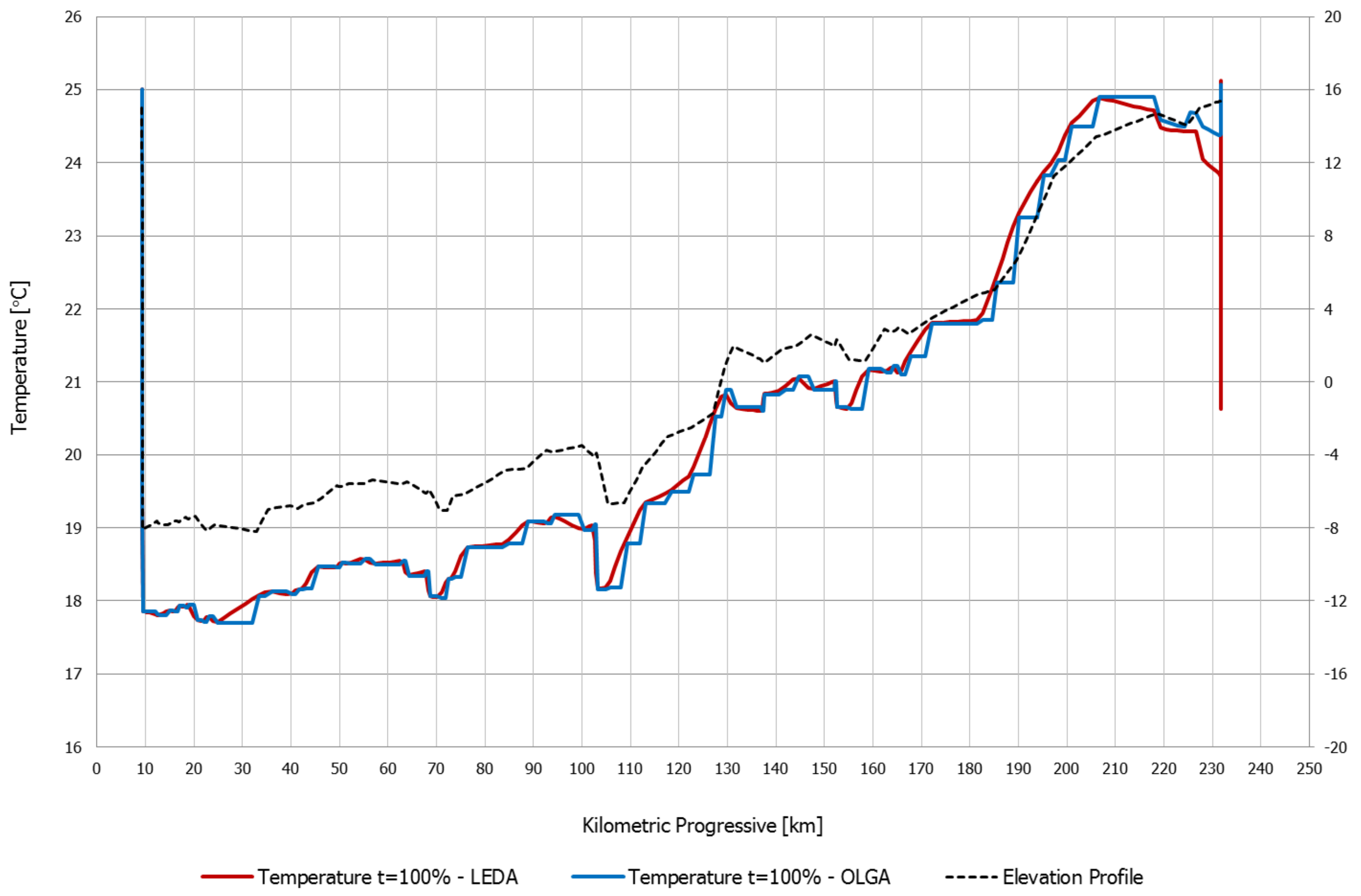
Trunkline Depressurization (B/D) – Dry Gas: COMPARISON



Trunkline Depressurization (B/D) – Dry Gas: COMPARISON



Trunkline Depressurization (B/D) – Dry Gas: COMPARISON



STREAMLINE PIPELINE ENGINEERING

F/L (10 inch) and T/L (32 inch)

Shut-down Simulation

Light Gas Condensate

Shut-down - Light Gas Condensate: SUM-UP

Compared Variables (for both Flowline and Trunkline):

1. Pressure along the pipelines at the beginning of transient analysis (the instant corresponding to 2.5% of the total time foreseen to reach steady state condition) and at the final instant of the shut-down i.e. when steady state condition has been achieved (t=100%).
2. Temperature along the pipelines during the shut-down (2.5% and 10% of the total time required to reach steady state condition).
3. Gas and liquid Hold-up along the pipelines at the end of the shut-down i.e. when steady condition have been achieved.
4. The deviation for both pressure and temperature, expressed in **percentage and** calculated using the following equation:

$$dev[\%] = \frac{x_{i}\,LEDA - x_{i}\,OLGA}{x_{i}\,OLGA}\,\%$$

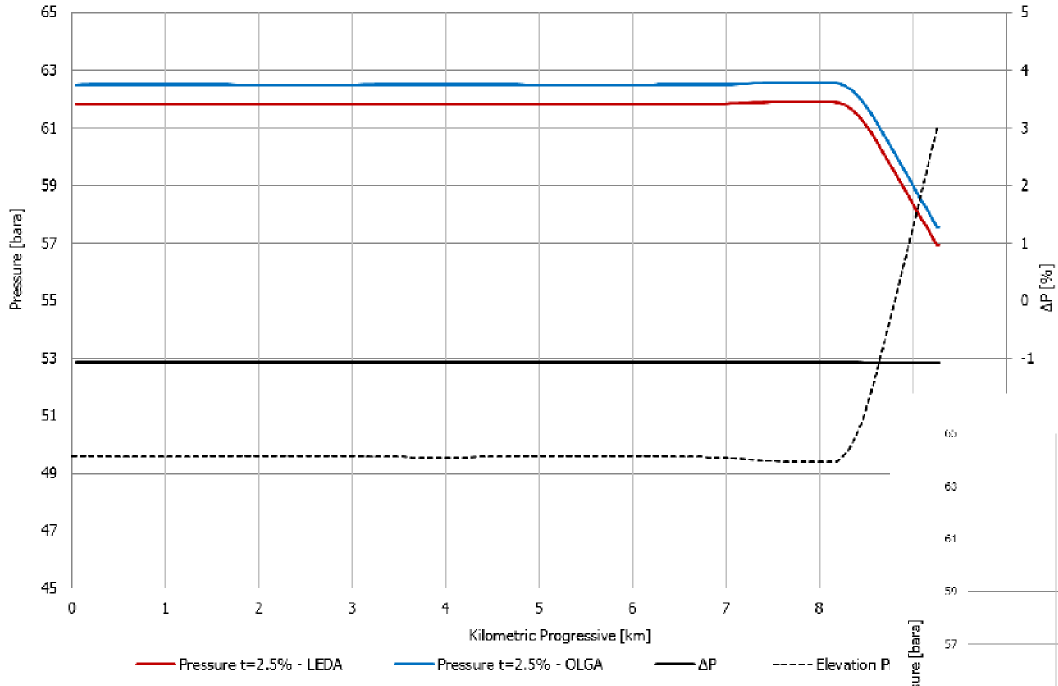
Remarks:

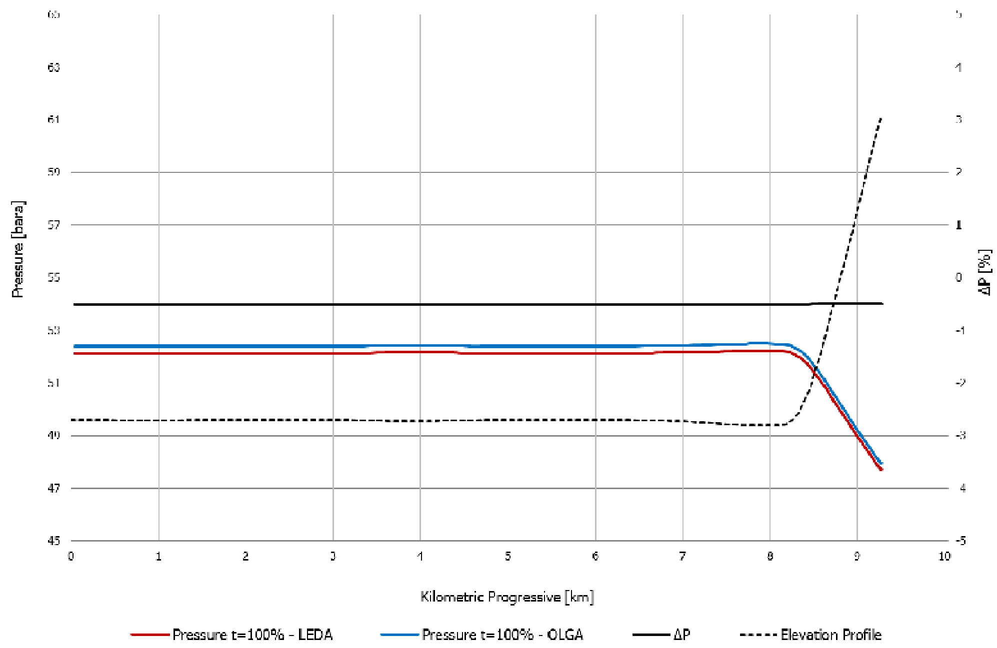
- No significant differences were noted for **Pressure** and **Temperature** along both Flowline and Trunkline**.**

- No significant differences were noted for **Gas and Liquid Mass Content** profiles along both Flowline and Trunkline.

