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MODULAR ARCHITECTURE OF SYSTEMS FOR THE REGENERATION AND RECIRCULATION OF PROCESS LIQUIDS, INCLUDING WATER AND AQUEOUS SOLUTIONS

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Abstract

Modern industrial sectors that use water in technological processes face significant limitations imposed by traditional water treatment methods. Currently, three main groups of technologies are employed: reagent-based chemical treatment (over 70% of the market), non-reagent treatment methods (less than 20%), and combined technologies (approximately 10%). However, these existing solutions no longer meet contemporary industrial demands, as partial purification or localized improvements in water quality are insufficient for modern production requirements.

Given the inability of established methods to effectively address current challenges, the author-drawing on recent innovative concepts advanced by specialists such as Illia Beda – proposes a comprehensive water-treatment technology. This approach is based on the use of complete, autonomous, and standardized technological modules that ensure scalability, adaptability, and seamless integration into various industrial environments.

Keywords: *Modular Structure; Structure of Systems for the Regeneration of Technological Liquids; Structure of Systems for the Recirculation of Technological Liquids; Regeneration of Water and Aqueous Solutions; Recirculation of Water and Aqueous Solutions; Unified Technological Modules; Reagent-Based Chemical Treatment Method; Additional Technological Procedures; Reagent-Free Method of Water Treatment and Purification*

Comprehensive Technology for the Treatment of Industrial Wastewater Using Sequential Autonomous Processing Modules.

At present, in various industrial sectors that use water for technological purposes, the following methods of treatment and purification of water contaminated by products and by-products of technological processes are commonly applied:

- Reagent-based chemical treatment, which includes several modifications

of this method as well as combinations with other technologies; this method and its variations are the most widespread, accounting for more than 70% of the water treatment market;
- Non-reagent water treatment methods, which also include several main modifications differing in their operational ranges and performance characteristics; these methods cover less than 20% of the water treatment market;
- Various combined methods, typically consisting of the first two approaches supplemented with additional technological procedures dictated by local conditions specific to each user of the technology; these methods account for approximately 10% of the market and show a tendency toward expansion.

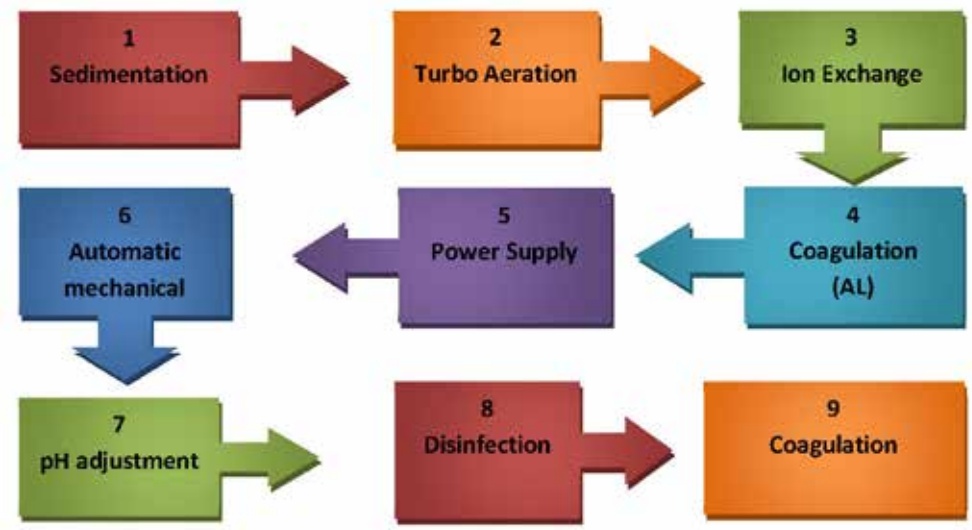
The challenges of water purification and conditioning identified to date cannot be effectively solved using known methods and technologies alone. The solution must be comprehensive, as partial solutions are not sufficient for any modern industrial process. Therefore, applying individual methods or their combinations does not address all new and continuously emerging requirements.

Considering the above and taking into account recent innovative concepts, the author proposes a comprehensive technology for the treatment of industrial wastewater, which consists of a series of sequential but functionally independent operations.

More precisely, all stages of water treatment can be viewed as consecutive modes of influence on the water, each based on different physical and chemical operating principles.

