EXPERIMENTAL STUDY OF ANTI-SCALE DEVICES EFFICIENCY

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Abstract

The flow of real liquid through the water pipes is connected with the generation of head losses. During the operation of the water pipes scales tend to build up on their walls. This causes reduction of a pipe diameter and as a result increases the hydraulic resistance and decreases the water capacity as well as worsens the water quality. One of the methods used to reduce the accumulation of water scale deposits in water pipes is application of the Magnetic Water Treatment technology. A special test rig was constructed. It was designed to monitor the change in head losses values of the steel pipes under the influence of the magnetically conditioned water. Magnetic devices used in this study are of a different construction and field strength. Studies were performed for three different flow velocities – 0.5, 0.7, 0.9 [m/s] (in test pipes), time period for each of them was 65 days. The results for the MWT devices were compared with the results gathered for test pipes with no device installed, with ION device and with a dummy magnetic device with an inert core. For each case, a graph of the distribution of the hydraulic loss values in time was plotted and a curve was fitted to it. Studies show that the use of the magnetic technology can be an efficient mean of scaling control. They also show how the results depend on the hydraulic parameters and the construction of the devices.

Streszczenie

Przepływ cieczy w przewodach wodociągowych związany jest z generowaniem strat na długości, nazywanych inaczej stratami liniowymi. W trakcie eksploatacji stalowych instalacji wodociągowych obserwuje się wytrącanie osadów na ściankach rur. Zjawisko to powoduje redukcje przekroju przewodu, a przez to zwiększenie oporności hydraulicznej instalacji, obniżenie jej przepływności, a także wpływa niekorzystnie na jakość wody. Jednym ze sposobów zabezpieczania stalowych systemów wodociągowych przed ww. niekorzystnym wpływem akumulacji osadów jest stosowanie urządzeń działających w oparciu o pole magnetyczne. W celu sprawdzenia ich działania skonstruowano układ doświadczalny, który pozwolił na śledzenie zmian wartości strat hydraulicznych przewodów stalowych zachodzących pod wpływem działania wody poddanej działaniu urządzeń magnetycznych (o różnej konstrukcji i wartości indukcji pola). Badanie prowadzono dla trzech różnych prędkości przepływu wody w przewodzie – 0.5, 0.7, 0.9 [m/s] w okresie 65 dób dla każdej. Otrzymane wyniki zestawiono z wynikami dla przewodów porównawczych oraz dla urządzenia działającego w oparciu o efekt ogniwa galwanicznego, następnie do rozkładu zmian ciśnienia dopasowano odpowiednie funkcje. Badania pokazały możliwość zastosowania ww. urządzeń do minimalizacji inkrustacji osadami przewodów wodociągowych, ukazały także ich zależność od parametrów hydraulicznych oraz konstrukcyjnych urządzeń.

Keywords: **Magnetic water treatment; Head loss; Water scales.**

1. INTRODUCTION

The flow of real liquid through the water pipe is connected with generation of the head losses. With the constant diameter of the pipe they are proportional to its length and with the turbulent flow to the sq. of fluid velocity. The hydraulic gradient is the measure of the major head losses:

$$I = \frac{\Delta h_l}{l} \quad (1)$$

$$\Delta h_l = I \cdot l \quad [\mathrm{m}] \quad (2)$$

The scales tend to build up on the walls of the water pipes during their operation. This reduces the pipe's diameter, increases hydraulic resistance and decreases water capacity. It also worsens the water quality.

Deterioration of water quality usually occurs during its transportation, due to chemical or bacteriological contamination. The source of these contaminants may be of internal (release of corrosion by-products, bacterial biofilms, etc.) or external (pipeline failure) origin [8, 10, 12, 13].

One of the methods used to reduce accumulation of water scale deposits in water pipes is application of the Magnetic Water Treatment technology [1, 5, 18].

The history of the MWT technology dates back to the beginning of the 19th century. In 1890's the first commercially available device was presented but it wasn't until mid 1950's, when some reports about the influence of the magnetic field on soluble components of water (e.g. calcium carbonate) were published and the technology became more widespread. However after the initial success, it became obvious that the results acquired were not always satisfying, that showed how complicated the nature of the interaction between magnetic field and water really was. Since that time further studies have been conducted. However the universal guidelines for proper matching the magnetic device and its parameters with the intended goal and place of application are still to be developed. That is why further studies on the matter should be continued [1, 2, 5, 18].

The effectiveness of the magnetic devices was studied in the experimental conditions resembling ordinary domestic water supply system with water temperature of around 10°C, one passage through magnetic device, moderate flow velocity. A variety of different physical water treatment devices was tested, with different construction types, magnets configuration and field strength.

Classification of MWT devices used was based on the "Classification of permanent magnet type MTD" proposed by *Gruber and Carda* – Fig. 1 [1, 9]. The strength of magnetic induction was measured using magnetic field strength meter Gauss-/Teslameter FH 54 Magnet-Physik Dr.Steingroever GmbH [11]. The measurement was taken according to the producer's instructions [11].

