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THE ANALYSIS OF THE EXPLOITATION OF THE WATER NETWORK ON THE EXAMPLE OF THE KROSNO WATER NETWORK

ANALIZA EKSPLOATACJI SIECI WODOCIĄGOWEJ NA PRZYKŁADZIE WODOCIĄGU KROŚNIEŃSKIEGO

W pracy przedstawiono analizę eksploatacji sieci wodociągowej na przykładzie wodociągu krośnieńskiego. Analizę przeprowadzono w oparciu o dane eksploatacyjne sieci wodociągowej uzyskane od MPGK Krosno Sp. z o. o. w latach 2005÷2009. Wyznaczono intensywności uszkodzeń, odnoszące liczbę awarii do długości przewodów wodociągowych. Przeprowadzono analizę wahań sezonowych w strumieniu uszkodzeń przewodów wodociągowych. Zakres pracy obejmuje również analizę produkcji wody oraz strat. Dokonano porównawczej analizy strat wody w pięciu systemach zaopatrzenia wody położonych w województwie podkarpackim.

1. Introduction

The goal of water distribution subsystem (WDS) is providing the water to the recipients with appropriate quality (according to applicable regulations), in the appropriate amount and under the appropriate pressure, as well as about the acceptable price [7]. In WDS the failures of the water supply system can occur, which cause disruptions in supplying water to recipients, and can also be a cause of deterioration of the water quality in the water network. The great spatial extensiveness of the network, spreading through the entire territory of supplying water, the diversity of applied materials and their age cause problems in their proper exploitation [4,5,6].

A primary goal of the work is analysis of the failure frequency and water losses on the example of the Krosno water network. The scope of the work also includes its characteristic. The analysis was carried out on the basis on exploitation data of the water network obtained from the Municipal Services Office in Krosno in years 2005÷2009. In the work the analysis of seasonal variations of the failures of water network was also presented.

2. The Characteristics of the Krosno Water Network

The area of supplying by the Krosno water network is spreading through the city Krosno and neighbouring administrative districts: Korczyna, Krościenko Wyżne, Miejsce Piastowe, Chorkówka, Wojaszówka and is supplied with water from three surface water intakes. Intakes in Sieniawa and Iskrzynia take water from the river Wisłok, whereas intake in Szczepańcowa from the river Jasiołka.

The designed maximum daily productivity of water intakes, equals the maximum production of treated water, which is 60 500 m^3/d. The participation of particular intakes is following:

- WTP Sieniawa 36 000 m^3 /d, which constitutes 59,5 %,
- WTP Iskrzynia 17 000 m^3 /d, which constitutes 28,0 %,
- WTP Szczepańcowa 7 500 m^3 /d, which constitutes 12,5 %.

Water Treatment Plants (WTP) in Iskrzynia i Szczepańcowa are located in short distances from borders of Krosno, whereas the Sieniawa intake is located in the distance of 24 km. In the fig. 1 a situational WDS map of Krosno was presented [11,12].

At present daily production of water in maximum periods of demand is 17 500 m^3/d. Water supply system (WSS) of Krosno administers almost a 300% power reserve in the scope of the possibility of the production of water consumption.

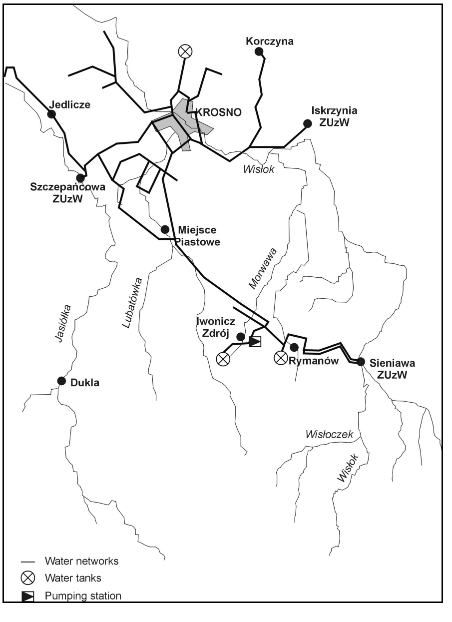

Fig. 1. Situational map of Krosno WSS

At present the water supply system has the total length of 596,9 km and is made from following materials:

- steel pipes – 34 %,
- pipes of the grey cast iron – 26 %,
- PVC pipes – 22 %,
- PE pipes – 18 %.

