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ADVANCED WATER PURIFICATION SYSTEM – CONTRIBUTION TO THE DEVELOPMENT AND PROMOTION OF ROMANIAN CULTURAL AND NATURAL HERITAGE

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Abstract: For the developers of processes and technologies, the use of water resources as sources of drinking water is a real challenge, in the context of sustainable development. The degree of pollution and contamination of the waters used as raw material in the analytical, pharmaceutical or industrial field incite researchers from interdisciplinary fields that aim at decontamination processes and technologies. The approaches are both theoretical and practical in nature, especially in relation to species and groups of chemical pollutants refractory to currently used degradation processes. As such, advanced physico–chemical processes were resorted to, as well as the development and implementation of numerical models, experimental studies, the design and realization of advanced filtration systems on a real scale. This work shows an advanced system of ultrafiltration and purification of water from the Danube with important bacteriological loads and various pollutants.

Keywords: numerical models, ultrafiltration, water purification, block system

1. INTRODUCTION

Analytical requirements contribute to the accuracy of water quality testing (*Prest et al., 2016; Schiermeier, 2014*). These requirements must take into account local resources and capacities; at the same time, they must allow variations depending on the methods used and the use of field tests (*Pinar–Méndez et al., 2022; Haas et al., 2019; Li et al., 2018; Shenga et al., 2016; Liu et al., 2016*). The potabilition of water means removing most of the organic, inorganic and biological components present in the water, so that the water obtained corresponds to national and international norms regarding drinking water (*World Health Organization, 2017*). A good quality drinking water *(Hou et al., 2018; Bruno et al., 2018; Li et al., 2017*) must be cold (5°C), with a pleasant taste, colorless and odorless, with an average content of mineral substances (calcium carbonates, magnesium, salts of sulfate with the mentioned metals). The socio–economic development of the territory depends on the centralized use of quality water, utility ensured in appropriate technical conditions related to the continuous increase in the degree of comfort and civilization *(Calero Preciado et al., 2021; Favere et al., 2021; Atnafu et al., 2022; Gunnarsdottir et al., 2020)*.

Ensuring that drinking water is free of microbiological hazards is the most important priority for people in accordance with the regulations and standards in force *(Pascual–Benito et al., 2020; Cuevas–Ferrando et al., 2020; Wang et al., 2018; Belila et al., 2016)*. Controlling microbiological contaminants in drinking water reduces the risk of disease transmission that can occur even after a single exposure (*Romero et al., 2021; Ferrari et al., 2019; Qu et al., 2015*).

In contrast to the acute and immediate nature of waterborne microbial diseases, the vast majority of chemical contaminants (e.g., arsenic, fluoride, nitrate, lead, and possibly manganese) present on a large scale in the country's water supplies, take effect only after a long period (years) of exposure. The specialized literature brings new methods of disinfection of aqueous systems that include nanostructured constituents with antibacterial action that cause disturbances in the permeation process of bacteria (*Luo et al., 2021; Acharya et al., 2020; Regula et al., 2014; Ulinici, 2012*). The disinfection correlation of properties with physical, especially nanostructured optical properties allows the characterization of the aqueous reaction medium (*Obare and Meyer, 2004*) by means of UV/VIS and Raman optical absorption spectroscopy. The water/particle contact systems allow photon transfer processes, of decomposition with the generation of free radicals, and the modeling of these intimate mass transfer processes is related to the transport phenomenon, the decomposition rate and the concentration of particles in the aqueous system.

The use of empirical models for real–scale systems is relatively difficult; retrieving information requires scaling rules that ensure geometric, dynamic and kinetic similarities between the laboratory model and the real–scale one.

2. MATERIALS AND METHODS

The techniques evolution and applications is closely related to technical calculation elements and software as well as data processing based on transport equations (mass, momentum, energy) of generalized quantities (density, fluid velocity field, generalized exchange coefficients, the flow regime, the volume element surface tension of the fluid).

