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Energy- and Resource-Saving System of Water Management for Fine Chemistry

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Water supply to chemical enterprises is one of the most important tasks of modern industry. Water is widely used in industrial production processes. Quality and cost value of the final product, as well as the service life of the equipment and industrial safety level, depend on the efficiency of water management systems. The water management system of the enterprise includes a significant number of local systems that ensure the functioning of individual production systems (subsystems) and in general case, have different requirements to water. It should be noted that for the operation of a local system, several others may be involved. For example, technically prepared or demineralized water can be used for distillation; cooling is carried out with circulating water; heating – with water vapour and the drainage can enter either the system of water treatment or the sewage collection system.

1. Introduction

The structure of a typical integrated system of water management of fine chemistry enterprises (SWME) is designed on a modular principle and consists of 7 local subsystems (Figure 1): water recycling (1); steam generation, collection and treatment of condensate (2); production of desalted water (3); production of high-purity water (4); collection and treatment of polluted water (5); industrial water purification (6); hot water (7).

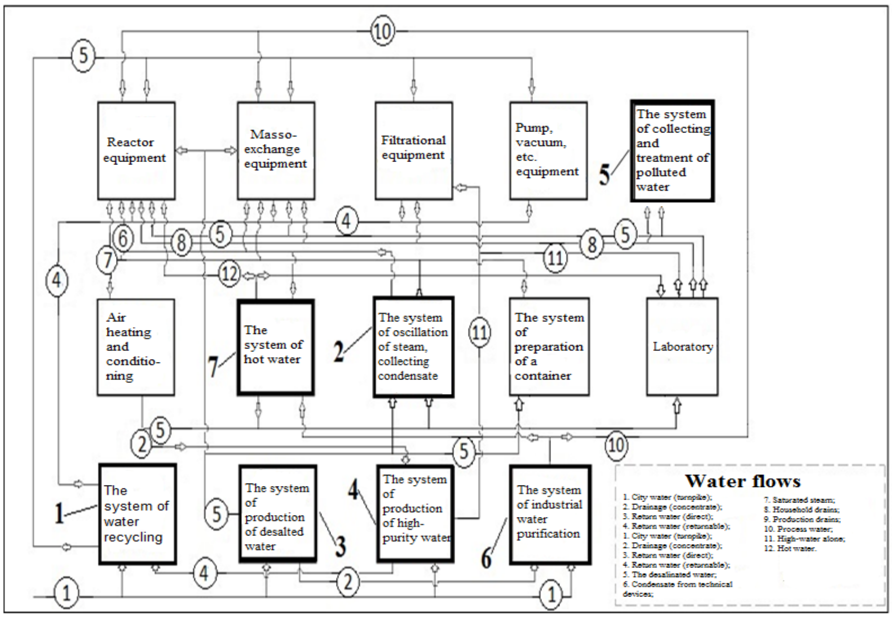

Figure 1: Flowchart of the integrated system of water management of fine chemistry enterprises

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Development of SWME was carried out with the help of the most modern and prospective system of computer support - CALS-technologies (Continuous Acquisition and Life cycle Support) (Saaksvuori and Immonen, 2010). Within the CALS, using application software such as CAE/CAD/CAM, PDM, MRP/ERP, SCM, etc., the information is created, stored and shared among the persons involved in the LC (Vinodh, 2011).
In the development of prospective chemical manufacturing it is shown that CALS-technologies and the main CALS-standard ISO 10303 STEP offer a way of a solution for the electronic representation of the design information by means of use of the standardized integrated description of a product. The designer's electronic description according to standard ISO 10303 STEP contains structure of categories, documents, status, groups of products with their versions, properties, classifications, etc. (Molina et al., 1999).
Life cycle (LC) begins with the inception of the idea of a new product and ends with the disposal of the manufactured product at the end of its useful life. In between, the lifecycle stages include marketing study, engineering, process design (PD), manufacturing itself, aftersales service, and use of the product (Dreyzis, 2013).
Today, CALS technologies are being implemented actively and successfully mostly at enterprises of the military-industrial complex. In the chemicals sector, the use of the CALS initiative is described primarily in publications by researchers from the Federal State Unitary Enterprise (FSUE) State Scientific-Research Institute of Chemical Reagents and High Purity Chemical Substances (known under the IREA abbreviation) and R&D Centre "Fine Chemicals" (RDC FC). Over the last 18 years, the two establishments solved several of the most topical problems of the chemicals sector using CALS-specific program complex (Bessarabov et al., 2015).
A typical application protocol for the permanent process regulation was created for the development of SWME on the basis of information CALS-standard ISO 10303 STEP (Figure 2). The information structure is based on the "Decree on technological regulations for production at chemical plant enterprises" (Lobanova et al., 2015).

