USE OF HIGH EFFICIENCY HEAT PUMP DESALTERS FOR WATER SUPPLY NEEDS

Igor M. Kalnin
Department of Refrigeration and Cryogenic
Moscow State University of Environmental Engineering
Russia, 105066, Moscow, Staraya Basmannaya st., 21/4
Tel/fax (495)267-0784, E-mail: kalnin@msuie.ru

Stanislav B. Pustovalov, Anatoly I. Savitsky
Department of Heat Pumps
Scientific & Industrial Firm «EKIP»
Russia, 111020, Moscow, Soldatskaya st., 3
Tel/fax (499)787-0267, E-mail: stanbp@mail.ru

Abstract

An effective method of desalination of salt water on the basis of heat pump desalters suggested. Perspective areas of use of heat pump desalters demonstrated.

KEYWORDS

Distillation, Heat Pump Desalter, Salt Water

1. INTRODUCTION

More fresh water is used by mankind and polluted in this process than regenerated and this disbalance is growing castrophically fast. UN experts predict that by 2025 about 5 billion of Earth inhabitants are going to experience the lack of fresh water for domestic and personal use [1]. Even for small countries the yearly average consumption of fresh water numbers in billions of cubic meters. This lack of fresh water can partly be compensated by desalting salt water, primarily the sea water, which constitutes 98% of total water reserves on Earth [1–3].

Desalting of sea water can by carried out by various methods such as electrodialysis, reverse osmosis, ion exchange, ion sorption on porous electrodes. However these methods are not widely implemented in practice which results in 96% of the total volume of desalted water derived in the world is produced by units altering the water aggregative state, that is by distillation. Heat consumption for producing 1 kg of freash water in one-stage distillation desalter is about 2400 kJ. Multi-stage distillation desalters allow radical lowering of heat consumption per 1 kg of fresh water produced by recuperating the heat of phase change to 250…300 kJ per 1 kg of fresh water which equals 70…80 kW·h/m^3 of fresh water with the number of stages of 8…10 [4]. Heat consumption in a four-stage distiller is 500…600 kJ per 1 kg of fresh water which equals about 130…160 kW·h/m^3 [5].

The suggested distillation method involves generation and recuperation of heat by implementing a reverse thermodynamical cycle (a heat pump cycle) with low-boiling working media which allows dramatically simplify the unit design and achieve lower values of specific energy consumption for fresh water production 20…30 kW·h/ m^3 [6].

2. HEAT PUMP DESALTER

2.1. Design and mechanism

The idea of implementing a heat pump into a distillation (desalting) unit was suggested in work [7]. However the suggested unit design featured low energy efficiency, complicated manufacturing process and a limited range of input parameters. The designed diagram of a heat pump-based salt water desalter (heat pump desalter - HPD) [8, 9] is depicted on Fig.1, a thermodynamical cycle of heat pumps is presented on Fig 2.