In order to define the relevant transport equations, select and implement the numerical method in systems with complex geometries or that include additional physico–chemical mechanisms (photonic adsorption, migration in the force field, decomposition and penetration), methods are needed that allow the hydrodynamic model to numerically solve the system of differential equations with certain boundary conditions.

This type of complex numerical models allows the simulation of the evolution in time and the behavior in steady state or flow of the fluid system. This type of modeling with the involvement of particle decomposition processes for purification and chemical reactions with natural organic matter can be applied in catalytic systems for the inactivation of microorganisms in aqueous environments under exploitation conditions. From the point of view of efficiency, there are laboratory studies related to the kinetics and optimal control of photolysis processes *(van der Helm et al., 2007; Beltrán, 1997*) but there are obstacles related to the experimental part and the modeling of systems on a real scale in order to obtain some parameters of calibration necessary for the dimensioning of technological processes and their automatic management. The specific configurations of the applications related to the treatment of water in the recirculation flow assume injection processes (ozonation), followed by advanced oxidation processes through the adsorption of an air/ozone mixture at a predetermined concentration and solubilization (*Ulinici et al., 2008*).

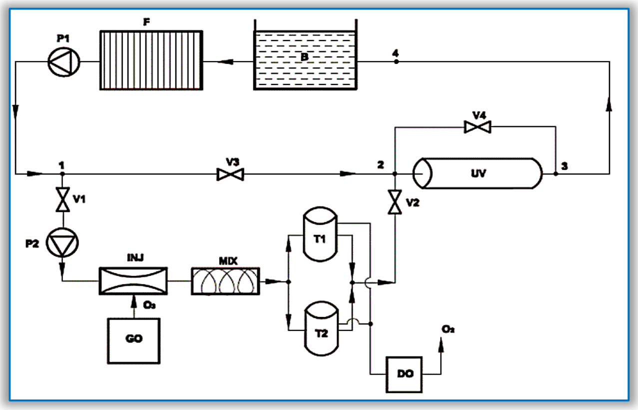

Figure 1 – Scheme of the ozone photolysis installation in a recirculation system under pressure

The numerical modeling of the system was customized for the modeling of the stages of ozone treatment and the decomposition of the advanced oxidation phase in the presence of UV radiation for different ratios of the relative intensity of the radiation for the system at the laboratory scale, according to the scheme in figure 1.

The study of this circuit system with advanced oxidation treatment allowed the development of a numerical model based on predictive analyzes of the evolution of ozone concentrations, evaluation of photolysis reactions depending on the concentration of the injected gaseous phase and the intensity of UV radiation. The model was used for the technological design at the laboratory scale and to establish the basic algorithms for the aqueous system. The UV photolytic transport model of ozone allows the interpretation of the numerical modeling of the ozone concentration variation in the volume area, according to figure 2 and depending on the intensity of UV radiation, according to figure 3.

The variation in the longitudinal plane of the O_3 concentration shows 2 minimum peaks, the first more pronounced due to the incipient loading of the flow, and a less pronounced one that marks the evolution of the colloidal system and the beginning of the change, i.e. of decomposition of the particles with a purifying role.

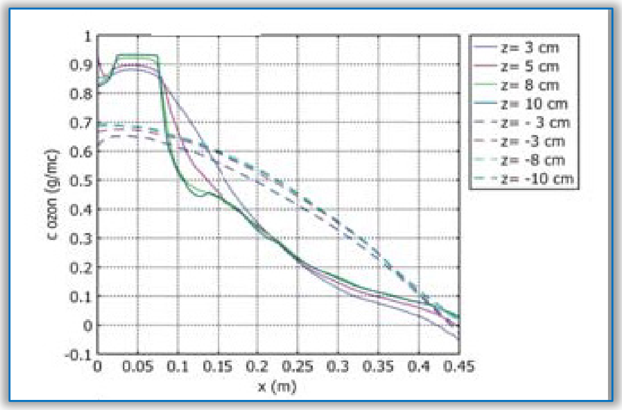

Figure 2 – Variation of O_3 concentration in volume (longitudinal flow)