STREAMLINE PIPELINE ENGINEERING

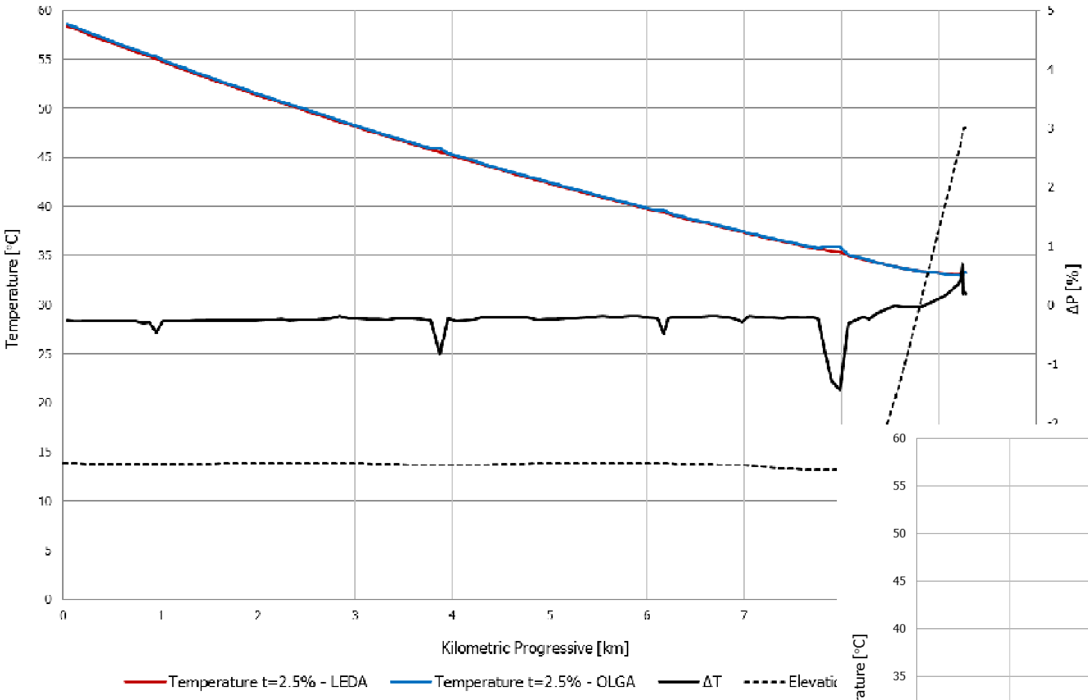
Flowline Shut-down – Light Gas Condensate: COMPARISON

