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THERMAL TREATMENT AS SUSTAINABLE SEWAGE SLUDGE MANAGEMENT

Recent changes to the sewage sludge management can be attributed to the restrictive deadlines of implementing EU regulations concerning wastewater treatment and sewage sludge utilization. Drying and thermal treatment of sewage sludge is becoming increasingly popular. From nearly zero share of thermal treatment methods in the sewage sludge management currently the share exceeds 35%. Implementation of numerous investments is facilitated by respective structure programs in the scope of environmental protection supported with EU funds. The analysis of chosen aspects of new operational experience constitutes the main part of the present paper. Analysed were domestic operational practices concerning the applied technologies of sewage sludge drying, their effectiveness and reliability. The aspect of effectiveness of flue gas cleaning with the use of sodium bicarbonate, method characteristic for many Polish sewage sludge incineration facilities, is discussed in detail. The analysis is based on the current operational data and own research.

1. INTRODUCTION

Supply with drinking water, construction and development of wastewater sewer system, building or modernisation of wastewater treatment plants and implementation of modern methods of municipal sewage sludge management are areas of infrastructure and environmental protection developing very dynamically in Poland in the recent years. Intensive conceptual and design works and investment efforts in the scope of water and wastewater management, and sewage sludge management in particular, are enforced by the provisions of the community law. Meant are the requirements transferred to the Polish law resulting mainly from the Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment and the Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, particularly the soil, when sewage sludge is used in agriculture.

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The beginnings of those actions go back to the year 2000, when for the purposes of bringing order to the national infrastructure, the EU pre-accession funds, Instrument for Structural Policies for Pre-Accession, ISPA for short, gained in popularity. The next stage of intensive works is the year 2004 of the Polish EU membership. Another stage of intensive actions for extension of wastewater treatment plants and modernising processes of wastewater treatment with the simultaneous development of projects aiming at environmental-friendly sustainable municipal sewage sludge management immanently connected with those processes began, financially supported by the EU Cohesion Fund.

A new view appropriate to the problem scale at the place and role of sewage sludge in the Polish water and wastewater management has emerged and been formed. There has begun elaboration and implementation of modern, in Poland almost unknown methods and technologies of sewage sludge management based on drying and incinerating of sewage sludge. This tendency fully corresponded to the one visible before in the developed EU15 member states, a tendency of increase in the share of thermal methods in municipal sewage sludge management. As an example can serve Germany where the share of sewage sludge incineration in its management amounted to 22.8% in 2001, and in 2010 even 53.2% [1]. At the same time the Poland's choice of the method based on drying and incinerating sewage sludge was not merely a passive reflection of the above mentioned tendency noticeable in the developed EU countries but a logical and well-founded indication of the optimal method of sustainable municipal sewage sludge management which in view of legal restrictions in the scope of landfilling and its agricultural as well as ecological applications pointed out the above mentioned method.

The current domestic legal conditions prove that estimates made at the beginning of 2000 concerning the management methods and the choice of management technologies of sewage sludge were accurate. Because restrictions resulting from the Directive 1999/31/EC on the landfill of waste and the Polish law in the scope of landfilling sewage sludge confirm that from 01.01.2013 on, its landfilling will be forbidden in Poland. And provisions on the agricultural and ecological applications of sewage sludge, laid down in the above mentioned Council Directive 86/278/EEC and extended in the Working Document on Sludge indicate that after many years of discussions and arrangements in the European Commission, they will finally come into effect at the turn of 2014/15.

As stated above, the choice of the method of municipal sewage sludge management by means of its drying and incinerating or co-incinerating has proven a well-founded step in view of the current legal conditions. However, achieving the current share of those methods reaching 35% from among the remaining sewage sludge management methods, when in 2009 it equalled ca. 3%, was by no means an easy task. Developing new concepts of sewage sludge management at the beginning of 2000, designing incineration facilities and sewage sludge incineration facilities, issuing tenders for their construction and finally the act of building and then the process of putting into operation and operation itself were for the domestic sector of municipal wastewater treatment a new and a very valuable experience. Chosen aspects of the mentioned scope, as evaluation of the building process of sewage sludge drying and incinerating facilities, analysis of their reliability, or experience resulting from the use of sodium bicarbonate as a reagent used in the majority of flue gas cleaning systems in the Polish sewage sludge incineration plants, together with the implications for the accepted methods of ash management will be investigated thoroughly in the present paper.

