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Investigation of Polyethylene Pipeline Behavior after 30 Years of Use in Gas Distribution Network

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Polyethylene (PE) gas pipes are introduced in Algeria in 1978 to substitute the old pipelines made by copper, steel and cast iron. These later were used for the distribution of natural gas with medium working pressure of four bars. In this study, the polyethylene pipes were extracted from the Algerian distribution gas network in order to study their characteristics after more than 30 years of use. Two different pipe diameters (Ø63 and Ø125) with different ages of use were characterized according to the specifications on the EN1555-2 standard. The dimensional, physical and mechanical tests were performed with the same parameters as a newly produced pipe. The results showed that most of the characteristics are still fitting the EN 1555-2 specifications except for the density and the oxidative induction time. These two later will be considered as two basic parameters for the future studies of the polyethylene aging.

Keywords aging, distribution gas network, pipes, polyethylene

1. Introduction

During the last four decades, the plastics pipe systems are widely used in the gas distribution network all around the world. They are well suited for use in underground pipe-work due to their flexibility to soil movements and their corrosion resistance (Ref 1). Among the many available polymeric materials, high density polyethylene (HDPE) is a natural choice due to its good properties, availability and cost (Ref 2, 3).

Polyethylene pipes are widely used all over the world due to their best characteristics compared to the conventional ones made from steel and cast iron. The PE pipes among many other advantages are characterized by their high flexibility, lightweight, strainability, ease of pipes connection and mainly the reduced cost of installation.

The large magnitude of polyethylene pipes in the gas distribution system is undeniable. The low life cycle cost and reliability will continue to encourage the installation of polyethylene mains and services (Ref 4).

The first polyethylene pipes were introduced in the Algerian gas network at the end of the 70th. Their high performance encouraged the substitution of the conventional metallic pipes and the widening of the gas distribution network in order to provide gas to the majority of the inhabitants.

Currently, the PE pipes represent more than 80% of the total Algerian gas distribution network. This later reached about 100,818 km length and supplies gas to 52% of the Algerian population (Ref 5).

As known, Algeria is a large country with different regions and different nature of soils. It is the tenth-largest country in the world and the largest in Africa. Algeria comprises 2,381,741 square kilometers of land, more than four-fifths of which is desert. The northern portion is an area of mountains, valleys and plateaus between the Mediterranean Sea and the Sahara Desert. Northern Algeria is in the temperate zone and enjoys a mild, Mediterranean climate (Ref 6).

The oldest PE pipes are used for more than 30 years; it becomes evident to study the variation of the properties of these pipes with the age of use.

The PE pipe industry estimates a service life for PE pipe to be, conservatively, 50-100 years provided that the system has been properly designed, installed and operated in accordance with industry established practice and the manufacturer's recommendations (Ref 7).

After more than 30 years of using PE pipes in the distribution gas network, it becomes evident to study the effect of aging on these pipes and to evaluate the effective change in their different properties. This is important for the companies to be able to predict when a pipe will need to be replaced. This helps with planning and cost management, as well as preventing leaks and bursts, which cause disruption and damage consumer-supplier relationships (Ref 8-11).

Frank et al. (Ref 12) investigated four different pipes used in the gas and water distribution in Austria with an age up to 30 years according a particular attention to material stabilization. They found that the pipes were still in a very good condition and are likely to be sufficiently safe to remain in use.

Oosterkamp et al. (Ref 13) studied gas pipeline to soil heat transfer. They investigated the effect of simplifications of the heat transfer model and varied the flow conditions at the pipeline inlet. The effects of rapid changes in gas mass flow rate and temperature at the pipeline inlet were studied. The case presented is representative for export natural gas pipelines, containing offshore and buried sections along the route. The results were compared to experimental data from an existing export natural gas pipeline.

Taherinejad et al. (Ref 14) studied dynamic simulation of gas pipeline networks with electrical analogy. A correction factor in the capacitor equation was used in order to improve the level of predicting mass storage inside the pipe elements. The model validation was carried out by comparing the results

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with some available experimental data and published numerical simulation results, which showed a very good agreement.

Urbanik et al. (Ref 15) analyzed the safety of functioning gas pipelines in terms of the occurrence of failures and presented assessment methods which advocates the integrated risk area identification method.

In a previous work, the long-term performance of butt-welded PE pipes in comparison to non-welded counterparts was studied. Old welded PE pipes with different ages that had been used in Algerian gas distribution systems for up to 30 years were investigated (Ref 16).

The aim of this work is to study the effect of aging on the characteristics of buried polyethylene pipes and to evaluate their properties. These buried pipes have different ages of use and were extracted from different regions.