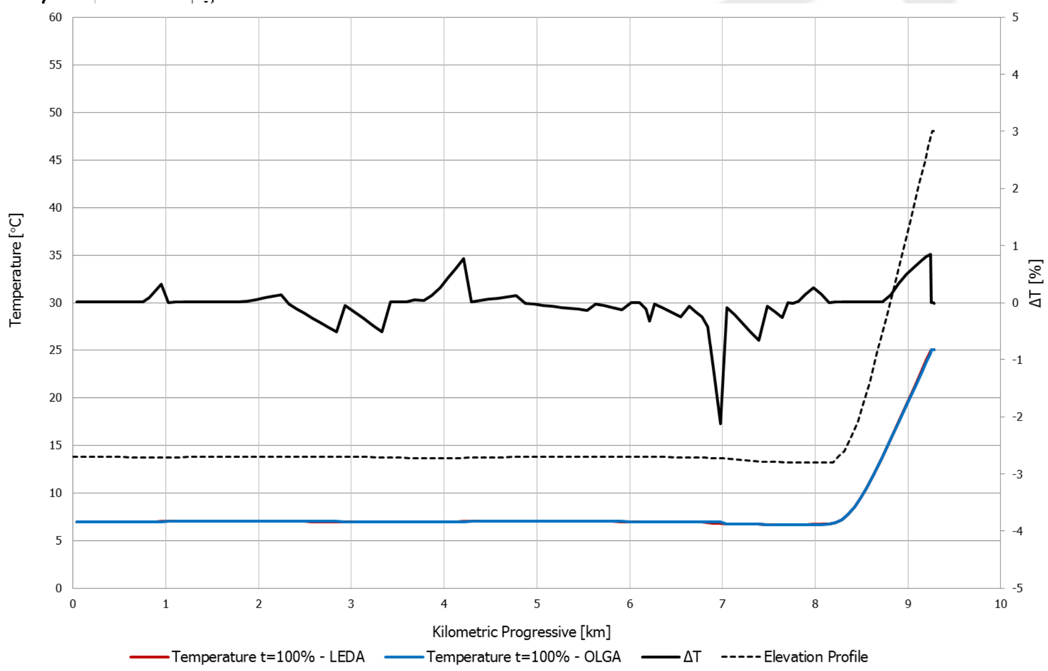




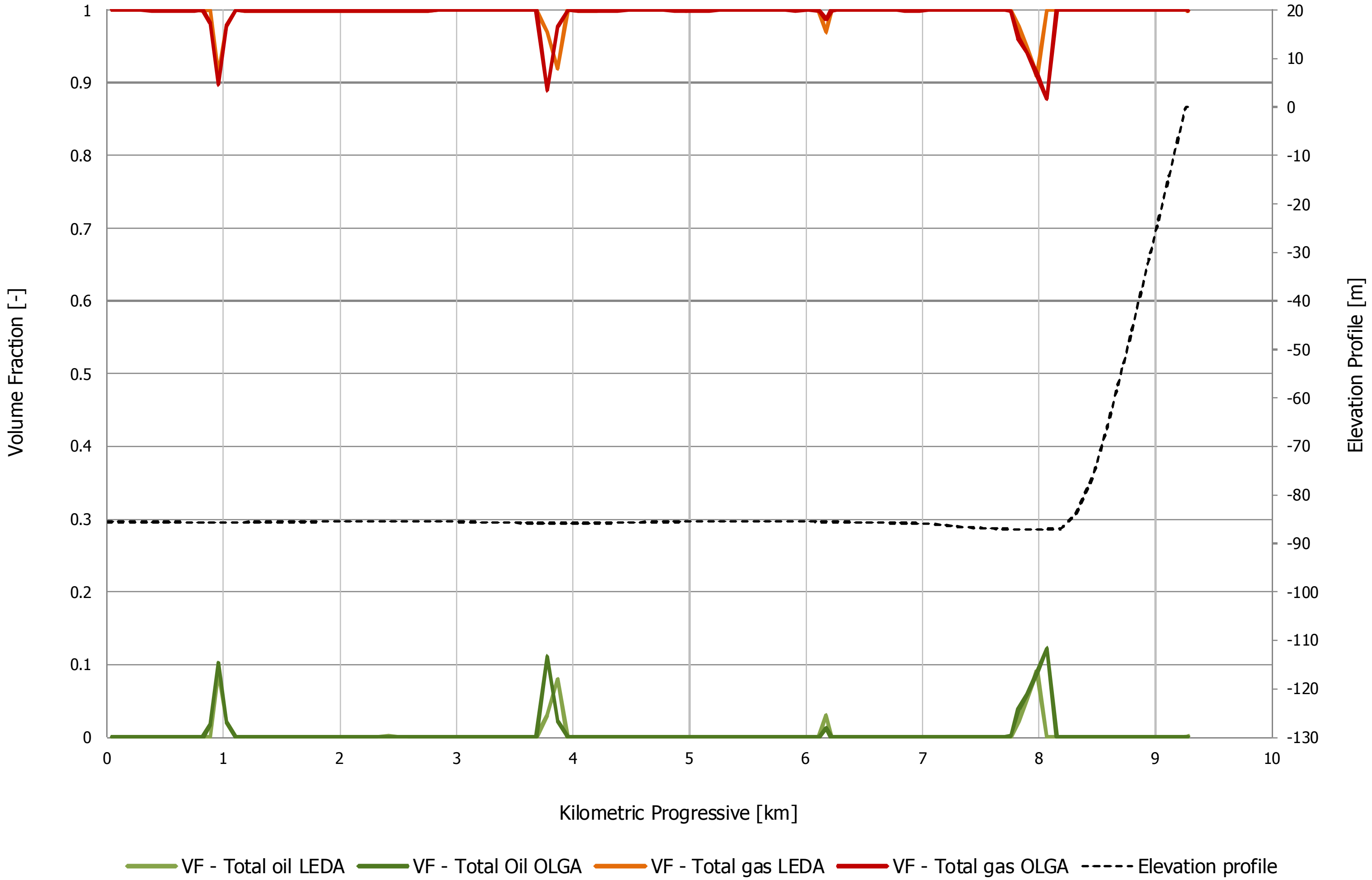
STREAMLINE PIPELINE ENGINEERING

Flowline Shut-down – Light Gas Condensate: COMPARISON

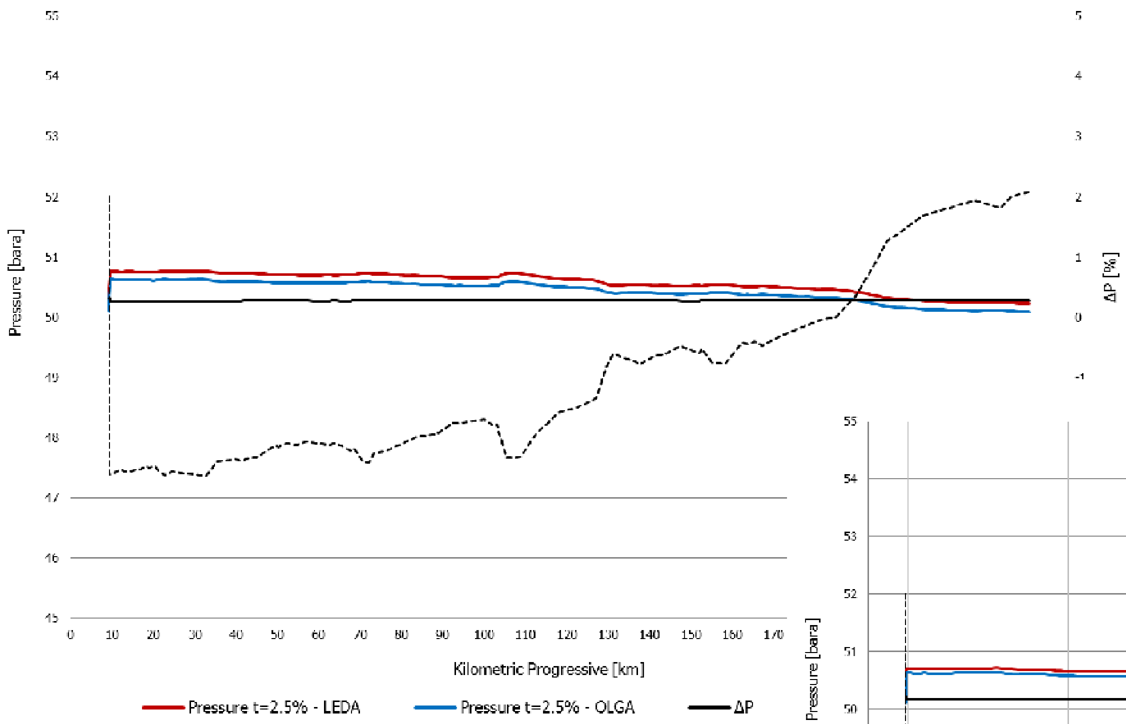


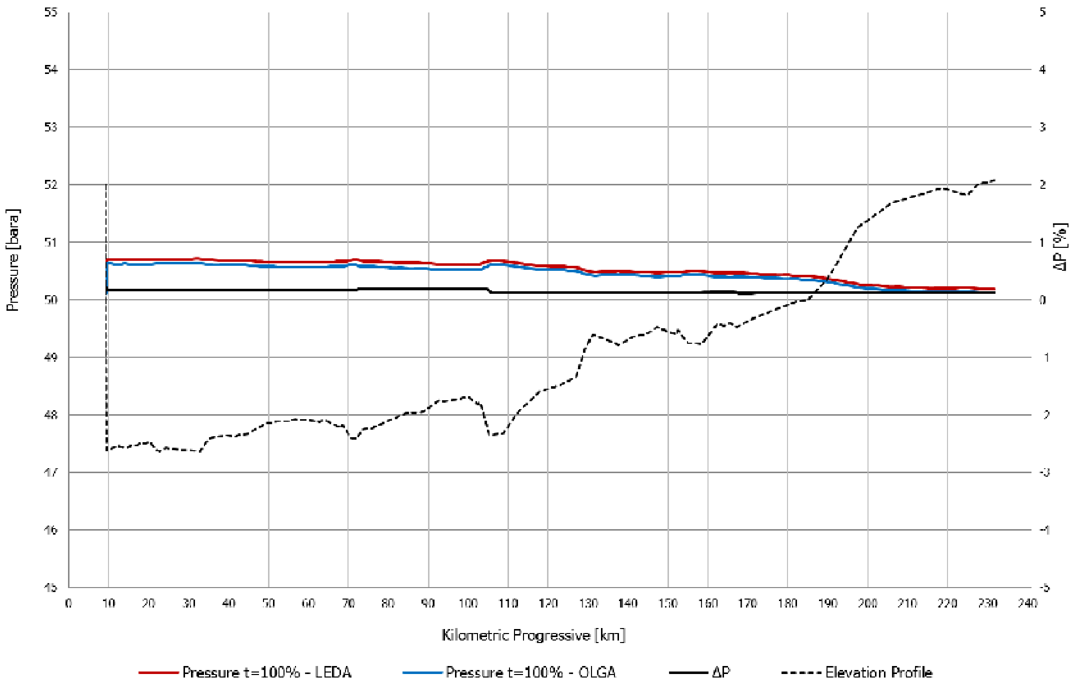


Flowline Shut-down – Light Gas Condensate: COMPARISON



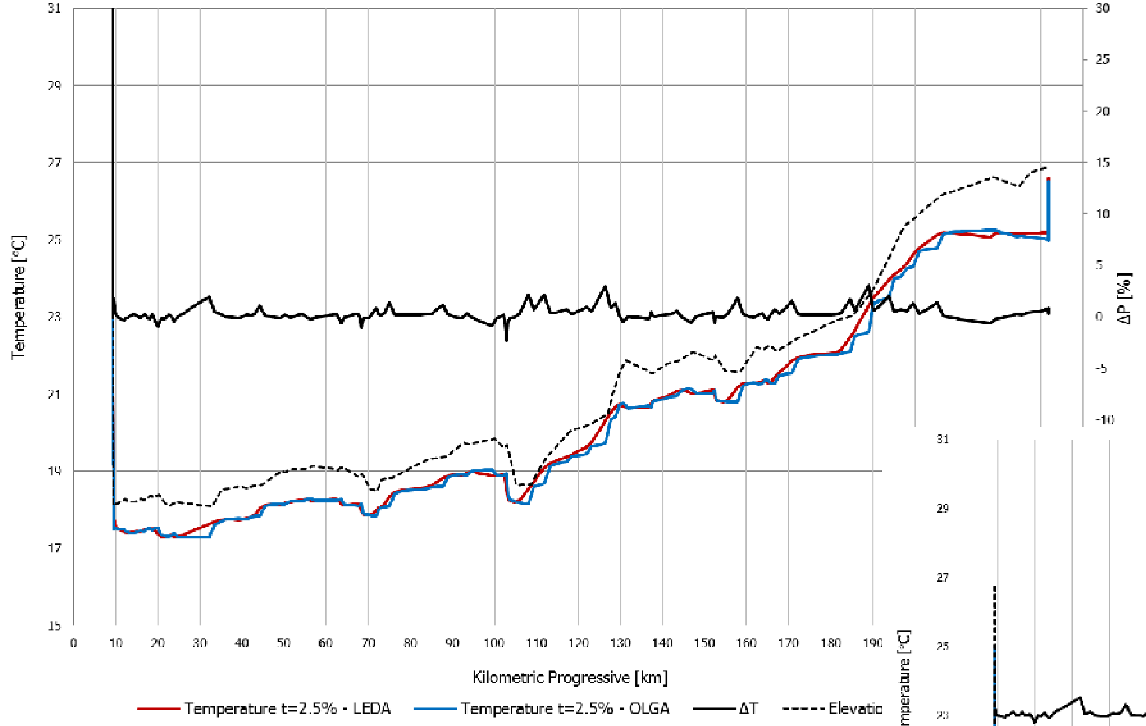
Trunkline Shut-down – Light Gas Condensate: COMPARISON

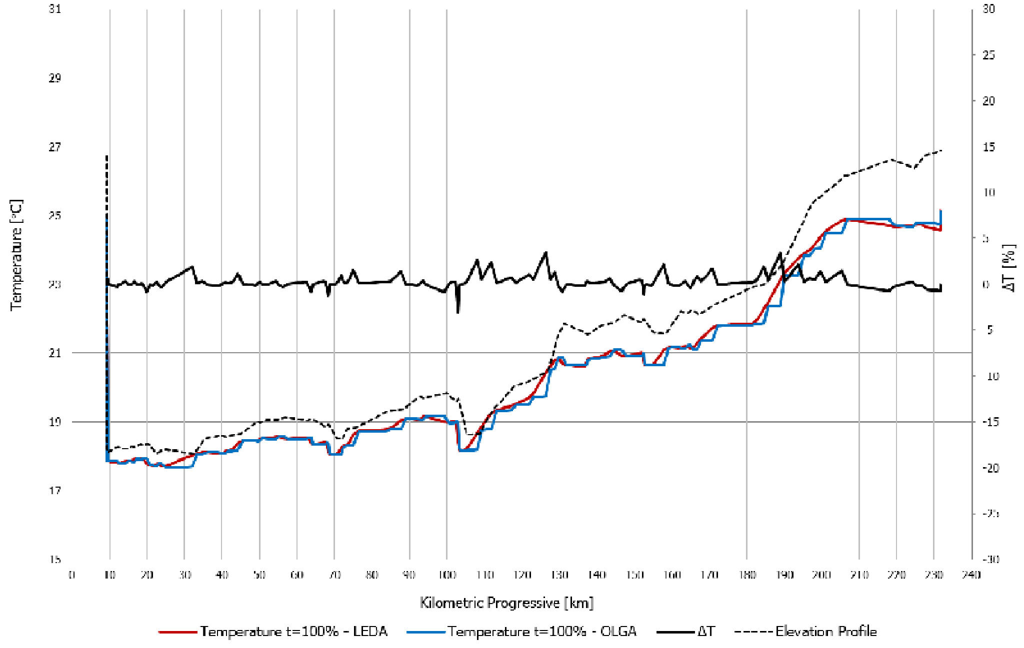




STREAMLINE PIPELINE ENGINEERING

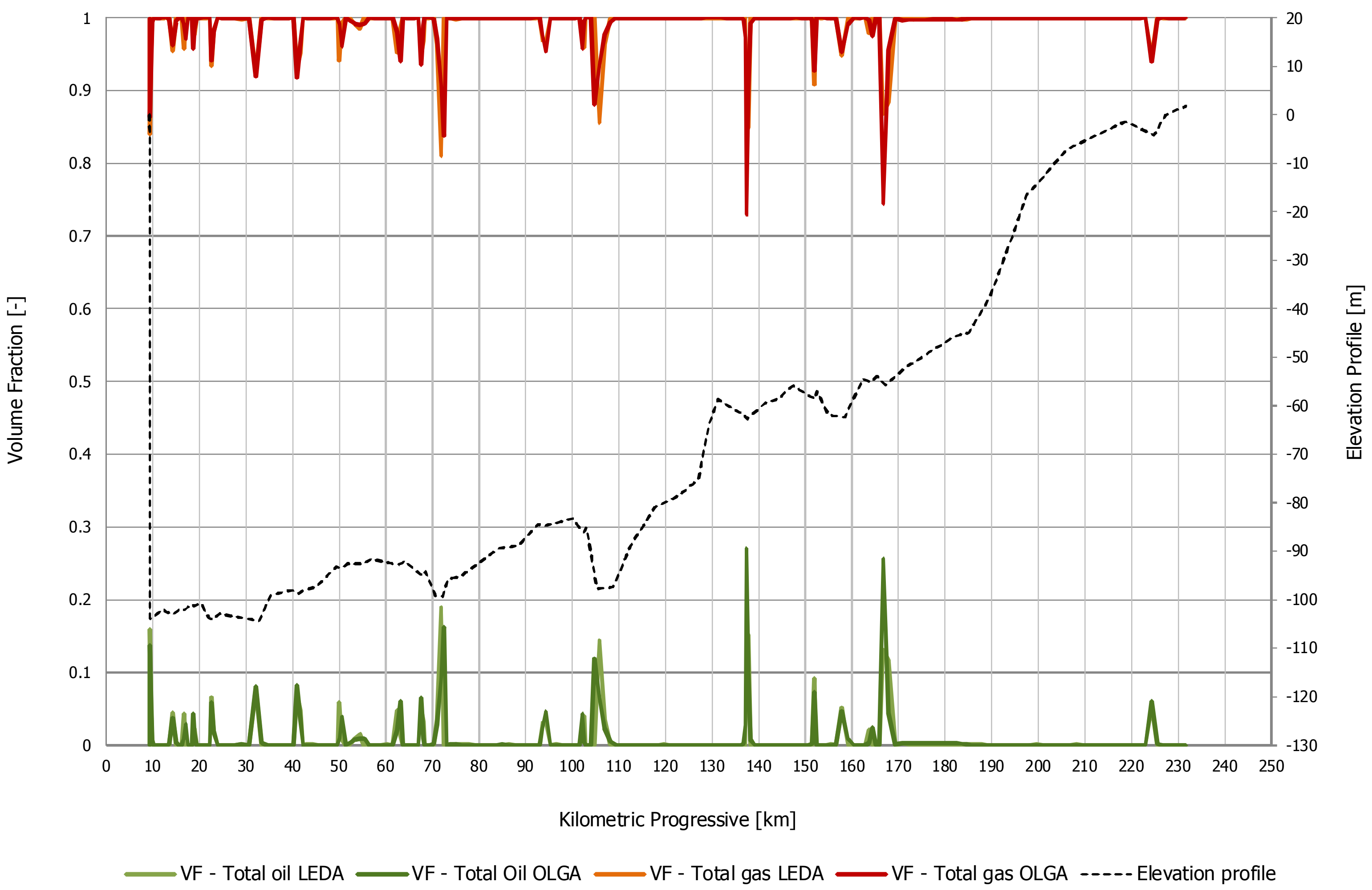
Trunkline Shut-down – Light Gas Condensate: COMPARISON





STREAMLINE PIPELINE ENGINEERING

Trunkline Shut-down – Light Gas Condensate: COMPARISON



Flowline (10 inch)

