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SCHEME OF MODULE ARRANGEMENT IN THE WATER TREATMENT, REGENERATION, AND RECIRCULATION SYSTEM WITHIN SMART HOME INFRASTRUCTURE. (Integrative Complex Water Purification Module for Smart Home Infrastructure Based on Multifunctional Electrochemical and Automated Water Treatment Technologies)

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Abstract

This article examines an integrative complex water purification module designed for the treatment of groundwater and water resources of similar quality in accordance with modern water supply standards and smart home infrastructure requirements. The proposed system is intended to provide automated multi-stage water purification, monitoring, and conditioning with a production capacity ranging from 1,500 to 3,000 gallons per day. Particular attention is devoted to the structural organization of sequential water treatment and monitoring units integrated into a unified technological cycle. The article describes the implementation of active monitoring systems based on electromagnetic resonance spectroscopy principles for real-time analysis of fundamental water quality parameters. The technological process includes primary sedimentation, gravitational separation, aeration, oxygen dissolution enhancement through an aerodynamic vortex foam generator, electrochemical processing, ion-exchange purification, and automated self-cleaning filtration systems.

The article further examines multifunctional electrochemical reactors equipped with water-permeable carbon–carbon electrodes capable of performing multiple electrochemical treatment operations without the use of chemical reagents. These operations include acidity level correction, disinfection, coagulation, flotation, and antibacterial treatment. Special consideration is given to the integration of sedimentation systems, contact grids, ion-exchange columns, and automated filtration modules into a coordinated infrastructure for continuous water regeneration and purification. It is concluded that the proposed integrative complex module represents a technologically advanced approach to water treatment infrastructure for smart homes and intelligent buildings, combining automated control systems, environmentally sustainable electrochemical technologies, and multifunctional purification processes into a unified high-efficiency ecosystem capable of meeting contemporary environmental, infrastructural, and operational requirements.

Keywords: *Smart home infrastructure; smart home infrastructure components; innovative smart home infrastructure components; innovative smart home infrastructure components for energy supply; innovative smart home infrastructure components for backup energy storage; innovative smart home infrastructure components for water supply, water treatment, regeneration, and recirculation; innovative smart home infrastructure components for clean air supply*

Integrative Multifunctional Water Regeneration, Treatment, and Recirculation System for Smart Home Infrastructure

Arrangement Scheme of Operational Modules in an Integrative Complex Water Purification Module at the Input of the Water Supply System

The integrative complex module, developed in accordance with the technical requirements of smart home infrastructure, is designed to treat groundwater and water resources of similar quality to the level required by modern water supply standards. The productivity of the integrative complex module ranges from 1,500 to 3,000 gallons per day.

The system includes a series of sequential water monitoring and treatment units. The process of passing through all stages of treatment and monitoring begins with a collector of all incoming water, in which comprehensive active monitoring of all fundamental water parameters is performed based on the principles of electromagnetic resonance spectroscopy.

After this stage, all water enters a sedimentation tank, the primary purpose of which is the initial sedimentation process and separation of the water flow into contaminated water containing sediment and water after gravitational sedimentation. The clarified water is supplied by means of a pump into a primary aeration column for aeration and maximum possible dissolution of oxygen in water, achieved through the operation of an aerodynamic vortex foam generator connected to a compressor.

After completion of the first aeration process and oxygen dissolution in water, part of the water together with foamed sediment is removed, while another part is directed into an electrochemical reactor with a multifunctional operational cycle and electrochemical cells equipped with water-permeable carbon–carbon electrodes.

From the electrochemical reactor, the treated water, processed in accordance with the specified multifunctional operational cycle, is directed into a sedimentation tank, where it is separated into two flows: one flow is discharged for disposal after the sedimentation section, while the second purified flow, processed through the combined multifunctional operational cycle of the electrochemical reactor cells and the contact grid of the sedimentation tank, is directed into ion-exchange purification columns.

After treatment in the ion-exchange purification columns, the purified water is directed into automatic self-cleaning filters, from which, after separation of sediment within the filters, the water is supplied into a second electrochemical reactor with a multifunctional operational cycle. The electrochemical reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents. Such operations include acidity level correction, disinfection, coagulation, flotation, and antibacterial treatment.

The water treated in this manner is then directed into aeration columns and forced oxygen dissolution columns, where oxygen is dissolved in water to the level of complete saturation. At the outlet of these columns, sediment and other foamed contaminants are separated from the main water flow and disposed of, while the remaining purified water is directed through a storage reservoir to end users.