The functional structure of the water network pipes is as follows:

- main pipes L_{mw} = 86,8 km; (DN 150÷500),
- distribution pipes L_{dw} = 245,9 km; (DN 80÷110),
- waterwork connections L_{wc} = 264,2 km; (DN 32÷63).

Exploitation time of the network:

- up to 5 years – 6 %,
- from 6 years to 10 years – 12 %,
- from 11 years to 20 years – 25 %,
- above 20 years – 57%:
  - from 21 years to 30 years – 22 %,
  - from 31 to 50 years – 33 %,
  - above 50 years – 3 %.

Cast-iron pipes are the oldest, their age is over 30 years, and in case of the city centre and the industrial district even 70 years. The cast iron was used in the construction of 60 % main and distribution pipes.

The PCV and PE application began in the 70s, about 80 % of water network is made from them in districts Turaszówka and Polanka and to a large extent estate housing of Traugutt. Structure of water networks is diversified both in terms of age and material.

3. Water losses

Analysis of water losses was based on data of the production and the water consumption. The value of losses takes into account the amount of water used for rinsing the network e.g. after repairing, because of the bad quality of water delivered to recipients. The amount of water for rinsing the water network in 2009 year was 136 619 m^3 and constituted 6 % of the entire volume of losses. Indicator of individual losses - q_{sj} calculated on the basis of the equation 1 and intensity of the network straining - q_{os} calculated according to equation 2 was presented in table 1. Individual water loss indicators exceed the acceptable value of indicator equal 0,40 $m^3/h\cdot km$ [1,3,8]. From 2008 a decrease of amount indicator q_{sj} is observed and for the 2008 year it is 0,356 $m^3/h\cdot km$. In table 2 water loss indicators in chosen water supply systems in the Podkarpackie Province were compared. An exceeded acceptable value of the indicator of individual water losses wasn't exceeded in any of the described cities.

$$q_{sj} = \frac{Q_s}{L} \quad [m^3 / h \cdot km] \tag{1}$$

where:

q_{sj} – indicator of individual losses, [$m^3/h\cdot km$];
Q_s – water losses, [m^3/h];
L – length of water network, [km].

$$q_{os} = \frac{Q_d}{L} \quad [m^3 / d \cdot km] \tag{2}$$

where:

q_{os} – intensity of the network straining, [$m^3/d\cdot km$];
Q_d – daily water supply, [m^3/d];
L – length of water network, [km].

Tab. 1. The production of water and water losses in the Krosno water network in years 2005÷2009

Year	2005	2006	2007	2008	2009
Water getting from surface intake [dam^3]	6062,7	6397,6	6086,4	5675,0	5190,7
Water losses [dam^3]	2072,7	2115,5	2091,9	1841,4	2037,3
Indicator of individual losses - q_{sj} [m^3/h·km]	0,411	0,417	0,409	0,356	0,390
Intensity of the network straining - q_{os} [m^3/d·km]	28,89	30,28	28,53	26,32	23,82

Tab. 2. Indexes of water losses in chosen water networks in the Podkarpackie Province in years 2005÷2009

Specification	2005	2006	2007	2008	2009
Water network "A"					
Water losses [dam^3]	51,7	46,8	50,7	45,8	44,9
Indicator of individual losses - q_{sj} [m^3/h·km]	0,106	0,096	0,104	0,094	0,092
Intensity of the network straining - q_{os} [m^3/d·km]	12,91	13,00	13,08	13,13	13,25
Water network "B"					
Water losses [dam^3]	42,7	40,1	38,7	38,0	37,2
Indicator of individual losses - q_{sj} [m^3/h·km]	0,029	0,027	0,026	0,025	0,025
Intensity of the network straining - q_{os} [m^3/d·km]	3,64	3,72	3,86	4,01	4,13
Water network "C"					
Water losses [dam^3]	47,7	49,4	46,8	49,7	51,2
Indicator of individual losses - q_{sj} [m^3/h·km]	0,030	0,031	0,029	0,031	0,032
Intensity of the network straining - q_{os} [m^3/d·km]	2,62	2,56	2,60	2,56	2,57
Water network "D"					
Water losses [dam^3]	32,0	31,0	31,6	30,6	30,7
Indicator of individual losses - q_{sj} [m^3/h·km]	0,026	0,025	0,026	0,025	0,025
Intensity of the network straining - q_{os} [m^3/d·km]	1,99	2,01	2,06	2,09	2,13
Water network "E"					
Water losses [dam^3]	378,7	377,6	376,8	376,6	369,8
Indicator of individual losses - q_{sj} [m^3/h·km]	0,181	0,180	0,179	0,173	0,169
Intensity of the network straining - q_{os} [m^3/d·km]	23,77	23,42	23,36	22,81	22,76

