Desalination 365 (2015) 316–328

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

# Thermo-economic analysis of two novel low grade sensible heat driven desalination processes

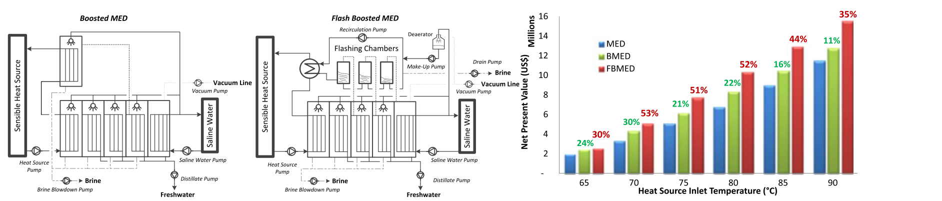
Bijan Rahimi [b,c], Jake May [b], Alexander Christ [b,c], Klaus Regenauer-Lieb [d], Hui Tong Chua [a,b,*]

[a] School of Environmental Science and Engineering, Taiyuan University of Technology, Taiyuan, Shanxi Province, China
[b] School of Mechanical and Chemical Engineering, The University of Western Australia, 35 Stirling Hwy, Perth, WA 6009, Australia
[c] School of Earth and Environment, The University of Western Australia, 35 Stirling Hwy, Perth, WA 6009, Australia
[d] School of Petroleum Engineering, The University of New South Wales, 330 Anzac Parade, Kensington, NSW 2033, Australia

## HIGHLIGHTS

- A thermo-economic model for two novel MED processes has been developed
- The specific capital costs of these processes are lower than standard MED process.
- The specific operating cost of FB-MED is comparable to standard MED.
- The unit product cost of FB-MED is 6% less than standard MED.
- The net present value of FB-MED is 53% greater than standard MED.

## GRAPHICAL ABSTRACT




Two novel low grade sensible heat driven desalination technologies have been compared favourably against the conventional MED for low grade sensible heat application.

## ARTICLE INFO

*Article history:*
Received 19 January 2015
Received in revised form 4 March 2015
Accepted 5 March 2015
Available online 19 March 2015

*Keywords:*
Waste heat
Multi effect distillation
Evaporation
Multi stage flash
Capital cost
Economic analysis

## ABSTRACT

Two novel desalination processes that utilise low grade sensible heat sources have been modelled and both have been shown to be more thermally efficient means of desalinating water than conventional Multi Effect Distillation (MED). The novel Boosted MED (B-MED) and Flash Boosted MED (FB-MED) processes are capable of higher production rates than conventional MED, enabled by the addition of process components and by an increase in specific electrical power consumption. A simple method of estimating the capital and operational costs of MED, B-MED and FB-MED desalination installations is presented. A generalised comparison of the economics of these three processes is conducted, asserting the economic viability of the novel desalination processes.


## 1. Introduction

Water scarcity has become a worldwide issue with the pollution of existing water supplies, increasing population and industry activity, uneven freshwater to population distributions and changing rainfall patterns mean that many regions containing populated centres are becoming less capable of meeting the water supply requirements of the residing populations [1–4]. Methods of attenuating such water supply issues include wastewater treatment and reuse, desalination, as well as water conservation schemes. Desalination is being increasingly adopted over traditional water supply methods due to the relatively greater cost-effectiveness and reliability [4–6]. Some eighty countries face severe water shortages [7], whilst some countries such as Kuwait, the United Arab Emirates and Saudi Arabia currently depend almost entirely on desalination for supply of water [5]. However, such processes predominantly require large amounts of electrical and thermal energy. When obtained from non-renewable sources, such energy use contributes somewhat to

* Corresponding author.
*E-mail address:* huitong.chua@uwa.edu.au (H.T. Chua).

http://dx.doi.org/10.1016/j.desal.2015.03.008
0011-9164/

the greenhouse gas emissions of the host region. Due to the greater availability and lower cost of fossil fuels in the Middle East, the use of thermal desalination processes such as Multi Stage Flash (MSF) is localised primarily within these regions [8]. In 1996, 10,000 tons/year of oil was required to produce 1000 $m^3$/day freshwater [9]. Conversely, membrane based desalination plants, which make up the majority of plants worldwide [6], are largely powered by electricity derived from non-renewable sources. Though more economical than renewable energy sources, the use of fossil fuels should also be framed within the context of the environmental implications including the greenhouse effect, carbon dioxide emissions and associated environmental pollution. Incorporating renewable energy sources into desalination has been shown to be both technically and economically feasible and it should be considered an incontestable goal of ongoing research into desalination technology to incorporate renewable energy technologies henceforth.

The increasing modernisation of economies the world over along with improved living conditions, and the globalisation of trade and commerce, are causing the global population to increase, albeit with the rate of increase declining since the 1950s and 1960s [10]. It is expected that the global population will reach a steady-state value of around 9–10 billion by the middle of the 21st century due to increasing levels of economic development [10], among other factors. Concurrently water desalination, by both thermal and membrane processes, is becoming cheaper owing to material improvements, process improvements and an increase in competition [2]. The global rate of installation of water desalination facilities is therefore increasing, with estimates of an approximate 55% increase in the number of plants installed in 2012 over the previous year [2]. The increased adoption of desalination represents a significant rise in global energy usage, due to the energy intensive processes required. For perspective, consider that the total amount of energy used for desalination worldwide has become comparable to the total energy requirement of a small industrialised country such as Sweden [11]. Any improvements into the energy utilisation and efficiency of desalination processes are therefore important, particularly those that incorporate the use of sustainable energy sources such as industrial waste heat, geothermal, solar and adsorption cycle. Among the mentioned sustainable energy sources for the purpose of desalination, using low temperature waste heat with an adsorption cycle is recently developed by hybridising MED with such a cycle [12–17].