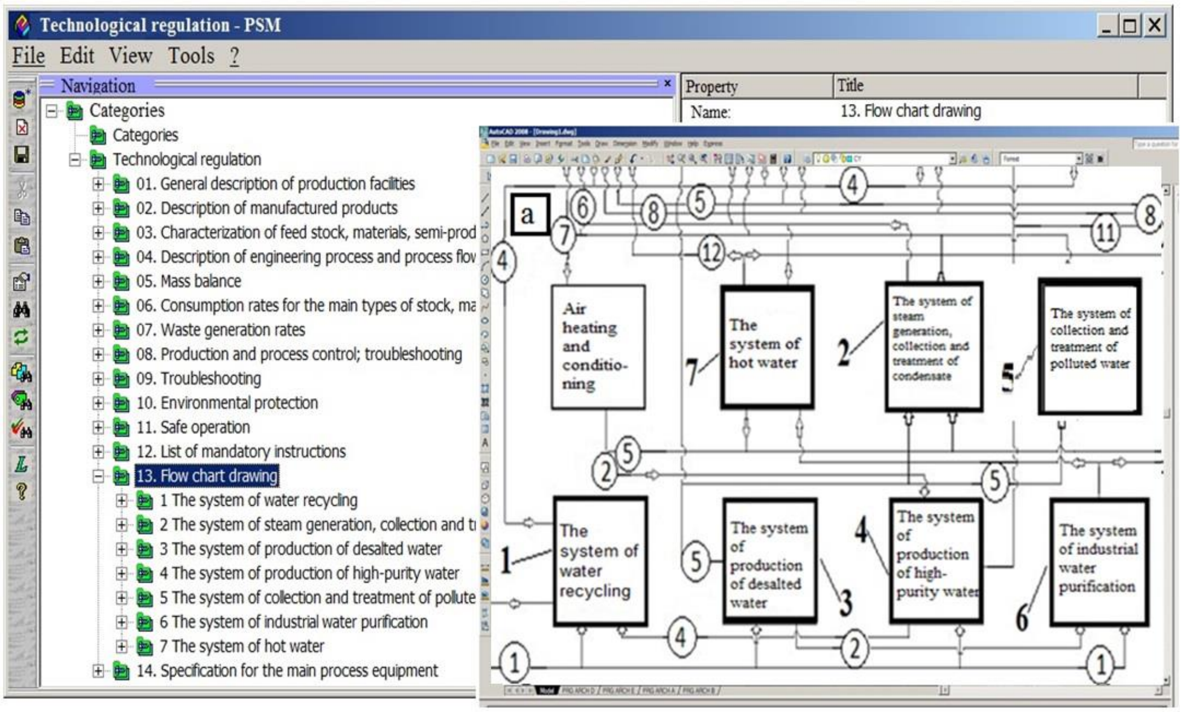

Figure 2: CALS-project of the technological regulation SWME (a - flowchart of the system)

The following 14 main upper level categories are listed in the standard scheme of the CALS project of the technological regulation of the integrated water system (Figure 2): general description of production facilities; description of manufactured products; characterization of feed stock, materials, semi-products and energy resources; description of engineering process and process flow diagram; mass balance; consumption rates for the main types of stock, materials and energy resources; waste generation rates; production and process control; troubleshooting; environmental protection; safe operation; list of mandatory instructions; flow chart drawing (Figure 2); specification for the main process equipment (Kazakov et al., 2015).

