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INVESTMENT COSTS OF SMALL WASTEWATER TREATMENT PLANTS WITH SBR REACTORS IN POLAND

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KOSZTY INWESTYCYJNE MAŁYCH OCZYSZCZALNI ŚCIEKÓW Z REAKTORAMI SBR W POLSCE

STRESZCZENIE: W oparciu o dane z 29 małych oczyszczalni ścieków z Sekwencyjnymi Reaktorami Biologicznymi, ustalono koszty inwestycyjne tych jednostek. W pracy podjęto próbę klasyfikacji struktury tych kosztów. Badania wskazują, że współczynnik relacji pomiędzy kosztami inwestycyjnymi jednostki i pojemnością oczyszczalni a Równoważną Liczbą Mieszkańców jest wysoki, odpowiednio: 0,801 i 0,864. Ponadto, koszty inwestycyjne oczyszczalni ścieków opartych na Sekwencyjnych Reaktorach Biologicznych w 2013 były dwa razy większe w porównaniu do kosztów z 2004.

SŁOWA KLUCZOWE: jednostkowe koszty inwestycyjne, małe oczyszczalnie ścieków, Sekwencyjne Reaktory Biologiczne

Introduction

Poland upon signing the Access Agreement to join the European Union declared to implement EU Directive No. 91/271/EWG concerning wastewater treatment (91/271/EWG Directive 1991). This Directive requires the construction of sewage collection systems and proper wastewater treatment plants in a specified schedule (deadlines). Following the Directive, Poland prepared the National Program of Wastewater Treatment, according to which all communities of Equivalent Inhabitants Number (EIN) exceeding 2000 should have such facilities by the end of year 2015. This also applies to all communities below 2000 of Equivalent Inhabitants, which had sewage collection systems before Poland jointed the EU. As a result, construction, extension, modernization or upgrading of many small and middle size wastewater treatment plants has to be done. There is therefore a need for costs analysis and development of meaningful and up-to-date indicators which would help to optimize the investments and their respective costs.

It is known that an effective and proven technology of wastewater treatment for small communities is Sequencing Batch Reactor (SBR) system[12]. In such reactors, biological treatment and sedimentation take place in one container in which there are the following treatment steps: filling up, aeration, mixing without and with aeration, settling (sedimentation/clarification), effluent removal, exceeding waste sludge removal. The duration of one entire cycle is usually from 4 to 8 hours and the time of each phase is controlled depending on treatment conditions[3]. In sequencing reactors there is limited growth of filamentous bacteria and sludge swelling as a result of equalization of flow and pollutants loading.

For several reasons, in Poland, the main criterion in the tenders selecting the contractor are investment costs in spite of the facts that sometimes costs of operation, life of plants or technological aspects could have an impact in deciding optimal solutions. Sometimes cheap initial costs of investment lead to higher costs of operation or shorter life of plants.

A literature review showed that for small wastewater treatment plants there is low correlation between unit cost indicators and capacity of the plants descri-

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[2] Metcalf&Eddy, Inc. „Wastewater Engineering: Treatment and Reuse", McGraw-Hill, s. 1840.