For the evaluation of the interdependence between the indicator of individual losses - q_{sj}, and intensity of the network straining - q_{os} the method of the linear regression was used (fig. 2). The coefficient of correlation indicate a very strong correlation and amounts R^2=0,8409.

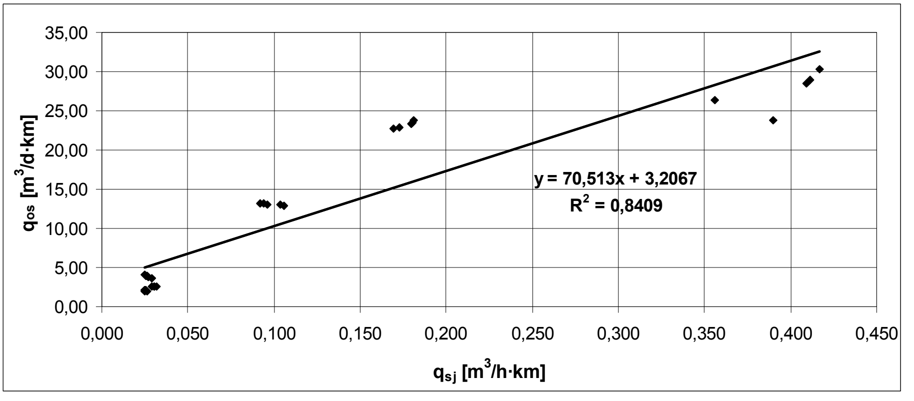

Fig. 2. Indexes of individual losses depending on intensity of straining the Podkarpacie province in chosen water supply systems in 2005÷2009 years

4. Failure Frequency of Water Network

In tables 3÷5 and in the figure 3 a number of the failures were compared on individual type of water supply system, relating to the number of failures to the length of the water networks. Presented values of failure intensity λ_j for main pipes - λ_M, distribution pipes - λ_D and waterworks connections - λ_C were calculated according to the equation:

$$\lambda_j = \frac{k_i(t, t+\Delta t)}{l_i \cdot \Delta t} \tag{3}$$

where:

- λ_j – individual failure intensity on the given type of the network, [number of failures/km·year];
- $k_i(t,t+\Delta t)$ – number of all failures in the time interval Δt on the given type of network;
- l_i – length of the given type of network (main, distribution, waterworks connections) in the given time interval, in which breakdowns appeared, [km];
- i – type of the network;
- Δt – time interval, [1 year].

Tab. 3. The failure intensity for the main network λ_M

Year	Length of main pipes L_M [km]	Number of failures	λ_M $[\frac{number\ of\ failure}{km \cdot year}]$
2005	86,8	84	0,97
2006	86,8	101	1,16
2007	86,8	75	0,86
2008	86,8	59	0,68
2009	86,8	46	0,53
λ_{Mmean} $[\frac{number\ of\ failure}{km \cdot year}]$		0,84	

Tab. 4. The failure rate for the distribution network λD

Year	Length of distribution wires L_D [km]	Number of failures	λ_D $[\frac{number\ of\ failure}{km \cdot year}]$
2005	241,1	51	0,21
2006	242,2	49	0,20
2007	244,6	40	0,16
2008	244,9	50	0,20
2009	245,9	46	0,19
λ_{Dmean} $[\frac{number\ of\ failure}{km \cdot year}]$		0,19	