2. CALS-project of the integrated water supply system of the enterprise

The most complex resource-saving system is the recycling water supply system. It consists of tanks (storage basins) of source water, coolers (cooling towers), pumping stations, warm water tanks, reverse osmosis units, equipment for cleaning, composition correction and chemical treatment of water.
The standard circulating water supply system developed for the plant EKOS-1 (Staraya Kupavna, Moscow region) is a closed system. It allows the reuse of industrial wastewater after purification at a closed-cycle wastewater treatment plant. The system completely eliminates the discharge of wastewater into water bodies or sewers.
The CALS-project for the circulating water supply system (Figure 3) was developed for the process compartment with three plants for periodic rectification. Heat exchangers, water-ring vacuum pumps, vapor-liquid shirts and condensers act as consumers in this scheme. All the equipment is entered in the database, where the directory "Apparatus" was created. The types of equipment (collectors, rectification columns, cooling towers, pumps, etc.) are chosen as "reference elements". For each element of the directory, you can attach the corresponding characteristic: the material from which the equipment is made; composite parts; strength characteristics. Addition of characteristics is held using previously created dictionaries.

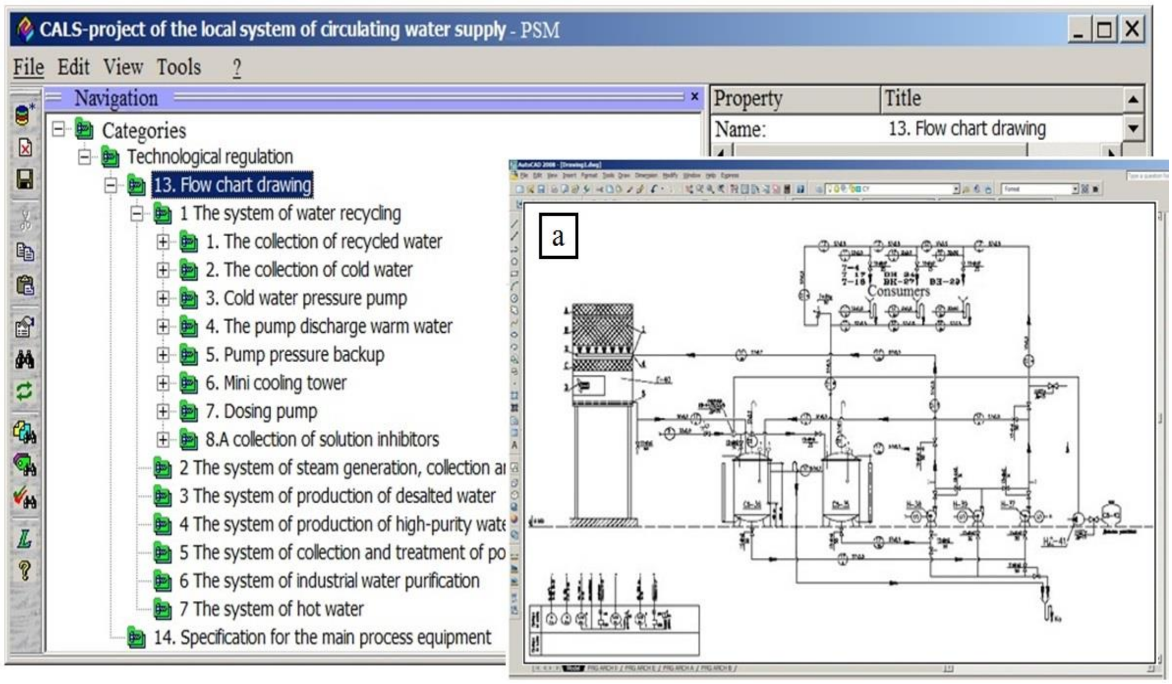

Figure 3: CALS-project of the local system of circulating water supply (a-technological scheme)

Technical (city) water is used for replenishment in the system of recycling water supply developed. Water used for cooling should not contain mechanical impurities and suspended particles. This leads to clogging of tubes and chambers of heat exchange equipment. In the initial water, organic substances may be present in quantities that cause the formation of biological deposits on the surfaces to be cooled. In this case, the water must be treated appropriately.
The water used for cooling should contain a minimum amount of salts of temporary hardness to prevent the formation of scale on the surfaces of pipelines. The permissible limit of temporary rigidity depends on the total chemical composition of the source water and the water supply system. Cooling water should not cause corrosion of the equipment. To prevent these problems, various reagents are used. Also, the problem of preventing contamination of recycled water by products of corrosion, dust, etc. is solved in the proposed recirculated water supply system. For this purpose, settling tanks and mechanical cleaning filters are used to remove large-dispersed suspended particles from the water.