The MTD models used were: Polar PD 15 MC (field strength measured in the magnetic rift – 580 [mT], variation of class I construction type), RAM (maximum field strength measured on the surface of the magnetic core – 109 [mT], variation of class III construction type) in three different length variations prepared for the purpose of this study. Those were RAM 20, RAM 30, RAM 50 where the number next to the RAM name corresponds to the length of the core in centimeters. The devices with shortened core (20, 30 [cm]) were experimental constructions. ION Scale Buster S15 based on the galvanic cells technology was used to compare it to the MWT technology. Also two test pipes were included into the test rig, one without any device and the other with the device identical to RAM 50 except for the core which was replaced by one made of an inert material, for the

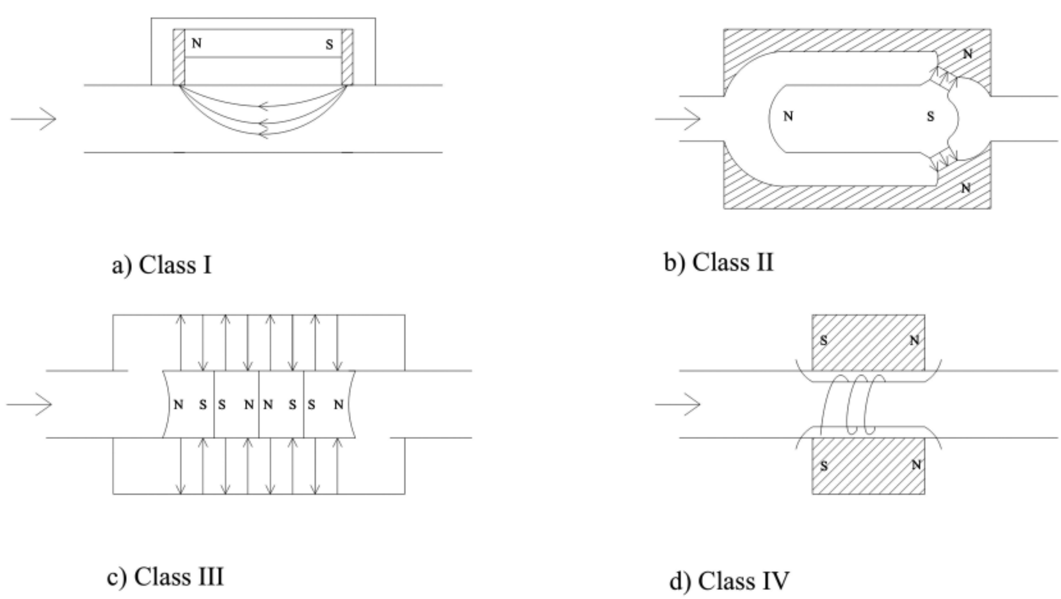

Figure 1.
Classification of permanent magnet type MTD proposed by *Gruber and Carda* [1, 9]

