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New MED based desalination process for low grade waste heat

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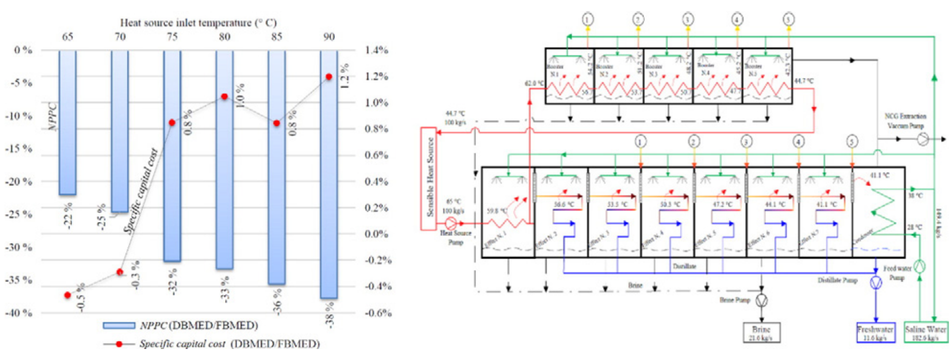
HIGHLIGHTS

- A new MED based desalination process, entitled DBMED, has been developed.
- Compared to an optimised conventional MED, it produces up to 45% more freshwater.
- The Jensen number is used to calculate *NPPC* and improve the capital cost function.
- Compared with the FBMED, it decreases the *NPPC* by up to 38%.
- The DBMED enjoys up to 2.6% decrease in the specific capital cost as compared to MED.

GRAPHICAL ABSTRACT



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ABSTRACT

We have developed a new distributed boosted multi-effect distillation (DBMED) process to effectively harness low-grade "waste heat" in the temperature range 65 °C–90 °C to address the problem of freshwater scarcity. Comparisons are made with multi-effect distillation (MED) and recently proposed advanced MED schemes, namely boosted MED (BMED) and flash boosted MED (FBMED) on the basis of waste heat performance ratio, normalised pumping power consumption (*NPPC*) and specific capital cost. The main advantage of DBMED compared to FBMED, is a 30.9% decrease in the average *NPPC*. Compared to FBMED, which has the highest waste heat performance ratio of systems described in the literature to date, DBMED has a similar average waste heat performance ratio and specific capital cost over the temperature range 65 °C–90 °C. For driving temperatures lower than 75 °C, DBMED has a better waste heat performance ratio by up to 7.3% while also reducing *NPPC* by at least 22%. At temperatures above 75 °C, the waste heat performance ratio of DBMED is greater than those of MED and BMED but less than that of FBMED by ≤4.5%, while having the advantage of up to 38% reduction in *NPPC* at 90 °C.

1. Introduction

Water is the only common compound which can exist as a solid, liquid and gas within the small range of temperatures and pressures available at the earth's surface. Of water extracted from the environment worldwide, 70% is used for agriculture, 20% for industry, and only 10% for domestic use; the current water consumption rate is around 340 million L per second. The world population tripled in the previous century, but water use for human purposes increased six fold. Yet nearly 20% of the world population does not have access to affordable and safe drinking water. [1–3].

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The Earth holds nearly 1.39 billion km^3 of water, 96.5% in the global oceans. For the remaining, nearly 1.7% exists in the polar icecaps, glaciers, and permanent snow, and another 1.7% exists in groundwater, rivers, lakes, and soil. It is enough for the seven billion people on earth but it is unequally distributed, much of it is affected by pollution and unsustainably managed [2,4,5]. By 2025, an estimated 1.8 billion people will live in areas threatened with complete water scarcity and near to two-thirds of the world population will experience water stress conditions [1,6].

To increase water supply over what is available, we can use desalination and rely on water reuse. We can depend on seawater desalination for a near limitless, steady supply of high-quality water, without damaging natural freshwater ecosystems [7]. In the field of desalination, three main approaches exist to separate water from salts. The first approach is to use thermal energy to reach phase change conditions for the water. Thermal desalination based on simultaneous evaporation and distillation accounts for a large portion of the world's desalination capacity. In the second category (reverse osmosis), a membrane and pressurised system are used to separate the components physically. Finally, there are chemical approaches to desalination. This third category is more varied than the other two and includes processes such as ion exchange and gas hydrate formation. Generally, it is found that chemical approaches are too expensive to apply to the production of fresh water [8].

Thermal desalination and reverse osmosis represent respectively 28% and 65% of the total installed capacity in the world [9]. One of the key obstacles to the extensive use of desalination is its large energy consumption. Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF) are examples of thermal desalination and require high thermal energy consumption [10,11]. Also, the high overall efficiency of the reverse osmosis process is at the expense of high operating costs stemming from consuming a large amount of electricity (4–5 kWh/m^3) with energy recovery and problems in the pretreatment section due to seasonal algal blooms, high biological activity, and turbidity. Hence, it is desirable to use waste heat (e.g. streams from power plants, oil and gas refining, geothermal heat, and other industrial processes) as an inexpensive means to provide the energy required for desalination [12,13]. The subject of this paper is the improvement of thermal desalination technologies suitable for waste heat consumption.