3. Local system for steam generating, and collecting and processing of condensate

Energy saving issues are mainly resolved in steam generation and hot water supply systems. The system of steam generation, collection and treatment of condensate includes generating equipment (e.g. boilers, steam generators); subsystems for feed water preparation, collection, correction, chemical treatment and return of condensate.

The developed technological scheme includes 2 autonomous subsystems: a subsystem of steam generation and a subsystem for collecting and processing condensate (Figure 4). The feedwater preparation subsystem is an essential component in the steam production system. The optimally designed system ensures uninterrupted and economical steam production. It reduces losses during blowing through the sludge, prevents corrosion of steam and condensate lines and prevents scaling in the steam generator, contributes to the prolongation of the service life of the steam generator, steam and condensate lines and associated fittings. Operation of steam boilers is allowed only on suitable water for them. The cost of water treatment is much lower than the cost of repairing the damage to the boiler plant.

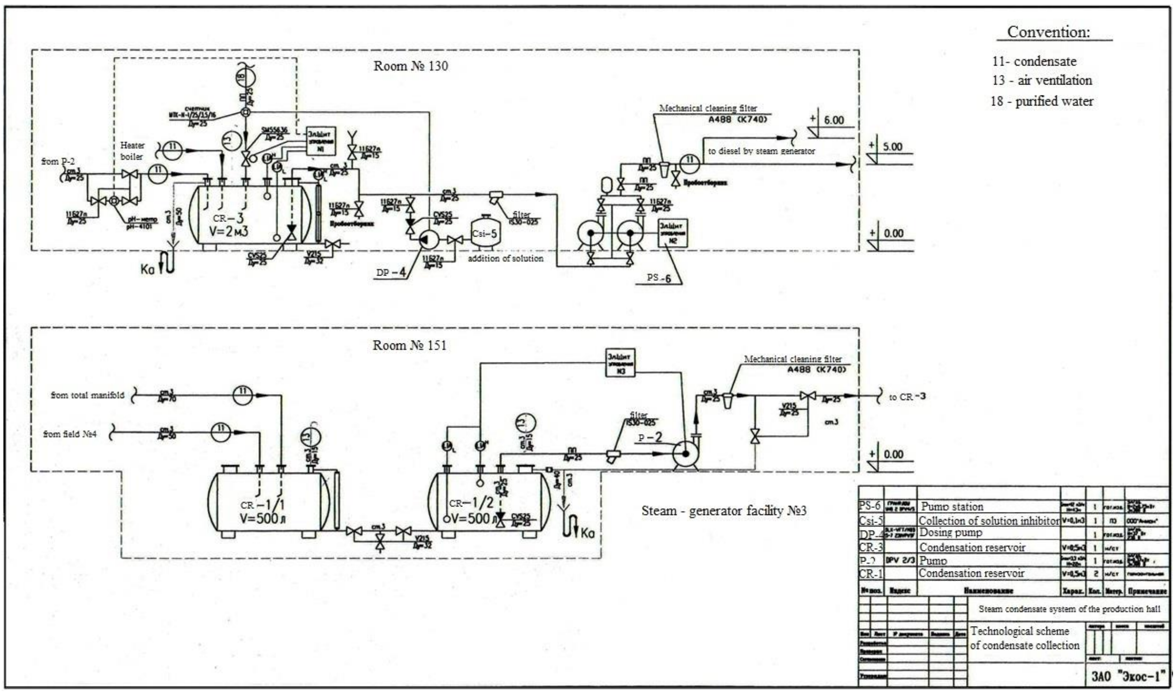

Figure 4: Local steam generation and condensate recovery system (condensate collection and processing subsystem)

In the developed subsystem (Figure 4), the condensate is collected in appropriate containers and then sent for processing. Depending on the requirements, different types of condensate treatment can be used.