The diagram designates the following components:

1 – reservoir into which water enters from the system or collector; this reservoir contains active online water contamination monitoring systems based on the principles of electromagnetic resonance spectroscopy (an invention of the project authors);

2 – primary sedimentation tank connected to pump 4 and equipped with a discharge line for sediment removal;

3 – compressor connected to aerodynamic foam generators in the columns for separation of sediment fractions and other contaminants;

4 – centrifugal pump with all necessary supporting infrastructure;

5 – column for aeration and oxygen dissolution in water, as well as for lifting foamed contaminants and organic matter into the upper section of the column;

6 – column for separation of foamed sediment and contaminants from the water mass;

7 – electrochemical reactor with a multifunctional operational cycle; the reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

8 – non-contact water quality monitoring system controlled by a dedicated processor connected to sensor modules installed at corresponding pipeline sections and operating on the principles of electromagnetic resonance spectroscopy;

9 – ion-exchange treatment columns having a sectional structure; depending on productivity requirements, the column may contain one, two, or three sections; such a structure allows one column to contain three ion-exchange materials, including the natural ion-exchange material zeolite;

10 – sedimentation tank receiving discharge from the electrochemical reactor and from which clarified water is supplied by a pump to the inlet of ion-exchange treatment columns 9;

11 – automatic self-cleaning mechanical filters capable of being replaced with membrane-based automatic filters;

12 – pump supplying purified water from sedimentation tank 10 to the inlet of ion-exchange treatment columns 9;

13 – pump supplying purified filtered water from filters 11 into the second electrochemical reactor with a multifunctional operational cycle;

14 – electrochemical reactor with a multifunctional operational cycle; the reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

15 – column for aeration and oxygen dissolution in water, as well as for lifting foamed contaminants and organic matter into the upper section of the column; an aerodynamic vortex foam generator is installed in the lower section of the column;

16 – column for separation of foamed sediment and contaminants from the water mass;

17 – innovative aerodynamic vortex foam generator, the inlet of which is connected to the compressor outlet;

18 – outlet and discharge line from column 6 used for separation of foamed sediment and contaminants from the water mass;

19 – discharge line for removal of sediment from sedimentation tank 10;

20 – discharge line for water treated in the electrochemical reactor into sedimentation tank 10; water in the electrochemical reactor may undergo several treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

21 – reserve discharge line for sediment removal from automatic mechanical filters or their membrane filter equivalents;

22 – final storage reservoir for treated water before supply for consumption;

23 – reserve discharge line for removal of accumulated sediment and contaminants from the storage reservoir;

24 – discharge line from column 16 for separation of foamed sediment and contaminants from the water mass.

Figure 1.

In the specified configuration, all integrated modules are multifunctional and may be adjusted for operation with several types of source water supplied to the input of the integrative complex module.

For monitoring and control of the electrochemical reactors, the structure of the integrative complex module includes a control and management system functionally connected to non-contact electromagnetic resonance sensor modules operating on the principles of electromagnetic resonance spectroscopy.

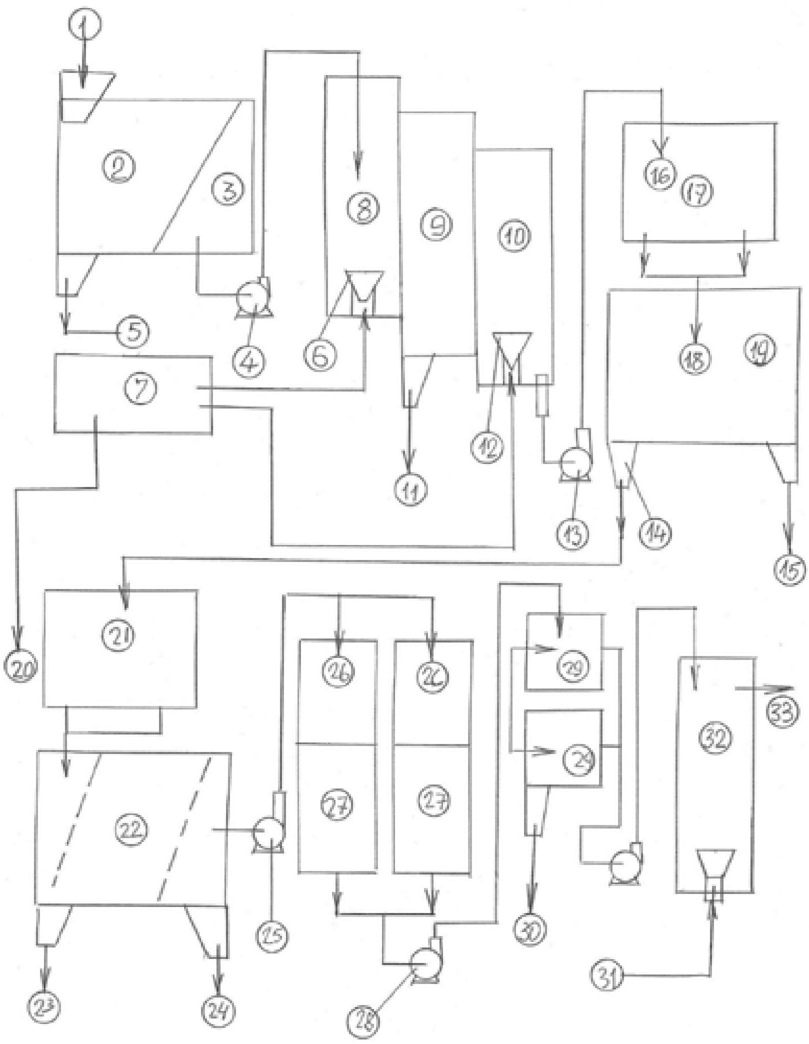
The specified system is capable of operating in a fully autonomous automatic cycle with complete monitoring of treatment results and water quality at all stages of the treatment process.