In combination with the latest innovative ideas presented and published by advanced specialists – primarily Illia Beda – the author proposes a complete technology that can be implemented through finished, autonomous, standardized technological modules arranged in the following configuration:

Figure – Diagram 1. *Nine primary technological modular compositions that incorporate all processing stages and operations required for the formation of a modular technological equipment complex intended for the purification, regeneration, and recirculation of process liquids, including water and aqueous solutions*



Of all the presented modules, Module 5 – the power supply unit – is relatively universal, while the remaining eight modules have a more specialized field of application:

Module 1 – Sedimentation Module, which may be implemented as either a sedimentation column or a sedimentation tank with a parallelepiped geometry.

Module 2 – Turbo-Aeration Module, which may have at least two configurations: one using foam generators and another employing a mixing device with real-time (online) homogenization.

Module 3 – Ion-Exchange Treatment Module, which can have numerous configurations, one of the most efficient being ion-exchange

columns equipped with capsules for ion-exchange resins made from carbon–carbon composite fabrics.

Module 4 – Coagulation Module, which uses aluminum ions as a coagulant, generated in electrochemical reactors with aluminum anodes.

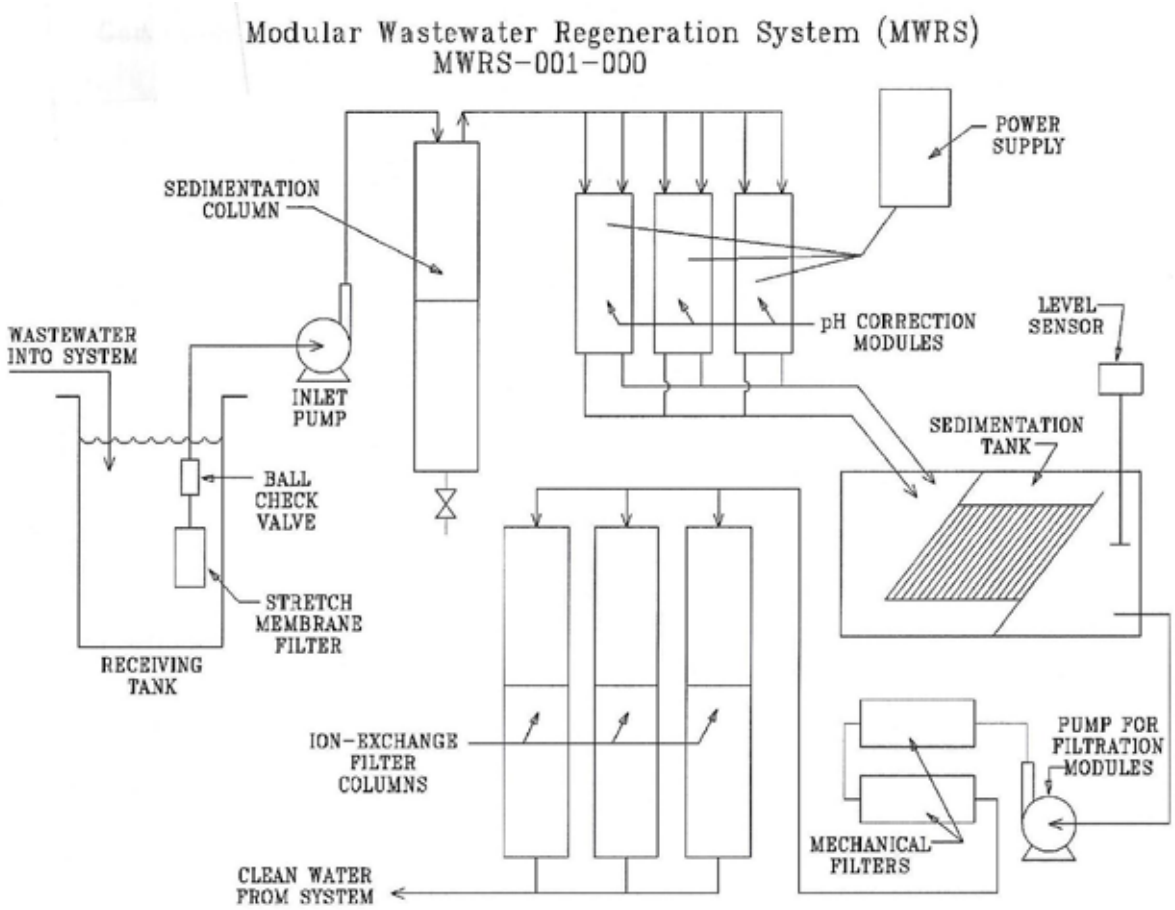
Module 6 – Automatic Mechanical Filtration Module, equipped with automatic cleaning for filtration sections and real-time (online) regeneration of filter elements.

