



Prevention of failure in a distillation unit exhibiting extensive scale formation

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ABSTRACT

Over a period of 2 years in service, a heavy scale buildup was observed at the outer surfaces of heating tube bundles that make up the evaporator shell of a multi-effects distillation vapor compression (MED-VC) unit employed in an onshore oil producing facility. The unit production rate dropped by 30% below design capacity due to scale formation. A series of acid cleaning procedures, including: 17 batches of 10% sulfamic acid and 12 batches of ethylenediaminetetraacetic acid (EDTA), were used to clean the scale deposit at 68 °C. However, these efforts met with limited success leading to an investigation into the cause of cleaning failure. Selected samples of the scale were removed and characterized using scanning electron microscopy (SEM) coupled with energy dispersive spectrometry (EDS), as well as X-ray diffraction (XRD) and wet analysis techniques. The scale was approximately 14 mm in thickness and primarily constituted of soft CaCO₃ closer to the tube metal surface and hard CaSO₄ deposit away from it. In addition to CaCO₃ and CaSO₄, significant proportion of the deposit comprised of organic matter. It is believed that the presence of organic matter within the scale was primarily responsible for the failure of EDTA and acid chemical cleaning procedures. To avoid MED unit failure due to continuous scale buildup, it was suggested that an appropriate hot alkaline cleaning agent (instead of acid cleaning) is used in order to remove the scale deposit rich in organic matter.

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1. Introduction

Desalination of seawater is the main process currently practiced for the production of potable water in the Middle East Gulf countries. The high temperatures encountered in this process causes scale buildup. This scale can be divided into two main classes; alkaline scales, e.g., calcium carbonate and magnesium hydroxide and non-alkaline scales, e.g., calcium sulfate [1–5]. Evaporator shell of multi-effects distillation vapor compression (MED-VC) unit comprises of heating tube bundles made of stainless steel, as shown in the schematic diagram of Fig. 1. The purpose of the MED-VC unit is to produce fresh water < 15 TDS, for use as boiler feed water (BFW), potable water blending and wash water for the de-salters. The distillate is produced by spraying seawater over tube bundles containing steam. The steam condenses to form distillate and the heat given up flashes off a proportion of the seawater to produce more steam, which is fed to tube bundles in the next cell and so on resulting in what is named as a 'multi-effect' process. The process takes place under vacuum, which enables flashing at temperatures, in the region of 43 to 60 °C. Each effect (cell) is at a lower pressure and temperature than the preceding. This operation reduces the formation of scaling which appears at higher temperatures (> 70 °C) and is energy efficient. A package boiler provides the steam for the vacuum ejectors and eject-o-compressor which supplies the heat to the system, by

combining steam from the boiler and some steam from the last cell and sending it to the 1st cell tube bundle. Steam enters the heating tube and is condensed by seawater spray at the outside. Due to heat transfer, some of the seawater is flashed to steam resulting in the liberation of salt. The chemistry of the seawater has been explained in details elsewhere [1–4]. Table 1 lists a complete analysis of the seawater feed to the MED-VC unit studied here.

The scale is formed on the tube surfaces by deposition of salt contaminants found in the feed seawater [6–9]. Factors affecting scale buildup are mainly salt concentration [1], operating temperature [10,11], fluid velocity [11–13], pH of water environment [10,12] resident time [12] and non-condensable (NC) gases such as CO₂ [14–22]. Scaling also depends on the roughness of the distiller materials and/or corrosion products [23,24]. The presence of NC gases is caused by the leakage of ambient air through instrumentation nozzles, flanges, man-holes, etc., into the parts of the evaporator operating under vacuum and the release of dissolved gases from the evaporating brine. It has been previously reported that even low concentration of NC gases notably reduce the overall heat transfer coefficient and consequently the performance of desalination evaporators [25–28]. For the sake of better understanding of desalination process, distiller characteristics and its operation conditions are listed in Table 2.

Anti-scale additive which is used by the water treatment industry for many years is the main method utilized to retard and control the formation of scale on the process equipment used in thermal desalination plants [29–36]. Polyphosphate was used as a scale inhibitor in the distillation unit studied here. It is known that polyphosphate