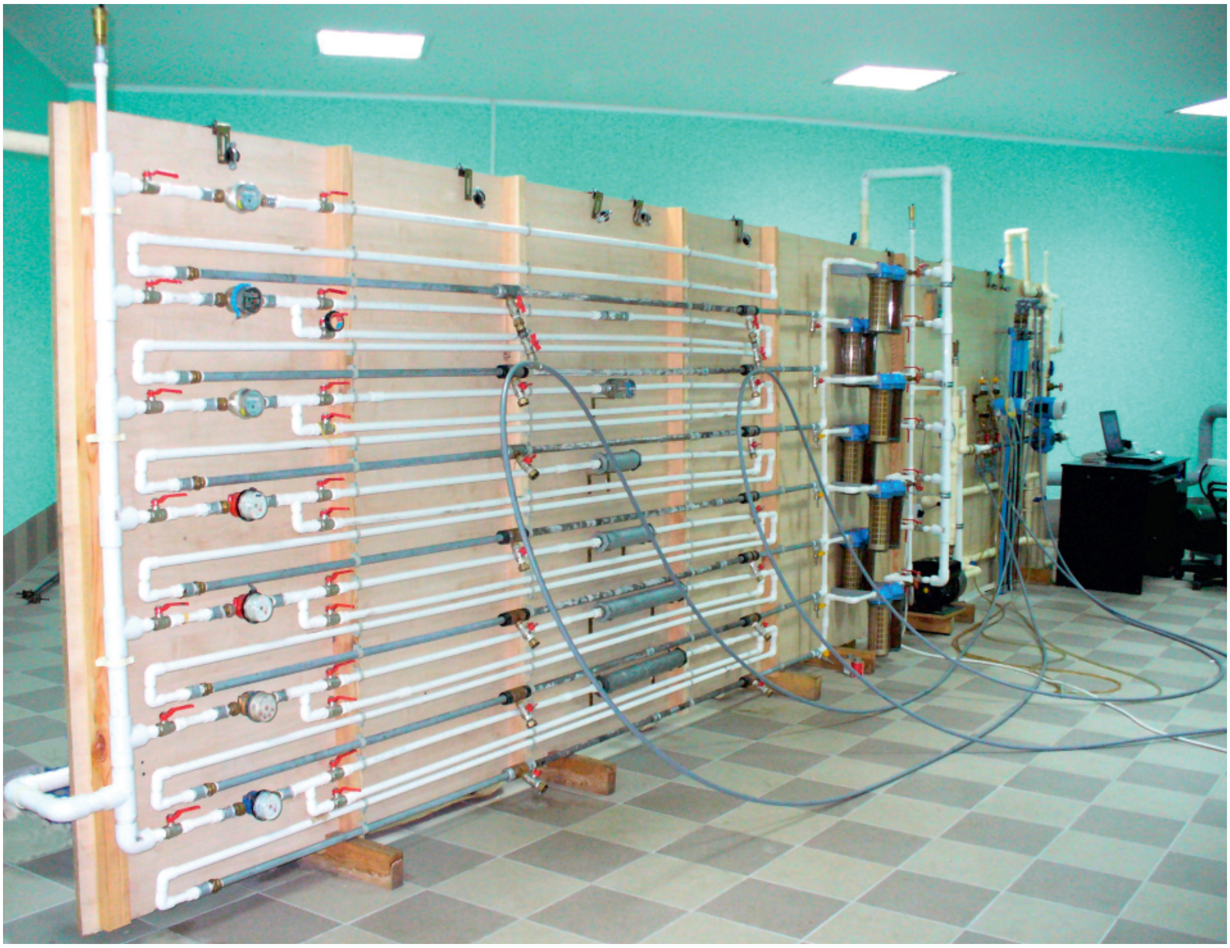

Figure 2.
Test rig – Experimental segments

purpose of this study named RA 50.

The purpose of the study was to determine whether using the selected types of MWT devices can generate acceptable results and to be an effective mean of corrosion and scale control in water systems, on condition that only drinking water acquired from the water system without any modification of its parameters is used. The results presented are a base for further analysis and comparisons with additional data collected during the whole experimental cycle.

2. TEST RIG, METHODOLOGY OF THE STUDIES

The design parameters of the test rig were based on previous studies, theoretical calculations and technical literature [6, 7].

The test rig – Fig. 2-4 consisted of seven independent segments, each with different test device and measurement segment. Flow through the system was provided by a Grundfos CHI-e 4.60 pump with an integrated variable frequency drive and system controller. Every segment consisted of a water meter, the tested device (except for segment no. 1 which had no device installed at all), PVC and steel tubing, test pipe (1.5 meter long, 15-year-old ½” corroded steel pipe). Test pipe was connected with the rest of the segment by a set of custom built pressure-equalizing chambers which allowed undisturbed pressure measuring [6, 7, 15, 16].

Differential pressure was monitored by a pair of Endress+Hauser Deltabar WZ 50/300 differential pressure transmitters.

The length of the steel pipes before (ld) and after (lo) testing pipe segment was based on CFD analysis [5] and the corresponding literature was set for 60d (60x internal diameter) and 30d. It allowed undisturbed pressure monitoring.

