Development of circuit solutions for a wind turbine on the basis of integrated membrane technologies for steam-gas thermal power plants

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Abstract. Currently, one of the most promising and effective ways to ensure the necessary quality indicators of desalinated water is the use of devices based on membrane separation technology. At the same time, of great interest are the schemes of water treatment plant, composed only of membrane modules of various purposes: ultrafiltration, reverse osmosis, electrodeionization. The advantages of membrane technology are due to low reagent consumption, easy operation, compact equipment and small amount of highly mineralized wastewater. The increased attractiveness of membrane technologies (especially in recent years) is due to the increase in the prices of reagents, ionites, primary water and also to the tightening of the standards for saline effluent. Thus, the aim of this work is to develop scientific and technical approaches to the creation of water treatment plant on the basis of modern membrane technologies for steam-gas thermal power plant and to develop approaches to design, specialized water treatment plant for humidifying dry air-cooling fan cooling cooling systems.

1. Introduction

In any country, energy is one of the basic sectors of the economy. The growth rate of other sectors of the economy depends on its condition and level of development. Energy creates prerequisites for the application of new technologies, provides a modern standard of living for the population. At the same time, the work of energy has a negative impact on the environment due to thermal pollution, emissions of fuel combustion products, noise and others.

In Uzbekistan, as elsewhere in the world, preference has been given in recent decades to the design of new power plants to units based on combined-cycle technology, which is one of the most promising areas for energy development. The use of combined-cycle technologies makes it possible to increase the economic efficiency and environmental performance of the energy system and reduce the construction time of power units. In this case, a steam-gas plant (SGP) heat recovery heat generator (HRSG) – the only power plants in the world whose efficiency, when generating electricity in condensation mode, reaches 55-60% [1, 2]. The operating costs of a modern steam-gas plant are half that of a dust-coal thermal power plant (TPP), and the unit capital costs are 2-2.5 times lower. The construction time of steam-gas plants with SD is much (2-4 times) shorter than the construction time of other types of powerful thermal power plants (TPP) [1].

For our country, an additional incentive in the construction of steam-gas plants is that the basis of the Uzbek fuel and energy complex is natural gas. A new factor in favour of the choice of steam-gas plants as the main power generation technology is the highly developed shale gas extraction technology in recent years. However, the cost-effectiveness and environmental friendliness of shale gas technology remain an open question at present [1-3]. Another promising source of natural gas could be gas hydrates, with deposits in the world's oceans [4]. Trial development of the gas hydrate field started in Japan in 2012. The estimated gas reserves in gas hydrates exceed the total reserves of conventional and shale gas by 200 times.

Steam-gas plants can also work when used in gas turbine installation of heavy fuel oil, crude oil, by-products of oil refining. According to Russian scientists, one of the promising trends in the development of energy technologies is the development of steam gas plants with coal gasification technology [5]. Thus, despite the controversy over the way gas fuels are produced, many studies indicate that the development of steam-gas technologies [1, 2, 5] is very promising.

In the preparation of additive water for the vapour cycle, the TPP uses various methods: chemical, membrane, thermal

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or a combination thereof. The following are the most frequently used technologies of water purification, their advantages and disadvantages are considered.

2. Methods

Reverse osmosis is one of the most commonly used methods of membrane separation [6]. This technology is based on the reversibility of the process of natural (direct) osmosis - spontaneous transition of the solvent through a semipermeable membrane into a solution. To process water using reverse osmosis technology, it is necessary to create an excess pressure (greater than osmotic) to cause water molecules to diffuse through a semipermeable membrane in a direction opposite to the natural (straight) osmosis [2, 7]. The process of desalination using reverse osmosis technology is well established in terms of its organization, hardware design and automation.

The main advantages of this method include: the compactness of the plants; the environmental friendliness of the process (due to the possibility of releasing the concentrate, the reverse osmotic desalination plant (reverse osmotic desalination unit) with salt retention up to maximum permissible concentration and no permanent highly mineralized effluents); no need for highly concentrated acids and alkalis; high degree of desalination (obtained permeate contains 1-2% of base salts).

The main disadvantages of this method: the need to desalinate permeate; high power consumption; high quality requirements for the water supplied to the reverse osmosis plant, which is difficult to provide on the «traditional» pre-treatment using clarifiers [2, 8].