Tab. 5. The failure rate for the waterworks connections λC

Year	Length of waterworks connections L_C [km]	Number of failures	λ_P $[\frac{number\ of\ failure}{km \cdot year}]$
2005	247,1	151	0,61
2006	249,9	204	0,82
2007	253,1	119	0,47
2008	259,0	147	0,57
2009	264,2	114	0,43
λ_{Cmean} $[\frac{number\ of\ failure}{km \cdot year}]$		0,58	

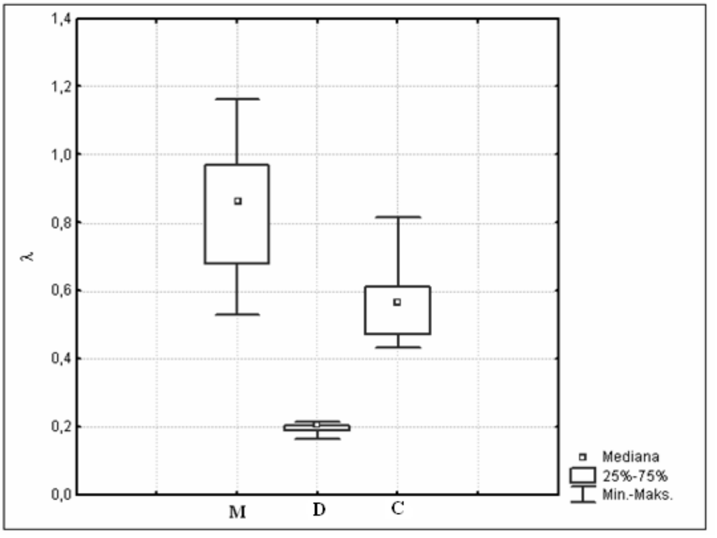

Fig. 3. The failure intensity for the main network - λ_M, distribution network - λ_D and household connections - λ_C

From the conducted analysis results, the failure intensities of water networks are [10]:

- failure intensity of main pipes λ_M = 0,84 [number of failure/km·year], in view of the required λ_{Mreq} = 0,3 [number of failure/km·year],
- failure intensity of distribution pipes λ_D = 0,19 [number of failure/km·year], in view of the required λ_{Dreq} = 0,5 [number of failure/km·year],
- failure intensity of waterworks connections λ_C = 0,58 [number of failure/km·year], in view of the required λ_{Dreq} = 1,0 [number of failure/km·year].

A detailed analysis of main pipes characterized by particularly high intensity of failure frequency showed that these pipes are made of cast-iron (with the medium age of exploitation - 40 years), particularly pipes along the following streets: st. Ściegiennego - λ = 7,58 [number of failure/km·year], st. Tysiąclecia - λ = 5,62 [number of failure/km·year], st. Bursaki - λ_R = 5,22 [number of failure/km·year], st. Pużaka - λ = 5,20 [number of failure/km·year].

5. The Analysis of Seasonal Variations of the Failures of Water Pipes in years 2005÷2009

A lot of phenomena are characterized by the unevenness and the changeability in the time, then it is so-called periodic hesitations, of which seasonal variations are a special case. Water consumption is characterized by unevenness in the sequence of twenty-four hours, but first of all in the sequence of the year [5]. A simple way of distinction uninominal periods is a method based on distinguishing seasonal variations [9].

The seasonal indicator S_i is calculated according to:

$$S_i = \frac{\bar{y}_i \cdot d}{\sum_{i=1}^{d_j} \bar{y}_i} \cdot 100 \tag{4}$$

where:

- S_i – seasonal indicator for subperiod;
- $\bar{y}_i$ – arithmetic mean of the magnitude of the examined occurrence in uninominal subperiods (January, with February, …, December) in years 2000÷2008;
- d_j – number of uninominal subperiods, $d_j = 4$;
- d – number of months in the year, d = 12.

The absolute levels of seasonal variations for individual subperiods are calculated according to the equation:

$$|g_i| = S_i \cdot \bar{y} - \bar{y} \tag{5}$$

where:

- $|g_i|$ – absolute levels of seasonal variations expressed in the same units as the examined phenomenon;
- $\bar{y}$ – average value of the examined phenomenon for d = 12, $\bar{y} = 5{,}145$.

Results of calculations were compared in table 6 and in fig. 3.

