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Transformation and sustainable development of sanitary engineering systems in the cities of the future

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Transformation and sustainable development of sanitary engineering systems in the cities of the future

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Abstract. The transformation of the sanitary engineering systems is constant and closely connected with the development of urban development theory and practice. It is also influenced by scientific and technological progress in other areas of human activity. The initiators of the revival and further development of the movement to build cities-gardens in the near future are engineers working to create a model for the sustainable development of urban sanitary improvement. At the beginning of the twenty-first century, the paradigm shift in the field of city sewerage construction technologies is due to the resumption of the search for resource-saving technologies that reduce the emission of pollutants into the environment due to the introduction of promising technological solutions for the separation of household wastewater into separate streams for the purpose of production of secondary products from wastewater components. A list of the main research directions on the modified technologies development that will ensure the sustainable sanitary systems development in the cities in the future was proposed based on a generalization of conceptual solutions for the transformation of the sewerage systems of cities and settlements.

1. Introduction

"Smart city" as an image of a city of the future is now the subject of systematic research of architects and engineers practicing in various fields of construction activity. Progressive architects claim that "creation of the so-called smart cities seems to be inevitable" [1]. Architects F.E. Gutnov and V.L. Glazychev noted that "the tendency towards modernism in the name of modernism was strong ... Recently hundreds of design models of the city of the future had to express something extremely new... Today urban planning consciousness should be called realistic which means taking into account the actual situation in the city economy, reconstruction technology, and culture development" [2]. The expressed idea by them "the conversion of monologue in urban planning into a dialogue between a professional designer and citizens" is an objective necessity for the development and city transformation into ecopolis expanded in the methodology of a new way of designing future scenarios – "future craft". The "future craft" method is based on "systematic research and construction of possible options for the future" [1]. Following this method, instead of predicting the future, scenarios of the future are proposed (usually in the form of the question "What if?") and then the results of changes in the new city model are analyzed by "public discussion".

Engineering and transport infrastructures are basic components of city environment. Lewis Mumford noted that the underground labyrinth of pipeline and cable networks is an "invisible city", which is a complex of integral components in the dynamic city environment [3]. In the article P.A. Wilderer [4] it was proved that sustainable development of urban infrastructure can only be ensured if the integrated development of management technologies is carried out in three interconnected and equally important systems: ecological, societal and economic.

The engineering infrastructure of the city includes life support systems, and sanitary engineering systems of water supply, sewerage, and solid household waste are of particular importance, since their condition determines the level of sanitary and epidemiological welfare of the population and the degree of improvement of the city.

The sewerage system as an element of the sanitary engineering system of the settlement performs a multi-level function complex. The target function of the urban sewerage system is to ensure favorable living conditions for people, respecting the principles of environmental protection and rational use of natural resources. The main functions are symbolically displayed in the form of a diagram shown in Figure 1.