2.1. SEWAGE SLUDGE IN POLAND AND OTHER EU MEMBER STATES

Description of the condition of sewage sludge management in the EU countries characterised mainly by the stream of the generated sewage sludge and the share of certain methods in its management can be found in numerous statistical analyses, as well as in some scientific papers. For evaluation of the condition of sewage sludge management in EU countries, the present paper refers to data quoted in statistical analyses [1–3], as well in scientific papers [4–6].

Table 1 presents data characterising municipal sewage sludge management in Poland elaborated based on [2] and [5], as well on the National Programme for Municipal Wastewater Treatment (hereinafter referred to as AKPOŚK) updated in 2009. This data was compared with similar indicators for European countries leading in this scope, that is for Germany, based on the data listed in [1, 3, 4] and for Switzerland [3, 6].

Indicators of the level of development of domestic sewage sludge management presented in the Table 1 for 2009 distinctly vary from those from Switzerland or Germany, being besides Holland the leaders among the European countries in this scope.

The share of thermal methods in municipal sewage sludge management listed in Table 1, amounting to ca. 3% in 2009 and resulting from incineration of sewage sludge in the then only sewage sludge incineration facility operating in Gdynia Dębogórze increased in 2012 nearly tenfold as will be demonstrated further and what is undoubtedly a significant change.

The conclusions resulting from the comparison presented in Table 1 make further actions in the scope of development of water and wastewater management in Poland necessary:

- The percentage indicator illustrating the degree of connection to the sewer system amounted in 2009 to barely 62%. In 2010 88.6% of inhabitants of Polish cities directed their sewage by sewer system to wastewater treatment plants, and in rural areas only 28.8% [2]. Also in this matter dynamic development resulting from the currently implemented projects of building a sewer system more than 30 thousand km long, what takes place mainly in small agglomerations in rural areas, can be noticed in the last years. It can be estimated that at the moment, in the second half of 2012, the degree of connection to the sewer system nationwide is significantly higher than in 2009 and might exceed 80%.

Table 1

Chosen parameters and indicators presenting the scope of development of the water and wastewater management in Poland compared with the achievements of Germany and Switzerland as of 2009

Parameter	Poland	Germany	Switzerland
Share of connection to the sewer system, %	62	96	97
Number of wastewater treatment plants	~1500	~10 000	300 higher than 10 000 PE
Mass of sewage sludge Mg dry matter/year	605 200	2 030 000	206 000
Mass of generated sewage sludge kg dry matter/(inhabitant·year)	15.8	24.7	26.7
Expenses for modernisation	~62.2 billion PLN[a]	~50 billion €[b]	n/s
Agricultural application, %	28	29 including composting	0
Natural reclamation, %	19	16	0
Thermal methods, %	3	52	97 + 3 export
Other methods, %	22	3	0
Landfilling	28[c]	0	0
Long-term method of sewage sludge management	thermal methods (big agglomerations)	thermal methods with upward trend	thermal methods only

[a]Concerns estimated cost according to AKPOŚK 2009, including 1.3 billion PLN for sewage sludge management.

[b]Concerns already borne cost [5].

[c]Together with sewage sludge on lagoons.

• Indicator of annually generated sewage sludge per capita expressed by its dry matter well illustrates the scale and effectiveness of the wastewater treatment process, the result of which is the stream of the mass of generated sewage sludge. An average inhabitant of Poland generating ca. 16 kg dry matter/year sewage sludge expressly differs in this respect from an average individual in Germany – ca. 25 kg dry matter/year or in Switzerland – ca. 27 kg dry matter/year. For statistical inhabitant of Holland, the indicator equals 22, of Austria – 32, and Great Britain – 29 kg dry matter/year [4]. Clear differences in comparison with the inhabitant of Poland, directly corresponding with the above mentioned percentage indicator of connection to the sewer system, indicate the increase in the stream of mass of sewage sludge awaiting Poland resulting from advancement of works on the current extension of sewer system and wastewater treatment plant. This phenomenon can be confirmed by further statistics showing the vast differences in the amount of generated sewage sludge that are visible between the EU15 and the new countries called EU12 in spite of including the disproportions in the number of inhabitants in those countries. In 2009, in EU15 the total amount of 10.2 million Mg dry matter sewage sludge/year was generated, what gives the average indicator of sewage sludge generated in the EU15 equalling 21.9 kg dry matter/(inhabitant·year), and in EU12 1.6 million Mg dry matter/year with the indicator equalling 11.l5 kg dry matter/(inhabitant·year) [4].

