Investigation on the detection of water leaks in small-diameter polyethylene pipes using Acoustic Emission signals

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Abstract: Active control of water losses is an essential strategy to increase the efficiency of urban water supply systems. This work deals with the early detection of leaks occurring in small-diameter service pipes of water distribution networks. Preliminary experiments were conducted in a test facility to assess the sensitivity of Acoustic Emission methods to leaking water flows. Acoustic Emission measurements were performed on an unburied polyethylene pipe with artificially generated leaks. A good correlation between several monitored parameters and the characteristics of the examined leaks could be identified.

Key-Words: Leak detection, Acoustic Emission, service pipe, water supply network

1 Introduction

Urban water distribution networks are affected by significant leakage issues, which result in large water losses possibly exceeding 30% of the input volume [1-3]. Hence, the implementation of proper policies to control water leaks represents a challenging but essential target for all the utilities involved with drinking water supply.

Many approaches for leak detection and location have been investigated, in order to implement effective Leakage Management strategies [4-14]. Among the available techniques, methods based on Acoustic Emission (AE) appear promising.

Acoustic Emissions are vibro-acoustic phenomena in the sonic and ultrasonic frequency range (up to 1 MHz) which propagates in solid materials as transient elastic waves. AE monitoring is a highly non-intrusive nondestructive testing and evaluation method [15], which is applied to several processes identified as sources of AE signals (e.g. crack formation and growth). AE methods were originally developed for pressure vessels, both to inspect them during pressure testing and to detect leakages (e.g. loss of coolant in nuclear reactor vessels). Also water flows leaking from pipelines generate AE, which propagate along the pipe walls. Indeed, AE methods for leak detection have been successfully applied also to water pipelines, in particular for medium/large-diameter distribution pipes made of steel or plastic or prestressed concrete [16-19], even if the technique effectiveness may be considerably affected by the specific boundary conditions of the system under investigation [20]. In general, better detection capabilities could be achieved by applying procedures for artificially amplifying the leak noise, e.g. gas injection or fluid pressure variation [14, 18]. It is worth noting, however, that such procedures may be unsuitable for practical use in some existing pipeline networks, since they require significant modifications of the system working conditions (which are not always allowed during normal operation, as in the case considered in this study).

This work investigates the detection of water leaks occurring in polyethylene small-diameter service pipes of water supply networks, by means of AE measurements. Leaks in customers' connections are generally characterized by low flow rates but long total runtime (i.e. the total period from the leak initiation to the burst repair). Since thousands of service pipes are present in each water district, also these leaks can result in high overall losses. Implementing an effective active control strategy for this kind of leaks is therefore as crucial as managing larger bursts in the water main pipelines. The long-term objective of the research, promoted by a local multi-utility, is the development of a system for automatic early detection of unreported burst leaks occurring in the service connections running from the water main to the users' metering points [21]. To the authors' best knowledge, no studies specifically investigated the use of AE methods for leak detection purpose in plastic small-diameter service pipes.

Preliminary tests were performed to assess the suitability of AE methods for the application of interest. The experiments were conducted on a test rig featuring an unburied small-diameter polyethylene pipe, which simulated a typical customer connection branch of the network. AE events were monitored by means of a wide-band AE sensor. Water leaks were artificially induced at different distances from the transducer. Measurements in both leaking and non-leaking conditions were carried out.

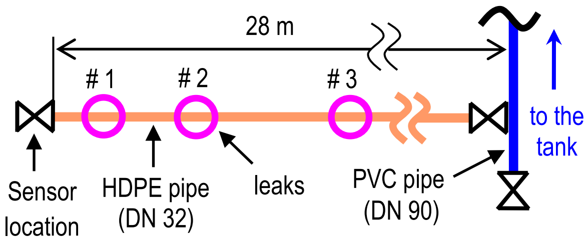
This paper describes the experimental setup and the test procedure, and reports the most relevant results of the analysis.

2 Experimental setup and tests

The test bed, sketched in Fig. 1, simulated a section of the water supply network. The polyvinyl chloride (PVC) pipe with outer diameter of 90 mm (DN 90) was used as water main. A high-density polyethylene (HDPE) pipe of length 28 m and smaller diameter (DN 32) was connected to the larger one as customers' service pipe. It was placed at a depth of about 0.5 m on a layer of backfill soil, but left unburied. Two-way shut-off valves were installed at both its extremities. A pressure tank fed the facility at a constant pressure of about 3.5 bar, which replicates the typical network operation.