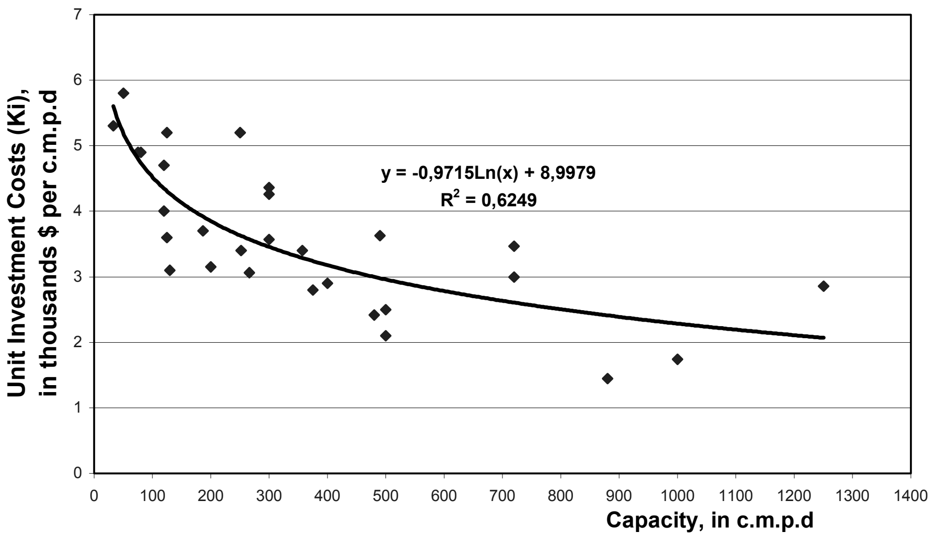
[3] Z. Mucha, *Kryteria i warunki racjonalnego stosowania małych wysokoefektywnych oczyszczalni ścieków. (Criteria and conditions for rational application of high efficiency small wastewater treatment plants)*, praca doktorska, Politechnika Krakowska, Kraków 2004.

bed in flow rates and equivalent inhabitants number for the same technological solutions[4, 5].

Methods

Data for the research was collected from the contractors and operators of 29 wastewater treatment plants with Sequencing Batch Reactors in Poland. The capacities of the plants were from 33 cubic meters per day to 1250 cubic meters per day, and EIN between 180 and 14950. The reactors were of the following constructions: concrete (20 plants), steel (5 plants), and plastic (4 plants). Technology of treatment consisted of mechanical pretreatment with application of a screen-sand removal facility, equalization tanks, sludge dewatering with press filters or centrifuges, and, in some cases, liming for sludge stabilization. An example of the technology for the plant of 374 c.m.p.d. and 2231 of EIN is shown in figure 1.

Figure 1
Relationship between Unit Investment Costs (Ki) of the SBR wastewater treatment plants and their design wastewater capacities



[4] D. Geenens, C. Thoeye, *Cost-efficiency and performance of individual and small-scale treatment plants*, "Water Science and Technology" 2000 t. 41(1), s. 21-28.
[5] H. Kroiss, S. Lindtner, *Costs and cost-effectiveness analysis for waste water services*, Proceedings of IWA Conference on Nutrient Management and Wastewater Treatment Processes and Recycle Streams, Krakow, Poland 2005, 19-21 September, s. 975-983.

Despite the fact that in most analyzed plants the permits did not require removal of nutrients, the effect of their removal has been observed, and moreover installations for precipitation of phosphorous with iron salts (ferrous sulphate) had been installed in majority of plants.

For comparison of the actual investment costs they were recalculated into 2013 prices applying inflation indices.

Unit investment costs were calculated dividing total investment costs within the boundaries of the plants (including Value Added Tax) by design capacities and Equivalent Inhabitants Numbers. The Least Square Method was used for identification of relationship between the unit investment costs indicators and flow rates or EIN.

The structure of investment costs were analyzed based on the example of three plants of different capacities and different biological reactors construction including one with a stainless-steel reactor, one second with a plastic reactor, and the third with a concrete reactor.

Statistical analysis of data, including correlation coefficient r, were done with application of Spearman method. Moreover, significance levels for hypothesis *Ho: RS = 0* (Spearman correlation coeff. equal 0) were determined. This hypothesis was rejected for significance level $\alpha<0.0001$. It can be concluded, that correlations studied are substantial.

Results and their discussion

The relationship between plants flow rates and Unit Investment Costs is shown on figure 1. It can be described by the following function:

$$Ki = -0{,}9715 \, Ln(x) + 8{,}998$$

Coefficient of determination R^2 of this relationship is 0.6249 and coefficient of correlation r equal to – 0.801.