- The stream of mass of so far landfilled sewage sludge, as well as temporarily landfilled on the premises of wastewater treatment plant and treated by means of alternative methods – amounting in Poland in 2009 to ca. 303 000 Mg dry matter/year [5], will be from 01.01.2013 on subject to management by means of methods other than landfilling as mentioned at the beginning. The date constitutes the introduction of a ban on landfilling of sewage sludge not fulfilling the criteria permitting its landfilling as specified in the regulation of the Minister of Economy (Journal of Laws of 2007 No. 121, item 832). This is yet another incentive for implementation of thermal methods which will allow one to reach this goal.
- Agricultural application of sewage sludge and its use for reclamation purposes, what in 2009 constituted in Poland ca. 282 000 Mg dry matter/year [5], might be soon significantly limited with regard to the expected restrictions concerning agricultural application of sewage sludge and resulting from the above mentioned Working Document on Sludge. Although this document is still being discussed in the European Commission, this should not exempt one from designing and implementing alternative, legally feasible solutions. One of such solutions is drying and thermal treatment of sewage sludge.

3. ANALYSIS OF OPERATIONAL PRACTICES OF INVESTMENTS IN THE SCOPE OF DRYING AND THERMAL TREATMENT OF SEWAGE SLUDGE

Projects implemented in the previous years in Poland in the scope of municipal sewage sludge management with the use of thermal methods can be divided into two main groups:

Consisting in building of only sewage sludge drying plant. General characteristics and analysis of built sewage sludge drying plants and those in an advanced investment stage illustrate Table 2 in Section 3.1. The choice of this way of use of thermal methods was mainly due to financial reasons. Not in every case of modernised or built wastewater treatment plants there were enough funds to finish the sewage sludge management process investing in building an incineration facility. The projects were cut down then to the construction of a drying installation for mechanically dewatered sewage sludge aiming at production of granulate with dry matter content above 90%. Generated granulate can be utilized in a co-incineration process in the domestic cement industry. Such a procedure is facilitated by the regulation of the Minister of the Environment of 12 September 2008 (Journal of Laws No. 183, item 1142) which regards sewage sludge as biomass and allows one to treat it in the recovery process as a neutral energy source concerning the emission of CO_2, what is commonly used in the in the clinker burning process with reduced CO_2 emission,

Consisting in building traditionally understood sewage sludge thermal treatment plants based on pre-dry and combustion installations. Table 3 in Section 3.2 presents characteristics and analysis of operation effectiveness of those plants.

3.1. SEWAGE SLUDGE DRYING FACILITIES, GENERAL CHARACTERISTICS, EVALUATION OF OPERATION

Sewage sludge drying facilities, similarly to sewage sludge thermal treatment plants are catalogued in detail and described in special documents in the EU countries leading in this respect. As an example can serve [1], where the mentioned facilities operating in Germany are catalogued in detail and characterised. So far, there is no elaboration of this kind in Poland. A very good place for it would be the National Programme for Municipal Sewage Sludge Management, necessary elaboration of which, not only in the mentioned aspect, is being reported by sector experts for a few years.

Table 2

General characteristics of sewage sludge drying facilities operating in Poland according to own research and as of 30.06.2012

1	2	3	4	5
Total number of drying facilities	Combined capacity [Mg dry matter/year]	Range of		
		Water evaporation efficiency [Mg H_2O/h]	Drying process [% dry matter]	Temperatures of the drying process [°C]
19	ca. 80 000	1–9.15	18–95	90–180
6	7	8	9	10
Energy carrier	Range of			
	Heat consumption index [kWh_{th}/kg_{H_2O}]	Electricity consumption index [kWh_{el}/kg_{H_2O}]	Achieved reliability [%]	Energy carrier prices [PLN/Mg dry matter]
Natural gas biogas, fuel oil	0.75–1.3	0.06–0.085	30–90	550–900

A detailed cataloguing and description of sewage sludge drying facilities operating in the country would go beyond the scope of the present paper, therefore Table 2 presents their general characteristics basing on author's research. The table includes operating drying plants, as well as those in the final design or construction stage. The table does not include drying facilities based on the use of solar energy of which there are about ten operating also in Poland with various results.