2. Experimental

The investigation of the PE pipes required their removal from the underground. So, a pre-selection based on the history of the gas network data permitted to select the samples needed for this study. This choice has taken into account the age of the pipes and the regions where they were used for gas distribution.

In this paper, two different pipes diameters (Ø63 and Ø125) having a variety of working ages and removed from different regions were considered. Tables 1 and 2 represent the different samples selected for this study.

The nonexistence of any archived data concerning the buried PE pipes test qualifications imposed to characterize them as new ones. The different characteristics studied were performed according to the specifications of the EN 1555-2 standard (Ref 17).

2.1 General Characteristics

The general characteristics are based on the visual observation of the tubes appearance, color and marking.

2.2 Geometrical Characteristics

The dimensions of the pipes were measured according to the EN ISO 3126. They were washed with water in order to remove any soil and dusts from inner and outer surfaces of the tubes. The measured dimensions are the mean outside diameter, the wall thickness and the out-of-roundness (ovality).

2.3 Physical Characteristics

2.3.1 Pipe's Density Determination. The density measurement was carried out according to the method A of the ISO 1183 standard using a GENIUS-SORTORIUS scale equipped with a density measurement kit. The immersion liquid used was «Propanol-2» having a density of 0.785 g/cm^3. The values of density were obtained by averaging the results of three measurements.

2.3.2 Melt Mass-Flow Rate. The melt mass-flow rate (MFR) was measured according to the EN ISO 1133 standard using a DAVENPORT-LLOYD melt flow indexer. The MFR values were calculated by averaging the results of three measurements performed at a temperature of 190°C and a loading mass of 5 kg.

2.3.3 Oxidation Induction Time. The oxidation induction time (OIT) was measured according to the ISO 11357-6 standard. Three samples of 15 $\pm$ 2 mg were cut from the surfaces of the pipes and analyzed using a NETZSCH-DSC 204 Phoenix Differential Scanning Calorimeter (DSC) at a temperature of 210°C. The OIT value was calculated by averaging of the results of three measurements.

2.3.4 Longitudinal Reversion (R_L). The R_L was measured according to the ISO 2505 standard. The test was carried out using a Memmert air oven at a specified temperature of 110 $\pm$ 2°C. The test time was selected on the basis of the pipe's thickness. For the two diameters tested (Ø63 and Ø125), the testing time used was 60 min and 120 min, respectively. The value of the R_L was calculated by averaging the results measured on three different sample pieces.

2.4 Mechanical Characteristics

2.4.1 Determination of Tensile Properties. Tensile properties were measured according to EN ISO 6259-1 and ISO 6259-3 standards using a ZWICK-Z020 tensile apparatus at a crosshead speed of 50 mm/min. They were obtained by averaging the results of five measurements.

2.4.2 Hydrostatic Strength Test. The test was performed at 80°C for 165 and 1000 h using an IPT airless blue line apparatus according to the EN ISO 1167-1 and EN ISO 1167-2 standards. The parameters for each test are listed in the EN 1555-2 standard. For each test, three samples were tested.

2.5 FTIR Spectroscopy

The Attenuated Total Reflectance (ATR-FTIR) spectra were recorded using a Perkin Elmer Spectrum Two FT-IR with UATR sampling accessory.

2.6 Scanning Electron Microscopy

The morphology of the pipes was investigated using a JEOL-JSM-6380 scanning electron microscope (SEM). The samples were first coated with a layer of gold with a thickness of 8-10 nm by sputtering then they are bombarded with an electron beam during scanning.

3. Results and Discussion

3.1 General Characteristics

After the removal of the pipes from the ground, it was observed that their external surfaces were covered with soil and dusts. Some of the pipe's internal surfaces were fully enveloped with a layer of dirt, but others were totally clean as shown in Fig. 1(a). Alter the pipes were cleaned with water, their visual observation revealed a non-deformed appearance (absence of scoring, cavities and other surface defects).

The color of the pipes was almost yellow for the two diameters (Ø63 and Ø125) except for P63/1, P63/12, P63/13, P125/7 and P125/8. The color of P63/1 was orange and that of the other ones was black with yellow stripes.

The marking legibility was maintained during the use of the pipes. No problems encountered for the reading of the pipes marking. Examples of pipes marking are presented in Fig. 1(b).