Artificial 20 mm longitudinal cuts (parallel to the pipe axis) were generated at three different locations along the pipe (Fig. 1). The distance of each leak from the terminal valve is reported in Fig. 1 too. The induced damages simulated one the most common kind of cracks characterizing burst leaks occurring in the HDPE service pipes managed by the local multi-utility, based on its maintenance records. Such cracks are expected to generate a leaking flow of about 200 l/h in the typical network functioning conditions, which is the target leak rate to detect. Pipe repair clamps were installed to rapidly switch between leaking and non-leaking conditions and vice versa (Fig. 2a, b).

An AE sensor (Mistras WSα, sensitivity 55 dB, ref. 1V/(m/s)) operating in the frequency range 0.1-1 MHz was installed on the pipe terminal valve (Fig. 3). This arrangement simulated the sensor setup possibly achievable in actual service pipes (with the sensor mounted near the customer water meter, i.e. distant from the water main). Acquisition and conditioning of the signals were performed by means of a Mistras USB-AE Node System and the software AEwin for USB. Since very few studies on small-diameter plastic pipes were found, a wideband analysis was performed.



Leak	Distance [m]
#1	1
#2	3
#3	8

Fig. 1. Schematics and characteristics of the test bed

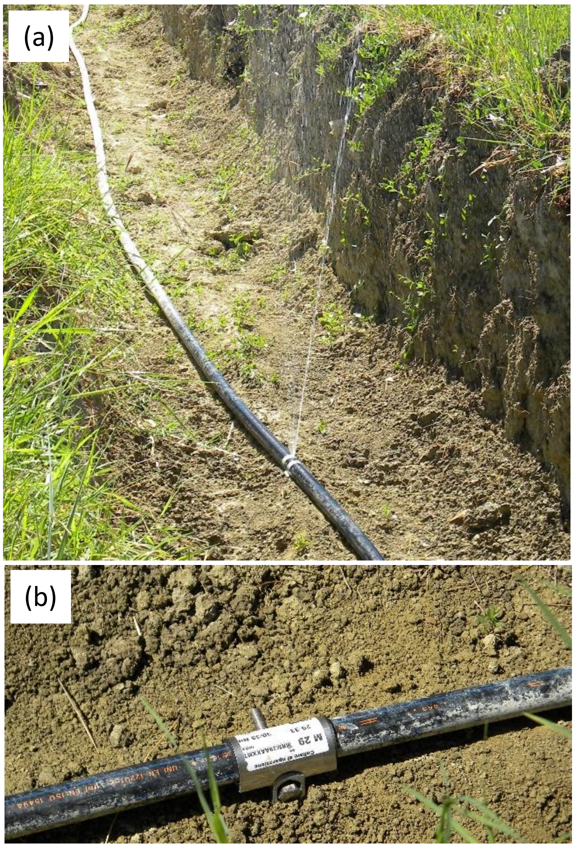


Fig. 2. (a) active leak and (b) leak deactivated using the repair clamp

Fig. 3. AE sensor close up

The acquisition setup featured a threshold of 28 db (which defines the minimum signal amplitude considered for identifying an AE event), a sampling frequency of 5 MHz and a proper set of timing parameters [22]. Time-driven measurements were adopted, namely acquisitions with a preset duration of 90 s. Indeed water leaks are expected to cause continuous AE signals, i.e. time-overlapping emissions (although some exceptions have been documented [14]), as opposed to processes such as crack growth, which are typically associated with burst AE, i.e. a discrete sequence of AE events.

Measurements were performed in three conditions: (i) the non-leaking state (referred to as *NL* hereafter), set by stopping all the leaks with the repair clamps; (ii) water leaking from the *j*-th active leak (*Lk-j*), a condition set by temporarily removing the corresponding repair clamp (Fig. 2a); (iii) all the leaks activated simultaneously (*Lk-123*). The first condition provided data on the environmental noise. The second and the third ones permitted to assess AE events related to active leaks. Many acquisitions were collected for each condition, in order to ensure repeatability. The terminal valve was kept closed in all tests. Consequently, on one hand, the flow rate inside the pipe was entirely ascribable to the leaking flow of an active leak, in order to simulate a condition of null water consumption by the customers. On the other hand, no flow was present at the sensor location.

All the relevant parameters characterizing AE were investigated to find possible correlations with the leaking conditions. In particular, the analysis focused on the trend of three parameters that appeared more sensitive to the presence of leaks, namely: (i) total amount of hits per acquisition, which coincide with the number of AE events for the adopted setup, where only one sensor is installed; (ii) cumulative counts, computed by summing the counts of all hits related to one acquisition; (iii) cumulative peak amplitude, computed by adding together the peak amplitude values of all hits related to one acquisition. The analysis of the distribution of the Average Frequency values (ratio of the counts of an AE event to the duration of the event, referred to as AF hereafter) over the RA values (ratio of the rise time of an AE event to the event peak amplitude) was also taken into account as a possible tool to achieve leak detection, as proposed in [17].