The comments to Table 2 and comments concerning the effectiveness and reliability of sewage sludge drying facilities operating in Poland are as follows:

• Column 2. The combined potential of domestic drying facilities equalling ca. 80 thousand Mg dry matter/year and the total dry matter of sewage sludge estimated by the author of the present paper based on data from AKPOSK 2009, equalling at the end of 2 012 631 thousand Mg dry matter/year indicate that the share of thermal methods based only on drying of sewage sludge will at the end of 2012 amount to ca. 12%. According to data presented in [7], the share of drying sewage sludge in Germany is slightly higher and exceeds 15%.

• Column 3. The range of efficiency includes the nominal amount of evaporated water within 1 working hour of the drying facility for all its lines, usually 2 or 3 lines. In the case of a single-line facility, the efficiency range equals 0.5–3.15 Mg H_2O/h].

• Column 4. Range of drying process begins in some cases from 18% of dry matter share achieved in the mechanical dewatering process of sewage sludge (on average ca. 20%) and usually exceeds 90% of dry matter.

• Column 6. The main energy carrier in the drying process is still in the majority of incineration plants natural gas. The use of biogas generated on the site of wastewater treatment plant for the needs of drying of sewage sludge represents an insignificant share. Very rarely waste heat from the drying process is used. Advisable are actions directed through optimising the drying process at the increase in its effectiveness.

• Column 7. The quoted range of unit index of heat consumption for the needs of water evaporation covers a large span. Only a small number of plants operate with the index from the lower limits of the range. Also this observation indicates the need to optimise technological lines of sewage sludge drying facilities in the aspect of increasing the effectiveness of the process.

• Column 8. Range of unit electricity consumption index lies in a typical range.

• Column 9. The achieved reliability of operation of a drying plant defined by the relation of the total working hours when the given drying installation reached the designed capacity of water evaporation to the planned number of hours of exploitation of the installation annually indicates that in this area there are the most crucial problems. Achieving reliability of 90% is still a rare case. This reliability is currently significantly lower. The author's research indicates that the most typical reasons for low reliability of operation of domestic drying plants are:

– mistakes in the design and construction stage resulting in a very long start-up stage and achieving designed parameters of the drying facility, sometimes even more than two year time,

– components and elements of the dryers most prone to failures are: conveyor and storage system for mechanically dewatered sewage sludge, sewage sludge jamming between conveying elements, drive shaft failures – of both conveyor systems and dryers, erosion damage to the elements exposed to the sewage sludge, failures of systems transporting sewage sludge to the drying installation, failures of condensation and water discharge systems and failures of systems for conveying, dedusting, and storing of granulate of dry sewage sludge.

• Column 10. Calculations illustrate the price range of high-methane natural gas as a popular energy carrier for the sewage sludge drying process. The calculations were based on data for the end of 2011. This cost constitutes about 75% of total operational cost of the sewage sludge drying facility.

From among the above analysed reasons deciding on effectiveness and reliability of operation of domestic sewage sludge drying facilities, the most significant is still their low reliability resulting in high failure frequency. Another characteristic aspect of operation of domestic sewage sludge drying facilities is high operational cost due to above all high cost of the most widely used energy carrier, the natural gas. One should also indicate great optimising possibilities, both in the aspect of increasing the effectiveness of the drying process as well as the degree of reliability of drying facilities what is currently undertaken by many operators.

Among many structurally different sewage sludge drying facilities analysed for the purposes of the paper and operating in Poland, the most reliable energy effective and representing a high level of reliability are belt dryers.

3.2. SEWAGE SLUDGE INCINERATION FACILITIES, GENERAL CHARACTERISTICS, EVALUATION OF OPERATION

Municipal sewage sludge incineration facilities operating since recently in many domestic wastewater treatment plants, called in the foreign technical literature facilities of the mono-type where only sewage sludge is thermally treated, surely make a more comprehensive solution to the problem of sewage sludge management than only its drying and directing granulate to co-incineration in cement works. Those issues are discussed in detail in [8], both in the aspect of process effectiveness, as well as energy use and cost.