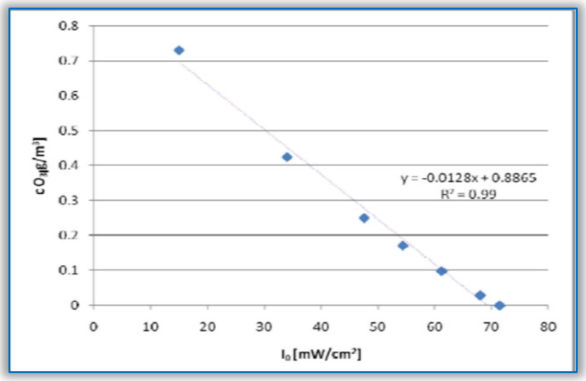

Figure 3 – Variation of the average concentration of O_3 depending on the intensity of UV irradiation

Also, the intensity of UV radiation shows a maximum in the zone of minimum intensity and decreases linearly with the intensification of UV radiation, due in particular to a more intense absorption correlated with the increased velocity of the fluid flow. The maxima of the O_3 concentration in the longitudinal plane coincide with the stagnation zones of the radial intensity distribution. The UV radiation intensity distribution model in the volume allows the analysis of different volumetric geometries with the possibility of expanding the model depending on new additional physico–chemical processes such as photocatalysis, sonolysis or electrochemical decomposition. The physico–chemical aspects involve both the approach of contact processes in different volume configurations as well as processes of oxidation by ozonization, advanced oxidation in photolysis system as well as their integration in different installations and complex systems. In addition to pathogens and chemicals that affect health, a secondary but important aspect is the parameters that influence the acceptability of water to consumers.

These parameters are typically related to the taste, smell, or appearance of drinking water and may lead consumers to reject drinking water and choose other water that is more aesthetically pleasing but potentially less safe. In addition, some of these parameters can cause operational problems, such as corrosion, clogged of filter media or degradation of distribution systems, which can indirectly impact public health by compromising the ability to maintain a safe drinking water supply. Typical parameters that can reduce acceptability are physical parameters (e.g., taste, turbidity, odour, colour) and some inorganic constituents and contaminants (e.g., iron, manganese, aluminium, sodium, sulphate, dissolved solids, pH, ammonia, chloramines, chlorides, chlorine, chlorobenzenes, copper, dissolved oxygen, hydrogen sulfide, zinc). In general, concentrations affecting acceptability are significantly lower than those of health concern. This type of parameters has no direct effect on health and is normally detected from an aesthetic point of view at concentrations lower than those of health concern (e.g., chlorobenzenes and some petroleum–derived hydrocarbons such as toluene, ethylbenzene or xylene). An exception is manganese, which is widely found in drinking water sources. Current standards include a health–based value for manganese of 0.4 mg/l. Above this concentration, the substance may cause acceptability problems in drinking water.

Water extracted from the environment (surface water) must therefore be continuously analyzed before being subjected to the appropriate treatment for drinking water, i.e. to satisfy a series of physico–chemical and organoleptic conditions that allow consumption without endangering health. By comparing the values of the quality indices, the specifics of different categories of water can be highlighted, as one can see in table 1, which leads to the conclusion that the technologies for obtaining drinking water must be adapted to the characteristics and specifics of the source used. The physical parameters include color, taste, odor, temperature, turbidity, solids, and electrical conductivity. On the other hand, chemical parameters include pH, acidity, alkalinity, chlorine, hardness, dissolved oxygen, and biological oxygen demand.

