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Boosted Multi-Effect Distillation for sensible low-grade heat sources: A comparison with feed pre-heating Multi-Effect Distillation

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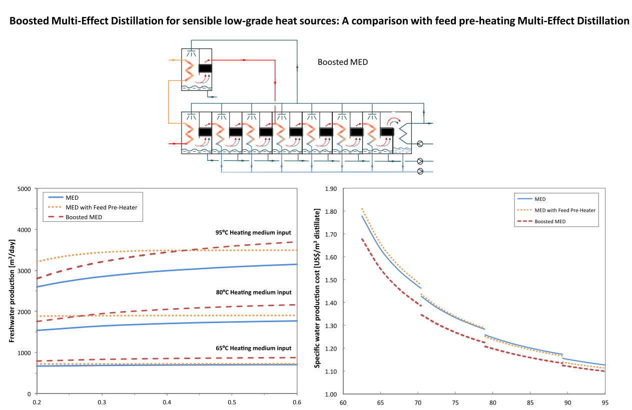
HIGHLIGHTS

- Critical considerations for advanced sensible heat driven MED systems are analysed.
- MED with feed pre-heating and Boosted MED are benchmarked against standard systems.
- Production rate increase, heat exchanger surface area and auxiliary power are evaluated.
- Boosted MED increases freshwater yield by up to 25% at reduced water production cost.
- Boosted MED is economically superior to MED with feed pre-heating.

GRAPHICAL ABSTRACT



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ABSTRACT

Sensible low-grade heat, such as process waste heat and many renewable energies, promises a vast potential for thermal desalination processes. Conventional Multi-Effect Distillation (MED) technologies, constrained by their inherent design, fail to unleash its full potential by a far measure.

We identified major drivers critical to the coupling of such heat source with MED technologies, and critically compared our recently introduced Boosted MED scheme against a variation of the commonly practiced feed pre-heating MED scheme, both of which are scalable system modifications that are better suited for the coupling. For most operational conditions germane to sensible waste heat sources and renewable energies, the Boosted MED system offers both a thermodynamic and economic superior performance, especially when low heating media temperatures prevail. From about 80 °C onwards, feed pre-heating becomes thermodynamically increasingly competitive, but due to the rising auxiliary power demand fails to surpass the Boosted MED on an economic comparison over the surveyed application range.

1. Introduction

Sensible waste heat sources and hot liquids generated from renewable energies are a promising sustainable energy source for desalination processes [1,2]. Its true potential remains hitherto untapped.

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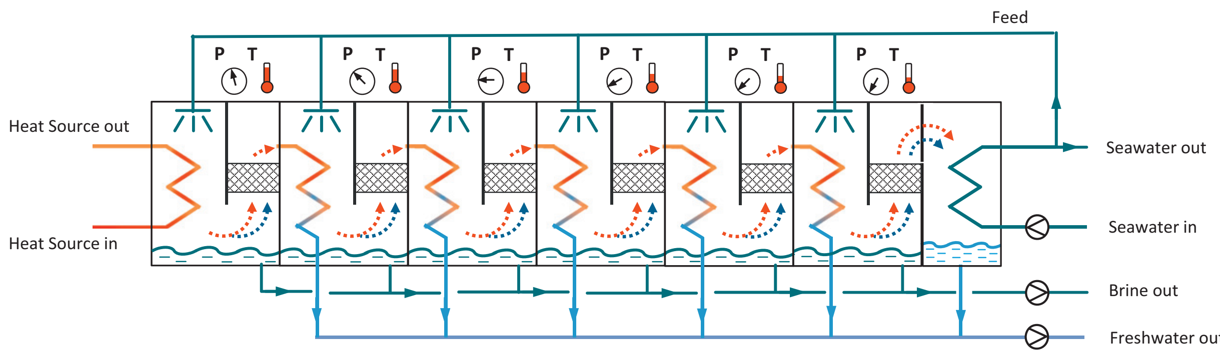

Fig. 1. Schematic of a conventional parallel feed MED system.

Besides the intrinsic large irreversibilities of the desalination processes, one principal reason is that conventional thermal distillation technologies, like Multi-Effect Distillation (MED), are almost invariably optimised for being steam driven [3–10]. Sensible heat sources in contrast require specific approaches to unlock their potential, which are not addressed by these technologies and the common industrial benchmarks [11]. Consequently the typically market approach of simply adapting a steam driven design paradigm to sensible heat sources leads to thermodynamically inferior performance, which is limiting the economic application range significantly. Improved technologies are required to stretch the viability of Multi-Effect Distillation, and rejuvenate the potential of waste heat streams and renewable energies for this mature and reliable desalination technology.