Table 3 presents general characteristics of domestic municipal sewage sludge incineration facilities.

Comments to Table 3 and those concerning the effectiveness and reliability of municipal sewage sludge incineration facilities operating in Poland are:

• Column 1. The number of 11 sewage sludge incineration facilities makes a total of 9 incineration facilities currently in operation (Łomża, Zielona Góra, Olsztyn, Gdynia Dębogórze, Szczecin, Bydgoszcz, Kielce, Cracow and Łódź) and 2 incineration facilities in the start-up process (Gdańsk and Warsaw).

• Column 2. The given combined capacity amounting to ca. 160 thousand Mg dry matter/year combines the capacity of all 11 incineration facilities including the biggest in Poland and one of the bigger ones in the EU countries, the sewage sludge incineration facility in Warsaw (ca. 62.2 thousand Mg dry matter/year). Taking into account that the stream of dry matter of sewage sludge estimated by the author of the present paper for the end of 2012 amounted to 631 thousand Mg dry matter/year, then the share of incineration of sewage sludge in its management would constitute ca. 25%. Considering the above mentioned 12% share of drying and co-incineration of sewage sludge, the share of thermal methods in domestic sewage sludge management would at the end of 2012 amount to ca. 37%, qualifying Poland to the group of in this respect leading EU countries.

Table 3

General characteristics of sewage sludge incineration facilities operating in Poland according to author's research and as of 30.06.2012

1	2	3	4	5
Total number of incineration facilities	Combined capacity [Mg dry matter/year]	Range of capacity [Mg dry matter/h]	Net annual work hours [h/year]	Range of content of dry matter in sewage sludge to be incinerated [% dry matter]
11	ca. 160 000	0.2–7.9	7000–8000	33–90
6	7	8	9	10
Rakings incineration	Types of furnaces	Management of ashes and flue gas cleaning residues	Range of achieved reliability [%]	Type of flue gas cleaning system
applied in large incineration plants	fluidized bed furnaces – 7 grate furnaces – 4	From landfilling methods to solidification	50–90	most common dry system

• Column 3. The given range of capacity includes the nominal stream of dry matter of sewage sludge to be incinerated in 1 hour of work of the incineration facility by its all lines, usually 1 or 2. The lowest value (0.2 Mg dry matter/h) concerns the smallest incineration facility in Łomża, the highest (7.9) the above mentioned 2-line facility in Warsaw,

• Column 5. The given range indicates that some incineration facilities pre-dry sewage sludge until auto-thermal combustion level is reached, constituting the majority of solutions. In the remaining cases, sewage sludge is dried to ca. 90% of dry matter and incinerated in this form.

• Column 6. Rakings, grease and other related waste from the municipal wastewater treatment process are incinerated together with sewage sludge, what is typical of large incineration facilities, still however creating many operational problems.

• Column 7. The majority of large incineration facilities offer technological solutions using stationary fluidised bed furnaces. It concerns 7 incineration facilities. The remaining ones have 4 grate furnaces.

• Column 8. The designed combustion process of sewage sludge involves in most cases advanced methods of disposal of ashes and flue gas cleaning residues mostly by means of their stabilization and solidification. In rare cases, residues after the combustion process and flue gas cleaning residues are landfilled in landfills built specially for this purpose.

• Column 9. The majority of new sewage sludge incineration facilities, though in operation for more than two years, still experience technical problems resulting from failures in their design or construction. It leads to numerous stillstands and results in a decrease in general reliability. The most significant problems are failures of systems conveying sewage sludge from buffer tanks towards pre-drying installation, failures of the dryers for pre-drying/drying sewage sludge, heat exchangers, flue gas cleaning systems as well as designed systems of solidification of solid process waste.