Figure 3.
Test rig – Measurement segment

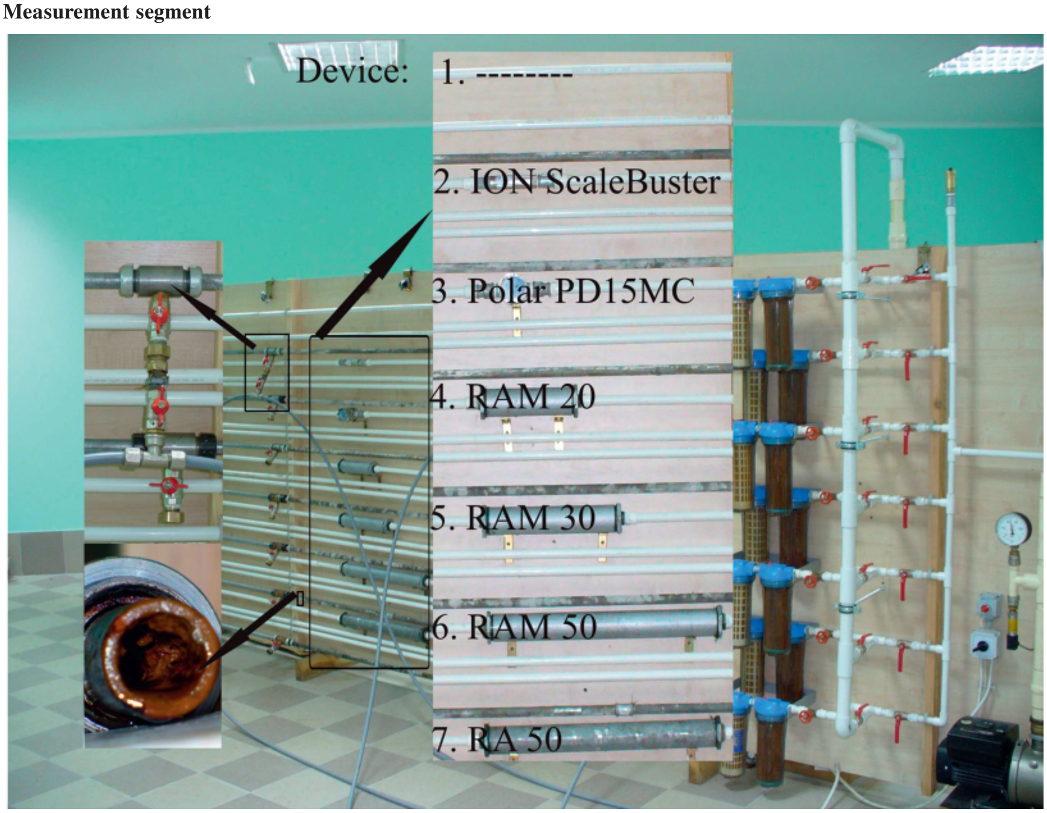

Figure 5.
Test rig – Experimental devices

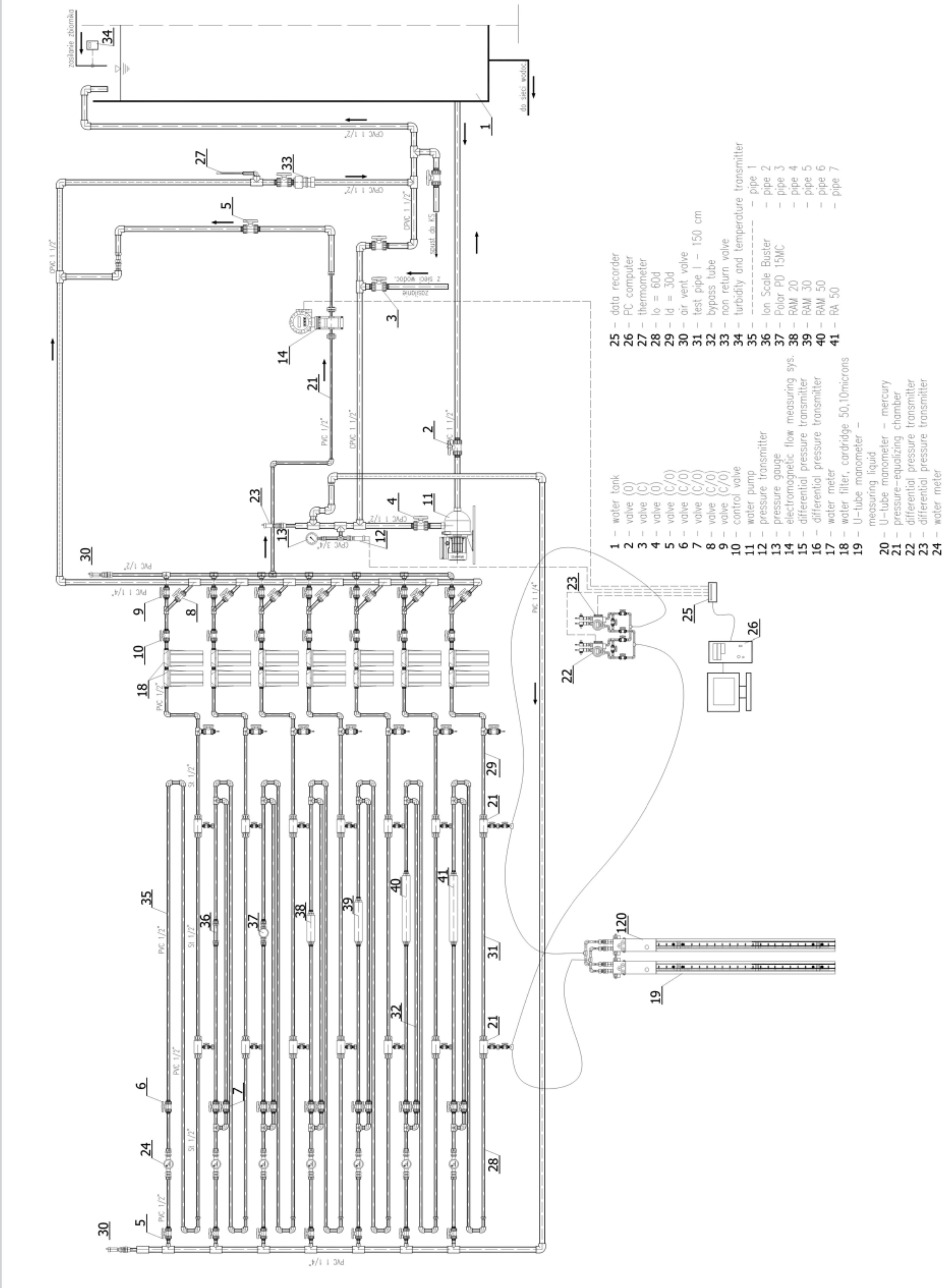

Figure 4.
Test rig

The flow rate through each segment was set to provide the flow velocity of 0.5-1.0 [m/s] for the tested pipe. The flow rate was monitored by Endress+Hauser Promag 50P electromagnetic flow measuring system. To ensure measuring accuracy, the length of the pipe on the inlet of the device was 60d and on the outlet 30d which is significantly more than the operating instruction [2] or norm requires [13].

The flow rate through each segment was regulated by a valve placed at the outflow of the filter set.

Three different flow velocities were chosen – 0.5, 0.7, 0.9 [m/s]. The experimental time for each of them was 65 days. The measurements were taken every 24 hours. Complete experimental cycles took 195 days. Each measurement took more than 4 minutes. Recording interval was set for 1 [s] for the three: Endress+Hauser Deltabar WZ 50 transmitter, Endress+Hauser Promag 50P electromagnetic flow meter and Aplisens pressure monitoring system and, 120 [s] for Endress+Hauser Deltabar WZ 300 transmitter which provided control value for Deltabar WZ 50 pressure measurements [3, 4].

Measuring range was set once at the beginning of every experimental cycle for each flow velocity. Before the first series started all segments were flushed (high velocity) for 3 days using the bypass tubes which prevented the contact of flowing water with devices under examination. That allowed testing pipes to be cleared of any loose or soft deposits.