Module 7 – Acidity and Alkalinity Adjustment Module.

Module 8 – Electrochemical Reagent-Free Disinfection Module.

Module 9 – Final Electrochemical Coagulation Module.

Figure 2. *Example of a Modular Composition: System for the Regeneration of Process Liquids, including Water and Aqueous Solutions*



As illustrated in the diagram, the system includes an intake tank equipped with several elements that enable the initial treatment of the spent process liquid. The liquid undergoes primary processing through a membrane filter connected via a check valve to the inlet pump, which delivers the regenerating liquid to the sedimentation column. Depending on the required flow rate, the sedimentation column may consist of one, two, or three sections.

After the first sedimentation stage, the liquid is directed to electrochemical reactors used for acidity and alkalinity correction. These reactors are controlled and powered by a multifunctional power supply source.

Once acidity is adjusted to ensure an alkaline state that provides optimal conditions for sedimentation, the liquid enters a specialized sedimentation module with a unique geometry that enables the separation of formed sediment conglomerates within the upward flow.

After the sedimentation process is completed, a level sensor activates a centrifugal pump that transfers the liquid to mechanical filtration modules, where remaining conglomerate particles that did not enter the sediment layers are retained.

Since the mechanical filters operate in an online mode, the pressure generated by the filtration pumps is sufficient to supply the filtered liquid to the ion-exchange columns.

Based on the conclusions and proposals outlined in the publications and patent applications of Illia Beda, as well as his multifunctional foresight regarding the development of eco-friendly technologies and advanced processing systems, the author of the present publication has significantly expanded the technical capabilities of the ion-exchange columns – a subject that merits more detailed consideration.

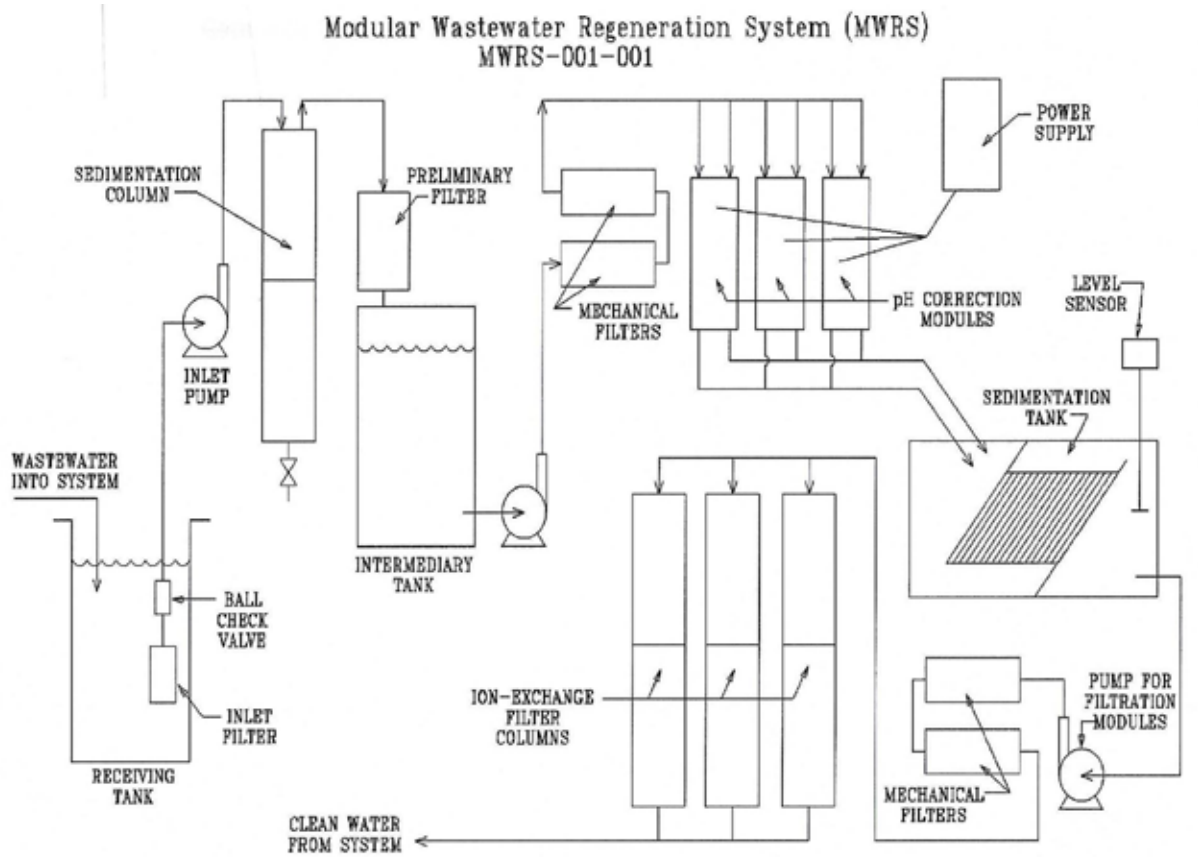
It is particularly important to emphasize that, in addition to synthetic ion-exchange resins, natural materials such as zeolite can also be effectively used for ion-exchange treatment.