De-ironing of condensate: If the condensate is not contaminated with oils, it is necessary to include a deironing filter in the first stage of the purification treatment of the condensate before the ion-exchange filters. This combines the functions of mechanical (deironing) and barrier (preventing accidental slippage of oils into the filtrate) filters. De-ironing filters can be loaded with acid cation exchanger, sulphon, styrene-divinylbenzene copolymer. If the condensate is not contaminated with petroleum products, then with an iron content of not more than 100 μg / kg, a special deironing filter is not installed. Its functions are performed by a cation exchange filter in the H or Na form loaded with a cation exchanger.

Condensate softening: If the condensate is contaminated with calcium and magnesium salts and used to make up high and medium pressure drum boilers, the cleaning is carried out according to the single-stage Na-cationing scheme. If the content of corrosion products in the condensate does not exceed 100 μg / kg, Na-cation exchanger filters combine ion-exchange and mechanical functions. If the content of iron in the condensate exceeds 100 mcg / kg, a special de-ironing filter is installed before the Na-cation filter. Wash the Na-cationite filter after regeneration followed by soft water to avoid saturation of part of the cationite layer with calcium and magnesium ions.

In addition to deironing and softening of condensate, a certain set of inhibitors is also used in the system. They are fed by means of a metering pump into the feeding water unit. Feeding water and water for condensate dilution comes from reverse osmosis units, distillator, etc. Inhibitors can be combined depending on the characteristics of the water.

In the subsystems of steam generation, steam boilers of different power (capacity) are usually used. They are designed to generate saturated or superheated steam. Boilers can use the energy of fuel burned in their furnace, electric energy (electric steam boiler) or utilize the heat that is released in other units (waste heat boilers).
There is almost complete return of condensate in the system. The temperature of condensate is maintained close to the boiling point (98 - 100 ^{0}C). This leads to thermal energy saving up to 15-20 %. Due to the operation of hot water supply system directly at the enterprise (no need in heat supply from outside organizations) up to 10-15 % of thermal energy could be saved (by eliminating losses during transportation and switching).

4. Local system for desalted water obtaining

Desalination of water is the process of reducing the total salt content to 5 mg/L and lower. Most often for desalination, the following methods are used: boiling; reagent ion exchange; membrane variant; nanofiltration; reverse osmosis; electric dialysis - elimination of salts by electric field; combinations of any methods (Gaoshen et al., 2017).
Each treatment option has its pros and cons. Common ion exchange is too expensive to maintain. This is due to the replacement of cartridges and the generation of waste that are difficult to dispose of. However, there are several indicators for such a method of water desalination. If there are more than two milligrams of salts in the water, then ion exchange will be beneficial. The salt content from water can be eliminated by standard boiling.
If water with certain characteristics is needed, then reverse osmosis is used. It is a classic method of water desalting. Among the advantages of reverse osmosis, several points should be noted: the simplicity and independence from the salt content of the source water, low energy costs, and low costs for service and maintenance. The water treatment system can be easily washed out, disinfected and cleaned. It does not require the use of strong chemical reagents and the need to neutralize them.
In this connection, reverse osmosis is used in the proposed system of desalinated water preparation (Figure 5). This is a water treatment plant (1). Drainage is taken to the collection tank of conditionally pure water.