Depressurization Simulation

Light Gas Condensate

Flowline Depress. (B/D) – Light Gas Cond: Sum up

Compared Variables:

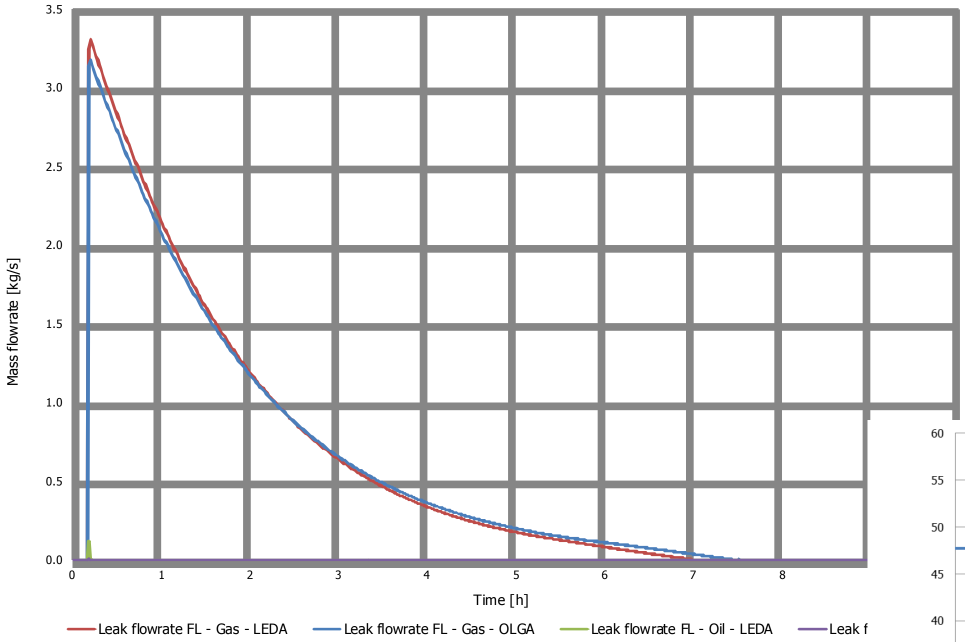
1. Leak vs. time at the Flowline discharge (Outlet).
2. Pressure vs. time at the Flowline discharge (Outlet).
3. Pressure along the Flowline at t=Tmin and at the 5% of the total time necessary for depressurization with the deviation.
4. Gas and liquid hold-up along the Flowline at the final instant of the depressurization.
5. Temperature along the Flowline approximately 1 hour after leak opening.
6. Temperature vs. time at the Flowline far end (Inlet).
7. Temperature vs. time at the Flowline discharge (Outlet).

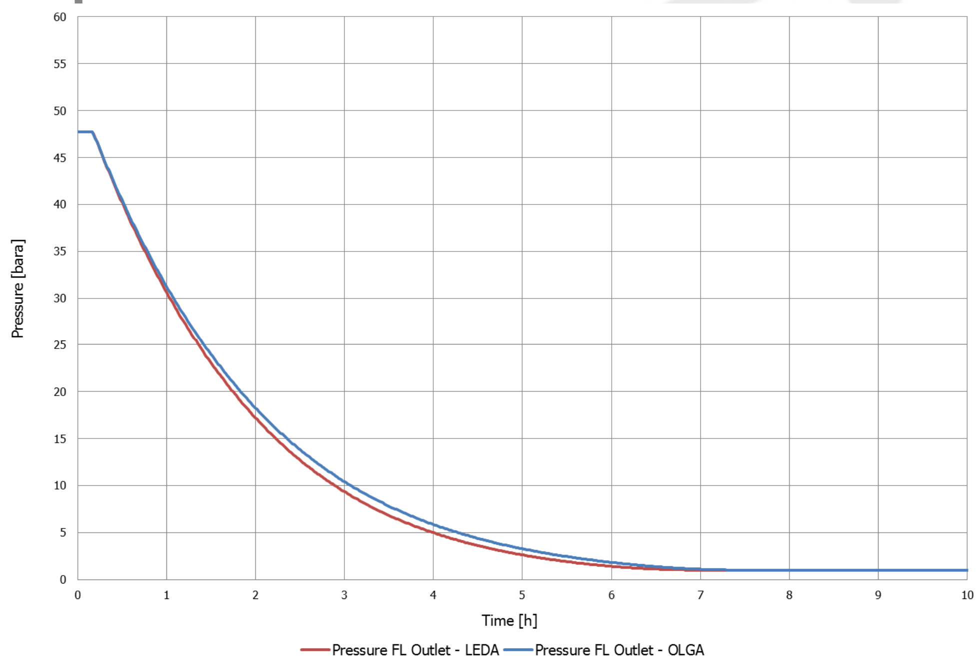
Remarks:

- No significant differences were noted for **Leak Flowrate, Pressure** and **Hold-up**.
- Minor differences were noted for **Temperature at the pipeline discharge** : within 1 °C.
- Different behavior is noted for the **Temperature at the pipeline far end**: LEDA indicates a cooling effect (lower temperature) which is not reported by OLGA.

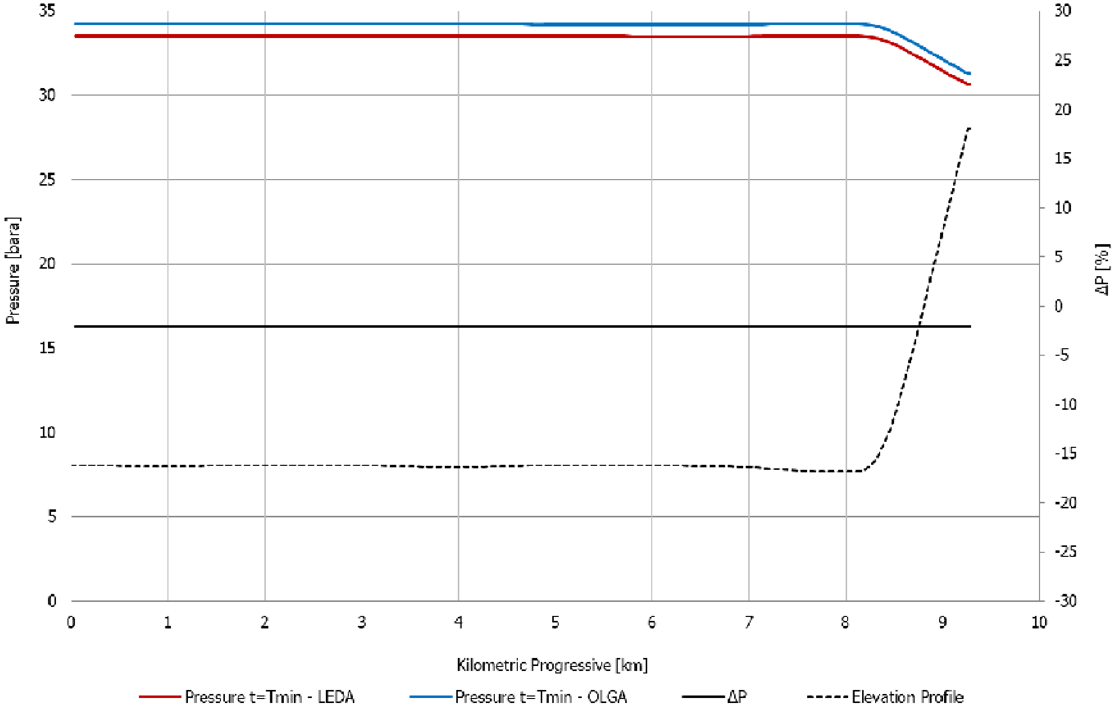
  The **Temperature profile** indicates that the low temperature is related to the gas phase (LEDA). OLGA reports a temperature that is a mean value between the oil and gas phase temperature reported by LEDA.

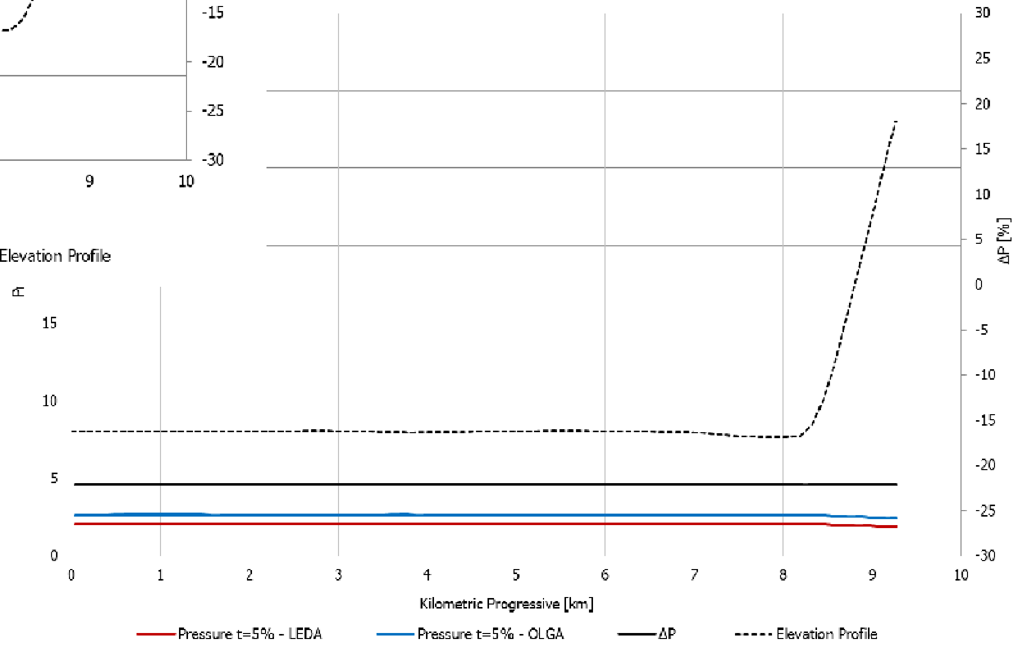
Flowline Depress. (B/D) – Light Gas Cond: COMPARISON