Under the modular scheme proposed by Illia Beda – where an ion-exchange column consists of at least two modules (sections) – it becomes possible to use several ion-exchange materials of different exchange capacities within a single column. For example, the upper section may contain zeolite, while the lower section may contain ion-exchange resin.

The combination of these materials provides the most optimal conditions for purification, regeneration, and recirculation.

This modular configuration is based on the technological principles described in the inventions of Illia Beda, a well-known innovator in reagent-free real-time intensive liquid-processing technologies, including systems for water and aqueous solutions in directed flows.

Figure 3. *A modular system featuring an intermediate module equipped with a preliminary inlet filter and a set of sequential mechanical filters located at the outlet of the intermediate module and before the inlet to the electrochemical reactors for acidity and alkalinity correction*

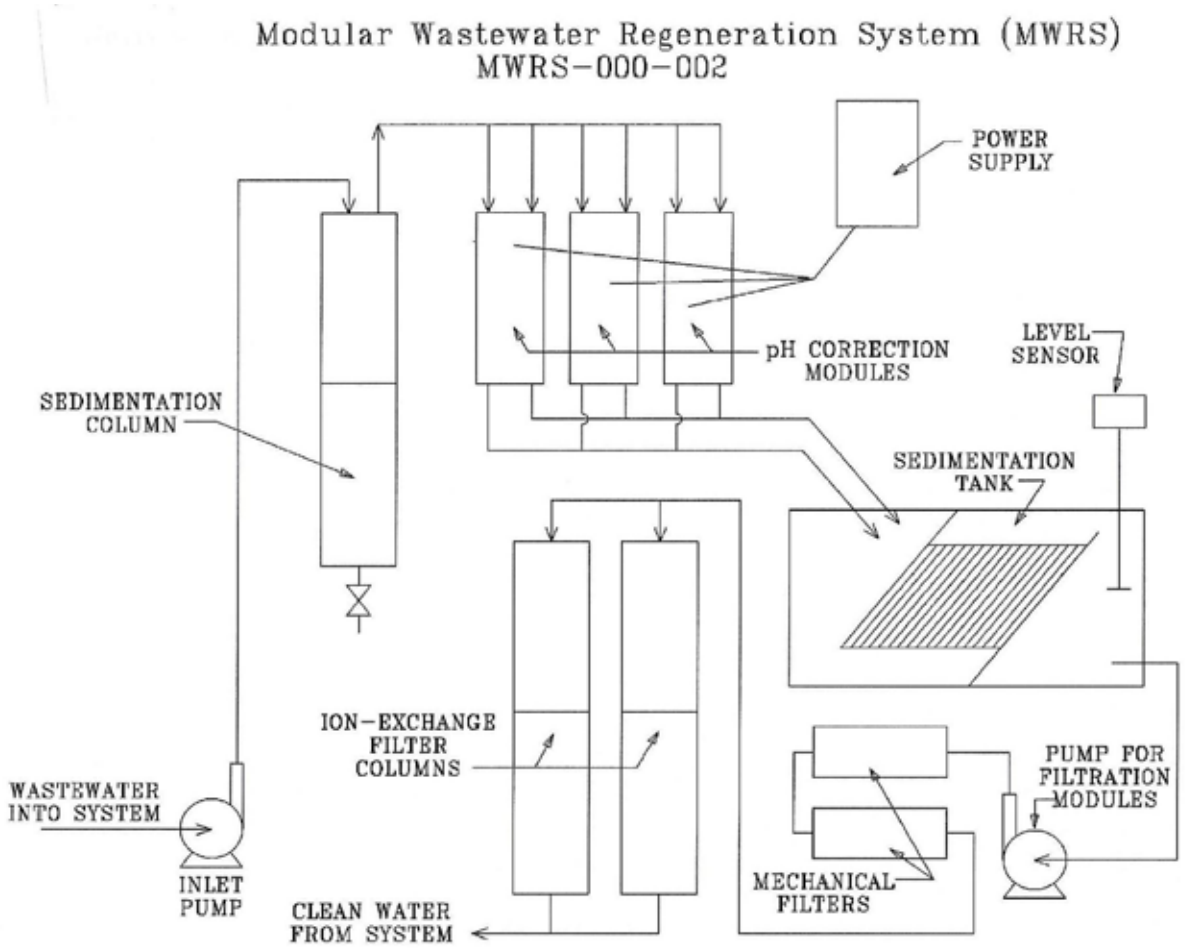


Practical implementation has shown that the hierarchical modular systems invented by Illia Beda – despite having a narrow technological

specialization – are sufficiently autonomous and operate within independent production – technological cycles without the use of chemical reagents or activating synthetic additives. This allows lower – level modules in the hierarchy to be effectively combined into higher-level modules while maintaining full economic and technological efficiency.

Furthermore, the absence of chemical reagents introduced into the process makes it possible to initiate and successfully carry out online recirculation immediately after the completion of the regeneration cycle, while preserving the high quality of process liquids and solutions.

Figure 4. *The most compact modular system without intermediate technological or structural elements*