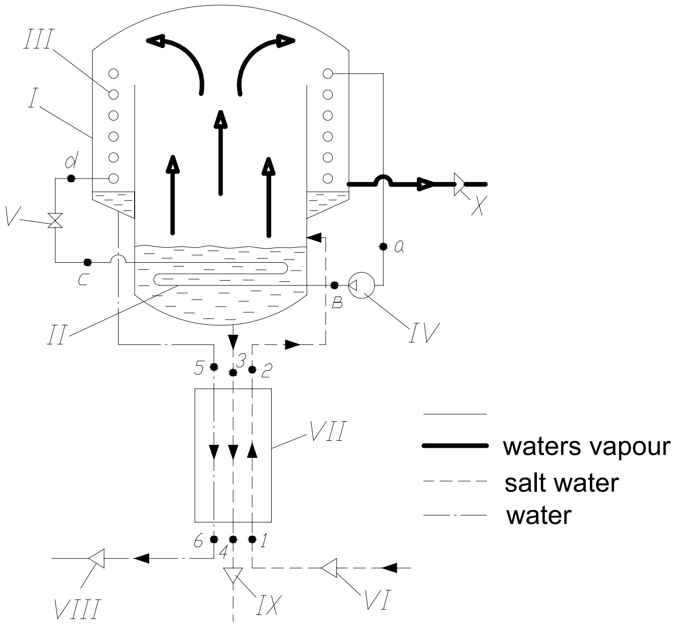

Fig. 1. Heat pump-based desalter unit diagram

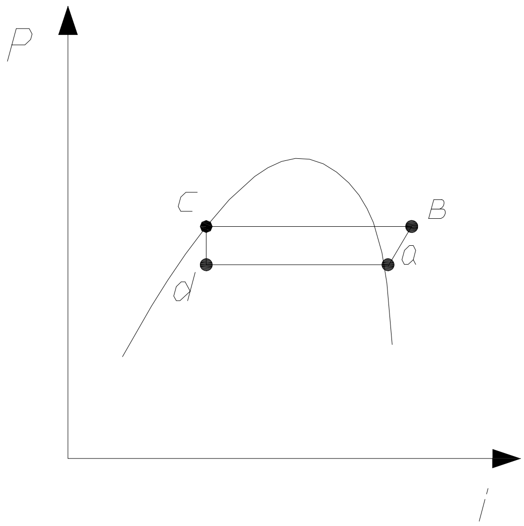

Fig. 2. A thermodynamical cycle of a heat pump in a desalter unit

A heat pump desalter (HPD) includes a pressurized vessel *I* with two heat exchange surfaces *II* and *III* located inside that form a close coolant circuit with compressor *IV* and throttle flap *V*. The coolant compressed in the compressor *IV* is condensed in the channels of heat exchange surface *II*. The salt (sea) water boils on the outer side of surface *II* drawing off the coolant condensation heat. The liquid coolant is thrttled passing through throttle flap V and the vapor-liquid mixture derived is sent to the chanels of heat exchange surface *III* with water steam being condensed on its outer side. The condensation heat is drawn off to the boiling coolant which is evaporized, sent to the compressor *IV*, compressed and then sent to the channels of heat exchange surface *II*. The salt water is sent by pump *VI* through a recuperative heat exchanger *VII* to the lower part of vessel *I*. The salt water passing the regenerative heat exchanger *VII* is heated by heat exchanging with flows of fresh and salt water coming out of vessel *I* pumped out by pumps *VIII* and *IX* respectfully. A vacuum pump *X* allows removing air dissolved in water from vessel *I*.

Obviously the work in the heat pump circuit has to provide the water vapor condensation heat transfer to a higher temperature level equalling the salt water boiling temperature.Since hydraulic resistance of water steam transportation between heat exchange surfaces may be reduced to a rather small value, the temperatures of water boiling and steam condensation may be considered practically equal in as a first approximation. Therefore the temperature difference limits the coolant circuit is operated within is determined in this respect only by the temperature drop required for heat transfer. At the same time the work in the heat pump circuit has to compensate the under-recuperation in heat exchanger *VII*.

2.2. Technical characteristics

With the use of HPD calculation method designed the principal technical parameters have been determined for the three unit classes:

- *Small HPD* – productivity 10…1000 kg/hr.
- *Medium HPD* – productivity 1000…10 000 kg/h.
- *Large HPD* – productivity 10 000 kg/h and more

Besides productivity, various class HPD differ by technical concept depending on the water supply object needs and the sources of water being desalted (distilled). Principal parameters of three HPD classes are shown in Table 1.