Table 1. Quality indicators for different types of water (*** "Virgil Madgearu" Technological Economic High School Iasi)

Indicator	Unit of measure	Determination method (STAS)	Distilled water	River water	Lake water	Underground water	Drinking water
Temperature	oC	6324/61	20	18	13.8	14	15
Turbidity	NTU	6323/61	0	190	3.5	0.7	4
Color	Mg/PtCo	7576/66	0	17	35	0	0
pH	–	6325/61	5.6	7.85	6.95	7.7	5.8
Fixed residue	mg/L	3683/53	15	325	124	235	2030
Suspensions	mg/L	3683/53	15	325	124	235	2030
Conductivity	µS		20	488	231	348	3700
Alkalinity (m)	m/L	6363/61	0.15	3.25	1.55	206	28.70
Total hardness	German degrees	3026/62	0	11.6	4.70	8.40	54.10
Temporal hardness	German degrees	3026/62	0	9.18	4.34	5.77	54.10
Permanent hardness	German degrees	3026/62	0	2.47	0.36	2.63	0
Dissolved O2	mg/L	6352/62	1.80	8.69	9.66	7.20	–
Oxidizability	mgKMnO$_4$/L	3002/61	1.58	48.3	28.7	5.69	8.80
CO_2	mg/L	3253/64	0	0	7.37	8.80	6.90
Ca^{2+}	mg/L	3662/62	0	56	21	39	48
Mg^{2+}	mg/L	(calculus)	0	17	8	28	7
Na^+, K^+	mg/L	(calculus)	6	44	12	99	30
Fe^{2+}	mg/L	8634/70	0	0	0	0.720	0
Fe total	mg/L	8631/70	0	0.5	0.6	0.835	0.031
Mn	mg/L	3264/62	0	0.025	0.025	0.10	0
Cl^-	mg/L	2049/52	4	46	8	11	37
SO_4^{2-}	mg/L	3069/68	0	60	19	6	50
CO_3^{2-}	mg/L	(calculus)	0	7	0	0	0
NH_4^+	mg/L	6328/61	0.019	0.296	0.469	6.0	0.051
NO_2^-	mg/L	3048/61	0.003	0.030	0.010	0.004	0
NO_3^-	mg/L	8900/71	0	4.761	0.332	0.455	2.082
N total mineral	mg/L	7312/65	0.016	1.314	0.443	5.125	0.510
PO_4^{3-}	mg/L	3265/61	0.090	4.468	0.010	0.250	0.034
P total	mg/L	1006/85	0.037	0.660	0.023	0.360	0.013
SiO_2	mg/L	3225/61	0.14	0.9	0.60	1.56	1.50
H_2S	mg/L	7510/66	0	0	0	3.20	0
Phenols	mg/L	7167/65	0.0017	0.007	0	0	0.0086

Where treatment is applied, turbidity provides an indication of the effectiveness of particle removal processes and/or the effectiveness of disinfection (as high turbidity may interfere with disinfection). Turbidity also provides an indication of rapid changes in the quality of the water source and the integrity of its distribution system.

Drinking water usually comes from underground or surface water, less often from other sources. Groundwater is an important source because, unlike surface water, groundwater is usually less or not at all polluted and can be potabilized with minimal measures, sometimes only with disinfection or without any processing. Surface waters differ according to many characteristics: flow and its variations (for flowing ones), temperature, concentration and nature of dissolved or suspended substances, biological and microbiological content, each mass of liquid water with its river bed and the living things in it being a distinct ecosystem. At the same time, fresh surface waters have many common characteristics: unlike underground waters, they are usually less mineralized, richer in biological elements, more influenced by other factors (natural and anthropogenic), more easily polluted, less stable in characteristics but also show capacities to self–maintain their quality.

Water purification and treatment systems are known and very varied. These devices help to remove contaminants that affect the taste, smell, color or quality of water; microbes can be removed including parasites, as well as lead, radon, nitrates, pesticides, radium, arsenic, etc. The granular activated carbon filter can successfully remove free chlorine from water, as well as insecticides, herbicides, trihalomethanes and volatile organics. Substances present in water, such as magnesium and calcium ions, lead to many problems because at high temperature they precipitate and deposit, so their removal becomes extremely difficult. Calcareous water is so harmful that it can cause household appliances to fail. In this case, mixtures of synthetic ion exchange resins (generally Na, K) are used that attract calcium and magnesium from the water, leaving it less hard. To remove sediments from the water content, special filters are used that prevent the passage of sand, rust and silt. Also, the amount of nitrites in the environment, which is increasing due to the intensive use of nitrogen fertilizers in agriculture, of nitrogen waste from animal farms, wastewater treatment, can be removed with resin–based denitrification equipment, too.

