AIR LIQUIDE - OXYGEN PIPELINE DN8”: SALTATION VELOCITY CALCULATION; INSPECTION, CLEANING AND BLOW DOWN OPERATIONS

Streamline Engineering - 2014

Abstract: The Oxygen Pipeline DN8” (length=34.4 km), owned by Air Liquide Italia, connects Castelnuovo del Garda to Lonato del Garda. The first aim of this study is to describe cleaning and inspection operations, which have been carried out in order to evaluate pipeline condition. During pigging operations (with nitrogen), it is necessary to reduce usury of cups and discs that leads to “flakes” formation. Pig flakes disturb the following oxygen transfer due to local combustions.

The main scope of this work is to optimize the blow down conditions in order to convey the flakes. Saltation velocity of the flakes has been chosen as the “characteristic parameter” of the transport phenomena and it has been estimated through a research of academic publications. Blow Down conditions have been selected in order to achieve the calculated saltation velocity along the whole pipeline.

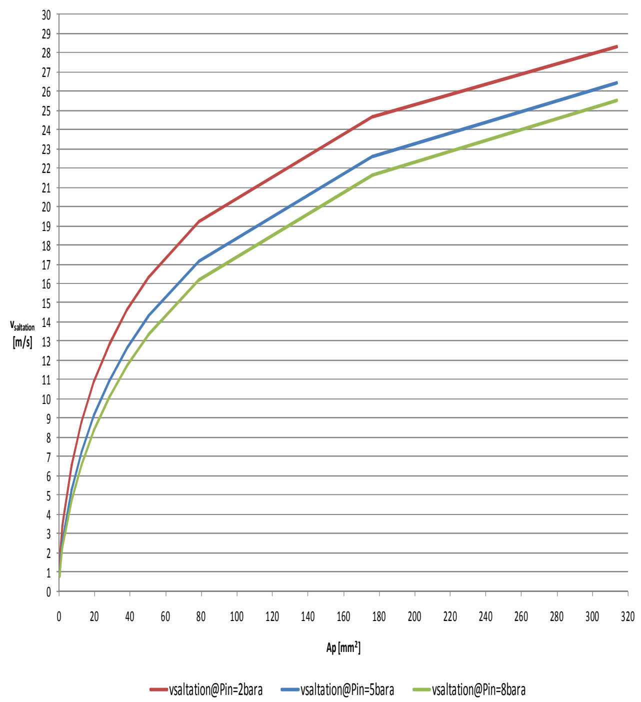

Figure 1: Nitrogen saltation velocity vs Urethane flakes Area for different inlet pipeline pressure

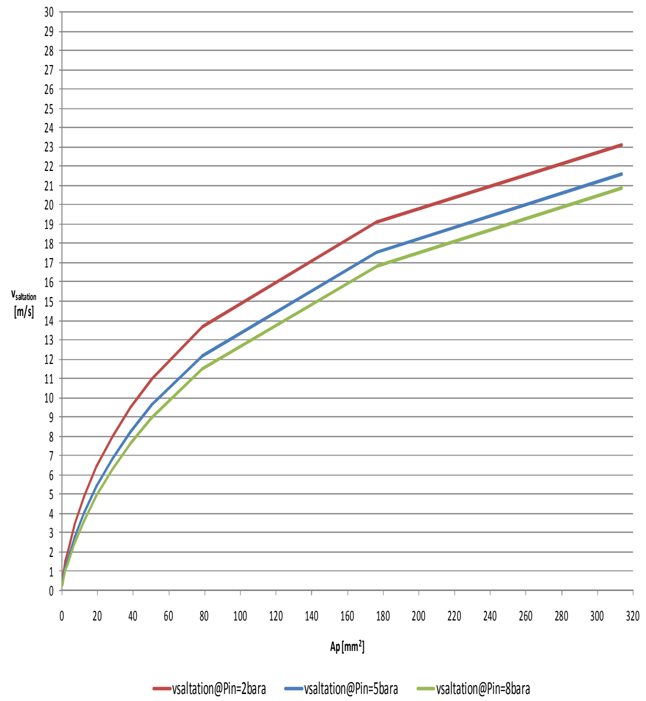

Figure 2: Nitrogen saltation velocity vs Polyurethane foam flakes Area for different inlet pipeline pressure