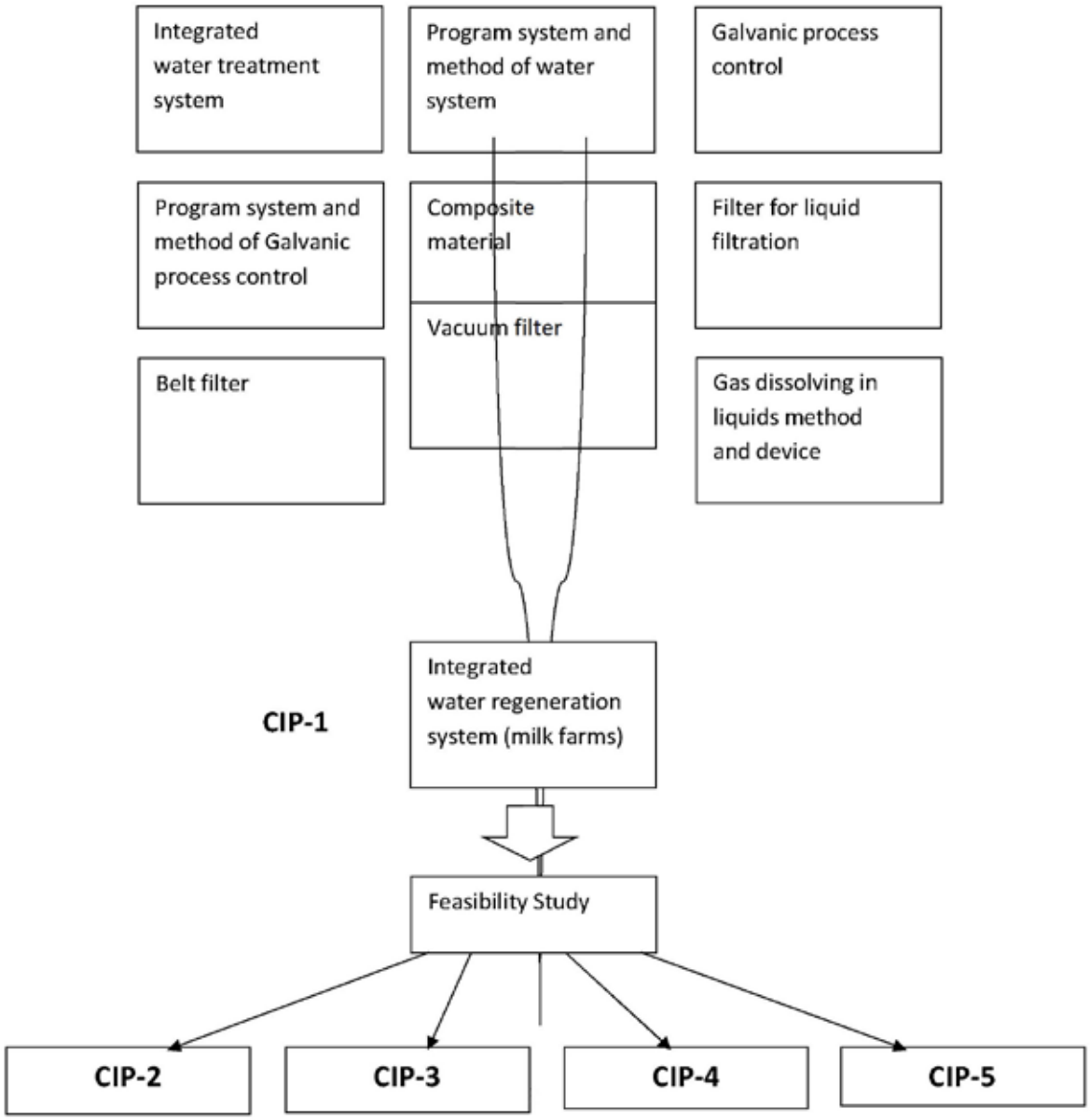


Thus, the presented figures and diagrams clearly demonstrate that the hierarchical structure of vertically integrated modular systems makes it possible to fully resolve both technological and environmental challenges while simultaneously meeting the needs of industrial facilities of any profile and any level of waste contamination, ensuring complete regeneration and subsequent recirculation of process effluents.

In this way, the approach also addresses the broader objective of gradually transforming industrial facilities of all types and levels of organizational flexibility into so-called "smart production" systems.

As shown in the presented algorithmic diagram – developed with consideration of innovative ideas and proposals derived from the inventions and publications of Illia Beda – a total of 14 objects are examined and represented in the diagram. Each of these objects is itself a complex of modules composed of autonomous modules of a lower combinatorial level.

Figure 5. *Basic IP*



Each module presented in the diagram qualifies as a subject of patent protection, and all possible combinations of these modules likewise constitute fully eligible patentable subject matter, including objects suitable for further patent continuation (in accordance with current U.S. patent legislation).

As of today, users of water-treatment technologies face a range of issues that prevent the auxiliary stages of water purification from achieving the same level of efficiency as the main technological processes. The major challenges include:

- continuous limitations on the availability of water resources that can be used in technological processes;
- ongoing deterioration in the quality of natural water resources suitable for industrial use;
- a constant increase in the cost of water resources;
- steadily tightening standards for wastewater discharge, which raise the cost of wastewater treatment;
- increasing requirements for the quality parameters of water used in technological processes;
- the emergence of new synthetic and organic materials due to the development of new and improved technological processes, which necessitates constant modernization of water-

treatment facilities or extremely broad functional capabilities, resulting in increased cost of both equipment and technological operations;

- the existence of numerous industrial facilities operating with outdated traditional equipment that has exhausted its service life, replacement of which requires significant investment or is not feasible at all.