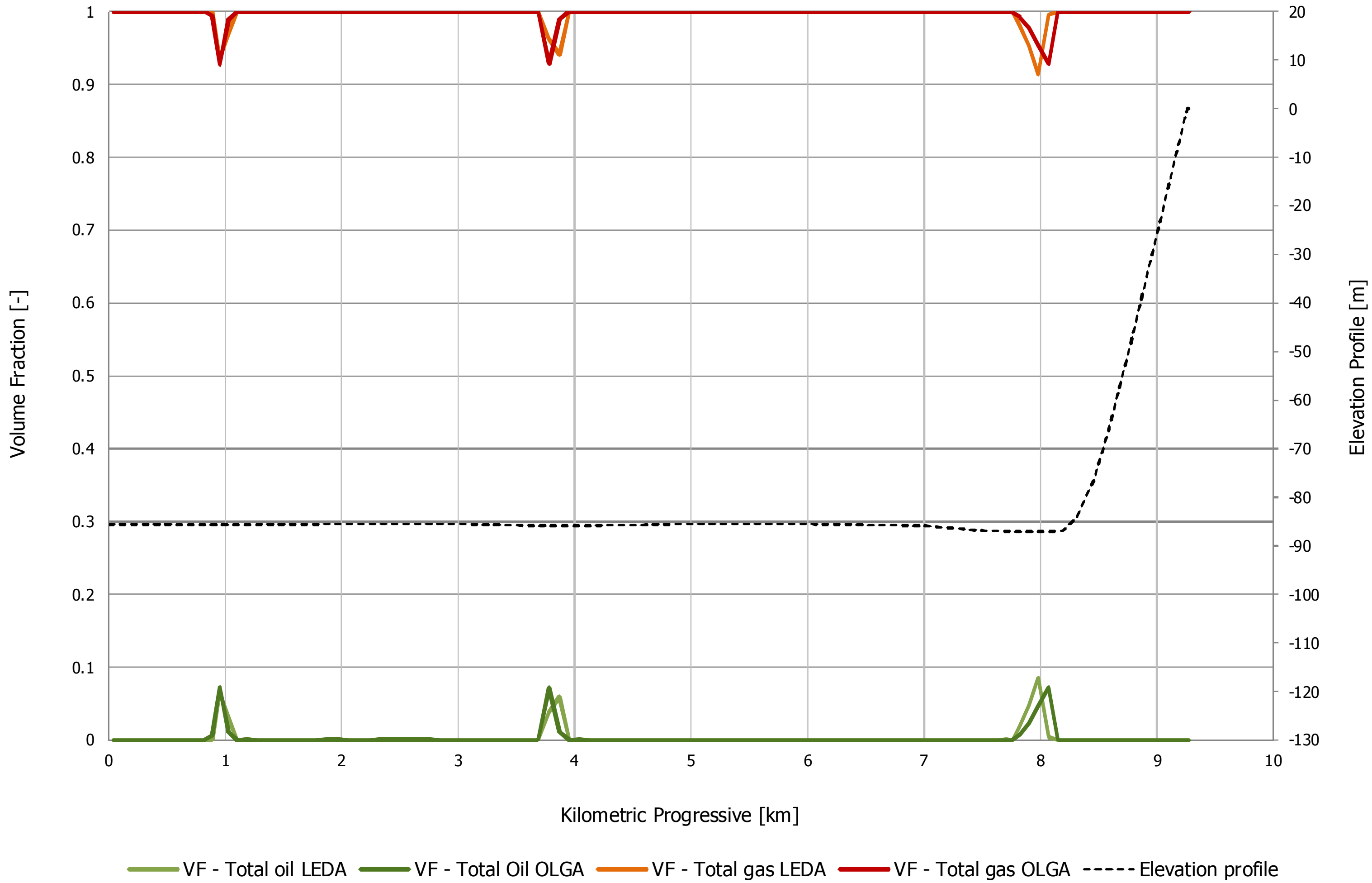


Flowline Depress. (B/D) – Light Gas Cond: COMPARISON

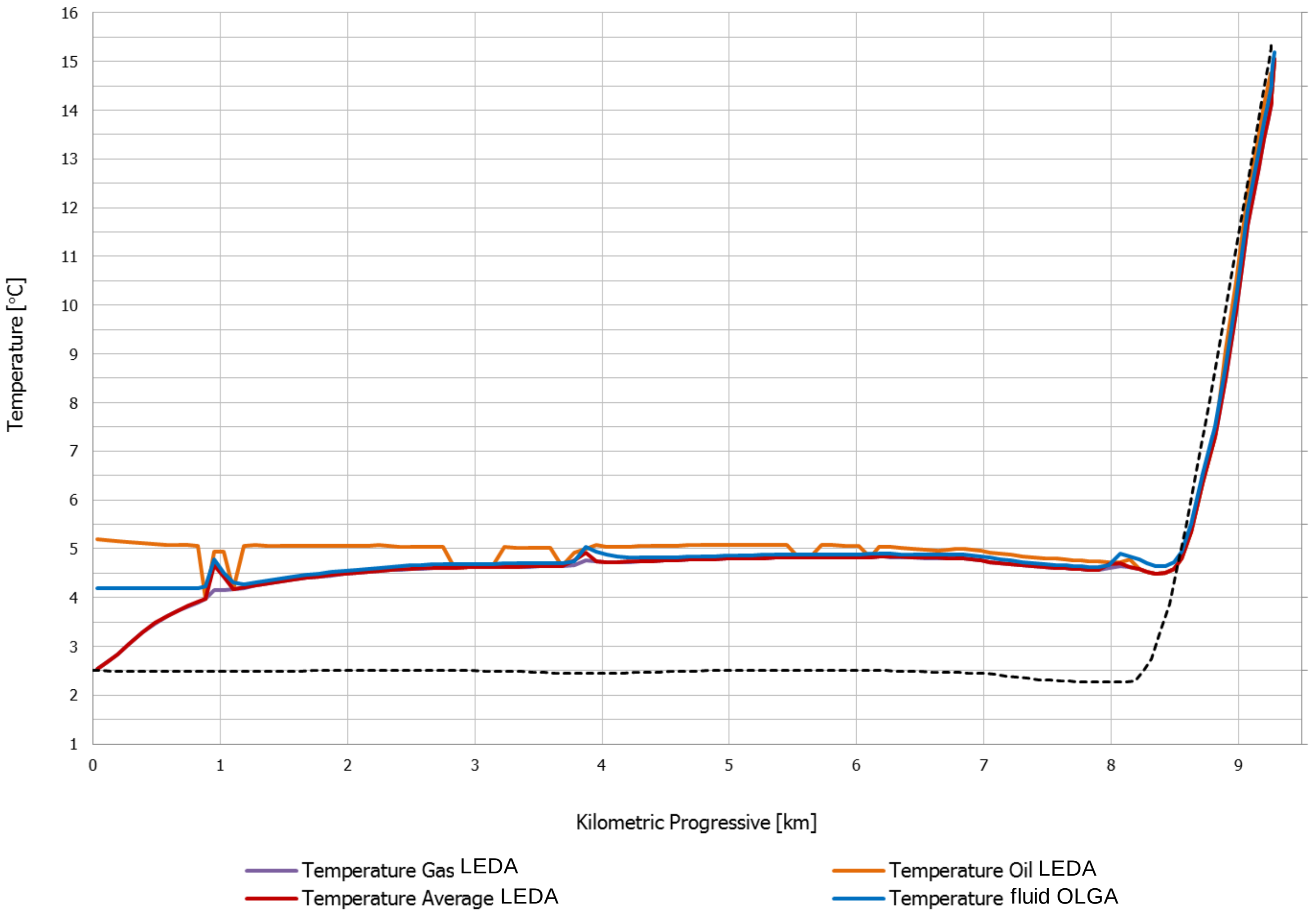




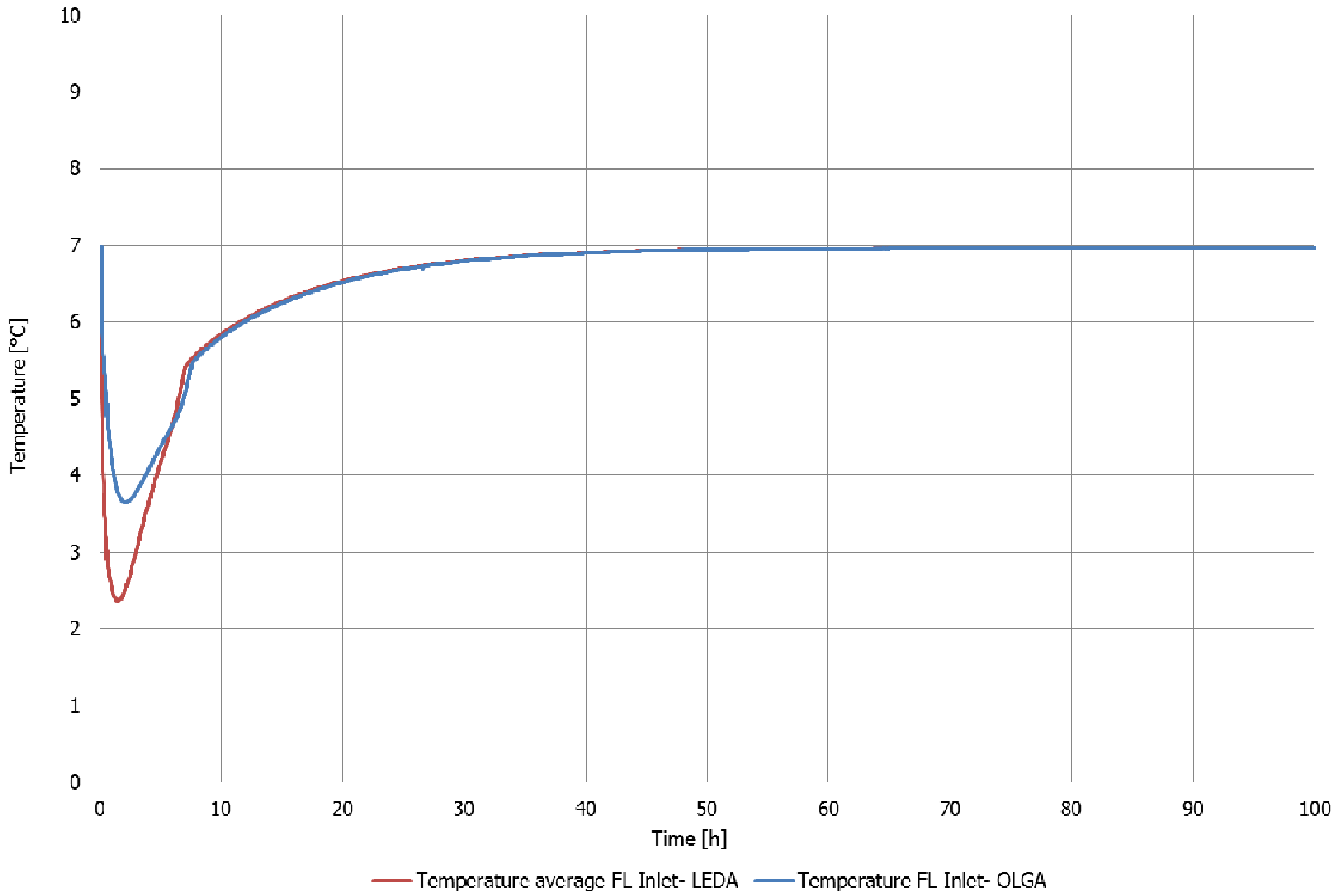
Flowline Depress. (B/D) – Light Gas Cond: COMPARISON