METHODOLOGY

“Saltation velocity” is defined as the lowest superficial gas velocity that can convey a solid material. In the literature, there are many correlations between $v_{saltation}$ and solid particle parameter (size, density, etc.). However these equations depend on the experimental apparatus but, mainly, on the pipe dimension or fluxed solids (studied as spherical particles). Anyway an important theoretical and practical approach has been carried out by the University of Pittsburgh (USA) and the University of Sendai (Japan). In the present study, the following publications have been examined:

- Pneumatic Conveying of Solids (Klinzing, Marcus, Rizk, Leung);
- Minimum transport velocity for horizontal pneumatic conveying (Matsumoto, Hara, Saito, Maeda);
- Effect of particle size on the minimum transport velocity for horizontal pneumatic conveying of solids (Matsumoto, Kikuta, Maeda).

The correlation of Rizk (Equation 1) has been used for saltation velocity calculation.

$$\frac{M_p}{\rho_f U_{SALT} A} = \left\{\frac{1}{10^{(1440x+1.96)}}\right\}\left\{\frac{U_{SALT}}{\sqrt{gD}}\right\}^{(1100x+2.5)} \quad \text{Equation 1}$$

$$M_p = A U_p (1-\varepsilon)\rho_p \quad \text{Equation 2}$$

where:

M_p	=Mass Flow rate of the particles	[kg/s]
ρ_f	=gas density	[kg/m^3]
P_p	=particle density	[kg/m^3]
U_{salt}	=saltation velocity	[m/s]
U_p	=velocity of the particle	[m/s]
A	=Area of the pipe	[m^2]
x	=particle diameter	[m]
g	=gravity	[m/s^2]
D	=internal diameter of the pipe	[m]
ε	=gas volume fraction	[-]

It has been assumed that the particle volume fraction A*(1-ε) is equal to the single particle area.

Besides, the formula applies only to spherical particle, nevertheless, pig flake is shaped like shown in Figure 3. It is thin, with maximum thickness equal to 0.1 mm. In order to use the correlation of Rizk, flake shape has been simulated as an empty spherical particle (coil shaped), which density decreases with increasing outer diameter.

Figure 3: Pig flake after blow down

It should be noted that the worst aerodynamic shape is the sphere and therefore the adopted approach is more precautionary. Furthermore, particles move at a velocity lower than the gas velocity due to drag forces. The difference between these values is called the slip factor. Depending on the size of the particles, the slip factor can range from 0.70 to 0.95. In this study, it has been chosen 0.8 based on flake density and shape. The adopted correlation is applicable to horizontal flow, whereas, for systems comprising both vertical and horizontal lines, as the pipeline under study, saltation velocity should be increased of 50%.

Once the needed saltation velocity has been defined, the best nitrogen washing procedure has been chosen between the two following alternative:

1. Nitrogen direct pumping from inlet pipeline to arrival;
2. High velocity pipeline blow down; this task would be achieved pressurising half of the line at 30 barg then carrying out the blow down through the second half of the pipeline. It must be highlighted that this solution requires to cut the pipeline in two parts and to install a new sectioning valve.

Software used for the analysis in transient conditions is LedaFlow by Kongsberg Oil & Gas Technologies.

Figure 4: Launching pig trap

Figure 5: Foam Caliper Pig

CALCULATION RESULTS

A nitrogen velocity of 10 m/s conveys solid particles with the following size and material:

- 28 mm^2 - flake made of Urethane (figure 1);
- 60 mm^2 - flake made of Polyurethane Foam (Figure 2).