Table 1. Principal parameters of HPD

HPD class	Productivity, kg/h	Energy efficiency, kW·h/kg	Steel intensity, kg/kg	Compact-ness, m^3/kg	Compressor used	Compressor drive energy source*
Small	10…1000	0.028	1.5	0.05	Piston-type Spiral	Electricity Diesel Petrol Natural Gas-Diesel Natural Gas
Medium	1000…10 000	0.024	1.35	0.04	Screw-type Centrifugal	Electricity Diesel Natural Gas-Diesel Natural Gas
Large	10 000 and more	0.02	1.25	0.025	Centrifugal	Electricity Natural Gas

* With internal combustion engines used for HPD drive the combustion heat can be utilized enhancing the unit energy efficiency by around 10%

2.3. Working media

To implement the suggested desalting method the media with low working pressure can be founf perspective, such as freon R123 or hydrocarbons (normal butane and pentane) [3]. When using normal butane as working media the maximum pressure in the heat pump cycle would not exceed 18 bar even in case of salt water boiling at ~ 100°C. For pentane in this case the maximum pressure is even lower and is ~ 7 bar. But its use requires measures to be taken to prevent the possibility of wet strokes in the heat pump compressor.

3. AREAS OF IMPLEMENTATION

3.1. Small HPD

The main area of the use of these units is autonomous water supply of remote coast locations experiencing the lack of fresh water. Such locations may include residential buildings, military, naval or emergency bases, fishermen towns, etc. Besides such units can be installed on smaller sea vessels, etc.

Another possible area of implementation is producing high purity distilled water from tap water for food industry and medical purposes. The closest analogy of such units is VC Norland (USA) [10]. But these units’ energy efficiency significantly decreases with the decrease of productivity which is in our opinion caused by a more complicated design of steam compressor. Besides the variant of sea water desalting was not considered for these units.

3.2. Medium HPD

The main area of the use of these units is autonomous centralized water supply of coast locations experiencing the lack of fresh water. Such locations may include villages, hotels, military, naval and emergency bases, fishermen towns, etc. besides such units can be installed on Navy vessels, fishing boats, merchant ships, etc.

Another area of possible use of such units is producing high purity distilled water from tap water for soft drinks production. The closest analogy of such units is VC Norland (USA) [10]. These units’ energy efficiency is comparable to the suggested but the cost of such systems would be much lower accroding to our estimates which is in our opinion related to a more complicated design of steam compressor. Besides the variant of sea water desalting was not considered for these units.

3.3. Large HPD

Currently the method of multiple-effect evaporation is used in desalting systems of nuclear power stations [2], which has a low energy efficiency compared to the suggested HPD, as shown above. Besides the heat pump desalters' mass, size, cost and operating parameters appear to be more beneficial than those of a multiple-effect evaporation systems.

A scheme of incorporating heat pump desalters into an nuclear power station circuit is analogous to a scheme of multiple-effect evaporation system's incorporation.

A perspective area of HP use are the currently developed low capacity floating nuclear heat and power stations (FNHPS). The HPD featuring small size and mass parameters can be located in the coastal buildings system or on a floating unit. Also unlike the case of multiple-effect evaporation, the main energy type required for fresh water production is electricity, which can be used to provide operative load reserve of power at low capacity FNHPS [11].

The use of electricity-driven HPD besides providing a solution for a problem of operative load power reserve is capable to increase the installed capacity utilization factor with the transfer of nuclear station to condensation mode without producing heat energy for desalting and increase of electricity production.

4. CONCLUSION

SIF "EKIP" in cooperation with other co-executors within the framework of Federal target program "Research and development in priority branches of science and technology in 2002-2006" has developed principal technical solutions for new generation heat pumps [12]. The theoretical calculation study proves the energy, economic, environment and social expediency of building salt water desalters based on heat pumps (heat pump desalters, HPD). This leads us to the following conclusions:

1. Since the HPD are built on the basis of heat pumps, it allows construction of HPD practically any capacity operating in a wide range of input parameters.
2. The use of different drive types allows broaden the implementation areas range and lower the fresh or distilled water production costs.
3. Environment-safe working substances are used as coolants.
4. Simple design (serial manufacture of main components can be set up in a very short period of time) and operation (full automation possible)
5. Besides main purpose the electricity-driven HPD can also be used as power load reserve of FNHPS or nuclear plants.

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