Measured values were recorded by an 8-bit data recorder and then transferred to a PC class computer. To assure the accuracy of the digital transmitters, measured values were confronted with the results taken from a pair of simultaneously connected U-tube manometers. One of them was filled with mercury and the other with measuring liquid (density $\rho = 2.0$ [g/cm^3]).

Temperature was measured by the turbidity and temperature Endress+Hauser Liquisys M CUM253 transmitter. Its sensor (with an integrated temperature sensor) was installed at the inflow of the water tank. Measured values resolution was 0.1°C. For control reasons the temperature was also measured by a mercury thermometer integrated into the test rig. During the whole experimental cycle the temperature of water was almost constant at the range of 9.5-10.5°C.

Experiment was performed in a semi-closed circulation (water from the tank was pumped for 6 [h] every day and then it was refilled). Water was pumped from the drinking water tank. Flow through the system was provided by Grundfos CHI-e 4.60 pump. The pressure in the rig was monitored by Aplisens PC-28 pressure transmitter and by a pressure gauge.

Water quality during the whole experimental cycle varied (at a normal rate for a drinking water system) however typical values for the duration of the experiment were: pH 7.21, turbidity 0.81 [NTU], conduc-

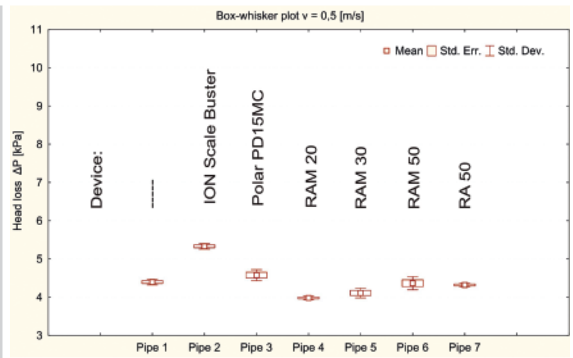

Figure 6.
Graph of the variability of the pressure loss ΔP of experimental pipes, flow velocity v = 0.5 [m/s]

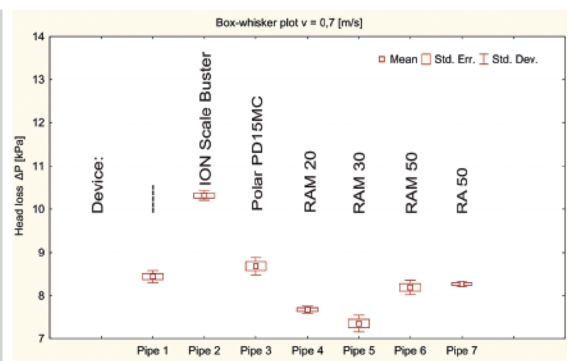

Figure 7.
Graph of the variability of the pressure loss ΔP of experimental pipes, flow velocity v = 0.7 [m/s]

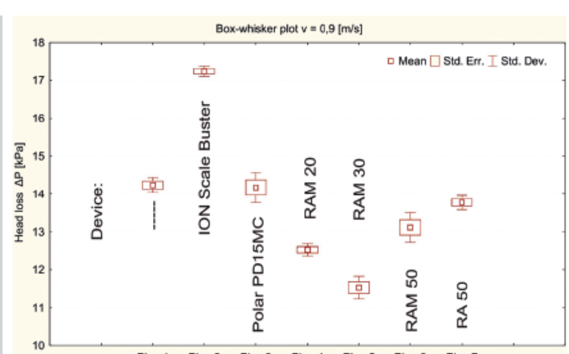

Figure 8.
Graph of the variability of the pressure loss ΔP of experimental pipes, flow velocity v = 0.9 [m/s]

Table 1.
Collation of coefficients of variation for v = 0.5, 0.7, 0.9 [m/s]

Pipe/Segment	Coefficient of variation [%] for v = 0.5 [m/s]	Coefficient of variation [%] for v = 0.7 [m/s]	Coefficient of variation [%] for v = 0.9 [m/s]
Pipe 1	0.84	0.83	0.72
Pipe 2	0.68	0.53	0.4
Pipe 3	1.64	1.17	1.43
Pipe 4	0.60	0.53	0.66
Pipe 5	1.59	1.38	1.31
Pipe 6	2.01	1.03	1.52
Pipe 7	0.61	0.34	0.69

tance 1038.0 [μS/cm], iron 0.115 [mgFe/dm³], calcium 141.54 [mgCa/dm³], magnesium 27.85 [mgMg/dm³], total hardness 467.70 [$mgCaCO_3/dm^3$], total alkalinity 5.24 [mmol/dm³], sulfates 153.62 [$mgSO_4/dm^3$].

3. RESULTS AND DISCUSSION

Variability of the results gathered for each experimental segment at a predetermined flow velocities were presented graphically in the box and whisker plots – Fig. 6, 7, 8 [17].

Coefficients of variation of each test pipe and flow velocities are gathered in Table 1.

Based upon the results presented in Fig. 6 to 8 and Table 1., testing devices installed in segments 3, 5, 6 were chosen for extended analysis (coefficient of variation > 1%) – devices POLAR PD15 MC, RAM 30, RAM 50 respectively.