In order to maintain this velocity along the entire pipeline, the pressurization of half part of the pipeline is the best examined cleaning solution. Due to high difference of pressure between the two sections, the valve opening imposes a high velocity in the second half of pipeline due to phenomena of pressure wave propagation. Figure 6 shows velocity trend after valve opening in different Kilometric Progressive downstream the sectioning valve.

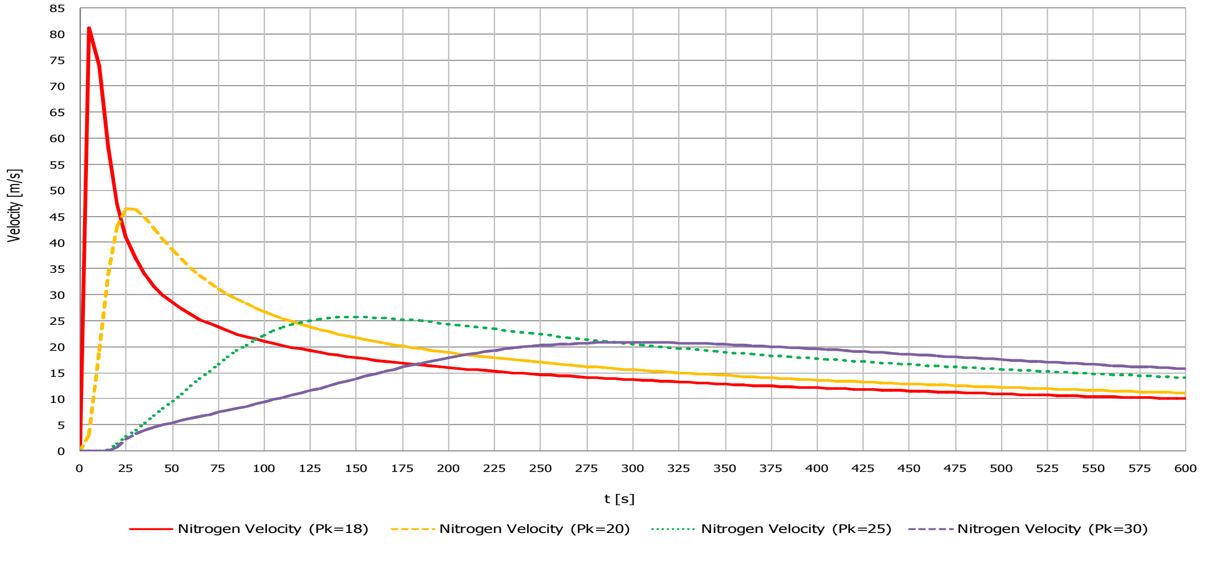

Figure 6: Nitrogen velocity after section valve opening placed at KP=17.7 (half pipeline)

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Furthermore, in order to control Blow Down operations, the pressure at arrival (KP=34) has been monitored as in Figure 7.