We had recently demonstrated that conventional performance measures adapted from steam driven systems like the Performance Ratio (PR) are incongruent with sensible (waste) heat sources, and had posited the Waste Heat Performance Ratio (PR_{WH}) as new benchmark. By addressing the unique nature of sensible heat sources, the theoretically available energy intake into the system by utilising the heat source down to ambient conditions is used as the benchmark instead of the actual energy used. We had demonstrated that this can lead to up to 40% increased production rates, when considered in the design process of a conventional parallel feed MED system [11]. This improvement is not achieved by using latent heat fundamentally better, but by better capitalising on the potential of waste sensible heat.

A new system design, the Boosted MED has been proposed [12] and successfully demonstrated by a pilot plant [13], is capable of further increasing the production rate from sensible heat sources by efficiently utilising the heating medium output stream.

We shall now expand this approach and benchmark this promising technology with a basic MED configuration and a modification of the commonly applied feed pre-heating, so as to arrive at the most economic operation.

2. Multi-Effect Distillation processes

Multi-Effect Distillation is a proven desalination technology utilising the differences in the volatilities of the fractions in a mixture for the separation process. In 2013 MED accounted for 8% of the globally installed desalination capacity [14]. It is also applicable to a plethora of liquids, including industrial wastewater, spent liquor from the Bayer process, or otherwise contaminated waters. We shall concentrate herein on seawater desalination, but the general approach can be equally applied to any of the abovementioned applications.

In MED units a series of evaporators, the so-called "effects" are generating water vapour at progressively reduced temperatures and pressures (Fig. 1). The freshwater vapour generated in one effect serves as the heat source for the subsequent effect. The effective reuse of latent energy enables large production rates. The number of effects determines the degree of internal energy reuse, and consequently the efficiency of the desalination unit itself. The process of reusing latent energy terminates when the cold end temperature, as imposed by the cooling source, is approached. A typical seawater cooled condenser is used to liquefy the vapour from the last evaporator. A partial feed preheating is achieved by extracting feedwater from the output stream of this cooling water.

In this article we focus on applications where *sensible* low-grade heat and waste heat sources are utilised as the principal heating medium; this subsumes industrial waste heat sources and renewable energies such as geothermal energy.

2.1. Variations of the MED process for sensible heat source

We had earlier demonstrated that when sensible heat is utilised, the non-isothermal nature of the heat input enjoins a compromise between the accessible temperature range and the number of effects so as to arrive at an optimal production rate [11,15]. As such a system design with a lesser number of effects, but consequently able to access a larger heating medium temperature differential *can* be superior to a highly efficient system in the conventional sense that displays a high *performance ratio*. Notwithstanding, the maximal achievable freshwater yield stemming from such optimisations is still limited to a fraction of the thermodynamic optimum.

In consequence, and referring to Fig. 2, even an optimised single MED system has to reject the heating medium at a relatively high output temperature (e.g. 50–60 °C and more), thereby leaving a substantial portion of the energy content untapped. Considering the still significant potential of this output stream it is desirable to further integrate this

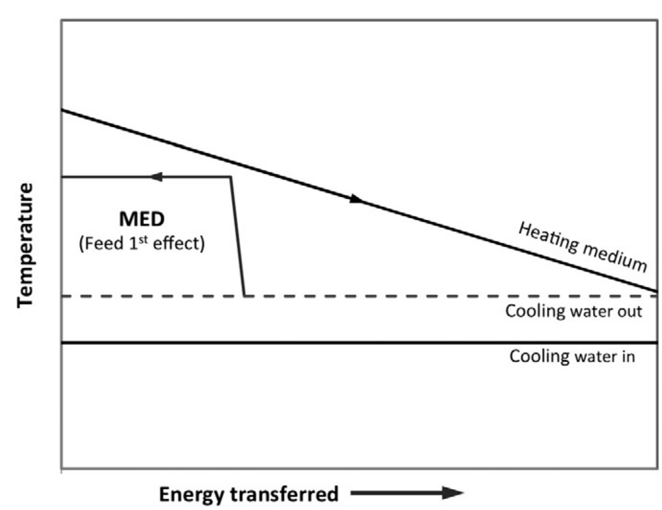

Fig. 2. Temperature profile of the first effect of a MED unit vs. that of the sensible heat source.