The last indicator from table 1 - total organic carbon - is relatively new for Uzbekistan. Until recently, the question of measuring the organic content in the additive water due to the lack of regulation of this indicator did not arise, but foreign experience shows that the reduction and maintenance of organic compounds increases the reliability of power plant equipment.

Table 1. Values of additive water quality standards for boiler recharge

Indicator	Natural circulation drum boilers 14 MPa	Direct flow boilers	HRSG
total hardness, $\frac{mcg-eq}{dm^3}$	1,1	0,21	Absence
Silic acid content, $\frac{mcg}{dm^3}$	105	22	21
Sodium compound content, $\frac{mcg}{dm^3}$	78	16	9
Specific electrical conductivity, $\frac{mcm}{cm}$	2,1	0,55	0,21
Total organic carbon, $\frac{mcg}{dm^3}$	is not normalized	is not normalized	290

In order to obtain desalinated water of the required quality (table. 1) at a water treatment plant based on «traditional» technology, for most water sources in accordance with Uzbek regulatory and technical documentation, it is necessary to apply a water treatment scheme, pictured. 1. Recommendations for the scheme are described in detail VNTP81 (ВНТП 81) [9,10,11].

The main part of water treatment plants operating in Uzbekistan were built in the 20th century according to this «traditional» or «classical» scheme, including lime and coagulation clarifier, or only with coagulation, mechanical filters with appropriate loading, one or two stages of desalination. Such a scheme is considered «traditional» for preparation of water to compensate for losses of steam and condensate at power units with drum boilers. On blocks with direct-flow boilers in the «tail» water treatment plant also put mixed-action filters. One of the reasons for the spread of this scheme is the possibility of its application for the purification of water of various quality composition (by salt and weighted substances).

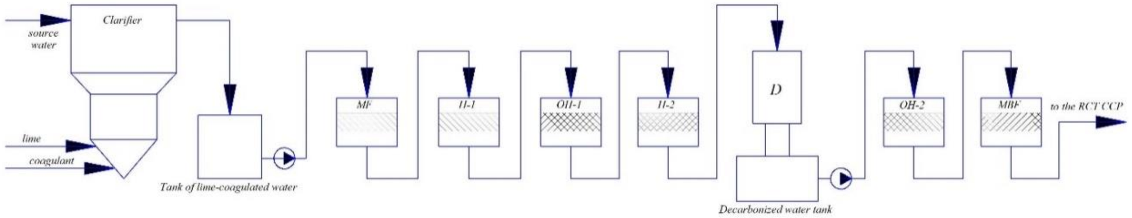

Fig. 1. «Traditional» preparation scheme for deeply desalinated water: MF – mechanical filter, H-1 and H-2 – H- cationic first stage filters, OH-1 and OH-2– OH-anionic first stage filters, D – decarbonizer, MBF – mixed-action filter, RCT – tank of spare condensate

Although it is possible to optimize the operation of this scheme in order to reduce the consumption of reagents [9, 12], today it is obsolete and does not meet modern environmental and safety requirements. In addition, it was designed to recharge drum and direct-flow boilers with high additive water consumption, and this circumstance also does not support the use of this scheme to obtain deeply desalinated water to feed boilers-steam gas utilities.

One of the first technological solutions to introduce membrane technologies into the «traditional» desalination scheme can be called replacement H-OH- ionic first-stage filters for reverse osmosis installation (Fig. 2). The introduction of reverse osmosis technology has made it possible to reduce tenfold the amount of sulphuric acid and caustic acid filters used in TPP for regeneration. The main load on desalination falls on the first stage of filters [13-16].