For each case, plots of the distribution of the hydraulic loss values ΔP in time T were plotted and then a curve was fitted to it. Fig. 9 serves as example.

The fitted function formula for segment 6 (RAM 50, Fig. 9) is:

$$\Delta P_6=((13{,}532)+(-0{,}015)*T)\text{for}(T<=37) \text{ and } ((13{,}143)+(-0{,}004)*T)\text{for}(T>37) \text{ [kPa]} \quad (3)$$

Results of the statistical analysis of segments 3, 5, 6 were presented in Fig. 10, 11, 12. Values of the coefficients of determination R^2 (where applicable) were 0.89-0.99. Due to the complex nature of the interaction between water and magnetic field (e.g. influence on the crystallization processes, etc.) [4, 17] these values were considered acceptable.

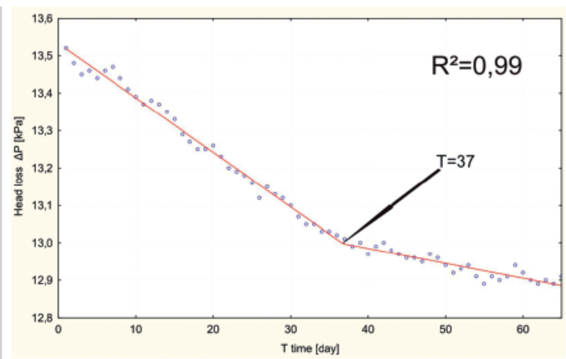

Figure 9.
Graph of the function curve fitted to the distribution of the hydraulic loss values ΔP in time T – pipe 6, v = 0.9 [m/s]

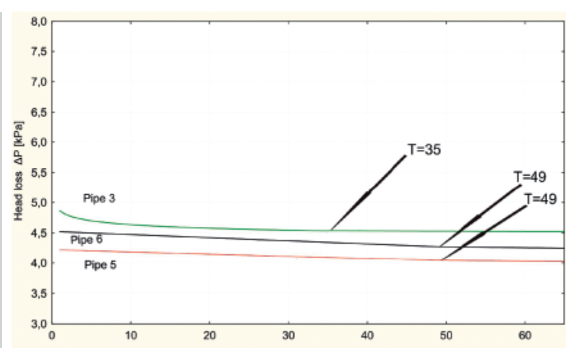

Figure 10.
Graph of the function curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.5 [m/s]

The fitted function formulas for segments 3, 5, 6 (POLAR PD15M, RAM 30, RAM 50) are:

$$\Delta P_3=((3{,}86873)+T\hat{\ }(-{,}11406))\text{for}(T<=35) \text{ and } ((4{,}55685)+(-{,}52e\text{-}3)*T)\text{for}(T>35) \text{ [kPa]} \quad (4)$$

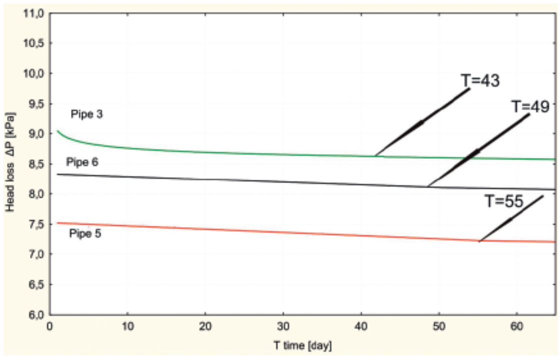

Figure 11.
Graph of the functions curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.7 [m/s]

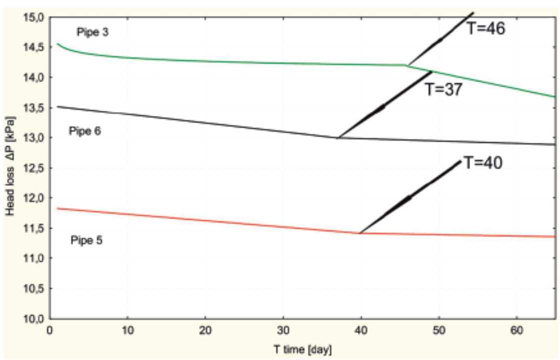

Figure 12.
Graph of the functions curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.9 [m/s]

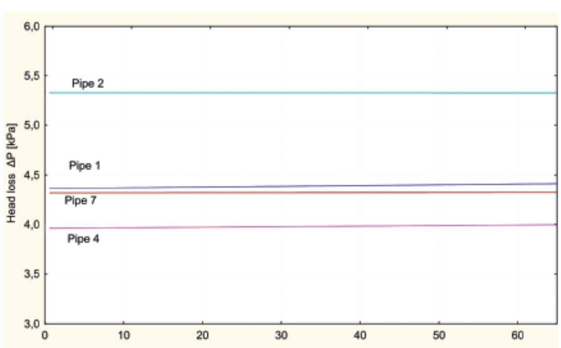

Figure13.
Graph of the functions curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.5 [m/s], Pipes 1, 2, 4, 7

$\Delta P_5 = ((4,227)+(-0,004)*T)for(T<=49)$ and
$((4,097)+(-0,001)*T)for(T>49)$ [kPa] (5)

$\Delta P_6 = ((4,527)+(-0,005)*T)for(T<=49)$ and
$((4,349)+(-0,001)*T)for(T>49)$ [kPa] (6)