Table 1 The list of buried pipes Ø63 extracted at different regions

N°	Pipe's Age, years	Manufacturer's name	Material and designation	Observations
P63/1	32	NIPAK	PE 2306	The oldest tube used in the Algerian gas network
P63/2	31	WAVIN	MDPE	The two pipes are: Manufactured by the same company, Made with the same material, Used for approximately the same age, Extracted in two different regions
P63/3	30	WAVIN	MDPE	
P63/4	26	WAVIN	MDPE	The two pipes are: Manufactured by the same company, Made with the same material, Used for the same age, Extracted in two different regions
P63/5	26	WAVIN	MDPE	
P63/6	18	EUROPLAST	PEHD	The two pipes are: Manufactured by the same company, Made with the same material, Used for approximately the same age, Extracted in two different regions
P63/7	17	EUROPLAST	PEHD	
P63/8	15	WAVIN	PE80	The two pipes are: Manufactured by the same company, Made with the same material, Used for the same age, Extracted in two different regions
P63/9	15	WAVIN	PE80	
P63/10	14	WAVIN	PE80	The two pipes are: Manufactured by the same company, Made with the same material, Used for the same age, Extracted in the same region
P63/11	14	WAVIN	PE80	
P63/12	10	ENPC CHLEF	P80	The two pipes are: Manufactured by two different companies, Made with the same material, Used for the same age, Extracted in two different regions

Table 2 The list of buried pipes Ø125 extracted at different regions

N°	Pipe's Age, years	Manufacturer's name	Material designation	Observations
P125/1	31	WAVIN	MDPE	The two pipes are: Manufactured by the same company, Made with the same material, Used for approximately the same age, Extracted in two different regions
P125/2	30	WAVIN	MDPE	
P125/3	26	WAVIN	MDPE	The two pipes are: Manufactured by the same company, Made with the same material, Used for the same age, Extracted in two different regions
P125/4	26	WAVIN	MDPE	
P125/5	19	EUROPLAST	PEHD	The two pipes are: Manufactured by the same company, Made with the same material, Used for approximately the same age, Extracted in two different regions
P125/6	17	EUROPLAST	PEHD	
P125/7	10	ENPC CHLEF	PE80	The two pipes are: Manufactured by two different companies, Made with the same material, Used for the same age, Extracted in two different regions
P125/8	10	ALPHACAN	PE80	

3.2 Geometrical Characteristics

The results of the geometrical characteristics of the two diameters Ø63 and Ø125 are shown in Tables 3 and 4, respectively.

For the Ø63 pipes, the mean outside diameter is somewhat higher than the EN 1555-2 standard tolerances except for P63/1, P63/6 and P63/8. The most values of wall thickness (e_{mean}) obtained, and all the values of the ovality are still complying with the standard.

For the Ø125 pipes, the values of the mean outside diameter, the wall thickness and the out of roundness are conform to the EN 1555-2 standard requirements.

These results confirm the visual observations that revealed the absence of any deterioration of the pipes regardless of their age or the region of use.

3.3 Physical Characteristics

The different physical characteristics of the removed polyethylene pipes are summarized in Tables 5 and 6 for the two diameters Ø63 and Ø125, respectively.

Table 5 shows that all the density results are lower than 930 kg cm^{-3} except for P63/1 (940.2 kg cm^{-3}); these values are not complying with the standard EN 1555-1 except for P63/1. Table 6 shows also that all the values obtained are less than 930 kg cm^{-3} except for P125/2 (940.2 kg cm^{-3}) and P125/6 (938.1 kg cm^{-3}); these values do not comply with the standard EN 1555-1.

It is not easy to explain these results due to the absence of the reference densities of these samples. However, knowing that the densities of MDPE, HDPE and PE80 are higher than 926 kg cm^{-3}, the lower values obtained may be explained by the mass loss due to the additives migration in soil over time.

As shown in Tables 5 and 6, the MFR varies between a minimum of 0.7 g 10 min^{-1} and a maximum of 1.3 g 10 min^{-1}. These values are still in accordance with the EN 1555-1 ($0.2 \leq \text{MFR} \leq 1.4$ g 10 min^{-1}). It is also noticed that there is no influence of the age or the region of use on MFR.

Since the joining methods, butt fusion and electrofusion, rely on melting of the plastic to form the joint, a change in MFR can have negative effects for the joint strength. Several guidelines state that butt fusion is most suitable for materials with a MFR-value of above 0.3 g 10 min^{-1} (Ref 18). The results obtained ascertain that no problems will be encountered in the case of joining the aged pipes with new ones.

