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Effect of reusing the advanced-softened, silica-rich, oilfield-produced water (ASOW) on finned tubes in steam-injection boiler

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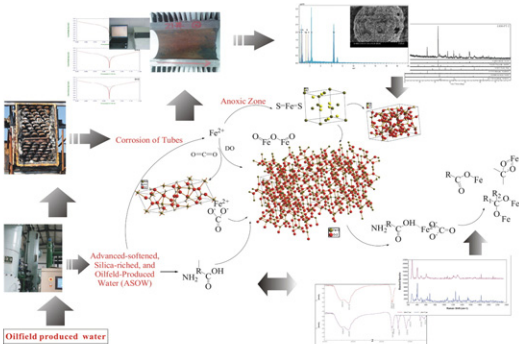
HIGHLIGHTS

- It offers an environmentally friendly method for disposing oilfield-produced water.
- Oilfield-produced water without desilication was reused as boiler feedwater.
- A 16-month pilot-scale test was conducted.
- Silicate deposition would not be formed in the finned tubes of boiler.
- Formation of deposition in finned tubes was attributed to corrosivity of feedwater.

GRAPHICAL ABSTRACT



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ABSTRACT

For reducing environmental pollution and saving water resources, ASOW is reused as boiler feedwater. One of key challenges for that is deposition in finned tubes, which is detrimental to thermal efficiency of boiler. To evaluate the reuse and explore the formation mechanism of deposition, a 16-month pilot-scale test was conducted. Silicon content and total hardness in ASOW were 238.93 mg/L and 0.031 mg/L, respectively. The corrosivity of ASOW was severe by electrochemical workstation. Morphology and composition of deposition were determined by scanning electron microscope-energy dispersive spectrometer (SEM-EDS), inductively coupled plasma-mass spectroscopy (ICP-MS), X-ray diffraction (XRD), laser Raman spectrum (LRS), and Fourier transform infrared spectroscopy (FTIR). These were measured both during the early stage of steam injection (ESSI) and later stage of steam injection (LSSI). Silicates were negligible, whereas siderite ($FeCO_3$), iron oxide (Fe_2O_3), and pyrite (FeS_2) were main crystalline phases indicating that deposition was mainly composed of corrosion products. Besides, Fe-carbonyl complexes were identified in LSSI, indicating that some organic substance have reacted with Fe during boiler operating. It is concluded that the formation of deposition is attributed to the dissolved oxygen and free carbon-dioxide in ASOW not to silicates. However, these can offer a reference for improving the reuse.

1. Introduction

Oilfields have been producing large volumes of water, during which large volumes of water and steam are injected into the reservoir to maintain pressure and enhance the oil extraction efficiency [1]. The

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Huanxiling Oil Production Plant in the Liaohe Oilfield, for example, produces 12,000 m^3/d of water. Attentively, it is just one plant of the Liaohe Oilfield. In addition, the daily global production of produced water is 250 million barrels, which is three times the amount of oil produced. This ratio increases with the maturity of the oilfields [2,3]. How to dispose the enormous volumes of oilfield-produced water has been a stubborn problem. Thus, development of effective disposal methods for the oilfield produced water is very important from both ecological and economic standpoints. However, reusing the oilfield produced water as feedwater in steam-injection boiler is an important aspect of responsible water management [4–6].

As is well-known, the soluble and amorphous silicates in the oilfield produced water are used to be transported, deposited, or reacted with divalent and trivalent cations, and then redeposited in steam-injection boiler. In addition, the silicate depositions have an obviously detrimental effect on the thermal efficiency and security of the steam injection system [7–10]. Therefore, controlling the silicon content in feedwater has been implemented by the stringent industry standards [11–13]. According to the British Standards and the American Society of Mechanical Engineers, the maximum silicon content has been established at a limit of 5 mg/L (calculated with SiO_2) for the pressure in range of 6.1–8.0 MPa steam injection systems, and a limit of 50 mg/L was established for that pressure in China. In order to satisfy the stringent standards, several techniques are commonly used to remove silica from water [14,15]. However, these techniques can result in large amounts of silica sludge and concentrated solutions, which cause serious secondary pollution and increase desilication costs. In China, desilication costs account for more than half of the total operating cost of oilfields [16].

In our previous work, we found that softening is more efficient than desilication in reducing deposition via lab test. The formation of SiO_2 in the deposition was negligible, even when the simulating boiler operated at a high silicate concentration [16] (was about 300 mg/L, calculated with SiO_2). Actually, the feedwater (ASOW) flows into the finned tube firstly before the radiant tube in steam-injection boiler in oilfield, and the heat transfer efficiency of finned tube is very important for improving the thermal efficiency of whole boiler. However, what effect can happen on the finned tube under the ASOW, what is the deposition of finned tube and how is it formed? These have not been reported in the literature.

