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EXPERIMENTAL INVESTIGATIONS OF HYDRAULIC RESISTANCE ON LIFTS IN PIPELINES OF A VACUUM SEWAGE SYSTEM

The results of research into hydraulic resistance on lifts for sewage flow in the pipeline of a vacuum sewage system were analyzed. An investigation of hydraulic resistance was carried out on the lifts of an experimental vacuum sewage system built in a laboratory. The research methodology comprised the measurement of a pressure drop on the lifts of pipelines of the outside diameters: 65 mm, 90 mm, 110 mm and three interface valve opening times: 6, 9, and 12 seconds. Based on the results obtained, empirical formulas were derived for calculating the hydraulic resistance on the lifts of pipelines in a vacuum sewage system.

1. INTRODUCTION

Many sewage systems in rural areas are currently being built in Poland. The present sanitary state in Polish small towns is far from ideal. Up to the end of 2004, only 34.4 thousand kilometers of sewage system network has been built in Poland [2]. By the end of 2004 out of the total of 41,200 villages, 87.6% did not have any sewage system, while only 7.3% villages were served by complete sewer systems and 5.1% were partly served. The construction of classical gravitational sewage systems is cost-prohibitive in rural areas with dispersed building practices; thus, vacuum sewage systems are more common.

Sewage flow in vacuum pipelines is a complex process dependent upon several factors [3], [4], [5], [8]. In spite of extensive research, the real hydraulic conditions in a vacuum sewage system still have not been completely recognized. Presently, a reliable method of dimensioning a vacuum sewage system is lacking. The dimensioning methods available in literature are based on quota methods from operational experience.

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In available literature, it is possible to find three methods of designing a vacuum sewage system: Polish, German and American [6]. At present, vacuum sewage systems are being designed in Europe, including Poland, based on recommendations contained in the German guidelines ATV-DVWK-A 116 [1] and the European norm PN-EN 1091 [7] as well as on experience gained during the operation of working systems. Designing vacuum sewage systems may be problematic due to the following unknown factors: the connection between real hydraulic resistances on lift during sewage flow in vacuum pipelines, the amount of introduced air, and the opening time of the interface valve.

This article presents the methodology and analysis of results from research regarding hydraulic resistances on lift for pipeline sewage flow in a vacuum sewage system. The range of the article includes the research of hydraulic resistances on lift in pipelines having the outside diameters of 65 mm, 90 mm, 110 mm and three interface valve opening times of 6 s, 9 s, 12 s. The investigations were carried out using an installation of an experimental vacuum sewage system built in a hydraulic laboratory.

2. DESCRIPTION OF THE MEASURING POST

The experimental vacuum sewage system having a scale of 1:1 was constructed in a laboratory. Materials and devices typically used for the construction of vacuum sewage systems were used to build the laboratory installation. Four emptying Roediger knots [3] were mounted at different heights with two located on the level of the floor and two at 2.0 m above the floor on scaffolding made of steel rails. As the vacuum sewage system is best built on flat lands, the difference between the altitudes of the pipeline levels in the installation is small, amounting to 3.0 m [1], [7]. Pipelines for the experimental vacuum sewage system were mounted on the appropriately prepared steel rail scaffolding. The total length of individual pipeline branches is as follows: pipelines with a 63 mm diameter – 96 m, pipelines with a 90 mm diameter – 44 m, pipelines with a 110 mm diameter – 42 m.

Figure 1 presents an installation schematic of the experimental vacuum sewage system. The observation posts from 1a to 6a, b, c, d were made from transparent PMMA pipes and the remaining piping network from PVC. The transparent segments of the vacuum pipes allowed the observation of medium flow structures under different conditions. The transparent container (18) prevents water from splashing onto the laboratory floor and a vacuum pump was used. The vacuum vessel (2) applied has a volume of 2.5 m^3. The media transported in the installation were water and air. The installation can operate in closed and open arrangements and under unsteady as well as steady conditions.

The operational sequence of the installation under unsteady flow conditions is as follows: after opening the throttling valve (17) and switching on the vacuum pump (1), an underpressure appears in the vacuum vessel (2) and in the arrangement of vacuum pipelines (3), (4), (5). When the underpressure (which is read from the electronic meter of the absolute pressure (15e)) is appropriate, a water pump is switched on (9) which pumps liquid from the vacuum vessel (2) through the pressure pipeline (10) to appropriate collection sumps (11a, b, c, d). Next, a control valve closes (8f), and a control valve opens (8e), along with appropriate control valves (8a, b, c, d). Interface valves open automatically in a random way, depending on the liquid level for individual collection sumps.