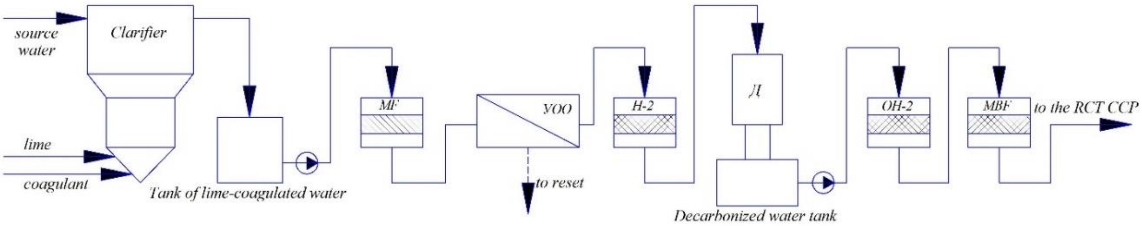

Fig. 2. The first stage of the introduction of membrane technologies into the «traditional» water treatment unit scheme: the installation of reverse osmotic desalination (reverse osmotic desalination plants -YOO)

Coagulation does not allow all the benefits of reverse osmosis to be fully exploited due to some drawbacks. The experience of operation of the reverse osmotic desolation plant with «classical» pre-treatment at the Tashkent TPP [20] showed that with high $pH = 9{,}8$ Refractory water supplied to the reverse osmosis plant increases permeate specific electrical conductivity (compared to the work at $pH = 8{,}1$ electrical conductivity higher 2 times, and at $pH > 9{,}8$ it can increase by 5 times).

The second disadvantage: when using the «classical» scheme of pre-treatment (and the condition of its smooth operation), the value of the colloidal index at best manages to maintain within SDI =4-5. In the table 2 the values of permissible specific demountability for reverse osmosis membranes are given depending on the value of colloid index (Silt Density Index -SDI) (according to membrane manufacturers) [10, 12].

Table 2. Specific fit $\left(\frac{litr}{m^2 \cdot hour}\right)$ for reverse osmosis membranes depending on the value of the colloid index of the SDI of the source water

Manufacturer	SDI<1	SDI <3	SDI <5
Dow chemicals (Filmtech)	36	27	20
Hydranautics	37	24	17

As follows from the Table 2, reduction of the colloidal index allows to increase the specific removal of permeate by 1.5-2 times. This, in turn, makes reverse osmotic desolation plants more compact.

Thus, having comprehensively studied the experience of the application of membrane technologies in the energy sector, taking into account the advantages and disadvantages of various water treatment technologies, and their interrelation, the author concludes that the creation of a water treatment plant consisting only of plants, based on membrane separation technology - ultrafiltration, reverse osmosis, electrodeionization (i.e. application of the concept of integrated membrane technology) - Most appropriate in the case of membrane technologies for water treatment of newly built steam-gas thermal power plants.

Results. Once the water treatment methods have been determined, the design of a water treatment plant based on integrated membrane technologies will immediately raise the question of the principle of interconnection of different basic units (modules or units) among themselves and with other elements of the scheme. To solve this problem, the author proposes to apply for integrated membrane technology (integrated membrane technology) the principle of collector-chain circuit (Figure 3).

The initial water is cleaned at a disk filtration plant, where suspended substances larger than 200 um are retained. After disc filters, a coagulant is added to the water if necessary, after which it is kept in coagulated water tanks for a relatively short time, and then it is fed to the ultrafiltration plant. The purified water after the ultrafiltration installation is collected in tanks of clarified water, from which pumping pumps are supplied to the installation of reverse osmosis of the first stage. To prevent the formation of mineral deposits on the membranes before the installation of reverse osmotic desolation,1 anti-scalant solution dosing is provided, and to prevent the penetration of free chlorine membrane elements, sodium bisulfite solution dosing is provided.