Tab. 6. Relative and absolute seasonal variations of the failures of water networks in years 2005÷2009

Months	Number of the failures					Σ	$\bar{y}_i$	S_i	g_i
	2005	2006	2007	2008	2009				
I	21	29	22	26	19	117	23,4	105,09	0,26
II	27	23	21	28	6	105	21	94,31	-0,29
III	26	20	19	17	12	94	18,8	84,43	-0,80
IV	29	41	13	26	27	136	27,2	122,16	1,14
V	24	24	18	11	21	98	19,6	88,02	-0,62
VI	18	29	17	20	17	101	20,2	90,72	-0,48
VII	13	36	27	24	20	120	24	107,78	0,40
VIII	18	32	16	26	20	112	22,4	100,60	0,03
IX	21	27	23	22	10	103	20,6	92,51	-0,39
X	29	38	19	21	21	128	25,6	114,97	0,77
XI	30	32	15	16	11	104	20,8	93,41	-0,34
XII	30	23	24	19	22	118	23,6	105,99	0,31
Σ	286	354	234	256	206	1336	267,2	1200,00	0,00

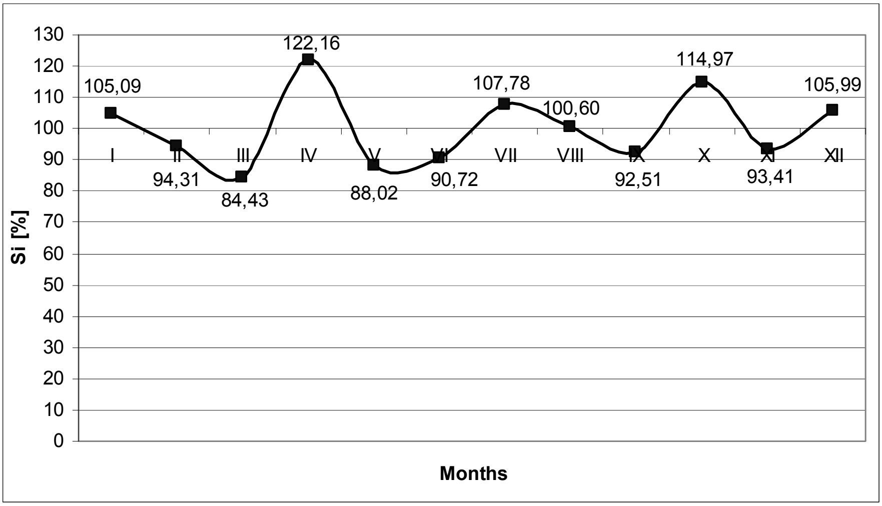

Fig. 4. Relative and absolute seasonal variations of the failures of water networks in years 2005÷2009

It results from calculations, that in the analysed period, water network isn't characterized by a distinct seasonal character of failures occurrence. The highest number of failures in proportion to the average occurred in April (22,16 %), and the lowest was in March (15,57 %). In September the number of failures every year was related to the average number of failures.

6. Summary

- The calculated individual water losses in the examined period of time, characterize the exploitation state in the Krosno water supply system, achieved the maximum value in the analysed period 0,417 [m^3/h·km]. Comparing received results with those introduced in the work [1] it stated that loss indexes developed on the similar level.
- The average failure intensity index for main pipes - λ_{Mmean} = 0,84 [number of failure/km·year], distribution pipes - λ_{Dmean} = 0,19 [number of failure/km·year] and waterworks connections - λ_{Cmean} = 0,58 [number of failure/km·year]. The value of the failure intensity of water networks correspond with national tendencies [2,12].
- In case of main pipes and waterworks connections the decreasing tendency of the value of failure frequency index of intensity is observed. Gradual lowering the value of failure frequency index is a result of investment-modernization undertakings led in the previous years (implementing the monitoring of the water supply system, the reduction and control of pressure in the water supply system, modernization of valve nods on the main and distribution wires, the exchange, the expansion and the modernization of the existing water supply system, leading the Active Detection of Leaks).
- Detailed analysis of the failure frequency and water losses of the water supply system, should be a main element of the managing system of the urban water networks, particularly in strategic modernization plans.

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