The oxidation induction time is a measurement of the stability of a sample and gives an indirect measurement of the level of effective antioxidants present (Ref 19). The OIT value can be influenced by a number of factors, for example, the concentration, dispersion and homogeneity of the antioxidant in the pipe, the pipe extrusion temperature, rate of cooling after extrusion, pipe storage condition prior to installation and the environment of the buried pipe (Ref 20).

In this paper, the analyzed samples were cut from the surface of the tube, knowing that it is the surface of the pipe which is most exposed to degradation phenomena. The OIT results presented in Tables 5 and 6 revealed that almost of the values are not conforming to the requirements given in EN1555-2 (OIT $\geq$ 20 min) except for P63/8, P63/10, P63/11 and P125/5. However, the values obtained for OIT confirm the presence of antioxidants which can still maintain the stability of the aged pipes from degradation.

Generally, a reduction in OIT values over the life of an HDPE pipe product indicates a consumption or elimination of antioxidant (Ref 21). The consumption of the antioxidant can occur during the processing or the storage of the pipes before their use due to the thermo and photo oxidation reactions which take place (Ref 19). The elimination of the antioxidant can be due to an attack by soil microorganisms or to a phenomenon of migration in the soil (Ref 22). It is also known that the measured OIT values are in linear relationship with the amount of the available antioxidant. The values obtained show the presence of the antioxidant in all the pipes tested unrelatedly of the age of these later due to the fact that the OIT of virgin PE does not exceed 5 min.

It is noticed that the OIT value of P63/13 does not exceed 10 min for a period of 9 years of use. Effectively, P63/13 was removed from a region situated in the south of Algeria. This later is characterized by its high temperatures exceeding 40°C in summer.

The longitudinal reversion (R_L) test measures how much the pipe expands with rising temperatures as well as if any

Fig. 1 Samples of extracted polyethylene pipes. (a) Polyethylene pipes before cleaning. (b) Polyethylene pipes marking. (The color of the printed information is different from the basic color of the pipes.)

Table 3 Geometrical characteristics of the aged pipes Ø63

Samples	Mean outside diameter, mm	Out of roundness, mm	Pipe's wall thickness e_{mean}, mm
P63/1	63.5 ± 0.10	0.6	6.1 ± 0.1
P63/2	63.9 ± 0.11	0.2	5.7 ± 0.0
P63/3	63.7 ± 0.10	0.6	6.0 ± 0.4
P63/4	63.7 ± 0.10	0.6	6.3 ± 0.2
P63/5	63.8 ± 0.12	1.4	6.3 ± 0.1
P63/6	63.4 ± 0.10	0.3	6.1 ± 0.2
P63/7	63.6 ± 0.11	0.9	6.4 ± 0.1
P63/8	63.5 ± 0.10	0.4	6.3 ± 0.2
P63/9	63.5 ± 0.06	0.3	6.3 ± 0.1
P63/10	63.5 ± 0.04	0.9	6.2 ± 0.1
P63/11	63.5 ± 0.07	0.3	6.0 ± 0.2
P63/12	63.7 ± 0.10	1.1	6.3 ± 0.1
P63/13	63.6 ± 0.10	0.9	6.3 ± 0.1

Table 4 Geometrical characteristics of the aged pipes Ø125

Samples	Mean outside diameter, mm	Out of roundness, mm	Pipe's wall thickness e_{mean}, mm
P125/1	125.5 ± 0.1	1.2	12.3 ± 0.1
P125/2	125.9 ± 0.5	1.2	12.2 ± 0.2
P125/3	125.6 ± 0.3	0.8	12.3 ± 0.2
P125/4	125.5 ± 0.1	0.9	12.4 ± 0.2
P125/5	125.8 ± 0.2	2.0	11.5 ± 0.1
P125/6	125.3 ± 0.1	1.5	11.8 ± 0.2
P125/7	125.5 ± 0.1	0.3	12.2 ± 0.2
P125/8	125.4 ± 0.2	2.2	11.8 ± 0.2