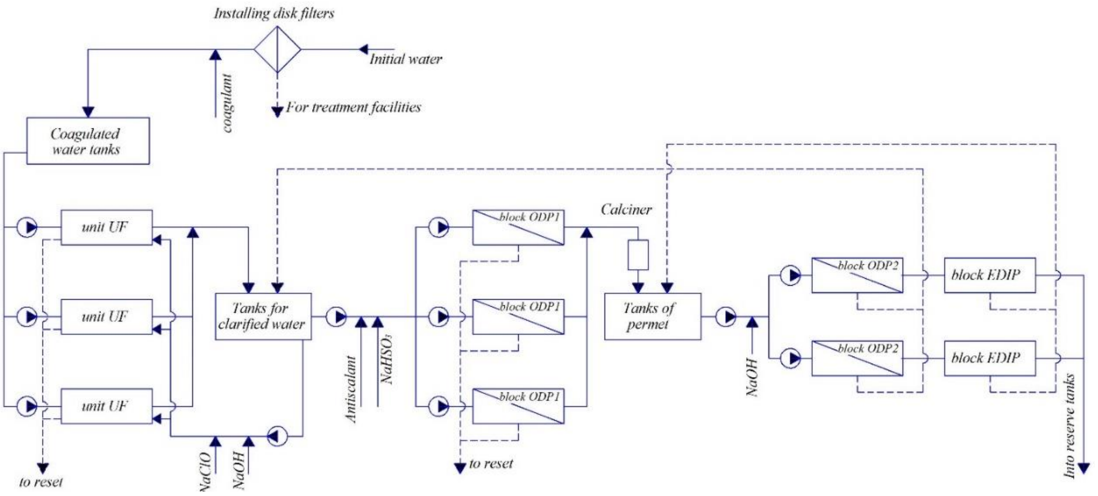

Fig. 3. Schematic diagram of desalted water treatment plant based on integrated membrane technology

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The permeate obtained for reverse osmosis desolutions1 is decarbonized and collected in permeate tanks. Reverse osmotic desalination plant concentrate $800 - 900\ \frac{mg}{dm^3}$ is dumped into the sewer. The basic modules of the first stage ultrafiltration and reverse osmosis plants are combined according to the collector principle, or the so-called «comb». During the operation of the «comb» water through the input collector is distributed on modules of one group (installation of ultrafiltration and installation of reverse osmotic decolonization 1), and then on the output collector collector collects in one stream. This approach is related to the fact that the installation of ultrafiltration and the installation of reverse osmotic desalination works in the most stressful conditions and for them the ability to quickly switch between modules (for repair or diagnosis of faults) is important.

From the permeate tanks water is supplied to the installation of reverse osmosis of the second stage and consecutively to the installation of electrodeionization, where deep desalination of water occurs. For chemical decarbonization, the membrane unit of the reverse osmotic desalination unit provides for alkaline to be metered into the water flow to the reverse osmotic desalination plants. The reverse osmotic desalination plant concentrate is returned to the tanks of clarified water, and the EDIU concentrate is returned to the tanks of permeate. The deeply desalinated water obtained at the EDIU is then fed into the storage tanks.

The second stage reverse osmosis installation and the electrodeionization installation are connected by a «chain». When preparing water according to the scheme «chain» collectors («combs») are also available, but there are only two - at the entrance and exit of water from the unit of water treatment plant. Application for the last stages of connection cleaning on the principle of «chain» allows to save on installation of auxiliary equipment (intermediate tanks, pumps, additional fittings) and to reduce the length of inter-modular pipelines. This is especially important because the devices based on membrane technology (reverse osmosis, electrodeionization, electrodialysis, membrane degassing) are very sensitive to the contamination (microbiological contamination) of membranes. Application of the «chain» at the final stage of desalination allows to minimize the number of tanks in the scheme of water treatment plant, and to refuse the installation of intermediate tanks, which can serve as a source of microbiological pollution as a result of «stagnation» of water.

At the same time it is important to note that the whole «chain» is reserved in this way. The use of the chain for the installation of reverse osmotic desolutions and electrodeionization unit (EDIU) is justified by the fact that the source water for it is the permeate of the first stage reverse osmosis installation, which, as mentioned above, significantly increases the reliability of the circuit and allows you to reduce the number of redundant equipment.

For each processing step (ultrafiltration plant, reverse osmotic desolation plant, EDIU) requires the installation of its own chemical washing station, because the use of a single chemical-resistant system will lead to the contamination of the membranes of the subsequent stages by the products of washing previous ones.

Special attention should be paid to the problem of preservation of high quality of the deeply desalinated water in the storage tanks (Pic. 3 is not shown). Due to the small consumption of water to recharge the recovery boiler occurs «stagnation» of water in tanks, saturation of water with carbon dioxide, there is a risk of microbiological contamination. To solve this problem, it is necessary to use hydraulic closures on the overflowing tanks of desalinated water and to protect the respiratory valves, for example, by installing special filters with rubberized lime (the use of protective films on the surface of the water mirror is undesirable, as these films can cause microbiological contamination of desalinated water).