Another cause of surface water alteration is algae toxins. The accumulation of the toxin occurs as a result of the appearance in very large numbers of blue–green algae (namely, cyanobacteria) in the surface water bodies used for water supply. Some species of cyanobacteria contain toxins with a harmful effect on human health (e.g., microcystins) and these toxins can be released into drinking water when algal cells are damaged as a result of climatic conditions. There are a number of toxins that have been identified but can be difficult to analyze at low concentrations in water.

Microbial indicators such as coliform bacteria and heterotrophic plate count (HPC) are also indicators for drinking water quality. Coliforms include a wide range of bacteria traditionally defined by their ability to produce acid from lactose or demonstrate the presence of the enzyme ß–galactosidase on laboratory media at 35–40°C. Coliform bacteria occur in both wastewater and natural water.

The group of coliform bacteria includes organisms that can survive and grow in water systems and plumbing. Coliform bacteria can be used to assess the cleanliness and integrity of distribution systems, as their presence can reveal growth and possible biofilm formation or contamination by ingress of foreign material, including soil or plant material.

Their presence in treated water samples may indicate the need to further investigate the cause of the contamination, rather than having any significance as a violation of a specified compliance numerical value. Total coliforms are of limited value in the standard, but can still be a useful operational indicator. If the drinking water supply is not disinfected, coliform bacteria can be detected regularly.

The heterotrophic plate count (HPC colonies) identifies a wide range of heterotrophic microorganisms, including bacteria and fungi, based on the ability of the microorganisms to grow on the specific medium and at a defined temperature during the time used for measurement. HPCs have no value as an indicator of the presence of contaminants or pathogens, but can be useful, and are better than total coliforms, for operational monitoring of the effectiveness of treatment processes (including disinfection) and the integrity of distribution systems.

Table 2. Basic indicators for drinking water quality (*** "Virgil Madgearu" Technological Economic High School Iasi)

Determined indicator	Unit of measure	Determination standard
Color	PtCo grade	SR ISO 7887/1997
Odor	–	STAS 6324/61
Turbidity	NTU	SR EN ISO 7027
Temperature	°C	STAS 6324/61
pH	pH	SR EN ISO 10523/1997
Dissolved oxygen	mg O_2/L	SR EN 25814 ISO 5814/1999
Determination of biochemical oxygen consumption BOC5	mg O_2/L	EN 1889–1/2003
Chemical oxygen consumption CCOCr	mg O_2/L	SR ISO 6060/1996
Ammonium NH4	mg N/L	SR ISO 7150–1/2001
Nitrates	mg N/L	SR EN 26777 C91/2006
Nitrogenous	mg N/L	SR ISO 7890–1/ 1998
Suspensions	mg /L	SR EN 872/ 2005
Conductivity	siemens	SR EN 2788 ISO 7888/1997
Chlorides	mg /L	SR ISO 9297/2001
Alkalinity	m/L	SR EN ISO 9963–1/2002
Detergents	mg /L	SR EN 903/2003

HPC results can be highly variable and actual numerical counting is limited, but the range of counts from regular sampling at specific locations within the distribution system using the same analytical method can be useful.

Changes of one order of magnitude from a normal expected range are indicative of a scaling or distribution system problem that requires investigation. It is obvious that such surface water does not meet the conditions stipulated by the rules in force for drinking water. As such, the ideal solution in these cases is a decentralized water purification equipment, installed directly on site. The role of this decentralized system is to decontaminate, purify and make water potable. This type of treatment system is used to restore water quality to the highest standards according to table 2, ensuring water safety from a bacteriological point of view, as required for water from the Danube. In this sense, an advanced purification system for water from the Danube was developed and implemented in partnership with Toma Treatment Group. The dynamic work with profound cultural–artistic significance called "Water collector" is part of the Ivan Patzaichin Memorial Ensemble (IPME). This work is located on the seafront in Tulcea, having a double role – as a source of drinking water for the general public, but also as a tourist attraction, offering a wonderful view, a gathering place, the place of departure (by kayak, canoe) to the wonderful Delta of the Danube.