Table 5 Physical characteristics of the aged pipes Ø63

Samples	Density, kg/m^3	MFI, g/10 min	OIT at 210 °C, min	L_R , %
P63/1	940.2 ± 0.8	1.3 ± 0.01	16.1 ± 1.1	1.5 ± 0.3
P63/2	909.1 ± 0.5	1.1 ± 0.10	11.6 ± 1.7	1.1 ± 0.1
P63/3	914.6 ± 0.6	1.2 ± 0.02	17.4 ± 0.6	1.3 ± 0.2
P63/4	912.8 ± 0.3	1.1 ± 0.01	15.5 ± 1.6	1.6 ± 0.3
P63/5	906.0 ± 0.2	1.0 ± 0.02	14.1 ± 0.1	1.4 ± 0.3
P63/6	921.8 ± 0.3	0.9 ± 0.03	14.6 ± 1.8	1.8 ± 0.1
P63/7	913.7 ± 0.5	0.9 ± 0.01	16.1 ± 2.3	1.4 ± 0.2
P63/8	923.0 ± 0.7	0.9 ± 0.04	23.3 ± 1.6	1.1 ± 0.1
P63/9	912.1 ± 0.8	0.9 ± 0.01	17.2 ± 1.1	1.1 ± 0.3
P63/10	906.5 ± 1.0	1.0 ± 0.02	20.1 ± 0.1	1.5 ± 0.2
P63/11	912.8 ± 1.0	0.9 ± 0.03	22.2 ± 0.1	1.4 ± 0.3
P63/12	921.3 ± 0.1	0.8 ± 0.05	18.7 ± 0.1	1.1 ± 0.1
P63/13	928.2 ± 0.4	0.9 ± 0.01	9.8 ± 0.3	1.3 ± 0.3

permanent changes can be observed due to the heating. The longitudinal expansion of the material is partly a consequence of internal stress in the pipe (Ref 18). As presented in Tables 5 and 6, the results of the longitudinal reversion of all the samples tested meet the requirements of the standard ($R_L \leq$ 3%). It is also observed that the original appearance of the pipes is preserved (absence of deteriorations).

3.4 Mechanical Characterization

A tensile test allows the characterization of mechanical properties of a polymer in terms of modulus, strength and elongation at break (Ref 23).

Tensile properties of the pipes Ø63 and Ø125 are given in Fig. 2. The results showed that, despite the period of operation, all the samples still exhibit a ductile character. As shown in Fig. 2(a), a slight decrease of strength modulus (Et) with age of use is observed for both pipes. However, the shape of the two curves is similar.

The results represented in Fig. 2(b) revealed that, globally, tensile strength at yield (σ_M) is not influenced by the age of use and the diameter of the pipe. Furthermore, it can be seen that all the values are higher than 15 MPa. Hence, they still conforming the specification ($\sigma_M \geq$ 15 MPa).

On the other hand, tensile strength at break (σ_B) decreased with the age of use of the two pipes. The values obtained for the

Table 6 Physical characteristics of the aged pipes Ø125

Samples	Density, kg/m^3	MFR, g/10 min	OIT at 210 °C, min	L_R, %
P125/1	920.7 ± 0.2	1.2 ± 0.01	15.3 ± 1.1	1.2 ± 0.20
P125/2	940.3 ± 0.6	0.9 ± 0.03	17.9 ± 0.4	1.2 ± 0.01
P125/3	913.7 ± 0.3	1.0 ± 0.01	15.1 ± 0.3	1.8 ± 0.50
P125/4	912.7 ± 0.2	1.0 ± 0.02	19.8 ± 0.9	0.4 ± 0.10
P125/5	910.3 ± 0.8	0.9 ± 0.04	21.4 ± 0.1	1.0 ± 0.21
P125/6	938.1 ± 0.5	0.9 ± 0.02	16.4 ± 1.0	1.0 ± 0.20
P125/7	928.6 ± 1.2	1.0 ± 0.03	16.0 ± 0.5	1.1 ± 0.22
P125/8	922.3 ± 1.2	0.7 ± 0.01	17.4 ± 1.4	1.3 ± 0.20