When the appropriate collection sump together with the sensor pipe fills with the liquid (6) the appropriate pressure is transmitted to the air controller through the impulse hose. Then the interface valve opens (7a, b, c, d) and the liquid from the collection sump is sucked out to the network of vacuum pipelines. After the liquid is sucked out from the collection sump, the interface valve remains open for a few seconds during which air is sucked into the experimental vacuum sewage system.

3. RESEARCH METHODOLOGY

The research of hydraulic resistances on lifts in the installation of experimental vacuum sewage system was carried out as the one knot – No. 1 (figure 1) – was in operation. The measurements were made at three lifts (4a), (5ab), (5abcd) located in the center of individual vacuum pipelines. The hydraulic resistances were measured at lifts of the vacuum pipelines as absolute pressures p_{bz} in the vacuum vessel (2) were being applied. The pipelines had the outside diameters of 65 mm, 90 mm, 110 mm and three interface valve opening times (7a): 6 s, 9 s, 12 s. The values of the absolute pressure p_{bz} were in the range from 0.20 to 0.45 bar with the interval of 0.05 bar. Three measuring series were carried out for each lift diameter in the vacuum pipeline and for each time of opening the interface valve. Before each measuring series when the system was off, the barometric pressure p_b was read from the electronic meter of the absolute pressure (15e). Since the current barometric pressure p_b during a given measuring series and the applied absolute pressure p_{bz} in the vacuum vessel were known, the underpressure in the vacuum vessel p_{vz} could be calculated. During the research, the constant value of the applied absolute pressure in the vacuum vessel was maintained by the valve (21) and simultaneously was observed from the absolute pressure electronic meter (15e).

When the interface valve is closed in individual vacuum pipelines, no liquid flow is observed. After opening the interface valve, a cork mixture of air and liquid flows through the individual vacuum pipelines (3) (figure 2). During the flow of the air–liquid mixture, the electronic meter of pressure difference (2) shows the hydraulic losses ΔH, occurring on the given lift (6) in the vacuum pipeline (1) by the applied absolute pressure p_{bz} in the vacuum vessel.

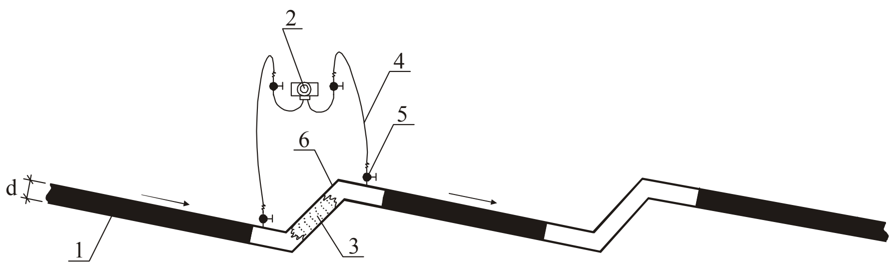

Fig. 2. Measurement of the difference of vacuum on lift:
1 – vacuum pipeline, 2 – electronic meter of the difference of pressure,
3 – cork of mixture of air and liquid, 4 – impulse hose, 5 – cut of valve, 6 – lift

4. DISCUSSION OF THE RESULTS

Figures 3, 4, and 5 present the results from the research of hydraulic losses ΔH as a function of the value of underpressure in the vacuum vessel p_{vz}. From these results (figures 3, 4, 5), it can be concluded that the individual measuring points lie near each other, creating distinct, trending lines for the individual opening times of the interface valve. The observed trend is mathematically best described by a second-degree polynomial. For the lifts on the 63 mm and 90 mm diameter vacuum pipelines, the trend