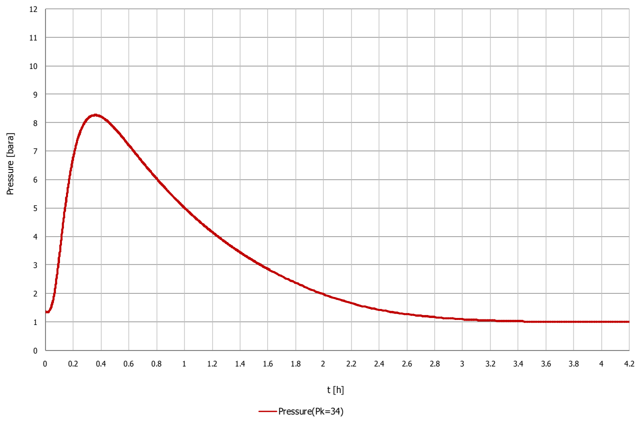


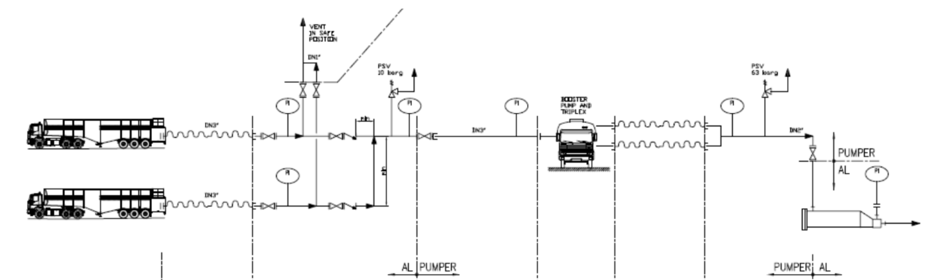
Figure 7: Pressure at arrival during Blow Down

Figure 8: Pressure gauge at arrival during Blow Down

Otherwise, direct nitrogen pumping carries a maximum inlet velocity equal to 5.5-6 m/s due to pipeline length and to choked flow generation along the pipeline.

For cleaning, inspection and Blow Down operations, the following data have been supplied to Air Liquide:

- Scheduling of the Operations;
- Volume of Nitrogen and number of liquid nitrogen tank trucks;
- Pressure and nitrogen flowrate in order to control velocities of:
  - Foam Caliper pig (Figure 5);
  - Bidirectional pigs (Figure 10);
  - Intelligent pig (Figure 11);
- Connection system (PFD in Figure 9) between tank trucks and pumper.



NAME	HOSE	MANIFOLD	BOOSTER PUMP SUCTION	PUMPER	INJECTION LINE	INJECTION MANIFOLD	PIPELINE
DN/FACES/RATING	3"-150#-RF	3"-150#-RF	3"-150#-RF		1"-600#-RF	2"-600#-RF	8"-600#
MATERIAL	AISI 304L + TEFLON	AISI 304L	AISI 304L		PLASTIC MATERIAL	CS	CS
DP [barg]	min 19	min 19	min 19		> 65	63	63
MOP [barg]	max 10	max 10	max 10		max 60	max 60	30
FLOWRATE	max 9000Nm3/h 14m3/h (liq)	max 9000Nm3/h ; 14m3/h (liq)	9000 Nm3/h ; 14m3/h (liq)		9000 Nm3/h	9000 Nm3/h	9000 Nm3/h
min T [°C]	-180	-180	-180		+10	+10	+10

Figure 9: Nitrogen injection system detail

CONCLUSION

- Inspection activities have been carried out according to the foreseen procedures, following the schedule of the operations.
- Estimated amount of Nitrogen was as accurate as necessary to carry out the operations.
- As shown in Figure 11 and in Figure 10, the pig velocity control was not able to avoid pig deterioration and presence of flakes was expected.

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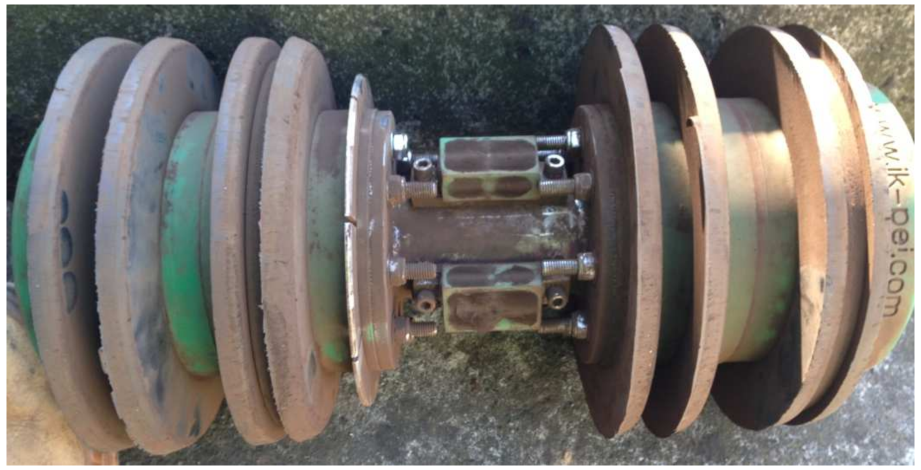