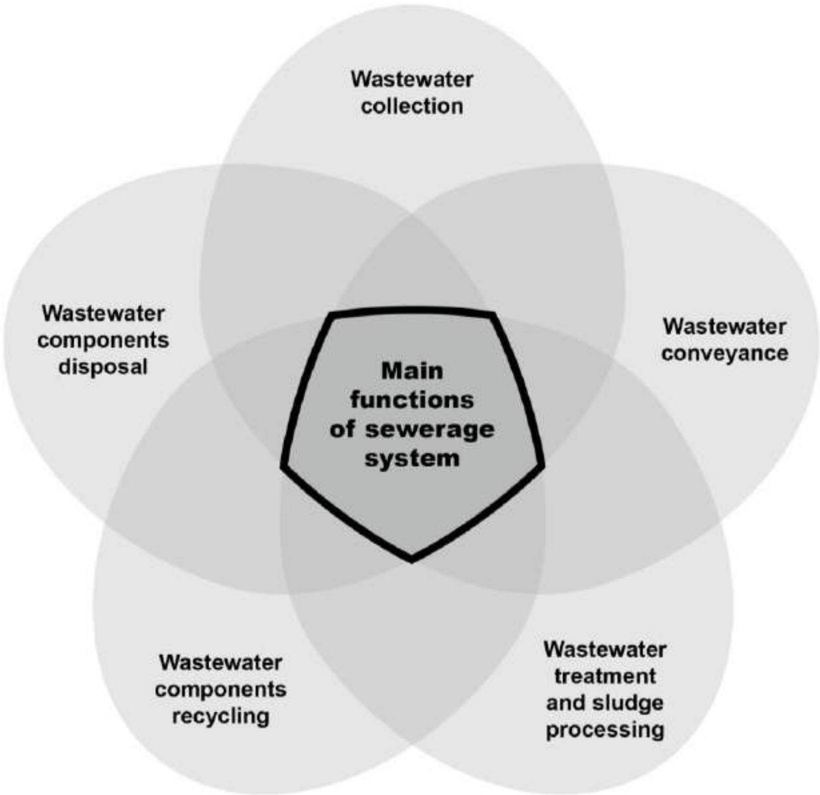

Figure 1. Main functions of the urban sewerage system.

2. Main stages of sanitary engineering systems evolution in cities and settlements

The urban sanitary systems transformation at any stage in the history of the human society development should be considered as “the evolution of public health engineering”, based on the definition proposed by F.E. Bruce: "health engineering is a synonym for sanitary engineering." It should be agreed with the author of [5] that public health engineering is “by no means the task of engineer alone”, but the field of interconnected activity of specialists from different branches of scientific knowledge.

Sewerage systems are being built for five millennia. The most widespread was the construction of drains (rain sewerage) for storm water diversion. The canals and piping networks for the disposal of household and fecal wastewater were built in antiquity for the improvement of the homes of wealthy citizens, as well as in the complex of buildings of city baths and public toilets. In the nineteenth century, in a number of cities, construction of sanitary engineering systems for water supply, sewerage, and solid household waste removal began not only for the improvement of the homes of ordinary citizens. This change in urban development policy occurred under the influence of revolutionary processes in various fields of science and technology, primarily in medicine. Practical actions to improve the sanitary engineering systems of cities are influenced by the results of research and development in the field of construction technologies and in other branches of science, based on a synthesis of experience in operating these systems and assessing the practical feasibility of reconstruction and technical re-equipment of existing systems infrastructure, as well as analysis of financial security of the implementation of the planned modernization or new construction facility sanitary systems.

In the history of the development of sanitary engineering system from the mid-nineteenth century to the present time, five stages can be distinguished [6]. The first stage a system of theoretical and regulatory provisions on the collection and disposal of wastewater, aimed at introducing new technologies prevailed: replacing cesspools with water closets and discharging human body wastes and sullage together with rain wastewater through a system of drainage pipelines and canals into water bodies without application treatment facilities. At the second stage – the system of joint sewerage should have been supplemented with facilities for mechanical and chemical treatment at the wastewater discharges into water bodies. In the third stage, the sewerage system should have been equipped with soil treatment facilities on agricultural irrigation fields or filtration fields. At the fourth stage – in composition of a centralized sewerage system for the disposal of household wastewater, mechanical and biological treatment facilities were to be used. At the fifth (modern) stage – in composition of a centralized sewerage system biological treatment facilities should be used for the neutralization of household wastewater, as well as for large treatment plants with wastewater discharge in sensitive areas of water bodies, tertiary treatment technologies should be applied to remove nitrogen and phosphorus compounds.

3. Analysis of promising technological solutions to improve the city sewerage system taking into account historical practice