3 Results and discussion

The considered AE parameters, namely Hits, Cumulative counts and Cumulative peak amplitude, are reported in Fig. 4 for all the tested conditions. The values are computed by averaging the measurements of each specific condition.

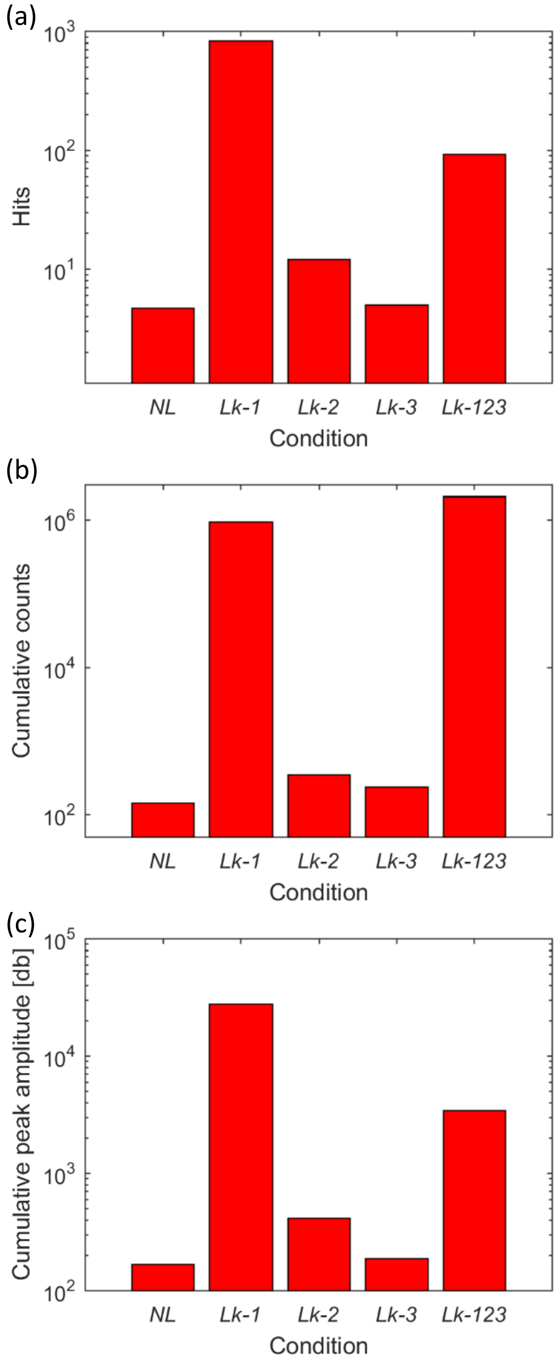


Fig. 4. (a) total hits, (b) cumulative counts and (c) cumulative peak amplitude

Some AE events can be observed for the non-leaking state. Since for this condition the flow in the test bed is null, such events are due to external disturbances.

Data concerning the conditions *Lk-2* and *Lk-3*, i.e. the most distant leaks, exhibit low signal levels, reasonably due to significant attenuation of the high frequencies in the plastic pipe. Consequently, the