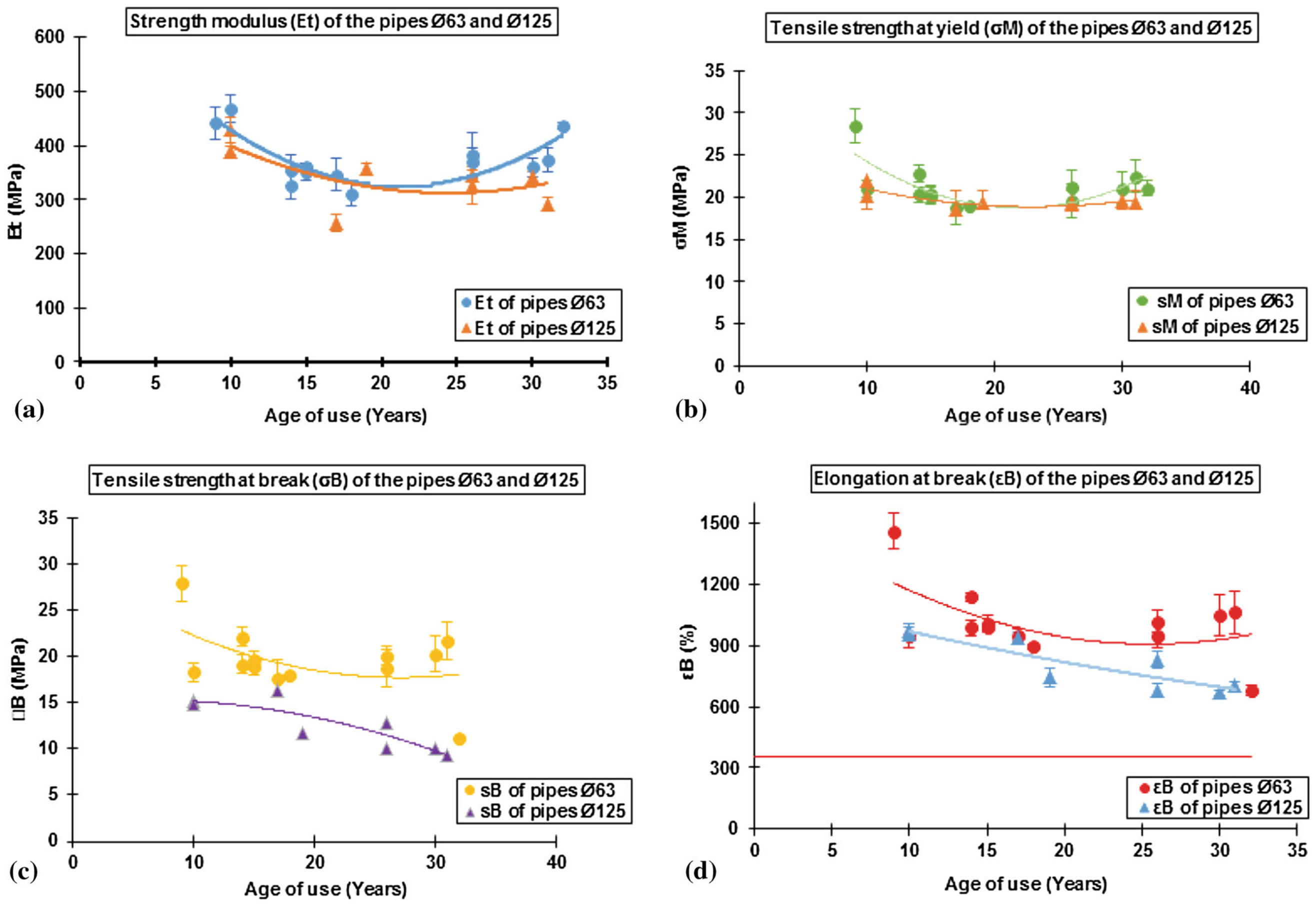

Fig. 2 Evolution of tensile properties of the pipes Ø63 and Ø125 with aging time

pipes Ø63 are higher than those of the pipes Ø125. The lowest values are obtained for the higher age of use as shown in Fig. 2(c).

The tested pipes of both diameters exhibited an elongation at break higher than 600% (Fig. 2d). These values are very far from the required one (350%). This may be explained by the retention of the ductile properties despite the age, the diameter and/or the region of use of the tested pipes.

Concerning the resistance to internal pressure, it was found that all the tested samples were still conforming to the standards. No failure during the test periods (165 h and 1000 h) for both diameters Ø63 and Ø125 occurred. It is to be noted that the test parameters are those used for new pipes. The absence of failure means that these pipes may be used for another 50 years.

3.5 FTIR Spectroscopic Characterization

The infra-red spectroscopic analysis was done in order to investigate the PE pipes oxidation. This technique is one of the most important spectrometric methods for the quantification and identification of oxidation processes in polymeric materials (Ref 24).

The formation of carbonyl products is one of the most common degradation mechanisms and can be investigated by FTIR-ATR spectroscopy with their specific infrared band in the region 1710-1740 cm^{-1} (Ref 25).