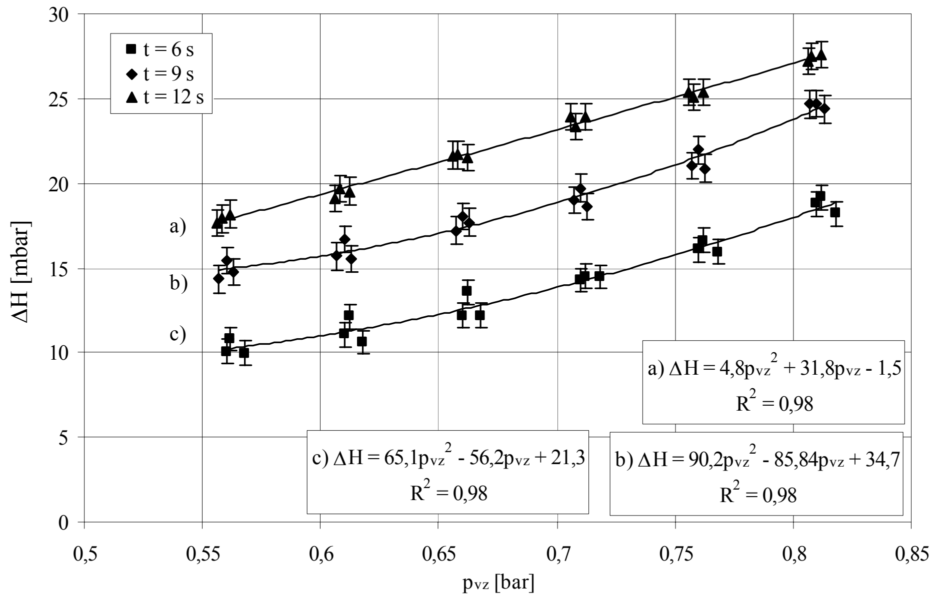

Fig. 3. Lift on the vacuum pipeline of 63 mm diameter

lines for the individual opening times of the interface valve lie relatively parallel. The distance between them decreases with an increase in opening time of the interface valve. However, for the lift on the 110 mm diameter vacuum pipeline, the lines of trend assume the opposite direction and intersect one another.

The coefficient of determination R^2 from the trial for individual lines of trend amounts to 0.98. This means that the hydraulic losses on the lifts in the vacuum pipeline of the given diameter depend in 98% on the underpressure value in the vacuum vessel p_{vz} and on the opening time of the interface valve t, while they depend only in 2% on other factors. Empirical formulas were derived (given in figure 3, 4, 5) to calculate the hydraulic losses ΔH on lifts in vacuum pipelines, depending on the underpressure in the vacuum vessel p_{vz} and the opening time of the interface valve t.

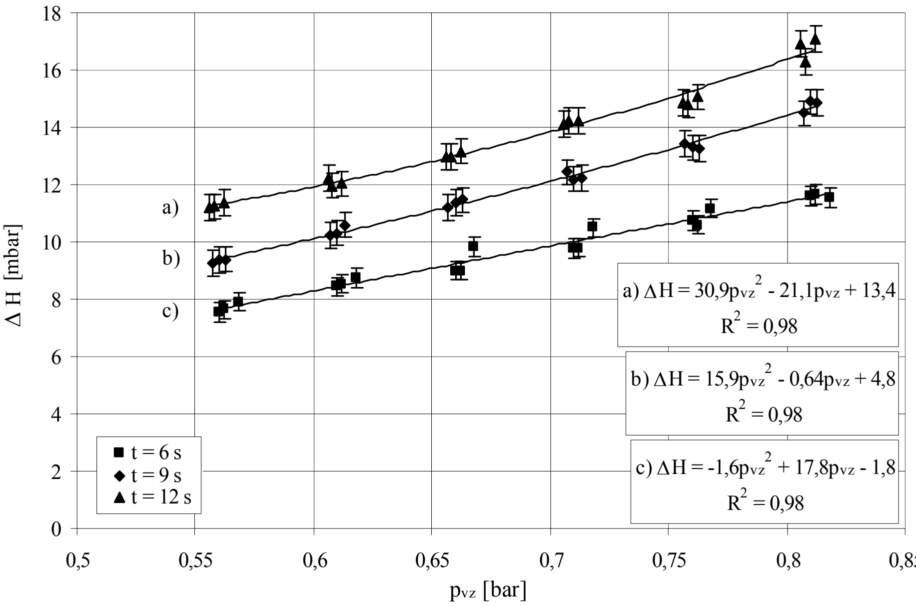

Fig. 4. Lift on the vacuum pipeline of 90 mm diameter

In table 1, the results of hydraulic losses $H_{\min}$ from the applied minimum underpressure in the vacuum vessel and hydraulic losses $H_{\max}$ from the applied maximum underpressure in this vessel as well as static losses h are compared. In table 2, the results of statistical calculations for the coefficient of variation V for the measured value of hydraulic losses ΔH are compared. A static loss h, according to ATV-DVWK-A 116 [1], is defined as the height of lift inside a vacuum pipeline. Tests show that the static losses h are higher on the lifts in vacuum pipelines than the minimum $H_{\min}$ and maximum $H_{\max}$ hydraulic losses. However, the coefficient of variation V for the measured hydraulic losses ΔH assumes small values and fluctuates between 6% and 29%, depending on the interface valve opening time and on the diameter of the vacuum pipeline lift.