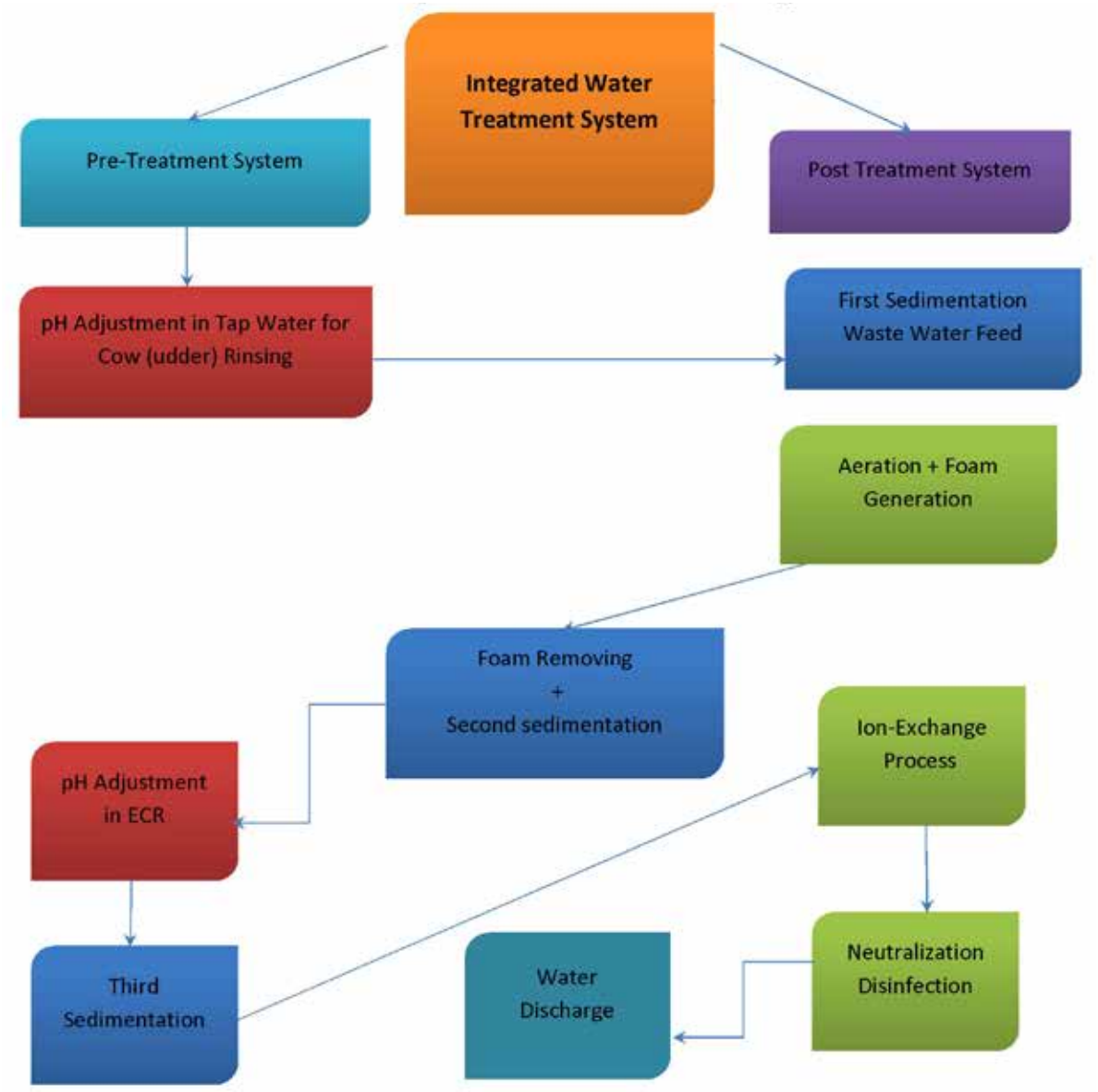
Patent and Licensing Landscape for the Proposed Technologies
Patentability of the Proposed Technological Methods

Based on preliminary studies and a patent search, the following topics have been identified for patent applications related to the proposed water-treatment methods:

- a module complex for advanced processing of water and aqueous solutions, and the associated method of its use;

Figure 6.

Integrated water treatment technology



- a method of comprehensive water treatment and the technological modules required for its implementation;
- a method for electrolytic extraction of metals from a water or aqueous-solution stream and electrode cells for implementing this method;

- a method of aerodynamic water foaming in a continuously flowing stream and a foam generator for this method;
- an integrated method of combined filtration with ion-exchange treatment and biosorption;
- an electrode cell for electrocoagulation with coaxial electrodes;
- an electrode cell for electrocoagulation with a continuously moving strip cathode;
- an electrode cell for acidity or alkalinity correction using blocks of polarizable soluble electrodes;
- an electrode cell for acidity or alkalinity correction with volumetric porous electrodes;
- an electrode cell for acidity or alkalinity correction with continuously moving strip electrodes;
- an electrode cell for electrochemical disinfection and associated electrode configurations for implementing the method.

For each patent application, prototypes and analogs have been identified among the inventions of Illia Beda – the originator of the proposed new methods. According to the results of preliminary patent searches and structural analysis, all listed technological solutions demonstrate full patentability.

Based on the above, it becomes possible – through vertical integration and modular composition – to develop a block diagram of an integrative technological complex in which flexibility and selectivity of each process are achieved within every module at the lowest hierarchical level.

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