The "Water collector" fountain promotes the nature and traditions of the Delta, contributing at the same time to the development of the region where it is located, serving as drinking water and as an entertainment point for locals and tourists.

The advanced water purification system is an assembly of two components. The first component is the device for receiving and storing water from the Danube. The "Water collector" has 24 radially arranged arms equipped with metal buckets enamelled in Lipovenesc blue, located on the circumference of the wheel. During rotation, these buckets take water from the Danube and spill it into a stainless steel basin located on the axis of the wheel, inside it, as one can see in figures 4, 5 and 6.

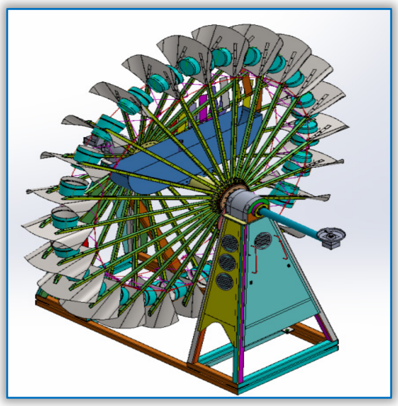

Figure 4 – "Water collector" device provided with a basin for water storage

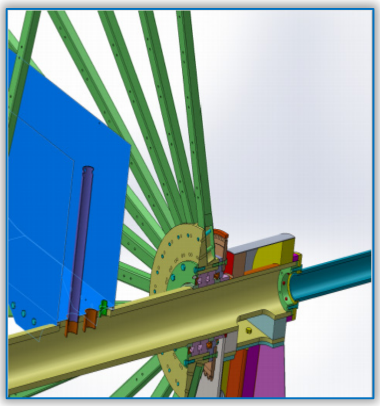

Figure 5 – 3D section of the wheel axle on which the water basin is fixed

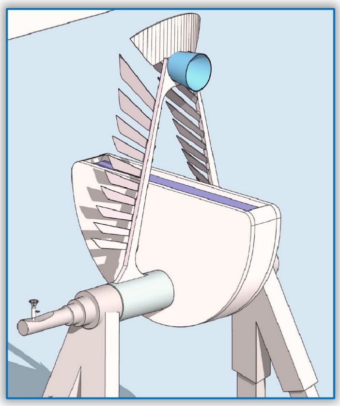

Figure 6 – Boom with 20 wings, a bucket, a shovel, sump, double shaft and public tap

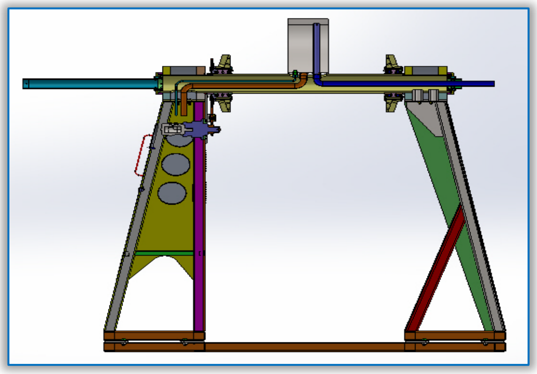

Figure 7 – Water suction pipe from the Danube, located in the wheel axle

Figure 8 – The assembly of the 2 devices for taking over and treating water from the Danube through filtration

On both sides of the kinetic structure, eddies are formed in a spiral from hundreds of vanes in the form of scales, a pragmatic solution for shading the water basin but also an aesthetic one. Part of the accumulated water is taken over by the water filtration and purification equipment, and the rest is evacuated through the "overflow" of the basin into a pipe located in the wheel axle, and from here it is discharged into the Danube through a waterfall located at the end of the wheel axle. Figure 7 shows the image of the water suction pipe from the basin for purification. The second component of the assembly shown in figure 8 is the water filtration and purification equipment. The advanced filtration and purification system is a state–of–the–art technology with a filtration fineness of 0.001µ and high treatment capacity, ideal for waters with very high bacteriological loads and various pollutants. The filterability system consists of 3 filters of different porosities, as one can see in the diagram in figure 9.