It is known that TVC-MED has the highest performance among all steam driven thermal desalination technologies [18–20]. It consumes less electrical energy and utilises the thermal energy in an optimised way as compared to the other thermal desalination technologies. However, in the absence of medium pressure (MP) steam and when the low grade sensible heat source (hot liquid medium) is the only available heat source, the conventional MED technology is a superior option. In our previous works [21–28] it has been shown that in case of using low grade sensible heat source instead of steam, both B-MED and FB-MED processes have higher thermal performance as compared to the conventional MED process, being the benchmark. It has been shown that the improved FB-MED process is capable of up to 50% greater production rates than conventional MED [21], whilst having comparable auxiliary power consumption. The FB-MED process is thermally efficient when utilising low grade sensible heat sources, meaning it is characteristically suited to the use of sustainable heat sources such as geothermal heat or industrial waste heat. Importantly, the FB-MED process is capable of greater waste heat performance ratios [26] than a comparable MED [21], meaning that the novel process is capable of better utilising the available energy of the heat source fluid (sensible heat source), which drives the desalination process. The production improvements exist as a result of novel process changes, which are only made possible by the addition of selected components and equipment. The additions of a series of flashing chambers or a booster module, which supplement the vapour production of the primary MED evaporators, and the addition of associated process pumps and components, represent the additional costs of both B-MED and FB-MED relative to the conventional MED alternative. This article pertains to the economic analysis of the above mentioned two innovative low grade sensible heat driven thermal desalination processes, namely FB-MED [21,27], as well as the B-MED process [22,28]. For this purpose, in this article, it is determined in a generalised manner whether the FB-MED and B-MED processes can be economically superior to the comparable MED process, despite the additional capital investment required. We had recently shown that, in terms of low-grade sensible heat applications, the B-MED process is economically superior to the feed preheating MED configuration [25], and hence the latter will not be compared in this article.

Many works have reviewed or evaluated the economics of desalination technologies. Hitherto the focus of such works predominantly being a review the state of the art [7,8,11,29–41]. Less frequent are reports on the economic viability of upcoming technologies that have yet to reach the stage of prototyping. Furthermore, most authors focused on the unit cost of distillate when comparing the economy of desalination technologies, with less priority given to annual cash flows, capital investment requirements and operating costs as a consequence. According to Badiru and Newnan [42,43], greater importance should be placed upon cash flows and the inherent monetary value of plant installations, implying that capital budgeting metrics such as net present value (*NPV*) and internal rate of return (*IRR*) are of greater use for comparison of engineering projects than estimates of unit product cost. This article reports a generalised method which was used to quantitatively compare the economic value of desalination installations using MED, B-MED and FB-MED, via such metrics as *NPV* and *IRR*.

## 2. Low grade sensible heat driven conventional MED, B-MED and FB-MED processes

The conventional MED process is a thermal process whereby feedwater is desalinated by means of phase change, in particular, the appropriately timed evaporation and condensation of water within the system. Fig. 1 shows the schematic layout of an MED system. A sensible heat source fluid exchanges its thermal energy with the feedwater, the water which is to be desalinated into the desired product. The exchange of heat takes place within a heat exchanger that is contained within each effect. In the first effect the heat source fluid loses a significant measure of thermal energy to the feedwater which evaporates into vapour. The vapour from the first effect, which has a high energy content is used to heat the feedwater within the heat exchanger of the second effect. As a result, the vapour condenses into the desired distillate product and the feedwater receives enough energy to produce a second measure of vapour. The vapour is used as the heat source within the third effect such that further vapour and distillate is produced. This process repeats in the same manner in each effect until the last, whereupon the incoming cold feedwater stream is used to condense the vapour produced within the penultimate effect. The distillate produced by each effect is collected for chemical preparation suited to its purpose. Similarly, the brine produced within each effect due the evaporation of the feedwater is collected for appropriate treatment and disposal.

The novel B-MED process, shown in Fig. 2, utilises a ‘booster unit’, an evaporator unit which receives the heat source fluid which has already been used to provide the necessary thermal energy for the primary MED effects. The heat source fluid, which still contains a considerable amount of useful thermal energy, is used to evaporate more feed within the booster unit [22], which causes a higher temperature drop for the heat source medium as compared to the conventional MED process. The vapour produced in the booster unit is then directed into an appropriate MED effect, supplementing the vapour and distillate production of the entire system. The B-MED process is particularly thermally efficient when utilising lower temperature heat sources, achieving production rates that are up to 22% greater than that of the optimised MED alternative utilising the same heat source [21].

It is worthwhile to mention that a state-of-the-art pilot plant consisting of two serially connected Alfa Laval's single-effect rising