Based on estimations between 20 and 50% of industrial energy input is lost as waste heat in the form of cooling water, heat loss from hot equipment surfaces and hot exhaust gases. With current efforts to improve energy efficiency in industry, recovering waste heat losses has provided an attractive opportunity for a less costly energy source that generates no additional emissions. Waste heat recovery opportunities are categorised by dividing temperature ranges into low, medium, and high quality of waste heat sources [14].

Use of sensible low-grade heat sources in the range of 65 °C–90 °C is the range of interest for this article. This range is attractive because many waste heat sources are available in this range and many at-risk developing nations, without the energy resources to install large desalination plants, can use available waste heat to implement desalination units and decentralise fresh water production. In this article, a new MED based technology entitled distributed boosted multi-effect distillation (DBMED), coupled with low-grade heat sources (<100 °C), will be presented and compared with the current technologies.

2. Conventional, boosted and flash boosted MED description

MED (Multi Effect Distillation) includes a set of stages (effects), a condenser and subsystems to bring in saline feedwater and the heat source (usually hot liquid water or steam) and to collect and remove the distillate and concentrated brine. Such an exemplar system is shown in Fig. 1. In the first effect the heat source (e.g. liquid water at 65 °C) is pumped into the hot side of the evaporator, while saline feed water is passed over the cold side of the evaporator. Due to the low prevailing pressure, the feed water boils at 50.3 °C, the steam passes through a demister and condenses on the hot side of the evaporator in the second effect, while the remaining liquid from the first effect is drained off as brine. In the second effect the condensing vapour (on the hot side of the evaporator) from the first effect becomes the pure

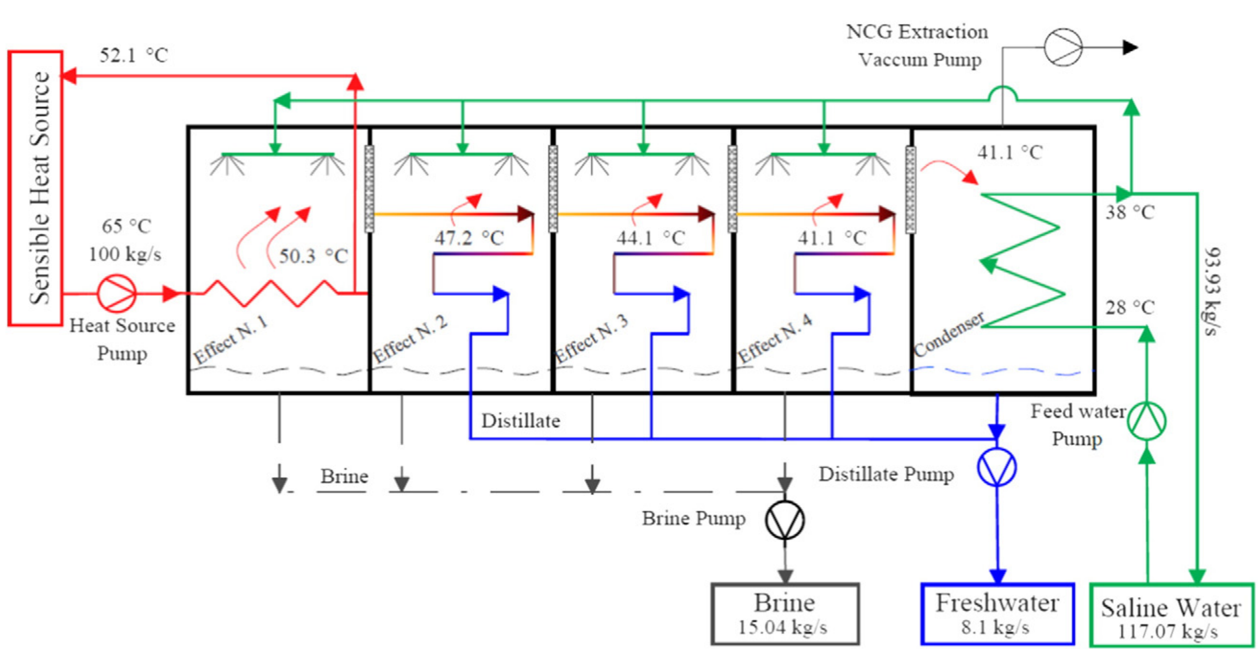

Fig. 1. Schematics of an optimised conventional MED design (numbers are for 65 °C simulation).