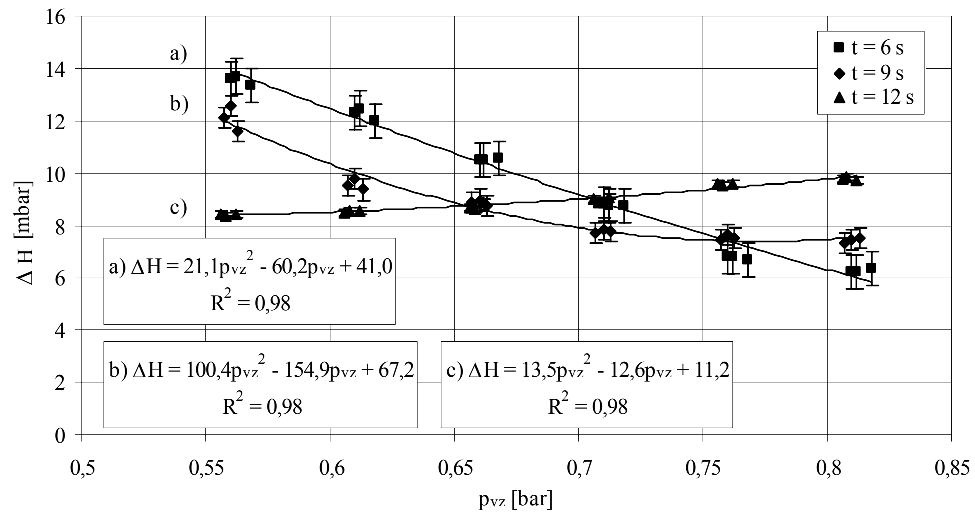

Fig. 5. Lift on the vacuum pipeline of 110 mm diameter

Table 1

Results of the measurement of hydraulic resistance ΔH and static loss h

Diameter of the pipeline (mm)	Time of opening the interface valve t [s]								
	6			9			12		
	Hydraulic resistance ΔH (m)		Static loss h (m)	Hydraulic resistance ΔH (m)		Static loss h (m)	Hydraulic resistance ΔH (m)		Static loss h (m)
63	0.10	0.19	0.30	0.14	0.25	0.30	0.18	0.28	0.30
90	0.08	0.12	0.42	0.09	0.15	0.42	0.11	0.17	0.42
110	0.14	0.06	0.35	0.13	0.07	0.35	0.08	0.10	0.35

Table 2

Results of a statistical analysis of the coefficient of variation for measured hydraulic resistances ΔH

Diameter of the pipeline (mm)	Time of the opening of the interface valve t (s)		
	6	9	12
	Coefficient of variation V (%)		
63	22	14	29
90	18	16	19
110	15	14	6

5. CONCLUSIONS

1. In the vacuum sewage system, the height of hydraulic losses ΔH on lifts in vacuum pipelines depends on the underpressure value p_{vz} in the vacuum vessel. On the lifts in vacuum pipelines of the 63 mm and 90 mm diameters, the hydraulic losses increase along with the underpressure in the vacuum vessel. However, on the lifts in the vacuum pipeline having an outside diameter of 110 mm, the hydraulic losses decrease as the underpressure in the vacuum vessel increases.

2. The interface valve opening time t and, in the process, the amount of air introduced to the vacuum sewage system affect the value of hydraulic losses ΔH on lifts in vacuum pipelines. On the lifts in vacuum pipelines of 63 mm and 90 mm outside diameters, the hydraulic losses increase along with the interface valve opening time and the amount of introduced air. However, on the lifts in the vacuum pipeline of 110 mm outside diameter, the hydraulic losses change slightly as the interface valve opening time and the amount of introduced air increase.

3. In the vacuum sewage system, the size of the lift diameter in the vacuum pipeline also has an influence on the hydraulic losses. Specifically, hydraulic losses decrease as the lift diameter in the vacuum pipeline increases.

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EKSPERYMENTALNE BADANIA OPORÓW HYDRAULICZNYCH NA WZNIESIENIACH W RUROCIĄGACH KANALIZACJI PODCIŚNIENIOWEJ

Przedstawiono analizę wyników badań oporów hydraulicznych na wzniesieniach podczas przepływu ścieków w rurociągach kanalizacji podciśnieniowej. Badania oporów hydraulicznych na wzniesieniach zostały przeprowadzone na wybudowanej w laboratorium eksperymentalnej instalacji kanali-

zacji podciśnieniowej. Metodyka badań obejmowała pomiary spadku ciśnienia na wzniesieniach w rurociągach o średnicy zewnętrznej: 65 mm, 90 mm, 110 mm i trzech czasach otwarcia zaworu opróżniającego: 6, 9, 12 sekund. Na podstawie otrzymanych wyników badań, wyznaczono empiryczne wzory do obliczania oporów hydraulicznych na wzniesieniach w rurociągach kanalizacji podciśnieniowej.