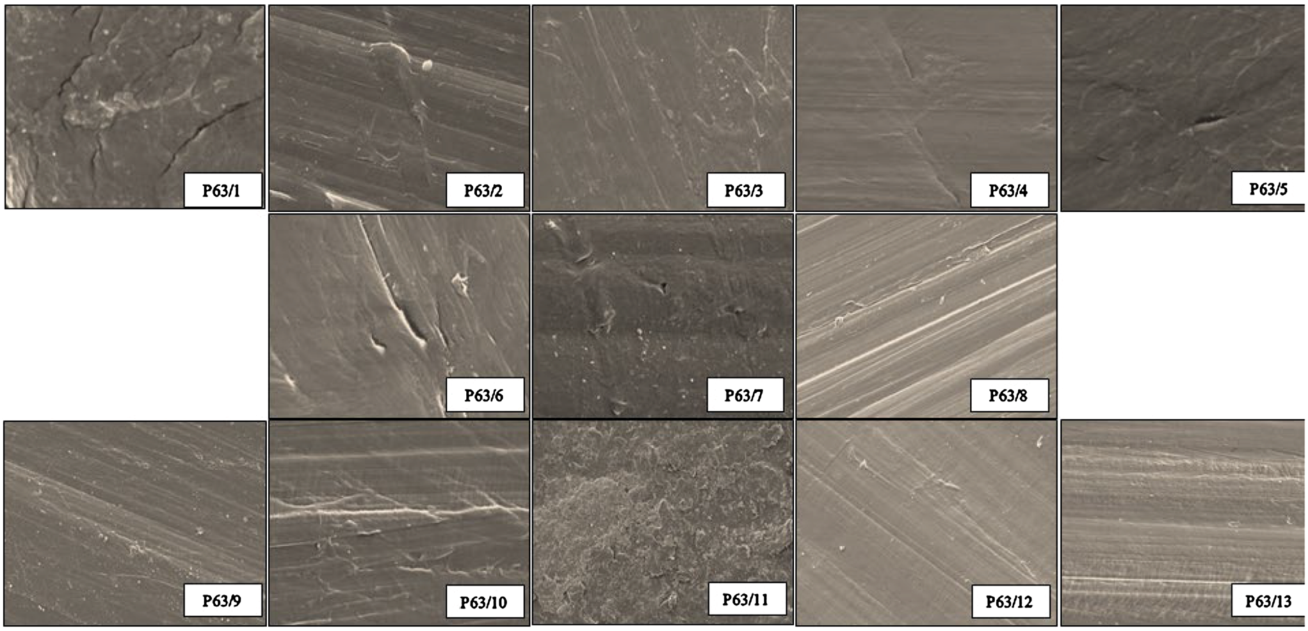

Fig. 3 SEM images of all the Ø63 samples (Gr× 1000)

The IR spectra obtained for both pipes Ø63 and Ø125 revealed the presence of two bands at 2918-2910 cm^{-1} and 2848 cm^{-1} corresponding to the stretching vibration of asymmetric and symmetric C-H bond of the CH_2 group (Ref 26, 27). The bands of the doublet 1471 and 1463 cm^{-1} are attributed to the bending deformation of the CH_2 groups in crystalline and amorphous phases, respectively (Ref 26). The bands observed at 721 cm^{-1} and 710 cm^{-1} correspond, respectively, to bending and rocking vibrations of crystalline and amorphous methylene group (Ref 27).

The IR spectra of the pipes Ø63 and Ø125 revealed the absence of absorption bands around 1720 cm^{-1} assigned to the C=O stretching vibration. As mentioned in the literature, the common presence of additives and carbon black in commercial PE-pipes can reduce the sensitivity of this technique and make difficult to derive information from such measurements (Ref 28). These results indicate that the molecular structure of the tested pipes is almost similar in spite of their differences (age of use, diameter, manufacturer and region of use).

3.6 SEM Characterization

Scanning electron microscopy is a commonly used technique for mapping the surface topography of polymers. This technique is useful to identify the change of fracture mechanisms from chemically driven crack to mechanically driven crack by the formation of visible striations (Ref 29).

The SEM images presented in Fig. 3 and 4 shows interesting aspects of the fractured surface of the Ø63 and Ø125 pipes samples.

For the Ø63 pipes (Fig. 3), the presence of multiple apparent cracks on the surface of the samples P63/1, P63/2, P63/4, P63/5, P63/6, P63/7, P63/10 and P63/11 can be observed. The SEM micrographs of the samples P63/3, P63/8, P63/9, P63/12 and P63/13 showed the presence of some irregularities on their surfaces. These defects are less important compared to that of the other samples.

The results of the SEM characterization of the Ø125 pipes (Fig. 4) showed an irregular morphology in the case of samples P125/1, P125/2, P125/3, P125/4, P125/5 and P125/7. Their micrographs showed numerous cracks quite pronounced. In addition, small holes have been observed on their surface. They are probably due to the migration of additives in the soil. The SEM images of the other samples (P125/6 and P125/8) revealed that the surfaces are fairly smooth and without visible cracks.

4. Conclusions

The characterization of the buried pipes used in the Algerian gas network for more than three decades permitted to investigate the behavior of the tested pipes with age.