Russian-Swiss doctor F.F. Erisman developed the fundamental principles of public hygiene and paid great attention to the issues of building and improving sewerage systems in settlements. In 1875, in a monograph [7] devoted to the theme of “cities improving” based on a comprehensive analysis of the advantages and disadvantages of carried away sewage and sewerage systems, F.F. Erisman concluded that for the rational improvement of cities, it is necessary to give preference to the sewerage system. Based on a generalization of information on the methods of settlements canalization, he put forward a hypothesis concerning the emergence in the distant future of cities of a new type in which “the current type of construction of large cities will be abandoned making them look like big barracks, and they will decentralize cities so that separate houses or groups of houses will be surrounded by a vast undeveloped space on which parks, orchards, and vegetable gardens will be planted”. Then, according to F.F. Erisman, the export system could be justified, and “collecting excrement in closets and vessels” with their subsequent recycling in the adjacent territory “would find a convenient and direct recycling.” With the implementation of such a decentralized scheme for the removal of human excrement, it will still be necessary to build a centralized underground network of canals “to remove slops unsuitable for fertilizing from buildings and to drain the terrain”. Conceptual decision of F.F. Erisman's layout of the "city of the future" practically coincides with the urban planning concept of the "garden city of tomorrow" proposed in Germany twenty-one years after the publication of his book [7]. The article by engineer A. Ensh [8] provides the information on the development of this concept at the turn of 1910. According to the information the idea of founding garden cities belongs to Teodor Fritsch, who published the book “Die Stadt der Zukunft in Leipzig” in 1896. As a result a syndicate (public organization) was formed in Berlin in 1898 to implement the ideas of T. Fritsch. The

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activity of this public organization was short and useless. According to A. Ensh, it is unfairly believed that the active development of the movement in favor of garden cities with the practical implementation of an innovative urban planning concept began only after the publication of the book "To-Morrow" by the English publicist Howard (Ebenezer Howard) in 1898. By 1909, the first garden cities and towns had been already built in England: Letchworth, Port Sunlight, Bournville, Earswik, and Hampstead. In his work, A. Ensh [8] pointed out that “the ultimate goal of the sprawling movement in favor of garden cities comes down to internal colonization destroying large cities crowding, causing increased morbidity and mortality, as well as the high cost of apartments, and industry decentralization" According to F.E. Gutnov and V.L. Glazychev [2], an analysis of settlement projects based on the concept of a garden city and the results of their implementation in the twentieth century showed that the idea of a garden city turned out to be “failed”, “utopian”, but “somehow, the dialogue of the city and the garden city continues, taking more and more diverse forms."

The initiators of the revival and further development of the movement to build garden cities in the near future are engineers working to create a model for the sustainable development of urban sanitary improvement. In order to prove the tendency there are modern data on the actual state of ecology in the urban and natural environment.

In the first quarter of the twentieth century, the dominant paradigm in the field of urban planning and sanitary improvement was the idea of canalization of towns according to a centralized scheme with the construction of municipal plants of biological treatment for urban wastewater (a mixture of household and industrial wastewater that was admitted to the urban sewerage system). For example, in construction set of rules (SP) 42.133330 "Urban planning. Planning and development of urban and rural settlement” stated that “in residential areas without centralized water supply and sewerage, the placement of multi-story residential buildings is not allowed". Decentralized water supply and sewerage systems may be used only for equipping low-rise construction territories and gardening associations of citizens and industrial factories.

At the beginning of the twenty-first century, a paradigm shift is taking place in the field of technologies for the collection, conveyance, treatment, and recycling and disposal of household wastewater and its components due to the resumption of the search and implementation of promising technological solutions for dividing household wastewater into separate streams for the purpose of production of secondary products from wastewater components [6]. Among the important factors that influenced this process, it should be noted:

- an increase in the world's population and an increase in the industrial production of goods and, as a result, an increase in the emission of pollution into the environment;
- the deepening crisis associated with the provision of cities and other settlements with quality drinking water;
- modern technical policy aimed at improving the energy and resource efficiency of technologies in all industries;
- the transition in municipal utilities of cities in a number of industrialized countries from linear one-way water supply to water reuse technologies and technologies for obtaining secondary products from wastewater components;
- accumulation of information over the past thirty years about the problems of neutralizing “emerging contaminants”, such as pharmaceutical, hormonal, narcotic drugs, nano-materials, and micro nano-plastics, and new products and wastes of chemical factories at classical wastewater treatment plants.

One of the main topics in the field of research on the treatment and reuse of household wastewater components is the discussion on the grouping of primary wastewater flows discharged directly from sanitary appliances and household equipment. Based on a generalization of information on this topic, an updated classification of wastewater types is proposed (Figure 2), discharged from sanitary appliances and household equipment [9]. The classification of types of household wastewater allows establishing a common terminology of the basic concepts in the field of sanitary engineering and is an

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important tool for decision-making in the design of new and reconstruction of existing sewerage systems in settlements.