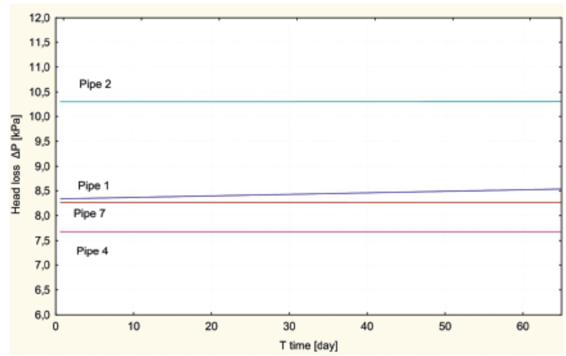

Figure 14.
Graph of the functions curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.7 [m/s], Pipes 1, 2, 4, 7

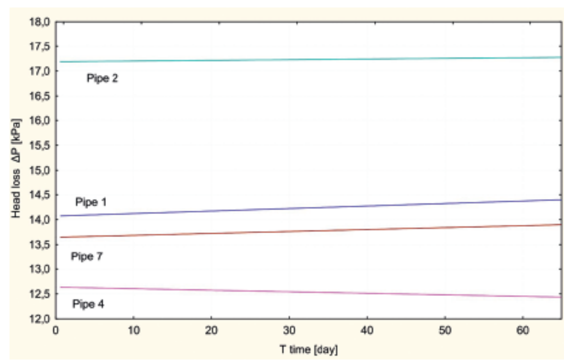

Figure 15.
Graph of the functions curves fitted to the distributions of the hydraulic loss values ΔP in time T, v = 0.9 [m/s], Pipes 1, 2, 4, 7

For v = 0,7 [m/s] (Fig. 11) the fitted function formulas for segments 3, 5, 6 (POLAR PD15M, RAM 30, RAM 50) are:

$\Delta P_3 = (8,044)+T^{\wedge}(-0,144))for(T<=43)$ and
$((8,702)+(-0,002)*T)for(T>43)$ [kPa] (7)

$\Delta P_5 = ((7,335)+(-0,002)*T)for(T>=55)$ and
$((7,526)+(-0,005)*T)for(T<55)$ [kPa] (8)

$\Delta P_6 = ((4,527)+(-0,005)*T)for(T<=49)$ and
$((4,349)+(-0,002)*T)for(T>49)$ [kPa] (9)

For v = 0,9 [m/s] (Fig. 12) the fitted function formulas for segments 3, 5, 6 (POLAR PD15M, RAM 30, RAM 50) are:

$\Delta P_3 = ((13,554)+T^{\wedge}(-0,114))for(T<=46)$ and
$((15,402)+(-0,026)*T)for(T>46)$ [kPa] (10)

$\Delta P_5 = ((1,325)+(-0,008)*T)for(T<=40)$ and
$((10,509)+(-,002)*T)for(T>40)$ [kPa] (11)

$\Delta P_6 = ((13,532)+(-0,014)*T)for(T<=37)$ and
$((13,143)+(-0,004)*T)for(T>37)$ [kPa] (12)

Table 2.
Collation of the percentage change in head loss values P in time T

Pipe Device	Magnetic Field [mT]	Change in the head loss value during 65 day period [%]		
		v = 0.5 [m/s]	v = 0.7 [m/s]	v = 0.9 [m/s]
1- None	-	+0.68	+1.66	+2.69
2 ION S15	-	+1.67	0.00	+0.29
3 Polar PD 15MC	580	-6.84	-4.06	-5.39
4 RAM 20	109	0.00	-0.39	-1.71
5 RAM 30	109	-4.73	-3.99	-3.58
6 RAM 50	109	-5.76	-2.89	-4.51
7 RA 50	-	-0.92	-0.60	+1.47
where "+" means growth, "-" reduction of the head loss, 100% – value of the major loss at the beginning of each cycle				

For v = 0,5 [m/s] (Fig. 13) the fitted function formulas for segments 1, 2, 4, 7 (-----, ION Scale Buster, RAM 20, RA 50) are:

$\Delta P_1 = 4{,}364+0{,}001*T$ [kPa] (13)

$\Delta P_2 = 5{,}330-5{,}940-5*T$ [kPa] (14)

$\Delta P_4 = 3{,}961+0{,}001*T$ [kPa] (15)

$\Delta P_7 = 4{,}316+23{,}215-5*T$ [kPa] (16)

For v = 0,7 [m/s] (Fig. 14) the fitted function formulas for segments 1, 2, 4, 7 (-----, ION Scale Buster, RAM 20, RA 50) are:

$\Delta P1 = 8{,}335+0{,}003*T$ [kPa] (17)

$\Delta P2 = 10{,}306+23{,}523-5*T$ [kPa] (18)

$\Delta P4 = 7{,}6762+3{,}089-5*T$ [kPa] (19)

$\Delta P7 = 8{,}2657-9{,}980-5*T$ [kPa] (20)

For v = 0,9 [m/s] (Fig. 15) the fitted function formulas for segments 1, 2, 4, 7 (-----, ION Scale Buster, RAM 20, RA 50) are:

$\Delta P1 = 14{,}072+0{,}005*T$ [kPa] (21)

$\Delta P2 = 17{,}189+0{,}001*$ [kPa] (22)

$\Delta P4 = 12{,}635-0{,}003*T$ [kPa] (23)

$\Delta P7 = 13{,}647+0{,}004*T$ [kPa] (24)

4. CONCLUSION

MWT devices can be an efficient solution to scaling problems in water pipes.