The specified system possesses a 100 percent level of operational flexibility and, during operation and configuration, is capable of changing the sequence and specific operational parameters depending on technical requirements and the characteristics of the integrated components and systems.

Example of an industrial modular system for water purification and regeneration using electrochemical methods.

Configuration with water regeneration for repeated reuse.

Figure 2.



Integrative complex module for water regeneration with preparation for recirculation; the entire regeneration process is performed without the use of chemical reagents.

The integrative complex multifunctional process for regeneration of water used at a single facility includes the following systems:

- input sedimentation without additional without additional processing;

- foam treatment with separation of sediment fractions and organic contaminants;
- separation of the foamed contaminant complex from contaminant-free liquid;
- repeated aeration of separated water with oxygen dissolution to the level of complete saturation;
- complex water treatment in an electrochemical reactor according to a multifunctional scheme, including acidity correction, disinfection, saturation with coagulants or flocculants, and return of water flows to a common acidity level;
- sedimentation within the discharge water flow containing coagulants or flocculants;
- repeated multifunctional treatment of the water flow from the sedimentation tank containing coagulants or flocculants according to the following final scheme: acidity correction, disinfection, and return of the entire treated water flow to a common acidity level;
- final sedimentation of all water treated in the second electrochemical reactor;
- treatment in ion-exchange processing columns, including sections containing natural granular zeolite instead of synthetic ion-exchange resin;
- treatment in automated self-cleaning mechanical filters or membrane filters;
- final aeration by means of aerodynamic vortex foam generation with oxygen dissolution to the level of complete saturation.

The diagram designates the following components:

1 – input sedimentation tank for formed sediment with functions for removal of formed sediment and transfer of clarified water to the next treatment stage;

2 – sedimentation section in tank 1;

3 – clarified water concentration section in tank 1;

4 – pump for transferring clarified water to subsequent treatment stages;

5 – system for removal of water containing formed sediment;

6 – aerodynamic vortex foam generator;

7 – compressor operating with three aerodynamic vortex foam generators;

8 – column for vortex foaming of clarified water;

9 – column into which foam from the upper section of column 8 is discharged, intended for aerodynamic vortex foaming of clarified water;

10 – column for vortex foaming, aeration, and saturation of treated water with dissolved oxygen to the level of complete saturation;

11 – discharge line for contaminants from column 9 receiving foam from the upper section of column 8;

12 – intermediate aerodynamic vortex foam generator;

13 – pump supplying water after treatment in column 10, with maximum air content and dissolved oxygen saturation, into the electrochemical cells of the first electrochemical reactor along the liquid flow path;

14 – discharge line for purified water after sedimentation following complex treatment in the first electrochemical reactor along the liquid flow path;

15 – contaminant discharge line from the sedimentation tank installed after the electrochemical reactor;

16 – water inlet into the electrochemical reactor cells after aeration and oxygen dissolution to the level of complete saturation;

17 – housing of the electrochemical reactor;

18 – discharge of water from the interelectrode space of the electrochemical reactor cells after completion of the treatment cycle;

19 – multifunctional sedimentation tank;

20 – outlet from compressor 7 to the inlet of the final aerodynamic vortex foam generator system;

21 – multifunctional electrochemical reactor for comprehensive final water treatment according to a multifunctional scheme, including acidity correction, disinfection, and return of the entire treated water flow to a specified common acidity level;

22 – multifunctional sedimentation tank;

23 – discharge line for contaminated liquid;

24 – reserve water discharge line from the clarified water section of the sedimentation tank;

25 – pump supplying water from the final section of the sedimentation tank to the segments of the ion-exchange columns;

26 – upper sections of the ion-exchange columns in which granular zeolite is used as the ion-exchange material;

27 – lower sections of the ion-exchange treatment columns containing ion-exchange resin;

28 – pump for transferring water after treatment in the ion-exchange purification columns into automated self-cleaning mechanical filters or membrane filters;

29 – system of automated self-cleaning mechanical filters with a pump for supplying filtered water into the final aeration and oxygen dissolution column to the level of complete saturation;

30 – sediment discharge line from the automated self-cleaning filters;

31 – final aerodynamic vortex foam generator;

32 – column for the final stage of aeration and oxygen dissolution in water to the level of complete saturation;

33 – regenerated water supply line for recirculation.

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