In this study, a 16-month pilot-scale test was implemented to evaluate the effect of reusing ASOW and explore the formation mechanism of deposition. The basic parameters of feedwater (ASOW) were monitored by IC, ICP-MS, TOC, some portable instruments and standard methods. CHI604D electrochemical workstation was used to discuss the corrosivity of ASOW. Scanning electron microscope-energy dispersive spectrometer (SEM-EDS), inductively coupled plasma-mass spectroscopy (ICP-MS), X-ray diffraction (XRD), laser Raman spectrum (LRS), and Fourier transform infrared spectroscopy (FTIR) were applied to the deposition analysis. According to these data, the effect of ASOW on the compositions and formation of deposition was explored. Obviously, it is of great importance for the reuse of ASOW in getting a clear understanding of the effect on deposition, and the positive results are important to improve the reuse of oilfield produced water without desilication as boiler feedwater. Furthermore, it also provides a reference for the sustainable development, energy conservation and emission reduction.

2. Materials and methods

2.1. Experimental system

A pilot-scale test was implemented for 16 months. The treatment process flow diagram for produced water in the pilot test was summarized in the Supplementary materials (Fig. S1). The figures of the stream-injection boiler (YZF11-21-P) in the pilot-scale test are shown in Fig. 1. Two new finned tubes, which were preprocessed with impeller blasting, were connected to the boiler at the early stage of stream injection (ESSI) and the later stage of stream injection (LSSI) as the targeted tubes before the test, respectively. Temperature in the targeted finned tube is 125 °C, which is in accordance with the temperature of industrial

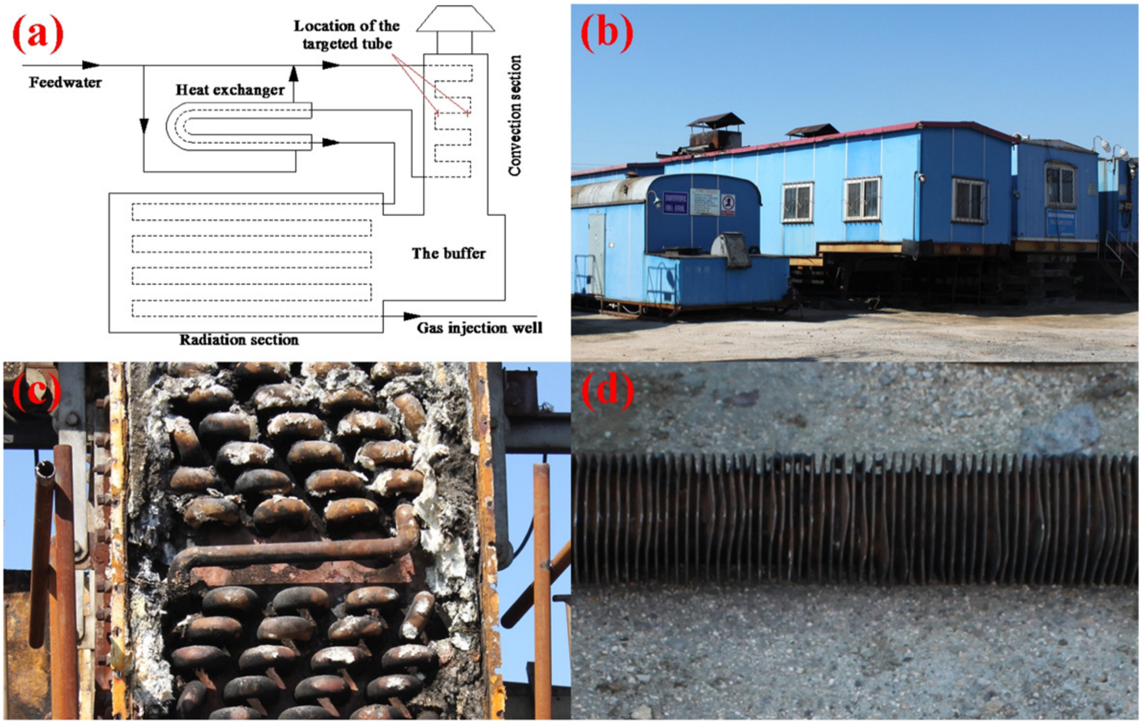

Fig. 1. Images of stream-injection boiler in the pilot-scale test: (a) structure diagram of stream-injection boiler, (b) image of stream-injection boiler, (c) image of finned tubes, (d) image of targeted tube.