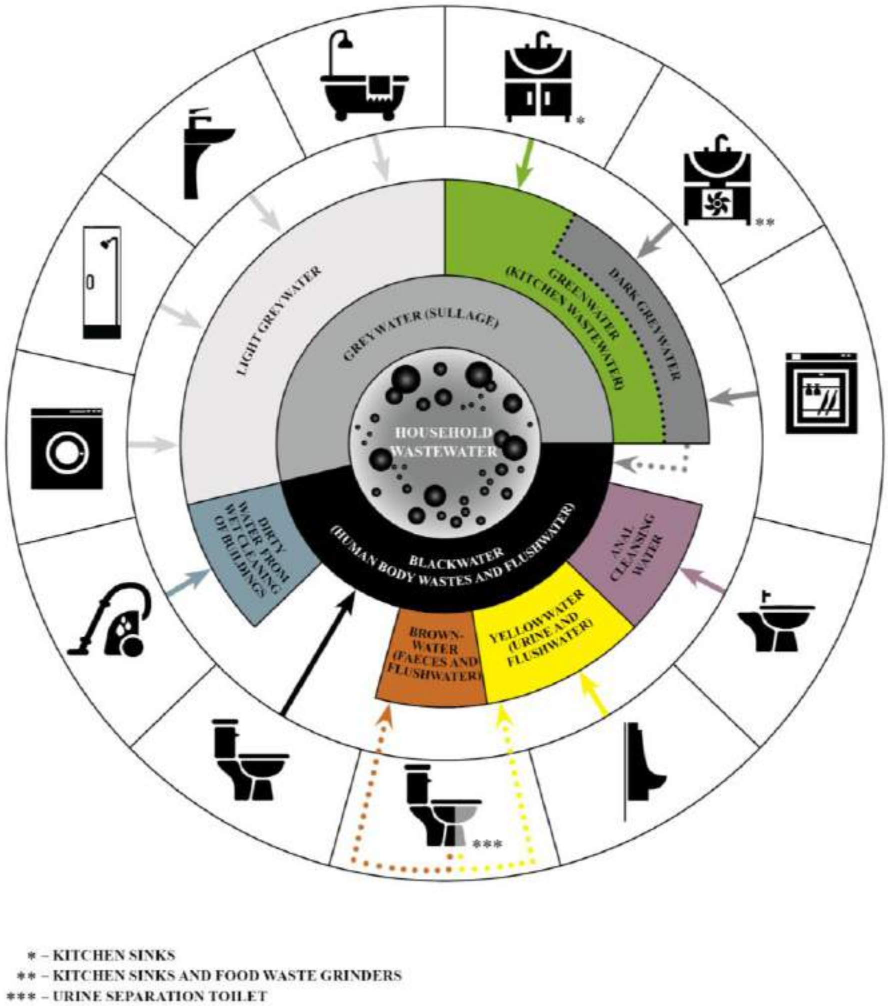

Figure 2. Classification of wastewater discharged from sanitary appliances and household equipment.

The analysis of technological solutions for the modernization of technology and equipment, which was used on a large scale in practice in the nineteenth century with carried away sewerage system, shows that these solutions formed the basis of the modern concept of dividing human excrement into separate streams and separating from sullage. As an indisputable argument in favor of introducing a “separation system” of sewerage, the hydraulic engineer M. Popov, the developer of the project in 1872 for the sewerage system of St. Petersburg, used the nature-based principle, arguing that “when installing latrines, special receivers for thick human body wastes, special for liquid, and in general, the division system should be inoculated, just as it exists in the structure of the animal organism” [10].