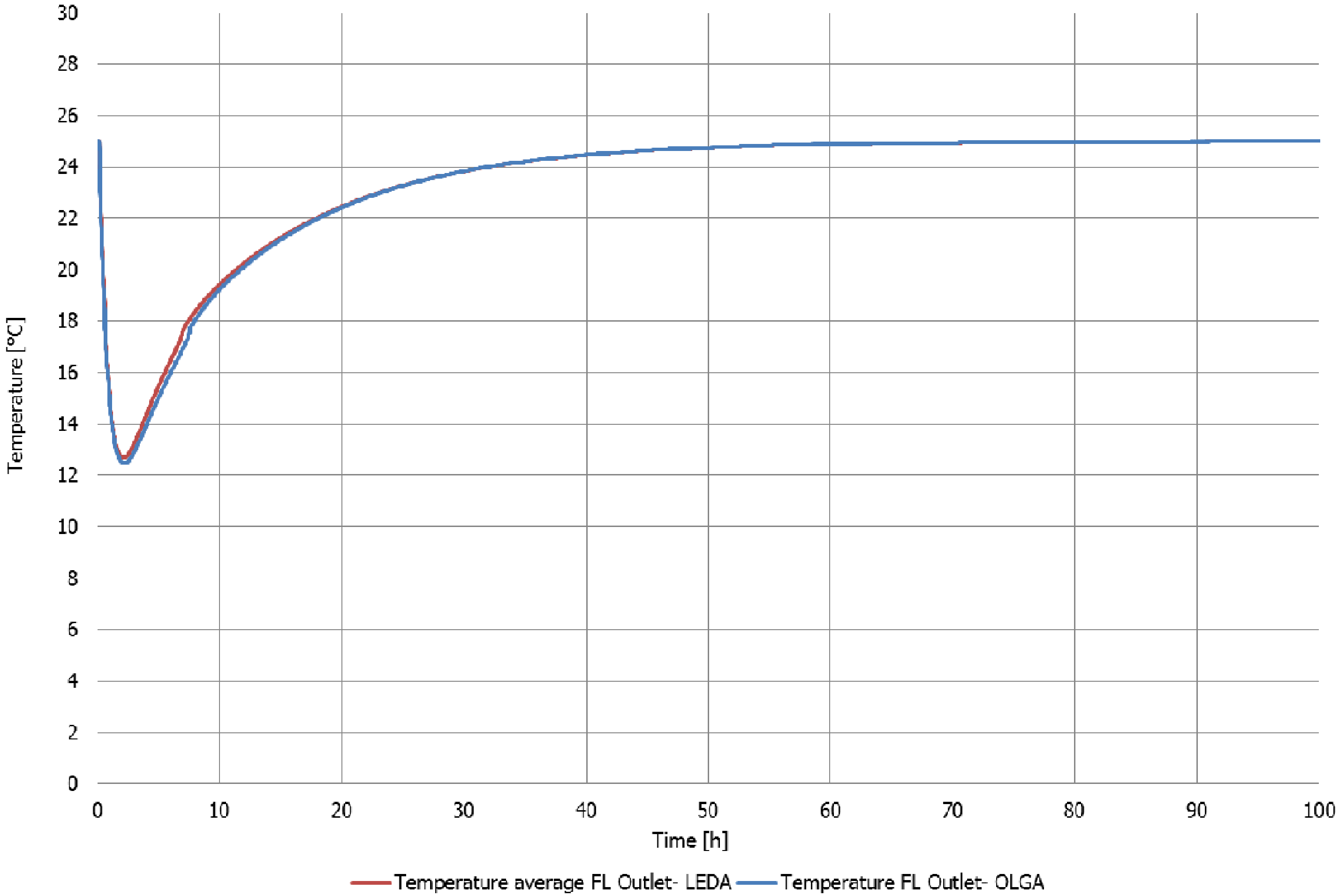
Flowline Depress. (B/D) – Light Gas Cond: COMPARISON



Flowline Depress. (B/D) – Light Gas Cond: COMPARISON



Flowline Depress. (B/D) – Light Gas Cond: COMPARISON



STREAMLINE PIPELINE ENGINEERING

Trunkline (32 inch)

Depressurization Simulation

Light Gas Condensate

Trunkline Depress. (B/D) – Light Gas Cond.: Sum up

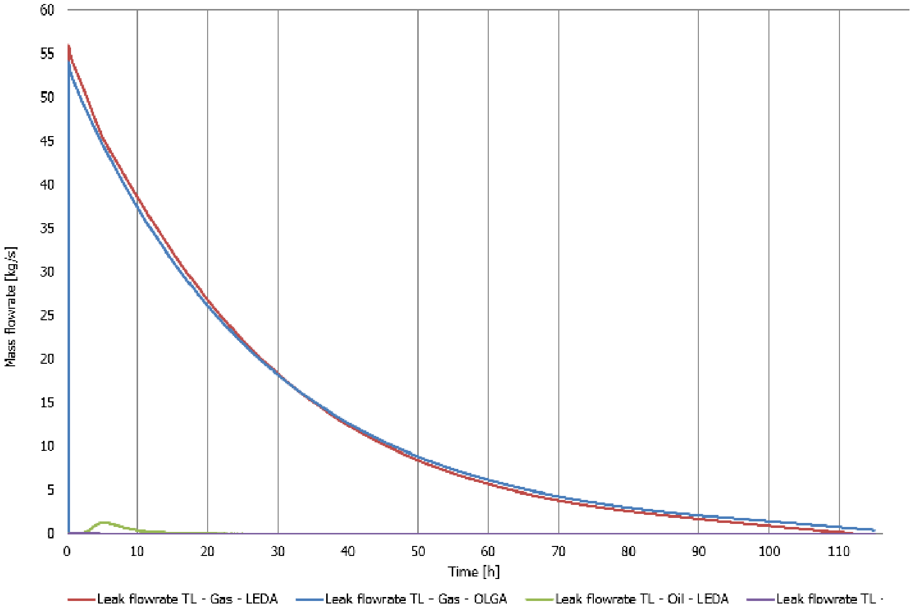
Compared Variables:

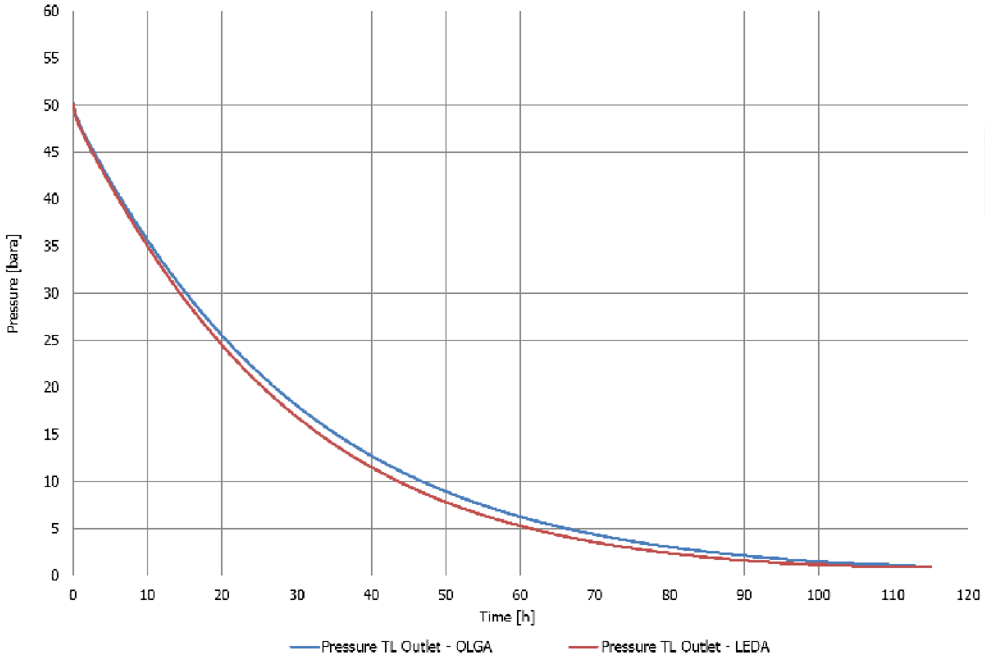
1. Leak Flowrate vs. time at the Trunkline discharge (Outlet).
2. Pressure vs. time at the Trunkline discharge (Outlet).
3. Pressure along the Trunkline at t=Tmin and at the 5% of the total time necessary for depressurization, with the deviation.
4. Gas and liquid Hold-up along the Trunkline at the final instant of the depressurization.
5. Temperature along the Trunkline approximately 1 hour after leak opening.
6. Temperature vs. time at the Trunkline far end (Inlet).
7. Temperature vs. time at the Trunkline discharge (Outlet).

Remarks:

- No significant differences were noted for **Leak Flowrate**, **Pressure** and **Hold-up.**
- No practical difference on **Temperature at the pipeline discharge end**.
- Different behavior for the **Temperature along the Trunkline at the pipeline far end extreme**: OLGA indicates a cooling effect (lower temperature) which is not reported by LEDA.

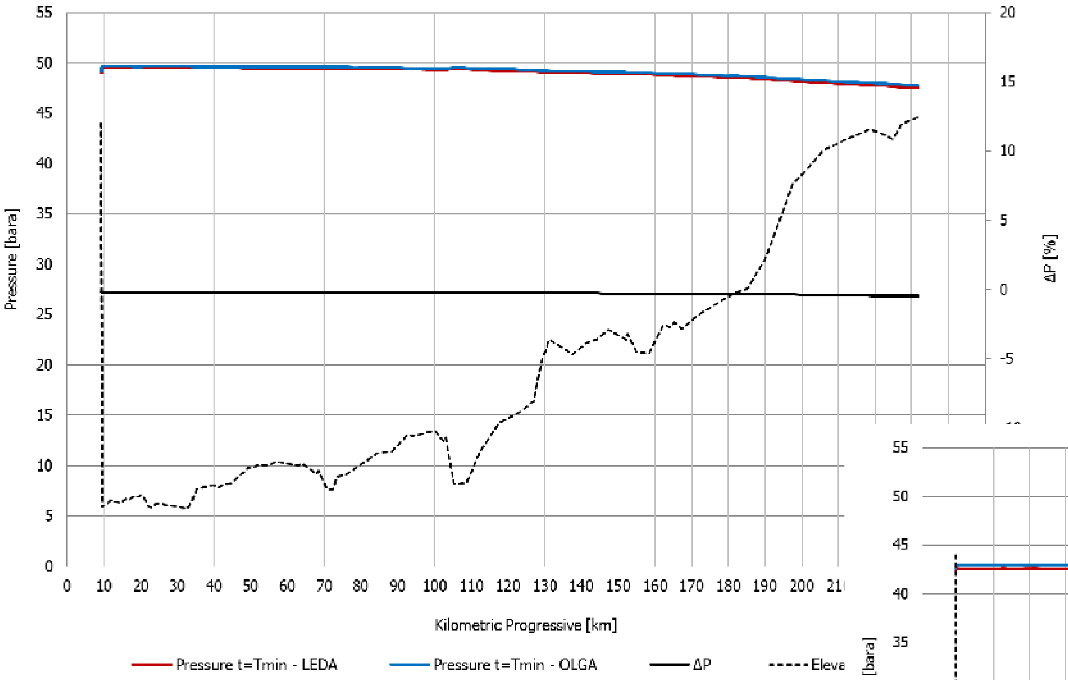
Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON

