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Desalination 126 (1999) 281–285

DESALINATION

www.elsevier.com/locate/desal

Desalination plant with absorption heat pump for power station

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Abstract

It is known that power stations use seawater for condensation of steam from turbines. In this case the temperature of seawater in condensers increases by 10–20°C. A large quantity of heat is lost in condensers. The energy can be used for desalination of seawater in a plant, which includes a low temperature vacuum desalting installation and a heat pump. In the heat pump the temperature of seawater increases by 60–80°C and is then transported to a vacuum desalting installation. Desalting water is then utilized by the power station. This scheme of a desalination plant is widely known and has practical application. It is difficult to combine a desalting installation and a compression heat pump in one technical system. It is interesting to consider operation of a desalination plant with an absorption heat pump. This heat pump does not use much electric power for transformation of heat, but it uses steam generated by turbines of the power station. In that it does not have a compression station is the main advantage of the absorption heat pump. There are simple schemes for combination of an absorption heat pump and a desalting installation to heat (steam) source of the power station. Thermodynamic and economic data of a combined desalination plant have been calculated. The specific expenditure of heat at desalination plants with absorption heat pumps is 2–2.5 fold lower than that of other power systems. Thus, the combined desalination plants with absorption heat pumps are of great interest for designers of desalination seawater systems at power stations.

Keywords: Heat pumps; Desalination plant; Seawater; Power station.

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1. Introduction

The main sources of electric and heat energy are thermal and atomic power stations with steam turbines. All power stations consume large amounts of fresh water and the requirements to the quality of water are very high. One of the most commonly used methods of supplying power stations with fresh water is their equipping with all sorts of desalination plants that process seawater or mineral water from natural sources into a distillate. In most cases power stations are equipped with desalination plants (thin film, multistage flash plants and

Presented at the Conference on Desalination and the Environment, Las Palmas, Gran Canaria, November 9–12, 1999, European Desalination Society and the International Water Services Association.

PII: S0011-9164(99)00183-6

other). This is accounted for by the possibility to use thermal power from steam-exhaust pipes of the turbines for heating seawater for desalination. In this case the power consumption for the production of desalinated water is not very high and it can be assigned to the power station own needs and included in the price of the product. However, presently even at the most advanced thermal desalination plants, the consumption of thermal power with a high temperature potential for distillate production amounts to 150–200 MJ/m^3 [1].

It is known that thermal and atomic power stations operating on the steam–water thermodynamic cycle cannot utilize all energy of the fuel used. At every power station, it is necessary to provide for the condensation of steam from turbines, which results in considerable losses of thermal power and heat pollution of the environment. Unfortunately, the temperature potential of the rejected heat flow is very low. The temperature of the seawater used for cooling the turbine condensers raises only by 10–20°C (Fig. 1). With the low temperature potential the expenditure of the cooling seawater for turbine condensers is very high and considerably exceeds the needs of any power station in fresh water. This does not allow efficient use of the thermal power obtained by the seawater when cooling turbine condensers in desalination plants or other recovery installations without additional heating. Thus, in the technological process of electric power production at power stations about 30–40% of consumed fuel is not recovered and is discharged in the environment.

At the same time the quest to decrease the consumption of the primary energy (fuel consumption) without decreasing or even increasing the production of electric power, heat, desalinated water or any other power-intensive product through most efficient method of its conversion is the main tendency of the modern energy saving policy in all developed countries throughout the world. The impossibility to lower the expenditures of the primary energy