Figure 10: Bidirectional pig (gauging plate) after and before cleaning operations

- As foreseen, the pipeline was sectioned in two parts in order to allow to lead the Blow down operations.
- A sectioning valve and the relative by-pass has been installed in order to operate the blow down as expected reducing the choked flow influence.
- Blow down, according to the study, has been carried out on both sides (parts) of the cropped pipeline. Therefore, the operation, has been done twice: one in a direction and one in the other.
- The request to have a wide opening to allow the blow down of the pipeline, in order to limit the backpressure in the pipeline, has been achieved discharging the gas through the pig trap opening closure.
- Results have been collected in a video that confirms:
    - The presence of a highly sound wave pressure at the pipeline arrival;
    - Together with the wave pressure a dust cloud reaches the pig trap, and it is evident the continuous discharge of powder;
    - after a short period of time a reduction in the dust (powder) transportation becomes evident;
    - Together with the powder, Pig flakes (Figure 3) have been conveyed by nitrogen flow.

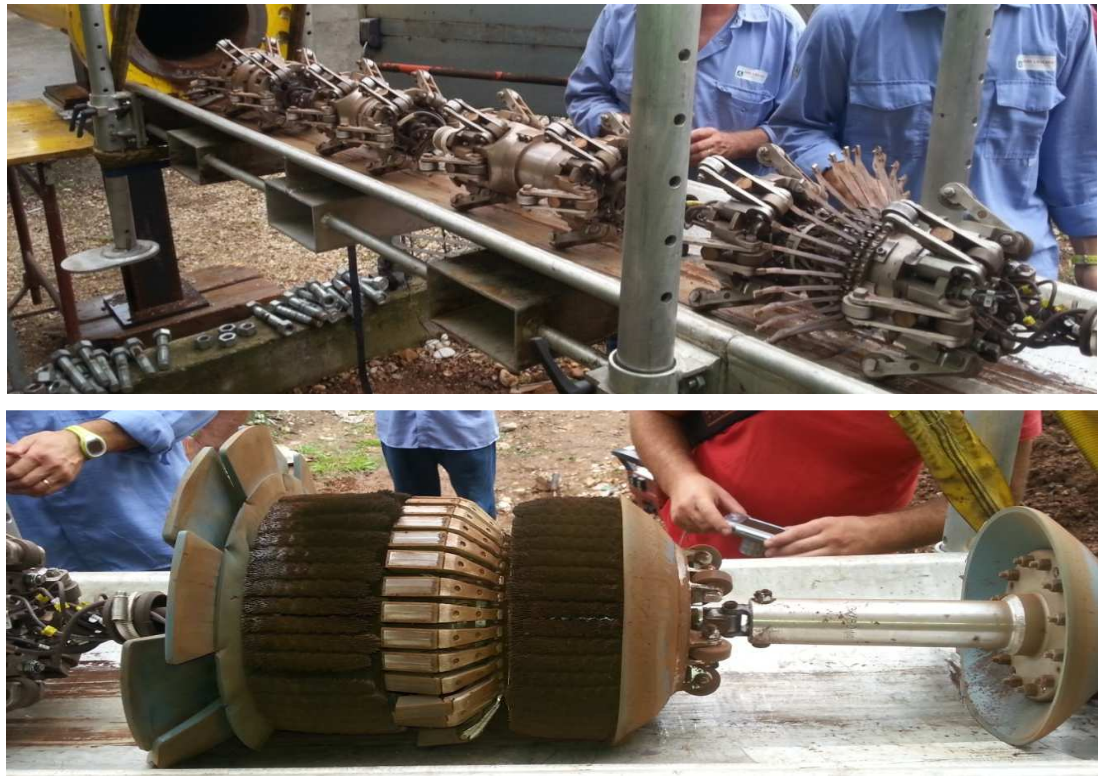

Figure 11: MFL pig after pipeline inspection

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