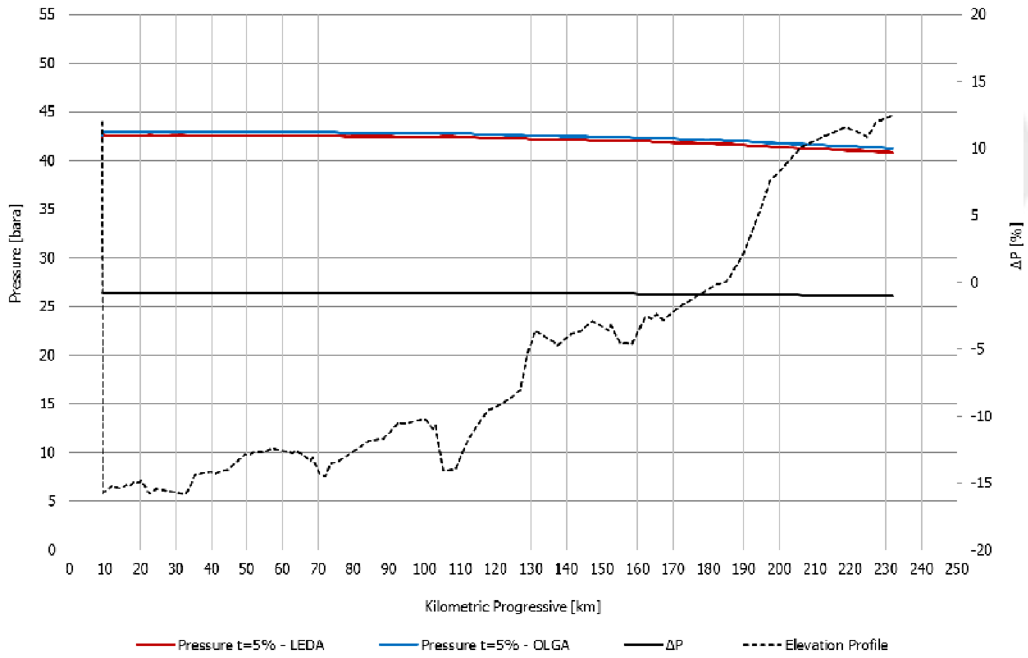




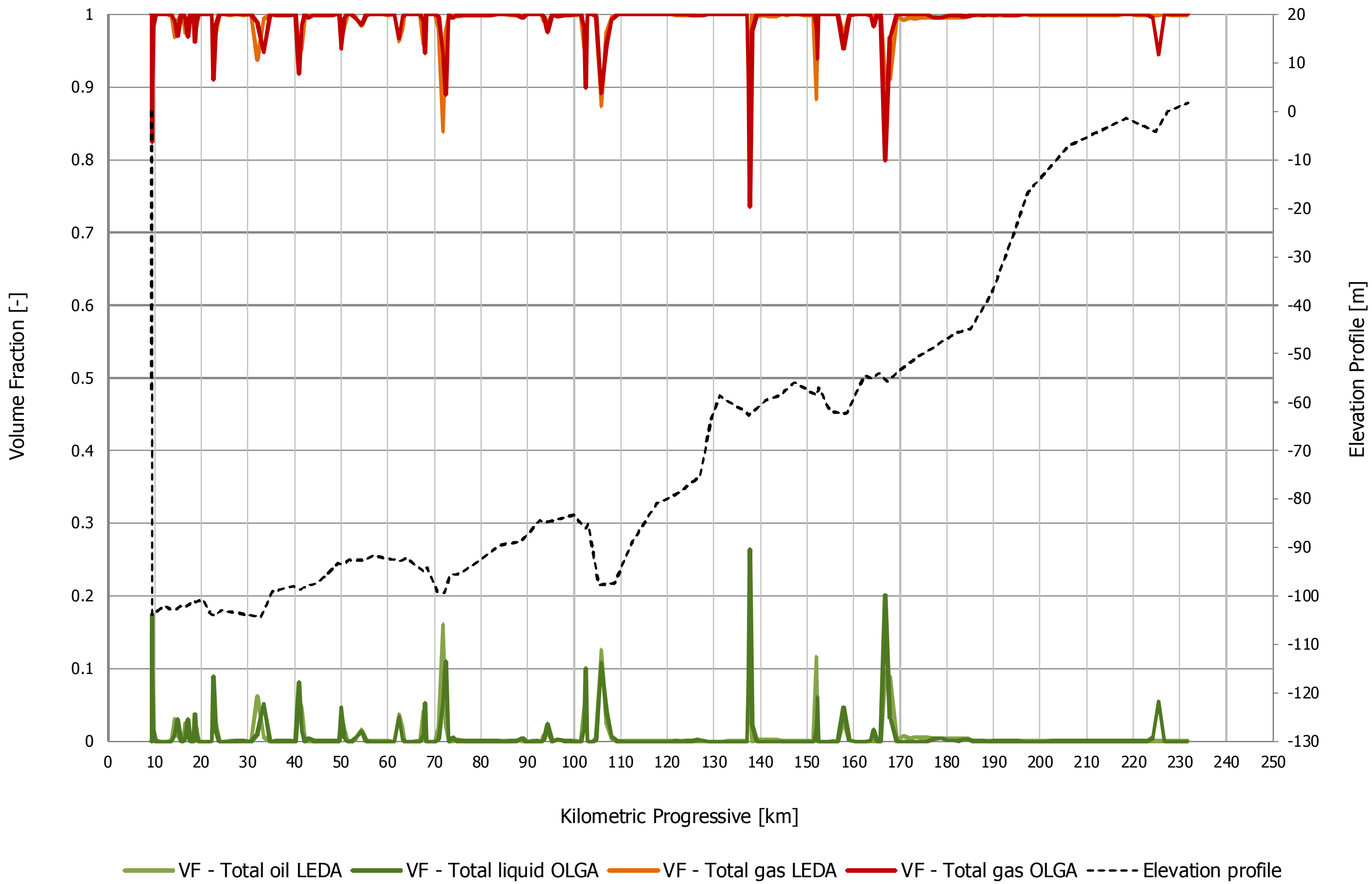
STREAMLINE PIPELINE ENGINEERING

Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON

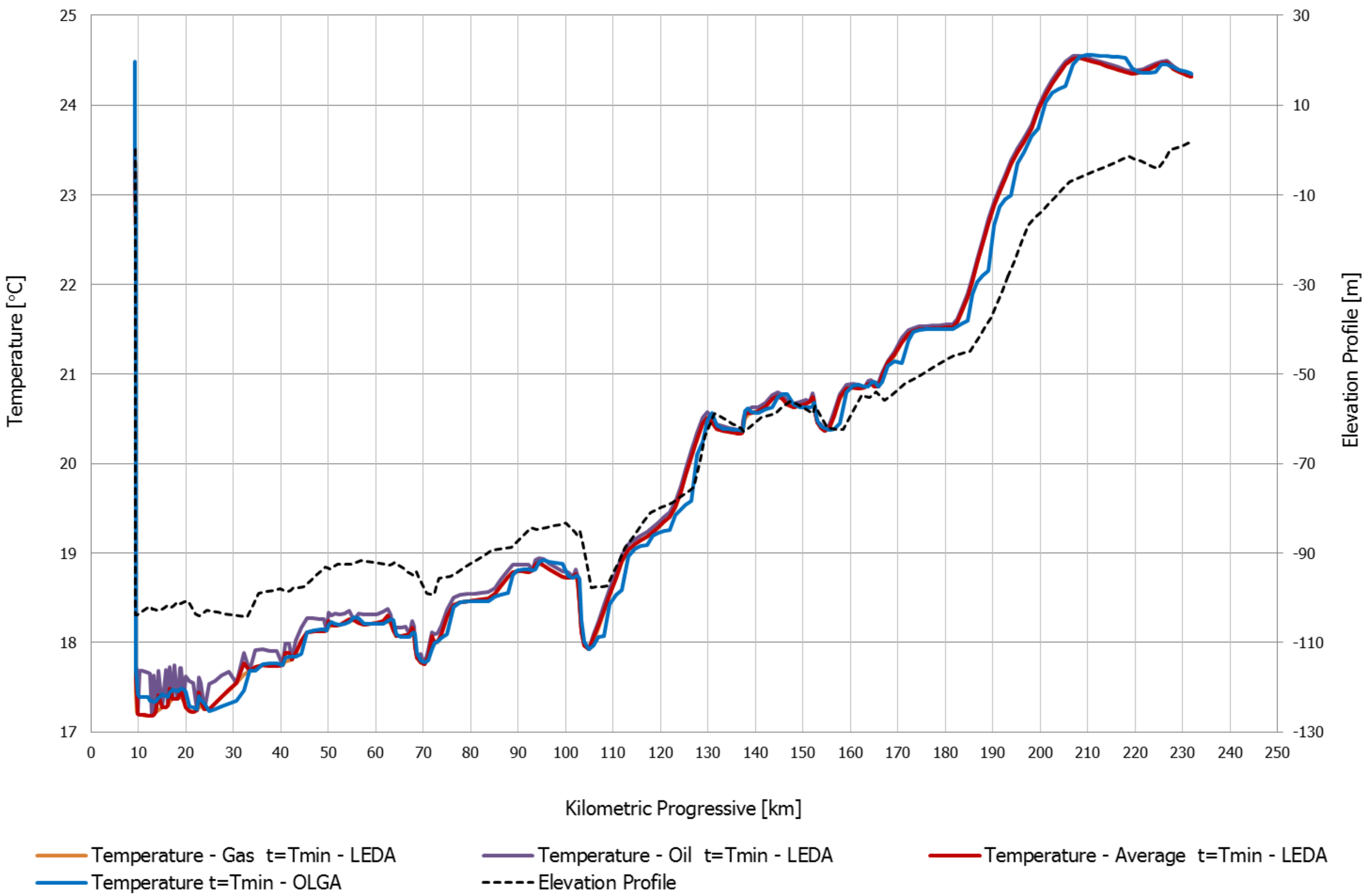




Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON

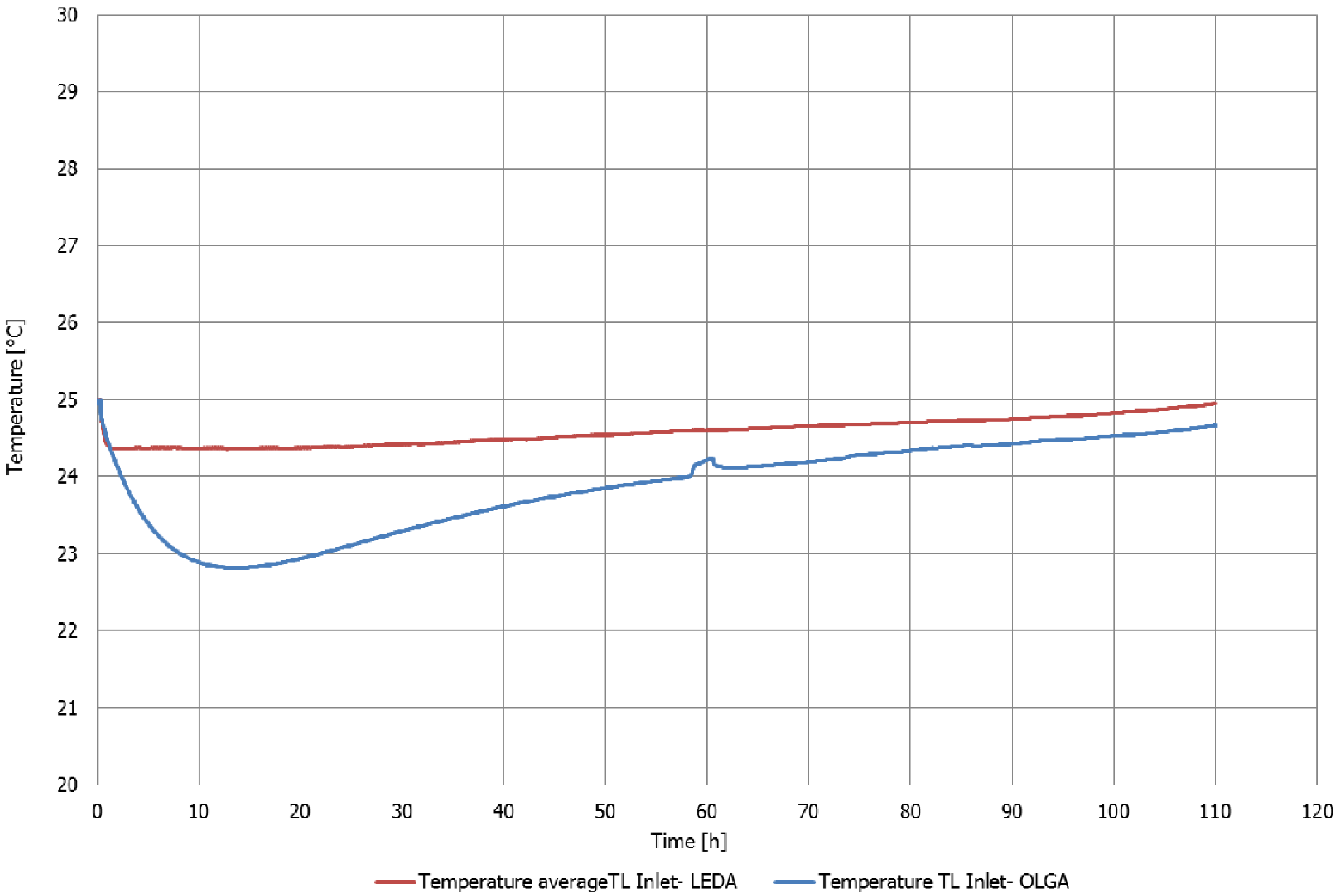


Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON

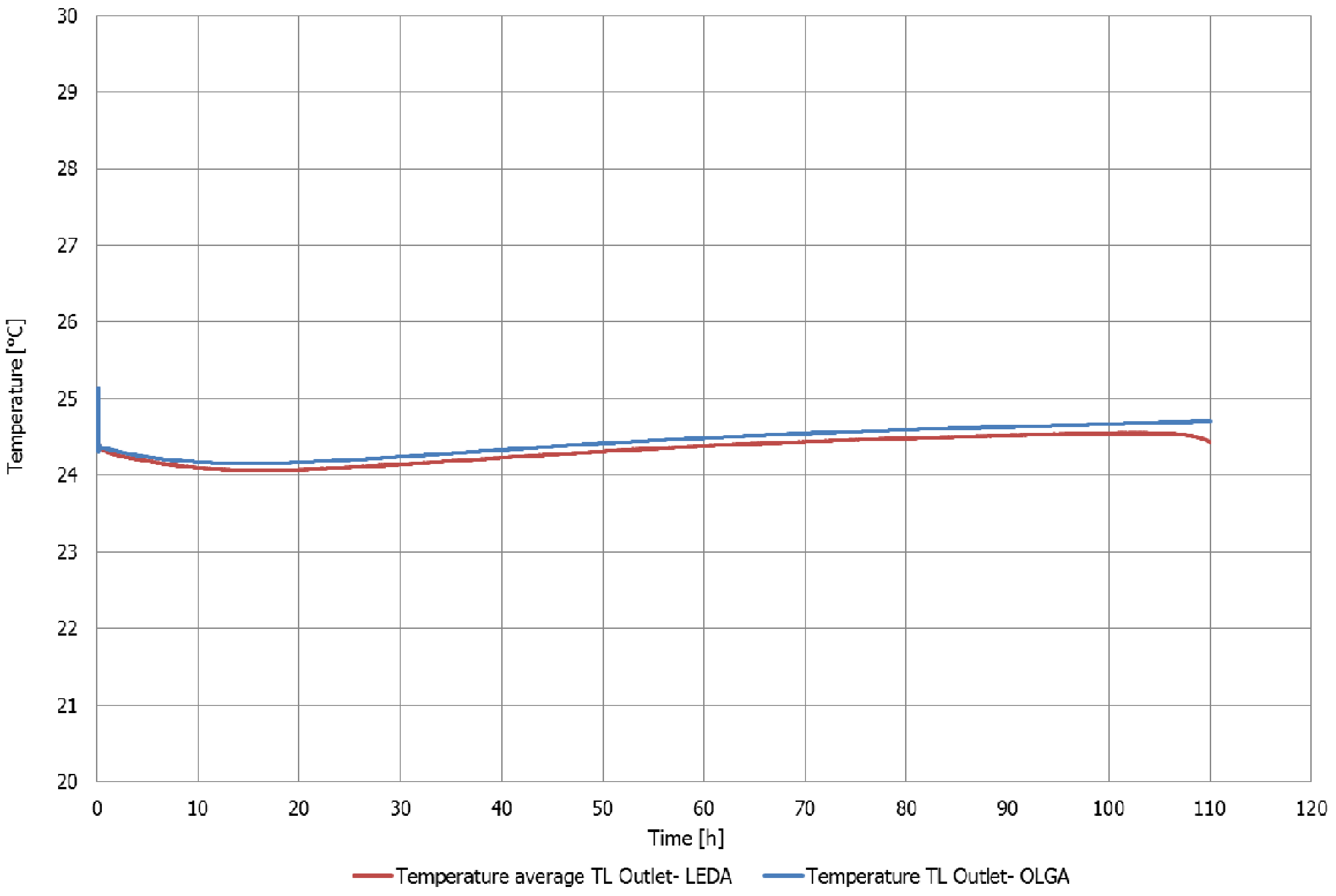


STREAMLINE PIPELINE ENGINEERING

Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON



Trunkline Depress. (B/D) – Light Gas Cond.: COMPARISON



Comparison Sum up

Conclusions – Summary of Main Issues

1. Input file conversion from Olga to LedaFlow (and vice-versa) was not found to be a smooth process, therefore extra attention should be paid when performing such activity.

2. Results of **Steady State** analysis for single phase fluids have shown a good match as reported in the following table. Not all the cases reached the steady state condition.

3. Results of **Steady State** and **Transient State** analysis for multiphase fluids have shown a good match when it comes to **pressure and temperature,** whereas differences were noted in **accumulated liquid and velocities,** as reported in the following table.

4. Significant difficulties were faced in input and run comparable cases for **Pigging, Ramp up and Turn down** (originally planned in the scope of the present work as important operating scenario) which resulted in abandoning of such comparison.

Conclusions – Summary of Main Issues

<table>
<tr><th>Simulations</th><th>Pipeline System</th><th>Operation Condition</th><th>Operation Details</th><th>Main Findings</th></tr>
<tr><td rowspan="4">Steady State</td><td rowspan="4">F/L and T/L:
- 8" and 24"
- 10" and 32"
- 12" and 36"
Receiving Pressure:
40; 60 and 80 bar</td><td rowspan="2">Single Phase transport</td><td>Gas</td><td rowspan="2">- Focus on P, T and Mass Content.
- No significant difference to be reported.</td></tr>
<tr><td>Liquid</td></tr>