As it is shown in figure 2, the coefficient of determination R2 of the relationship between Unit Investment Costs (Ki) and EIN is equal to 0.8116, which corresponds to a coefficient of correlation *r* equal to – 0.864. The relationship can be described by the following function:

$$Ki = -\,0.1706 Ln(EIN) + 1.7672$$

It can be noticed that Investment Costs for several plants of the similar capacities are different. It is mainly due to the setting of some reactors in buildings (indoor) and the application of equipment of different prices, such as e.g. centrifuges or presses.

The relationship between the unit costs related to the active volume of technological reactors of the SBR plants, and to the capacity of treatment plants described by a function: $Ki = -0.5173 \, Ln(EIN) + 5.6447$, and a value of the determination coefficient R2 is equal to 0.9115 and the correlation coefficient r equal to – 0.918 (see figure 3).

Figure 2
Relationship between Unit Investment Costs (Ki) of S the SBR wastewater treatment plants and their EIN capacity

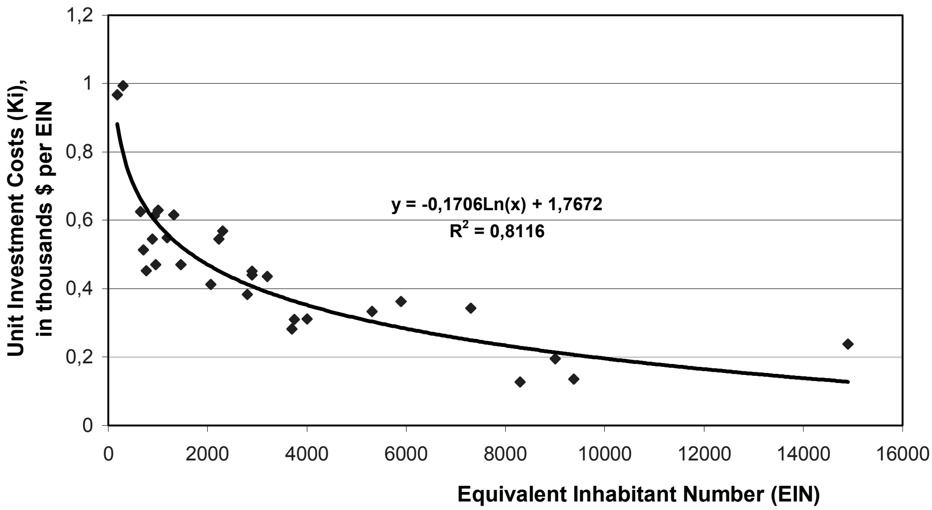
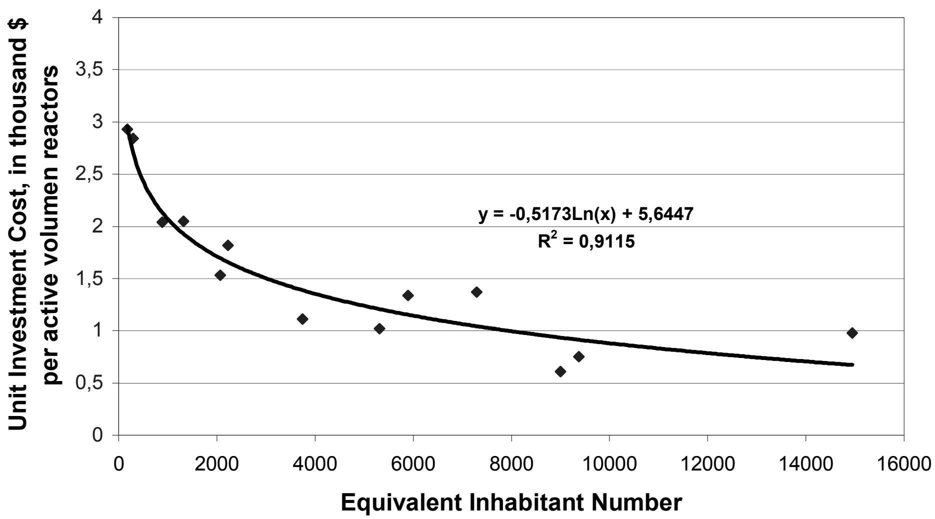