The proper choice of the device type fitting the hydraulic conditions in a mounting place is a necessary condition for its effectiveness.

Comparison of the results gathered in Table 2 for MWT devices with stronger magnetic field strength (580 [mT]) with the results of the devices with weaker field strength (109 [mT]) shows compensation of the effects through the extension of the contact time with the weaker magnetic field.

The results of three variations of the RAM devices show the extension of contact time with the magnetic field (through the change of the length of magnetic core) as an effective mean to improve the efficiency of the devices.

REFERENCES

[1] *Baker J.S., Judd S.J.*; Magnetic amelioration of scale formation. Elsevier Science Ltd., Water Research Vol. 30, No. 2, p.247-260, 1996

[2] *Brower J.*; Magnetic Water Treatment, Pollution Engineering, No. 2, p.26-28, Feb 2005

[3] *Endress+Hauser*; Przepływomierz elektromagnetyczny Promag 50, Instrukcja obsługi. (Electromagnetic Flow Measuring System Promag 50, Operating Instructions) BA 046D/06/pl/04.00 (in Polish)

[4] *Endress+Hauser*; Przetwornik różnicy ciśnień Deltabar S, Instrukcja obsługi, BA 174P/00/pl/07.98a. (Differential pressure transmitter Deltabar S, Operating Instructions) (in Polish)

[5] *Gabrielli C., Jaouhari R., Maurin G., Keddam M.*; Magnetic water treatment for scale prevention. Elsevier Science Ltd., Water Research Vol. 35, No. 13, p.3249-3259, 2001

[6] *Grajper P.*; Eksperymentalne wyznaczenie miejscowych strat ciśnienia w kolanach 90° współczesnych systemów instalacyjnych. Rozprawa doktorska (Experimental determination of the minor head loss in the 90° elbows in modern plumbing systems. PhD thesis) – Instytut Inżynierii Wody i Ścieków Zakład Wodociągów i Kanalizacji, Politechnika Śląska, Gliwice 2004 (in Polish)

[7] *Kołodziejczyk L., Mańkowski S., Rubik M.*; Pomiary w inżynierii sanitarnej. (Measurements in sanitation engineering) Arkady, Warszawa 1974 (in Polish)

[8] *Krogulska B., Wichrowska B.*; Wpływ instalacji wodociągowych na jakość wody. (Influence of indoor plumbing systems on the water quality) Polski Instalator 2/94 (in Polish)

[9] *Krope J., Kozic V., Tiar I., Kiker E.*; Laboratory measurements on magnetic water treatment device, IECON'01: The 27th Annual Conference of the IEEE Industrial Electronics Society, p.2190-2193, Denver 2001

[10] *Lehtolaa M.J., Miettinena I.T., Keinanena M.M., Kekkia T.K., Laineb O., Hirvonenc A., Vartiainenb T., Martikainenc P.J.*; Microbiology, chemistry and biofilm development in a pilot drinking water distribution system with copper and plastic pipes. Water Research Vol. 38, p. 3769–3779, Elsevier Science Ltd, 2004

[11] *Magnet-Physik Dr.Steingroever GmbH*; Miernik natężenia pola magnetycznego FH 54, Instrukcja obsługi. (Magnetic Field Strength Meter Gaussmeter/Teslameter FH 54, Operating Instructions) BA 0420020102 (in Polish)

[12] *McNeill L. S., Edwards M.*; Iron pipe corrosion in distribution system. Journal AWWA, July 2001, p.88-100

[13] *Percival S.L., Knapp J.S., R. G. J. Edyvean R.G.J., Wales D.S.*; BIOFILMS, MAINS WATER AND STAINLESS STEEL, Water Research Vol.32, No.7, p.2187-2201, Elsevier Science Ltd, 1998

[14] PN-EN 6817:1996; Pomiar strumienia masy lub strumienia objętości cieczy przewodzącej w przewodach. Metoda z zastosowaniem przepływomierzy elektromagnetycznych. (Measurement of conductive liquid. Flow in closed circuits – methods using electromagnetic flowmeters) (in Polish)

[15] PN-EN ISO 5167-1:2005; Pomiary strumienia płynu za pomocą zwężek pomiarowych. Kryzy, dysze, zwężki Venturiego wbudowane w całkowicie wypełnione rurociągi o przekroju kołowym. (Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 1: General principles and requirements) (in Polish)

[16] PN-ISO 4064-3:1997; Pomiar objętości wody w przewodach. Wodomierze do wody pitnej zimnej. Metody badań i wyposażenie. (Measurement of water flow in fully charged closed conduits – Meters for cold potable water and hot water – Part 3: Test methods and equipment) (in Polish)

[17] StatSoft, Inc. (2007). Electronic Statistics Textbook. Tulsa, (http://www.statsoft.com/textbook/stathome.html), StatSoft, 2007

[18] *Wang Y., Babcin A.J., Chernyi L.T., Chow R.S., Sawatzky R.P.*; Rapid onset of calcium carbonate crystallization under the influence of a magnetic field, Elsevier Science Ltd., Water Research Vol.31, No.2, p.346-350, 1997