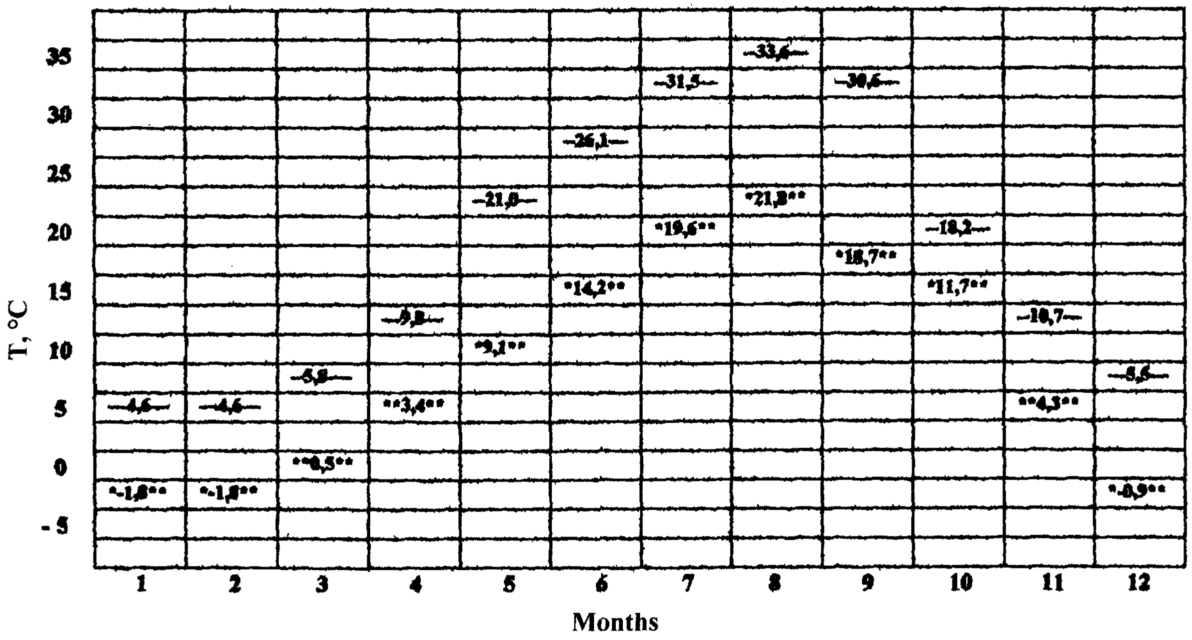

Fig. 1. Seasonal variations in temperature of cooling seawater before and after condensers at the Vladivostok power station (1998).

becomes the main disadvantage of the existing power technologies, which are now commonly accepted by manufacturers, but already do not suit the society. Rapid growth of power consumption involves not only the exhaustion of natural resources. The problem of heat discharge and the biosphere preservation from heat pollution is becoming more pressing.

2. Discussion

One of the most efficient trends in the power engineering development associated with fuel saving and environmental protection is the large-scale use of heat pumps. Heat pumps convert the natural heat of the low temperature potential as well as industrial heat waste to heat with a higher temperature potential suitable, in particular, for seawater desalination. In the past few years the use of heat pumps as alternative sources of energy for many technological processes is rapidly growing. IEC has established a technical committee for research of development prospects and raising the efficiency of heat pumps application. The committee report shows that by the year 2000 the total productivity of heat pumps will reach 100–150 MW [2].

Unfortunately, heat pumps are not yet widely used in seawater desalination. To a large extent this can be accounted for by a considerable difference between technological parameters of desalination plants and conventional heat pump installations, including both the capacity and the temperature difference of their operational processes. Among the most widely used types of heat pumps are compressor units where power is consumed by compressor drives. These units are not large power plants—in many cases their heat productivity does not exceed hundreds of kW. Such heat pumps operate as local heating devices and provide heating of various media in heat-exchange units of low capacity.