The described principle of the design of water treatment plants according to the collector-chain scheme has already been applied in practice and has been successfully used for the creation of the water treatment plant of the Tashkent TPP [20, 21]. The economic rationale for the above approach to the design of water treatment plants based on integrated membrane plants is illustrated in figure. 4, which presents the nature of dependence of specific capital costs for the construction of a water treatment plant on the required productivity.

3. Results

The conducted calculation study showed that with the increase in the productivity of the water treatment plant, unit capital costs are reduced. This is partly due to the fact that the cost of auxiliary equipment (tanks, metering installation, pipe, fittings) is not very dependent on the performance of desalted water. While ensuring the requirements of reliability and technological stability of the water treatment scheme, it is important to reserve the main equipment of the water treatment plant. For the classical scheme based on ion exchange technology, the principle of reservation applies to each stage of the filter:

$N_{\text{project}} = N_{\text{expluatation}} + 2$, in N_{project} – filter count, $N_{\text{expluatation}}$ – number of filters in operation, 2 - reserve (one filter in regeneration and one in reserve (repair)). At the same time, it is recommended to select the equipment of maximum unit capacity. The application of this reservation method to membrane plants without any revision cannot be said to be correct, as this may result in a significantly more complex and expensive installation.

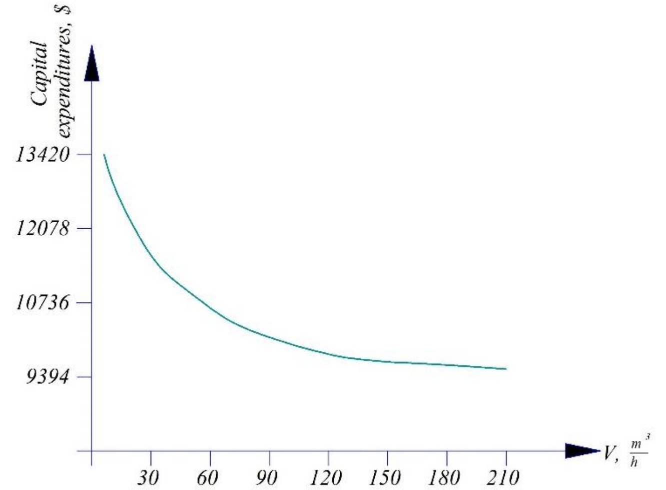

Fig. 4. Dependence of specific capital costs for the construction of a water treatment plant based on integrated membrane technology on the required productivity

In order to ensure the necessary level of stability of the water treatment plant on the basis of integrated membrane technologies taking into account the interconnection of the equipment reserve, the author proposes the following approach to the selection of the amount of equipment to be reserved. In the first stage it is necessary to define the main performance indicators of the water treatment plant:

1. Minimum average daily productivity (to ensure a sustainable operation of the water treatment plant at minimum loads).
2. Nominal capacity

3. Peak (maximum) performance.

When justifying the choice of integrated membrane technologies for a water treatment plant to recharge the SD in terms of economic efficiency, attention should be paid to: that there is quite a lot of work in the literature comparing the cost-effectiveness of desalinated water treatment schemes [1, 2, 5]. In this case, as a rule, the most effective is the one that is considered in the concrete work. On figure. An example of a graph of the operating costs of a desalination plant is given [20].