<tr><td rowspan="2">Multiphase Transport</td><td>Gas-condensate</td><td rowspan="2">- Focus on P, T, Gas and Liquid Content, Gas and Liquid Velocity, Flow Regime.
- No significant differences to be reported on: P, T, Gas Content and Velocity, Flow Regime.
- Differences to be reported on: Liquid Accumulation and Velocity along the pipelines.</td></tr>
<tr><td>Gas-condensate + Water</td></tr>
<tr><td rowspan="4">Transients</td><td rowspan="2">F/L: 8"
T/L: 24"
Rec. P: 60 bar</td><td rowspan="2">Shut-down</td><td>Single Phase (Gas)</td><td rowspan="2">- Focus on P, T, Gas and Liquid Content at the end of the shut-down.
- No significant difference to be reported.</td></tr>
<tr><td>Multiphase Transport (Gas Condensate)</td></tr>
<tr><td rowspan="2">F/L: 10"
T/L: 32"
Rec. P: 40 bar</td><td rowspan="2">Depressurization
(from 1 end)</td><td>Single Phase (Gas)</td><td rowspan="2">- Focus on P, T, Gas and Liquid Content and Depressurization Flowrate.
- No significant difference to be reported on: P, T, Depressurization Flowrate and Mass content vs. time.
- Differences to be reported on Minimum Temperature, mainly at the pipeline far end.</td></tr>
<tr><td>Multiphase Transport (Gas Condensate)</td></tr>
</table>

Indications on
Possible Further Developments

Further Works

1. To progress in the comparison of these two Codes considering other typical transient simulations for pipeline systems such as:
   - Turn-down and Ramp-up analysis, to investigate liquid inventory vs. flowrate, liquid accumulation velocity, onset of fluid-dynamic instabilities, slugging at the outlet.
   - Re-pressurization and re-start analysis, starting from the already performed simulations of shut-down and depressurization.
   - Pigging analysis, possibly including simple sweeping pigging (single pig) and more complex pigging (launch of liquid batches in between two pigs).

2. To share and discuss the results obtained through the present work with other Entities as a contribution to the comparison between Olga and LedaFlow.