It follows from the above that power stations are a powerful source of waste heat and at the

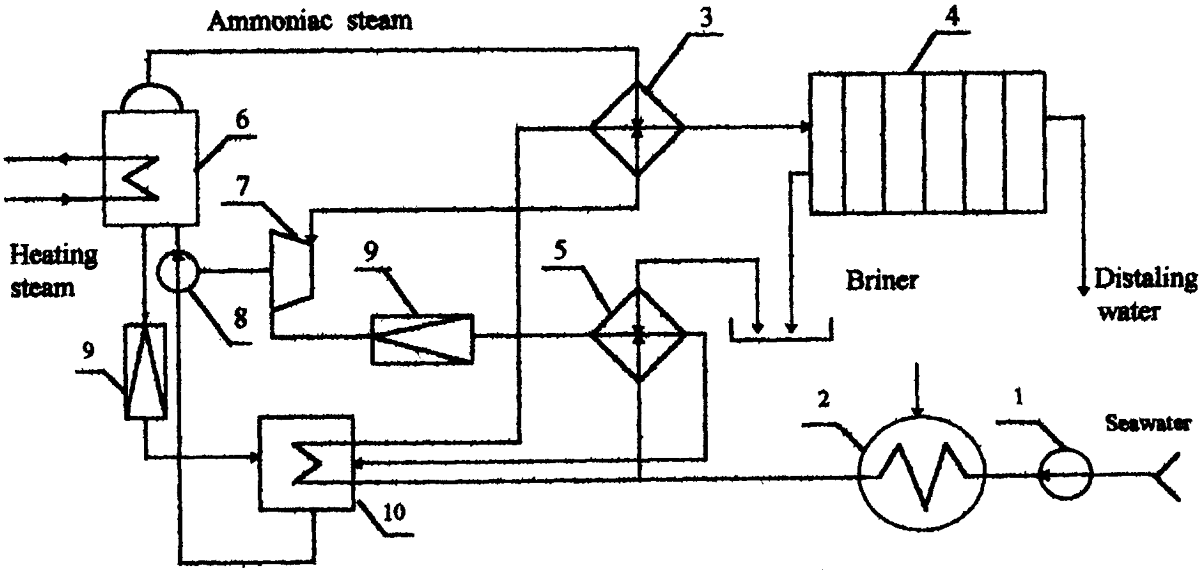

Fig. 2. The scheme of desalination plant with AHP. 1, circulator; 2, condenser; 3, heater; 4, desalting installation; 5, seawater cooler; 6, generator; 7, turbo-expander; 8, main pump; 9, pressure regulators; 10, mixer.

same time they frequently use a considerable amount of heat for distillate production at the desalination plants either for their own needs, or for outside users. Therefore we will look more closely at the prospects of heat pump application at power stations.

For power desalination technologies, absorption heat pumps could become most promising in terms of heat utilization. Absorption heat pumps (AHP) have no compressor unit, which is their main advantage. Therefore AHPs can be of unlimited capacity and they can use steam from exhaust pipes of turbines as a heating medium. Also they use a minimum amount of expensive electric power. The basic scheme of a combined plant with absorption heat pump for obtaining desalinated water at an electric power station is given in Fig. 2. The circulator 1 feeds the seawater from the intake to the condenser 2 of the turbine steam power installation of the power station. Then the cooling seawater flow is divided between two paths. The flow with lower rate is fed to the additional seawater heater 3 and then to the desalting installation 4. The main flow passes through the seawater cooler 5 and serves as a heat source for AHP. After the heater 3 the seawater can be heated up to 60–80°C and higher. This thermal potential is sufficient for seawater desalination in vacuum desalination installations (e.g., thin film of multistage flash) [3]. A cyclic process of water-ammonia mixture conversion takes place in AHP. Ammonia steams from the generator 6 are fed to the heater 3, behind which the turbo-expander 7 is located. The turbo-expander actuates the main pump 8. The flows of water-ammonia mixture and ammonia steams pass through the pressure regulators 9 to the mixer 10.

The advantage of this scheme consists in the absence of compression processes in the heat pump. AHP application allows seawater heating to rather high temperature. This is achieved by feeding the heating steam from the turbine exhausts pipes at a pressure of 0.15–0.2 MPa to the AHP steam generator. Up to 75% of the thermal potential of the cooling seawater after it passes through the condensers can be abstracted in the cooler. This considerably decreases the power station heat discharge. In summer when the seawater temperature rises to 20–25°C an additional amount of natural heat can be utilized in AHP. This allows setting the heat pump on the reverse, i.e. to carry out preliminary seawater cooling before it passes to condensers for raising the power station efficiency.