• Column 10. Flue gas cleaning system is most commonly used. All analysed national sewage sludge incineration facilities fulfil the emission standards absolutely required by the EU law and the Polish law. The most widely used reagent, e.g. for incineration facilities in Cracow, Łódź, Warsaw, Kielce or Gdańsk is sodium bicarbonate. The author of the present paper devoted several studies and not published so far elaborations on the issue of effectiveness of flue gas cleaning from domestic sewage sludge incineration facilities with the use of this type of reagent, more and more popular in incineration facilities of solid waste and sewage sludge in EU member states and in the world [9]. The conducted research for a few new national sewage sludge incineration facilities has shown that the practical application of the reagent in the form of sodium bicarbonate ($NaHCO_3$) for effective flue gas cleaning takes place in those incineration facilities with disproportionately high $NaHCO_3$ sewage sludge ratio. It has no justification from emission requirements and causes a rise in operational cost related to the cost of reagent and above all to all costs of increasing amount of the waste product to be utilised. Respective results for the analysed incineration facilities, expressed in the index of unit consumption of sodium bicarbonate per 1 ton of dry matter thermally treated sewage sludge, illustrates Table 4. The names of certain incineration facilities have been kept secret on purpose.

Although the analysed sewage sludge incineration facilities do not have to be the same with respect to demand for the analysed reagent as the concentration of sulfur and other acid components contained in the combusted sewage sludge, what mainly determines the degree of consumption of reagent of the type, nevertheless the results presented in Table 4 indicate profound differences in relation to own calculations. Calculations were conducted based on average typical domestic concentration levels of pollutants contained in sewage sludge typical of large agglomerations. The results confirmed by operational data gathered from the analysed incineration facilities prove significant over-dosing of the expensive reagent, causing a proportional growth in the mass of the final product from flue gas cleaning.

Table 4

Indices of unit consumption of sodium bicarbonate as the main reagent in flue gas cleaning systems of chosen domestic sewage sludge incineration facilities [kg $NaHCO_3$/Mg dry matter]

Author's calculations	Incineration plant			
	No. 1	No. 2	No. 3	No. 4
26.54–30.58	25.39 for initial project guidelines	72.21 for initial project guidelines	44.56 for actual data	152.70 for initial project guidelines
	46.15–66.78 for current operational guidelines	58.65 for actual operational data		93.9 for actual operational data

It is well known that with the increased consumption of the reagent, the stream of process waste constituting flue gas cleaning residues grows proportionally. They are rich in salt compounds and their chemical compositions cause that their management process by means of solidification, what is provided in the contract procedures of many sewage sludge incineration facilities, is complicated and expensive in operation.

Table 5

Share of thermal methods in sewage sludge management in Poland in 2009 and according to the estimates for the end of 2012

State of sewage sludge management	According to	
	Data from 2009	Estimates for the end of 2012
Stream of dry matter of generated sewage sludge, Mg d.m./year	605 200	631 000
Share of drying and co- incineration of sewage sludge, %	1	12
Share of sewage sludge incineration, %	2	25
Total share of thermal methods, %	3	37
Share of other methods, %	97	63

The much increased use of sodium bicarbonate indicated in the present paper and difficult at the present stage to justify, being visible in the operational practice of the analysed sewage sludge incineration facilities, is the object of research of the author of the present paper, based also on direct analyses of chemical composition of flue gas cleaning residues. The results of the mentioned analyses may contribute to optimising the flue gas cleaning process taking place in the majority of domestic sewage sludge incineration facilities based on the use of sodium bicarbonate what will lead to minimising the operational cost resulting from solidification of process waste.

A summary of the study of the current condition of the Polish sewage sludge management and share of the thermal methods based on drying and incinerating of municipal sewage sludge in Poland at 2009 has been compared in Table 5 with the state at of end of 2012 estimated by the author of the paper and supported by detailed data. Comparing the results presented in Table 5 with results of Table 1 confirms the veracity of a number of theses outlined in the introduction.

4. SUMMARY

The present paper is a synthetic overview, analysis and evaluation of achievements of the Polish municipal sewage sludge management within the last ten years when its significant development and modernisation related to Poland's accession to the EU took place.

The most dynamically developing method of municipal sewage sludge management based on its drying and incinerating was analysed separately. It was confirmed that regarding the currently abiding legal regulations, it can be referred to as sustainable management. Currently implemented investments in Poland in the scope of drying and incinerating sewage sludge underwent a synthetic authorial evaluation and it was pointed to both mistakes, as well as possibilities of their correction.

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