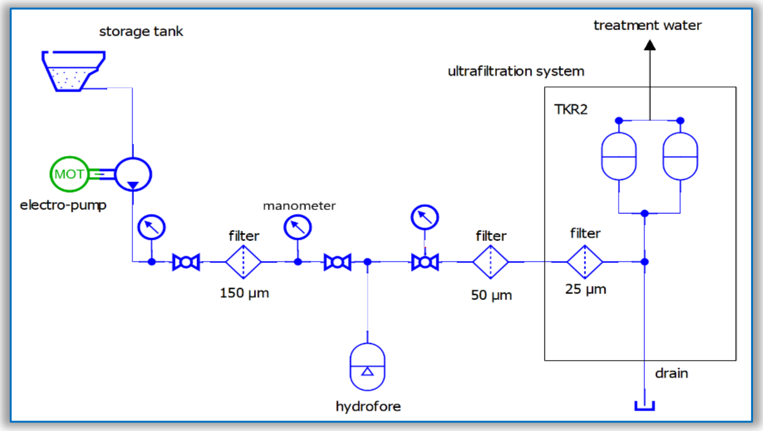

Figure 9 – Scheme of the advanced treatment system by multiple filtration of water from the Danube

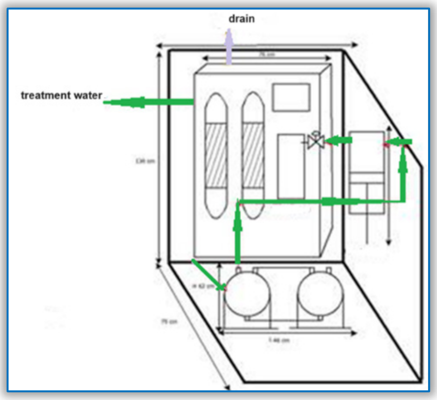

Figure 10 – The water circuit through the block system of water treatment by multiple filtration and ultrafiltration

This filtering system consists of 3 types of filters, namely, a Big Blue sediment filter with 150 µ, a NW 32 sediment filter of 50 µ, and a 25 µ sediment filter attached to the TKR2 type ultrafiltration system capable of retaining turbidity, bacteria, algae and viruses from the water. This system ensures drinking water (without bacteria, impurities and toxic substances) for the population of the area. The ultrafiltration system has 2 cartridges that self–clean every hour in countercurrent for 1 minute on each membrane, having therefore a regeneration time of 2 minutes. The water purification system is a "block system", as one can see in figure 10.

The "block system" is provided with Gardena 3000/4 hydrophore, which ensures a pressure of 2.2 bar for the proper functioning of the Danube water treatment filters.

3. CONCLUSIONS

The water purification system brings together both technical and artistic aspects to promote the Romanian cultural and natural heritage. In addition to scientific knowledge, the work conveys a note of passion and understanding of what water represents for the people of the Danube Delta. In response to this challenge, the National Institute of Research & Development for Optoelectronics INOE 2000 – Subsidiary, Hydraulics and Pneumatics Research Institute in collaboration with INMA and TTG (Toma Treatment Group) has created a set of 2 systems, one for taking over and supplying water to the population, and the other for making water from the Danube potable. The ensemble of two water treatment systems includes an advanced system for purifying water from the Danube that has a state–of–the–art technology, with a filtration fineness of 0.001µ.

Applying this water purification strategy, the authors of the work offer safe water to the population of the area, for tourists, visitors and locals who can access it from the Ivan Patzaichin seafront in Tulcea. This new techno–art type concept of Danube water purification contributes to the development of Romanian ecotourism. Adopting the vision of balance between ecotechnology and the cultural–artistic aspect belongs to the Danube Delta ecosystem.

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