Total thermodynamic efficiency of the AHP power cycle for performing desalination process at the power station can be expressed as the heat utilization factor:

$$\varphi = \eta_T (Q_1 - Q_2)/Q_1$$

where Q_1 – heat expenditure in the form of heating steam fed to the AHP generator; Q_2 – useful heat abstracted from seawater for desalination; η_T – general factor of heat losses for the whole combined plant.

The value of the heat utilization factor depends first of all on working temperatures of all flows of the heat carriers passing through AHP units. The calculated values for the scheme under consideration at constant η_T are given in Fig. 3. It follows from the results obtained that within the working temperature range typical for vacuum desalination plants φ factor can reach 4–5.

Desalination plant productivity for the scheme under consideration depends on the power station waste heat capacity. As a first approximation, assume that the heat utilization

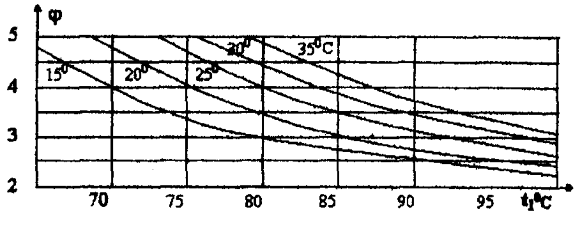

Fig. 3. Dependence of heat utilization factor on water temperature before desalting t_1 and cooling seawater t_2.

factor for AHP is 3–4. Then with the power station capacity of 600 MW waste heat power used by AHP can reach 400–500 MW. Power expenditures for steamed water desalination from the turbine exhaust pipes will reach 60–80 MW. This will make it possible to obtain 10,000–12,000 m^3/h of desalinated water, which by far exceeds the requirements of the power station of such capacity. The desalination plant specific power indices relating to heat expenditures will be in the range of 25–30 MJ/m^3, which suggests that the economic feasibility of desalination plants mounted at the power station in combination with AHP can substantially increase. The cost of desalinated water production at such plants approximates that of the drinking water (\$0.1–0.15 per m^3) [4].

Today wide experience in operation of low-temperature vacuum desalination plants with the production capacity of 10,000 m^3/h and over has been gained throughout the world. They are of modular structure, which allows configuration of desalination plants of any capacity. Working temperatures of such plants range from 60°C to 90°C, which agrees well with AHP temperature characteristics [5,6].

The basic units of absorption heat pumps are designed on the basis of standard power equipment. It is worthwhile, for example, to use power evaporators for thermal demineralization as ammonia steam generators. Besides, the scheme allows use of standard steam-to-water heat exchangers and pressure regulators for decreasing the pressure of water-ammonia mixture. Considerable difficulties arise in selecting basic heat exchangers for seawater cooling. This is connected with the necessity to transfer large amounts of heat at a low temperature head in these units (not more than 15–20°C). The reduction of size and specific quantity of metal per heat exchanger can be achieved only through the maximum increase of heat transfer coefficient. However, such heat exchangers are widely used in different technological processes, including those used at desalination plants.

3. Conclusions

- As fresh water requirements in all world countries are constantly growing, it is necessary to equip all coastal power stations with desalination plants so that they could provide for their own needs.
- The structure of the power station with the desalination plant must include the systems for heat utilization discharged from turbine condensers. These systems can work on the basis of the scheme of absorption heat pump.
- The use of desalination plants with AHP at power station allows not only utilization of waste heat, but also production of additional energy in the form of natural heat from seawater.
- Nowadays standard desalination and power equipment can be used for AHP application at power stations.
- Application of thermal vacuum desalination plants for AHP makes it possible to lower the cost of 1 ton of desalinated water production by 2–2.5 fold.

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