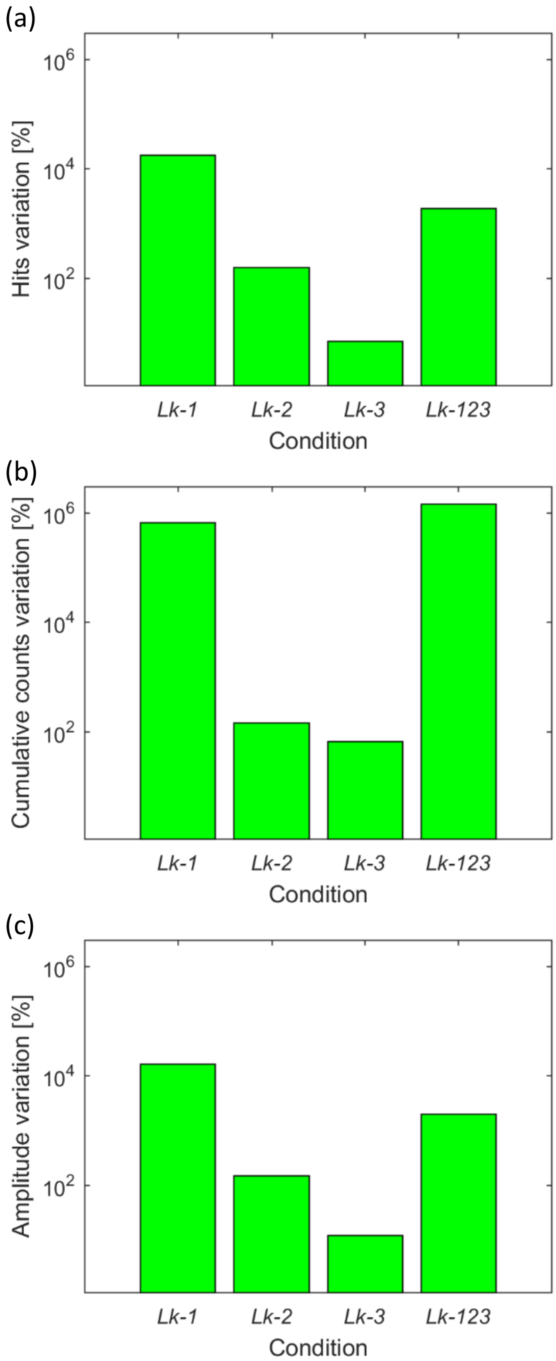


Fig. 5. Percentage variation of (a) total hits, (b) cumulative counts, (c) cumulative peak amplitude

corresponding acquisitions appear characterized by burst signals rather than continuous ones.

As for the leak detection performance, all the leaking conditions are clearly revealed by an increment in all the monitored AE parameters. As expected, the increment is remarkable when the nearest leak is active (conditions *Lk-1* and *Lk-123*), whereas it rapidly decreases as the leak distance grows. The trend of the cumulative counts is also consistent with the variation of the leaking flow rate. Indeed more counts are detected when all the leaks are active. Conversely, the condition *Lk-123* shows less hits than *Lk-1*. This anomaly is reasonably ascribable to the higher average signal level characterizing the former condition (26 db instead of 24 db), which affect the identification of AE events in the continuous signals (since the timing parameters are kept unaltered). The same behavior characterizes the cumulative peak amplitude too, since it partially depends on the number of hits.

The percentage variation of the parameters in the leaking conditions, with respect to the non-leaking state, is computed to better compare their sensitivity to leaks (Fig. 5). The values related to the cumulative counts are higher for all the leaking conditions, and in particular for the most distant leak (*Lk-3*). Hence, the cumulative counts seem potentially more suitable to assess the presence of active leaks. Due to the good correlation with the leak characteristics, such parameter also appears possibly effective to provide information about the leak distance and/or its leaking flow rate. Further test will be performed to achieve a satisfactory degree of confidence in the detection, in particular for distant leaks.

The distribution of the AF over the RA values is also computed for all the tested conditions. Figure 6 reports the comparison between conditions *NL* and *Lk-3*, shown as example. Apparently, the leaking condition exhibits a larger percentage of *tensile-type* AE events, i.e. characterized by higher values of the AF to RA ratio (as opposed to *shear-type* AE events, which feature lower ratios). This behavior is consistent with the result obtained in [17], and permits to detect the leak. However, further data are required to confirm the effectiveness and the convenience of this kind of analysis for leak detection purpose.

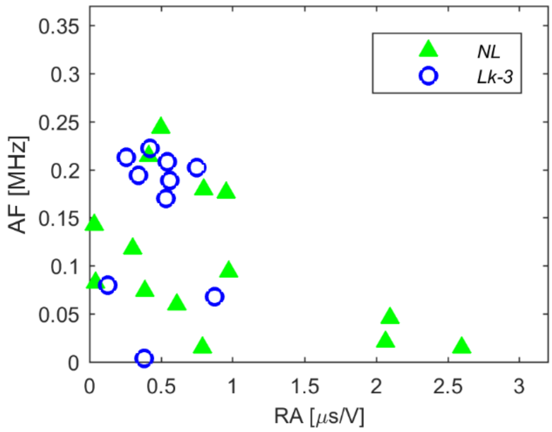


Fig. 6. Diagram of AF vs. RA, comparison between conditions *NL* and *Lk-3*.

4 Conclusion

This study investigated leak detection in water-filled small-diameter plastic pipes with AE methods. Experiments were carried out in a test bed that simulated the water leaks typically occurring in service pipes of the water supply network. In particular, the possibility of detecting leaks without altering the typical operational conditions of the network was assessed.

The tests provided promising results. The AE technique showed an acceptable sensitivity to the presence of active leaks. The trend of at least one AE parameter, namely the cumulative counts, exhibited a direct correlation with both the leak distance and the leaking flow rate.

Nonetheless, further investigations for enhancing the sensitivity to distant leaks seem advisable, in order to achieve reliable leak detection capabilities. In particular, new experiments will be conducted on a buried facility to assess the influence of the surrounding medium on the propagation of AE along the pipelines.

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