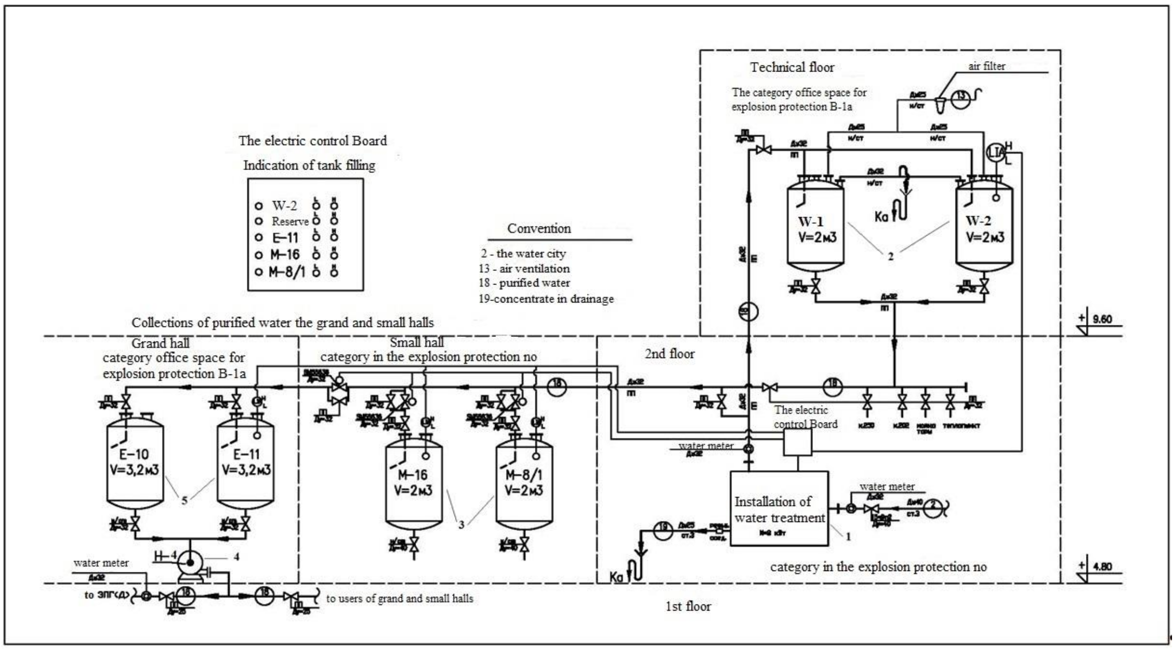

Figure 5: Local system of desalinated water preparation

The system includes 5 main units:

- Water treatment plant. In this case, a reverse osmosis unit is used.
- Water tanks (W-1, W-2) are filled by the pump with a water from the treatment plant. The distribution of demineralized water is carried out through those tanks: across the unit; to storage tanks (M-16, M-8/1); to the secondary system of demineralized water distribution by sections.
- Consumable consumers capacities (M-16, M-8/1).
- Demineralized water distribution system for a separate large consumer (site). It includes tanks (E-10, E-11) and a pump (H-4).

- Capacities of purified water to provide demineralized water to individual consumers.

After the desalination system, the water is collected in a collection tank of clean water and sent for further use. The water obtained in this system feeds steam generating plants and is used in preparation of the product, as well as in the local system to obtain high purity water.

The local system for obtaining high-purity water is used to operate the filtration equipment, as well as to ensure that the laboratory is functioning properly. The product enters the system inlet after desalination (Figure 5). The system includes circulating osmotic plants, sorption, ion exchange, filtration and distillation units, water storage and distribution facilities, accumulation of drainage and other drains, chemical treatment and equipment regeneration.

The local system for collection and treatment of contaminated water includes intermediate storage tanks, pumping stations, local treatment facilities for chemical treatment, settling, cleaning, pumping to external receivers or use at a given plant.

A local system for cleaning industrial water is used to receive and to prepare external or artesian water. It includes receiving main and distribution pipelines, pumping stations, and equipment for water treatment (averaging, softening, deironing, disinfection, etc.).

The local hot water supply system (HWS) is used to supply production and auxiliary premises with hot water. It includes a system of boilers, storage tanks and pumping stations. In the schemes of water treatment for HWS, special treatment of water is required, due to technological requirements. Hot water from production processes can also be used in the HWS system. For example, water from heat exchangers also returns to the hot water supply system.

5. Conclusions

Balanced and interactive operation of all subsystems of WME will help to reduce the water consumption by the enterprise in general by 20 % and energy consumption by 15 %. It also helps to decrease the loss of water and industrial and semi-pure wastewater, to reduce the negative impact of the enterprise on the environment and also to increase the efficiency and safety of production. Development of the SWME was carried out under the most perspective system of computer support – CALS-technologies. This allows to improve the quality of research and design work, as well as to provide full computer support for all stages of the life cycle.

Acknowledgments

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