The visual observation of the pipes revealed the conservation of the shape and the absence of any deformation.

A comparison of the results obtained with the original pipes was not possible due to the lack of information on buried pipes. The tests were carried out according to the specifications of the standard EN 1555, and the tests parameters were identical to those used to characterize a new pipe.

The geometrical and mechanical characterizations showed that the tested pipes are still in good condition in spite of their age, the material designation or the region of use. It is also noticed that the MFR and the longitudinal reversion are still confirming the specifications of the standard EN1555.

The density measurements showed a mass loss in the case of almost all the buried pipes tested due to the migration of the present additives into the soil. Furthermore, the obtained OIT values do not comply with the requirements of standard EN1555 but they confirm the residual presence of antioxidants which can maintain the stability of aged pipes against degradation phenomena. On the other hand, the surface morphology obtained by the SEM analyzes indicated the presence of more pronounced micro-cracks with the age of the pipes.

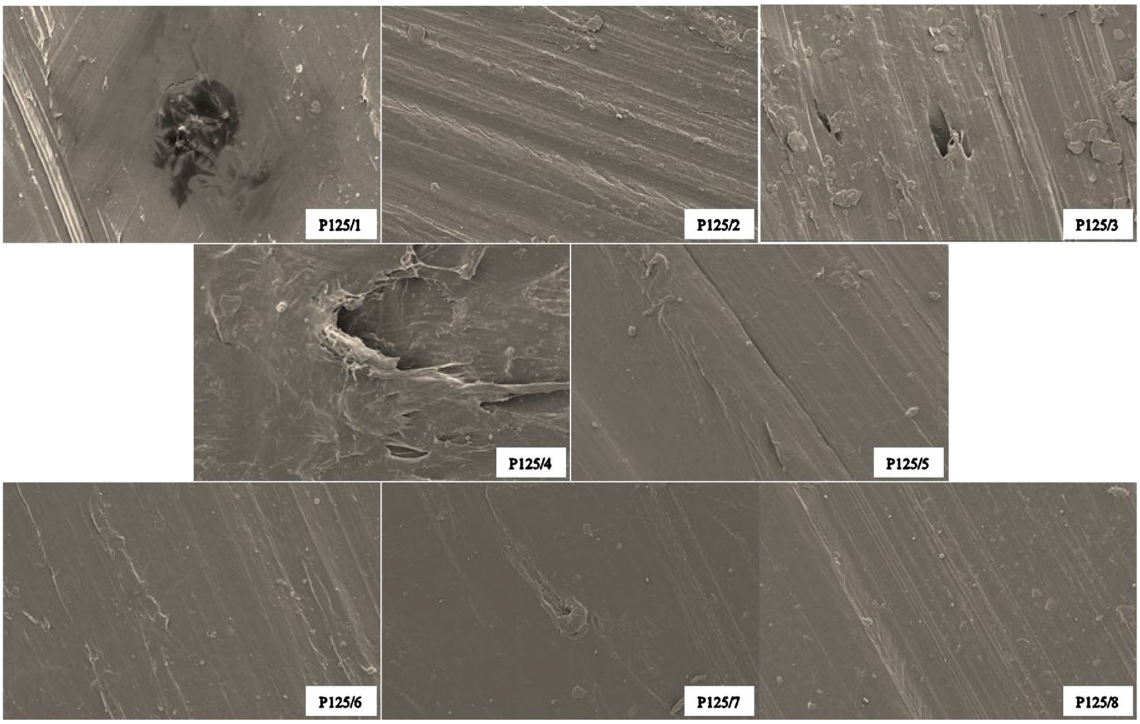

Fig. 4 SEM images of all the Ø125 samples (Gr× 1000)

Finally, the results showed that most of the characteristics are still fitting the EN 1555-2 specifications except for density and oxidative induction time. These two later will be considered as two basic parameters for the future studies of the polyethylene aging.

The investigation of the old pipes characteristics revealed that the use of polyethylene pipes is the perfect choice for the gas distribution in terms of durability and stability even after many years of use. It is recommended to ensure a periodic control of the buried pipes. This may be achieved by performing the OIT analyses. These tests are easy, not time consuming and allow a relatively rapid evaluation of the presence of the antioxidant in the samples tested.

This study was carried out in Algeria, a large country with different regions and different nature of soils; a Mediterranean climate covers the North, while a desert climate prevails on the South. It has been found that density and OIT are important detection indexes of PE aging. So, the rest of the world, such as humid areas, is equally applicable.

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