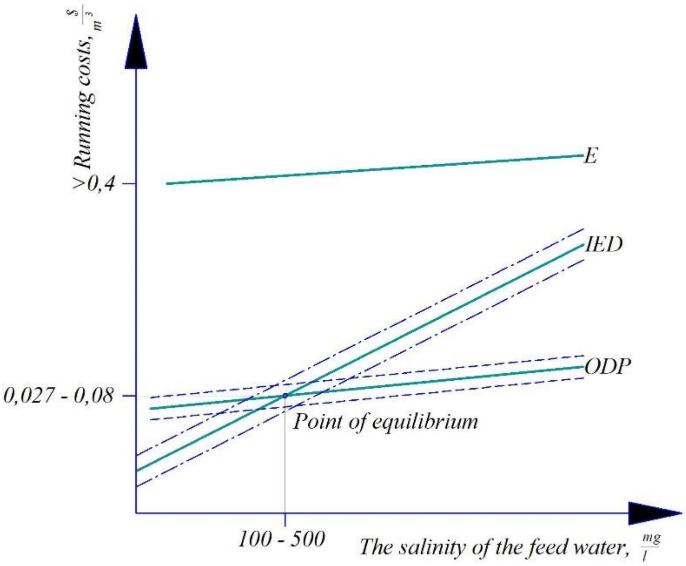

Fig. 5. Comparison of the dependence of the cost of water purification by ion-exchange desalination (ID), reverse osmosis (RO), and evaporation (E) on its salinity (performance is equal)

As you can see from the graph, the equilibrium point is in the area where most of the water sources are located by salt content, so it is rather difficult to assess the cost-effectiveness of ion exchange and reverse osmosis without taking into account additional factors [18, 19]. In addition, this relationship describes the behavior of the graph in the area of high water treatment plant productivity.

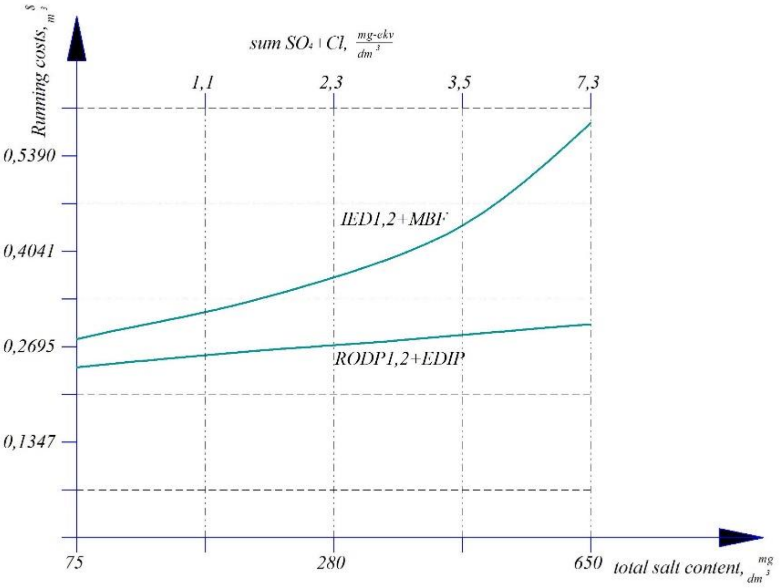

Fig. 6. Table showing the dependency of saline treatment on desalination maintenance costs for the 3-step desalination scheme (IEDI1,2+MBF) and fully membrane desalination schemes (reverse osmosis desalination plants 1,2+EDIP) at the accepted capacity of the deep salt water treatment plant 30 $\frac{m}{hour}$

The calculation carried out by the author on the basis of the methodology set out in [21] shows that for water treatment plants of steam-gas thermal power plants, where the recharge of desalinated water rarely exceeds $30\ \frac{m^3}{hour}$, The schedule of the operating costs of the desalination plant will be as shown in picture 1. 6.

The nature of the dependencies is related to the fact that, for the technology, ion-exchange desalination, the number of reagents for regeneration (which contribute significantly to operating costs) is highly dependent on the salt water content of the source water. For membrane technology, there is no such strong dependence. With increased salt retention, the osmotic pressure increases, so it is necessary to raise the working pressure of the pump, which leads to higher energy consumption. There is also an increase in the dose of antiscalant and the frequency of membrane washing. However, compared to the required increase in reagent costs in ion exchange technology for membrane plants, the increase in operating costs is much less.

4. Conclusion

Thus, for a low-productivity water treatment plant, the application of membrane technology is efficient in terms of operating costs across the entire range of the quality of the source water. However, it should be noted that depending on the specific area of construction of a water treatment plant, local electricity prices, ionic, membrane, reagent and their delivery ion exchange technologies may still be preferable to membrane at low salt treatment of source water (less than $100\ \frac{mg}{l}$). In addition, at low cost, ion-exchange technologies can be advantageous in water treatment schemes that have already been cleaned (e.g., tap water), because such water has a higher cost, Therefore, there is a need to keep the water treatment plant's own needs to a minimum.

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