Legislative and normative consolidation of the concept of the diversion of multi-apartment residential buildings of greywater and blackwater in one stream to the treatment plant of a centralized sewerage system prevents the implementation of advanced modified technological solutions for the urban sewerage in practice. The key factor determining the volume and level of experimental research and full-scale testing of technological solutions for dividing household wastewater into several streams with the aim of separate treatment and recycling of wastewater components is the development and approval of regulatory documents that regulate basic sanitary rules and technological standards for the application of such technologies [6]. The development of modified technological solutions for the sewerage of settlements and the introduction of energy-efficient solutions for water reuse should be based on a systematic analysis of the whole variety of known technological solutions and taking into account historical practice. The boundaries of the search for optimal solutions should be maximized and an adaptive design strategy should be used, according to which each action should be selected depending on the results of the previous action in the process of testing modified technologies. The search for optimal solutions for the development of sanitary systems in the cities of the future is to be carried out on the basis of modernization of the whole complex of five interconnected processes for the sewerage of the settlement: collection, conveyance, treatment, recycling, wastewater disposal and the wastewater components disposal. It should be added that the development of the concept of separating human excrement and sullage into separate streams is an integral part of research work for the practical implementation of the basic principles of a large number of modern innovative concepts [11–13]: “Sustainability Development”, “Cities as Sustainable Ecosystems”, “Decentralized Sanitation and Reuse (DeSaR)”, “Source Separated Concept”, “Integrated Water Resource Management”, “3R – strategy of Reduce, Reuse, Recycling”, “One Water Concept”, “Zonneterp (Greenhouse Village)”, the popular movement “Eco- or Green City” etc.

The transition from traditional technologies for collecting, conveyance and treating the combined stream of blackwater and greywater to technologies for separate processing of streams that form household wastewater and recycling of wastewater components in large cities is still planned in the long term. The limiting factors of this transition process are the lack of projects and funding programs approved by municipal management organizations aimed at implementing costly modernization of the existing urban sewerage system, as well as traditional thinking about wastewater management in cities based on the experience of operating a classical centralized sewerage system for a century for the joint disposal and treatment of blackwater and greywater. The important circumstance is that the widespread introduction by the beginning of the twentieth century of a centralized sewerage system instead of carried away system made it possible to significantly reduce the mortality of citizens from infectious diseases. Despite these circumstances, the authors of [13] believe that "decentralization is a necessity that is inevitable." It should be noted that a decentralized and centralized sewerage system is “the property of the first South Asian urban culture in the Indus Valley,” called the Harappan civilization [14]. The analysis of the information presented in [13–15] allows concluding that in the period 3200 BC – 1900 BC in the Indus Valley (modern Pakistan) cities had five types of sewerage systems: a decentralized system for collecting household wastewater in storage tanks and filter wells (an analogue of the carried away sewerage system); a decentralized system for collecting household wastewater in combination with a separately functioning centralized rainwater disposal sewerage network; combined system (in the city, decentralized and centralized systems were simultaneously used in different zones of the city); centralized system for the conveyance of household wastewater to agricultural land; centralized system for the conveyance of household wastewater with the installation of pits (sumps) at the outlets from the buildings before connecting them to the street sewerage network. The latter type of sewerage system is classified as a “settled sewerage” [16]. This system is considered promising for small settlements and has been used in Australia since 1962 and in the United States since the mid-1970s.

Reuse of treated greywater in the urban sector (for example, for flushing toilets, for parks, gardens, and fields irrigation) is already finding practical application in a number of countries, for example, Japan, South Korea, Singapore, Australia, and the USA [4]. The question of the possibility of using wastewater as an additional source of drinking water, considered, for example, in [4, 13] is disputable and is described in article [17] as “unscrupulous ecological fanaticism”. In Russia, in accordance with the Water Code, the discharge of normally treated wastewater into surface water bodies is prohibited even in the second and third zones of the sanitary protection zone of water intakes for drinking water supply, and the use of treated wastewater for these needs is strictly prohibited.

The technologies for the use of rain water in urban and agricultural sectors are now sufficiently tested and are increasingly used in practice. In the field of technologies for collecting, conveyance, treating and recycling of rainwater, as well as with household wastewater, a promising area is the separate collection and treatment of rainwater from the roof of buildings and surface wastewater (rain, melt and flush water) from roads and sidewalks.