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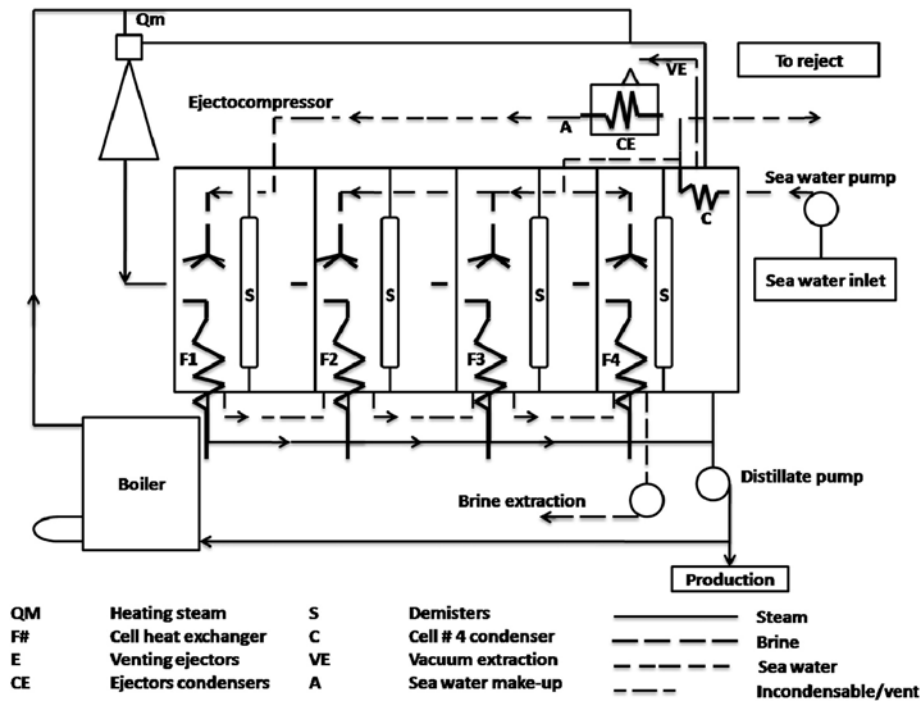


Fig. 1. Schematic diagram of the MED unit.

can be used to combat the formation of alkaline scales [1,37]. Their use as scale inhibitors is rarely used in MED plant and restricted to operating temperature below 90 °C, since it could be hydrolyzed at higher temperature and form calcium phosphate which is difficult to remove [1]. Moreover, it tends to produce additional scale in the form of thick muddy deposits [37].

Progressive scale buildup at the outer surfaces of heating tubes of an evaporator is an inevitable process. Even with stringent control of feedwater and condensate chemistry, scale formation and deposition will occur [38]. The main problems caused by scales include an increase in tube wall temperature, which can lead to a decrease in overall efficiency [39,40], and tube ruptures [41,42]. The increase in tube wall temperature is due to low thermal conductivity of scales as compared to metal [43–45]. The reduction in heat-transfer can lead to the design temperature of the tube wall being exceeded, which in turn may lead to failure of the tube by creep rupture. Since scaling

impedes heat transfer, more fuel is required to produce a given amount of steam, thus reducing overall efficiency. This results in an increase in energy cost and a loss of process reliability [46–48]. Eventually, removal of scale becomes essential if damage to the tubes is to be prevented. One way of removing scale is to chemically clean the MED-VC unit [49]. Chemical cleaning is a multiple stage process that seeks to remove all the existing scale from the internal components, leaving a clean passivated waterside system [50]. The scale deposits are classified as soft, hard, silica and organic scale. Within low vapor space temperatures operation ranging from approximately 58 to 38 °C in the MED-VC process, scaling should not be much of a problem. However, it has been observed that if various factors are not taken care of, excessive scaling can occur in MED-VC units [51].

The MED-VC unit studied here operated at relatively low top brine temperature ranging from 38 °C to a maximum of 58 °C with a low vacuum of 60 mm Hg. It appears that operating temperatures of the MED-VC unit are well below the saturation limits of problematic scalants found in sea water (Fig. 2) [52–54]. The unit produced fresh water (<15 TDS) to be used as boiler feedwater (BFW), wash water and for fresh water blending. The shutdown frequency to clean scale buildup was expected to be in excess of 6 months. The unit was in operation for over 28 years and it had undergone approximately 20 cleaning cycles since its inception. On most occasions, cleaning did not remove all scale deposits. On this particular occasion, a large proportion of deposit remained intact even after vigorous cleaning procedure which involved 17 batches of 10% sulfamic acid and 12 batches of EDTA [12] at 68 °C. The main objective of this investigation was to identify the cause of the chemical cleaning failure of the MED-VC unit and provide recommendations to prevent such occurrences in the future.

2. Experimental procedure

A scanning electron microscope (model JEOL JSM-6490LA) coupled with energy dispersive X-ray spectrometer (model JEOL EX-54165 JMU) was used to metallurgically evaluate various sections of scale deposits recovered from several sections of the tubes of

Table 1
Chemical composition of the in-take feed seawater.

Parameter	
pH	8.23
Con., ms/cm	59.51
TDS, evaporation, ppm	48,560
Total hardness, ppm as CaCO ₃	7950
Total alkalinity, ppm as HCO ₃ ⁻	164
p-Alkalinity, ppm as CO ₃ ⁻	6
Chloride, Cl ⁻ , ppm	24,413
Sulfate, SO ₄ ²⁻ , ppm	3380
Magnesium, Mg ²⁺ , ppm	1629
Strontium, Sr, ppm	9.4
Iron, Fe, ppm	0.02
Fluoride, F ⁻ , ppm	1.3
Potassium, K ⁺ , ppm	504
Sodium, Na ⁺ , ppm	14,195
Calcium, Ca ²⁺ , ppm	499
Total suspended solids, ppm	4.0
Specific density, kg/m ³	1.032
Total Organic Compounds (TOC) ^a , ppm	3.65

^a The value given represent concentration average during the period 2005–2009.

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