Figure 3
Unit investnent costs of active volume of technologicala reactors in corelation to size of wastewater treatment plant described in Eqivalent Inhabitant Number (EIN)



Costs structures of the construction of small-scale treatment plants are presented on three diverse examples, each of different size and technical solutions. The analyzed facilities are plants with reactor tanks of synthetic materials, stainless steel and concrete. Table 1 presents the features and plants units having an impact on the investment costs, technological infrastructure area and unitary coefficient of total treatment plant area.

The coefficient of technological tanks is comaprable and falls between 0,24 and 0,30 c.m. per EIN, and the cost related to these volumes in different solutions is between 1,05 and 2,04 thousands $ per c.m. of volume of technological tanks.

The area coefficient of the technological infrastructure is lower when higher reactors made of steel are constructed, and is equal to 0.06 square meters per EIN. This factor is at least three times lower than the other solutions. Technological equipment and their installation amounts to half of the overall investment costs of treatment plants.

Table 1

Cost structure of small wastewater treatment plants with SBR

Features and elements of the plants which have impact on investment costs	Plants with contracts for entire facilities		Plants with seperate contracts for the phases of construction
Plants capacity, in c.m.p.d/EIN	120/855	1250/14950	357/2231
Plants objects	plastic tanks installed in the buildings, station for taking transported wastewater, equalization pond	outdor steel tower tanks	indor concrete tanks
Sludge treatment	separate aerobic stabilization, mechanical thickening and textile bag dewatering filter	separate aerobic stabilization; centrifuge dewatering; and disinfection	simultaneous stabilization; press filter dewatering
Total unit costs, in thousands $ per EIN	0,61	0,24	0,54
Indicator of technological tanks volume; in c.m. per EIN	0,3; with pond 0,18; without pond	0,24	0,3
Unit costs, in thousands $ per 1 cubic meter of technological tanks volume	2,04; with pond	1,05	1,82
Area covered with buildings and technological objects; in sq. m.	320; with pond 226 without pond	900	405
Indicator covered area, in sq.m per EIN	0,37 with pond 0,26 without pond	0,06	0,18
Lot area (fenced area), in sq.m.	1800	2100	1600
Indicator of plant area, in sq.m. per EIN	2,1	0,3	0,72
Costs element	cost structure [%]		
Installation and technological facilities	45 (including 11% for the tanks)	63,4 (including 24,4% for the tanks)	33
Construction work	34	21,2	47
Infrastructure and land development (roads, footpaths, fences, vegetation)	11	8,1	9
Outside sewers	10	7,3	11

When subtracting the costs of tanks from the costs of entire equipment purchased and adding them to the cost of construction, the strcuture of investment costs are similar for analyzed plants. This means that the highest costs are related to construction costs and plants installation and equipment cost and thast they are from 45% to 47% and from 33% to 39% of overall costs respectively. The costs of outside installations and landscape development are from 7.3% or 11% of overall investment costs.

It should be mentioned, that for all equations, coefficients of determination R2 (often considered as measures of bias of a model) were high, meaning that the models were well-fitted.

Conclusions

There are the high coefficients of correlation between the investment costs of small wastewater treatment plants with SBR costs and Equivelant Inhabitants Number – 0.801 and – 0.864. respectivaley.

The study shows that coefficients of correlation between the unit investment costs and plant capacity, as well as Equivalent Inhabitants Number are high: – 0.801 and – 0.864 respectively

Investemnt costs of wastewater treatment plants with SBR type biological reactors in year 2013 were twice higher compering to the costs in year 2004.

Developed indicators of investment costs can be used in feasibilities studies as well for comparisons with the costs proposed by the contractors during the tenders procedures.

Literature

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