In a number of modern cities in industrialized countries, despite significant progress in their comprehensive improvement, there are separate zones in which buildings are not connected to a centralized sewerage network. For example, in Japan before the Second World War, the most common collecting of human excrement was toilets equipped with a cesspool (pit latrines), and by 2000, according to the Japan Sewage Works Association, only 91% of residents used toilets flush toilets; 71% of household wastewater was discharged through a centralized sewerage system to a treatment plant, and 29% of wastewater was treated at a local treatment station, of which about 8% were pre-collected in storage tanks and delivered by vacuum auto-boilers to the treatment plant [18].

In order to increase the level of comfortable living of a person in an urban environment, it is necessary to develop rational new rules for city planning and development, taking into account the implementation of modern hygiene standards, sanitary and ecological rules aimed at achieving sustainable urban development. When developing new rules for city planning and development that meet the criteria for sustainable development, it is necessary to consider the trend towards a decentralized sewerage system. The advantage of the system makes is due to the necessity of building in cities of the future a separate system of sewerage networks, an additional set of engineering constructions (treatment stations, water storage, pumping stations, distribution networks of reclaimed water supply, etc.) necessary for the reuse of treated wastewater and the sludge extracted from wastewater. To place in the city blocks construction zones of communal infrastructure objects intended for reuse of wastewater components, the formation and reservation of land plots at the stage of development of urban planning documentation (general and project plans for city blocks) is required.

The analysis of the current state of the cities air environment and planning the construction of decentralized sewerage system with a complex of engineering objects for water treatment and treated wastewater reuse as well as sludge recycling are the primary tasks connected with the technology improvement of the treating sewage gases generated at pumping and treatment stations as well as wastewater in ventilation systems of sewerage networks of external (street) sewerage and internal sewerage of buildings. The technologies for the neutralization of gas emissions into the atmosphere containing hydrogen sulfide, ammonia and the foul-smelling thiols compounds (mercaptans) have been developed to a sufficient degree and are described, for example, in the reference book of Degremont Company [19]. These technologies are used in industrially developed countries at urban and industrial wastewater treatment plants, as well as at sewage pumping stations near city blocks. The issue of sewage gases treatment entering the urban environment through the fan riser pipes in buildings should be resolved in the near future at a modern level, taking into account historical practice. In the past, for example, to improve urban hygiene in 1900, N.A. Chesnokov [20] proposed "to burn and neutralize" sewage gases generated in street networks of sewerage and vented to the atmosphere at a level of 0,2 m above the roof of buildings through the fan pipes of the risers of the internal sewerage system of building.

It should be agreed with the authors of the book [1] that in the future, with the development of the scenario of filling the city space with “smart dust” creating a large-scale network of wireless microdevices and nanosensors, it will be possible to access a range of data. The introduction of new digital technologies and tools in the urban environment will increase water resources management efficiency and the search for modified technologies for the sustainable development of urban sanitary engineering systems.

4. Conclusion

The transformation of urban sanitary engineering systems takes place continuously in close connection with the development of the theory and practice of urban planning, as well as under the influence of scientific and technological progress in other areas of human activity.

When developing new rules for planning and building cities that meet the criteria for sustainable development, it is recommended to take into account the trend of transition in the future to a decentralized sewerage system, the application of which demands the construction of an additional set of engineering objects for the reuse of treated wastewater and sludge isolated from wastewater in the cities of the future.

The transition from a centralized to a decentralized scheme of the sewerage system with the introduction of technologies for separate processing of streams forming household wastewater and its components recycling is a promising trend for solving the problems of water resources management nowadays and in the future.

The task of ensuring sustainable development of sanitary engineering systems in the cities of the future by reducing pollution emissions into the environment and improving energy and resource efficiency of technologies used for wastewater processing and its components recycling should be carried out on the basis of modernization of the entire complex of five interrelated processes for settlement sewerage: collection, conveyance, treatment, and wastewater and its components recycling.

Planning of construction in the cities of the future decentralized sewerage system with a complex of engineering objects for treatment and reuse of treated wastewater and sludge recycling is priority task of radically improving treatment technologies of sewage gas generated at the pumping stations, treatment plants, as well as in ventilation pipe system of outdoor (street) sewerage and internal sewerage of buildings.

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