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A new system design for supercritical water oxidation

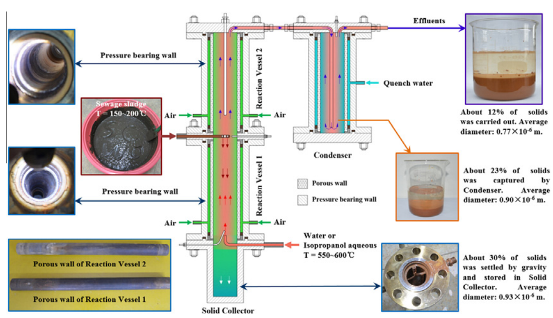
Zhong Chen [a,b,c], Guangwei Wang [a,b,c], Fengjun Yin [a,c], Hongzhen Chen [a,c], Yuanjian Xu [a,c,*]

[a] *Chongqing Institute of Green and Intelligent Technology (CIGIT), Chinese Academy of Sciences, Chongqing 400714, PR China*
[b] *Key Laboratory for Solid Waste Management and Environment Safety, Ministry of Education of China, Tsinghua University, Beijing 100084, PR China*
[c] *Key Laboratory of Reservoir Aquatic Environment, Chinese Academy of Sciences, Chongqing 400714, PR China*

HIGHLIGHTS

- A lab-scale SCWO system based on DGSWR was described in detail.
- Gas seal of DGSWR was verified under supercritical conditions.
- Sewage sludge with 2.62–11.78% DS was safely treated.
- Gravity sedimentation of solids partially achieved.

GRAPHICAL ABSTRACT



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ABSTRACT

As the main obstacles for the industrialization of supercritical water oxidation (SCWO) technology, corrosion and plugging are mostly occurring in the high pressure high temperature (HPHT) sections, including preheater, reactor, heat exchanger and cooler. In this paper, a lab-scale SCWO system based on dynamic gas seal wall reactor (DGSWR) has been described, tested and discussed in detail. The results showed that the preheating problems of waste with high solid content has been solved and the "gas seal" of DGSWR has been successfully verified under 28–29 MPa and around 400 °C. Sewage sludge with 2.62–11.78% dry solid has been degraded and the COD removal efficiency can reach up to 99.15%. However, the solid particle sedimentation was only partly achieved. According to the results analysis, based on the Stokes' Law, both small particle size and counter-current of upward reaction medium and downward solids are responsible. Future improvements for the SCWO system were also discussed at the end of this article.

1. Introduction

For environmental awareness, water is undoubtedly the optimal reaction medium. But at room temperature, the reaction is too slow for most redox reactions, especially for the destruction of organic wastes. One of main reasons is the solubility in water for both organic waste (mostly nonpolar) and oxidant (mostly oxygen) are very low at room temperature. Interestingly, this property is overturned in supercritical water (SCW, T_c = 373.946 °C, P_c = 22.064 MPa [1]), which can be completely miscible with organic compounds and oxygen [2]. Besides, SCW also possess other unique properties [2,3], such as high diffusivity and density, low viscosity and inorganic solubility. Supercritical water oxidation (SCWO) is a redox reaction to destroy organic compounds in SCW with the participation of oxidant (such as air, oxygen and hydrogen peroxide etc.) [2]. In general, most of organics can be

* Corresponding author at: Environmentally-Benign Chemical Process Research Center, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, No. 266 Fangzheng Avenue, Shuitu Hi-tech Industrial Park, Shuitu Town, Beibei District, Chongqing 400714, PR China. Tel.: +86 23 65935819.
E-mail address: xuyuanjian@cigit.ac.cn (Y. Xu).

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nearly completely degraded by SCWO in less than 1 min [3], and the products are the environmentally acceptable effluents, such as H_2O, CO_2, and N_2 etc. [4]. As the excellent merits, the SCWO has been hailed as an emerging and environmentally-benign technology for the treatment of various hazardous wastes in the last three decades [4,5].

The SCWO, as such a great potential technology, its commercial development is actually far lag behind the expectation. Most of the full-scale commercial plants have been shut down and only two of them are in operation as of January 2012 [6]. Corrosion and plugging are the main obstacles [2–7]. To overview the typical SCWO process (Fig. 1), it can be found that both corrosion and plugging are mainly occurring in the high pressure and high temperature (HPHT) sections, and the details are discussed as fellow:

1.1. Preheaters

The oxidant preheater can be slightly corroded in the presence of water, such as the wet air without dehydration. The ion product of water will maximize under subcritical conditions, which will lead to corrosion problems in both pure water preheater and aqueous waste preheater [8–10]. Some salts dissolved in the waste stream will precipitate out with the increasing of temperature [10] and some organic compounds in the aqueous waste will polymerize in the absence of oxidant [3,10]. Both of salt precipitation and polymerization may lead to plugging problems in waste preheater.

1.2. Reactor

The heteroatoms (S, Cl, P, N, etc.) contained in the organic waste will be dissociated to form corresponding acids in reactor. The SCWO reactor, where is a harsh chemical and physical environment of presence of acids, high concentration of oxidant, high temperature and high pressure, should undergo severe corrosions [8–10]. The inorganic salts for several reasons [7] would like to precipitate from SCW to scale on the surface of reactor and leads to severe plugging problems.

1.3. Cooler and heat exchanger

Same as in the process of preheating, the cooling and heat exchanging should undergo the subcritical conditions, under which the corrosion of water is much higher [8]. The effluents containing various acids, if without neutralization, will lead to severe corrosion in cooler and heat exchanger, which is more severe than that in reactor [8–10]. Part of salts failed to separate in reactor will also result in plugging problems in cooler and heat exchanger.

So far, a "super material" that can withstand all corrosion conditions in SCWO has not yet been reported [8]. If any, the plugging and others problems will also hinder the development of SCWO. Therefore an appropriate system design for SCWO is necessary.

In this paper, the focus of anti-corrosion and anti-plugging has been expanded from reactor to the whole HPHT sections (see Fig. 1). A novel reactor concepts named as "Dynamic Gas Seal Wall Reactor" (DGSWR) [11] was adopted, which was optimized from "Transpiring Wall Reactor" (TWR) and was designed to handle the reactor corrosion and plugging problems. A technology of multi-feed injection was designed to handle the waste preheating problems. A lab-scale SCWO device based on this novel design was manufactured and tested under 28–29 MPa around 400 °C.

2. A new SCWO system design

A new SCWO system with a maximum treatment capacity of 2 kg h^{-1} at 15% dry solids (DS) has been designed in CIGIT based on the preliminary researches [11,12]. The system was particularly descripted in the following four parts as illustrated in Fig. 2.

2.1. Reactor design

As the heart of SCWO, reactor always suffers from both corrosion and plugging. Several types of reactors have been invented to handle these problems. The related reviews can be found in literatures [2,7–9,13]. The DGSWR was adapted in the new system. The basic structure of DGSWR is the same as that of a TWR: a double wall reactor consists of outer pressure bearing wall and inner transpiring wall (also named as porous wall). Transpiring fluid fills the annulus between the two walls and continuously flows through the transpiring wall to form a protective film on the inner surface of transpiring wall. The protective film is a mobile surface and can protect transpiring wall from corrosion and salt deposition [2]. Pure water was used as the transpiring fluid in TWR and was replaced by air in DGSWR, which is the essential difference between these two types of reactors. Based on the special physical properties of air, DGSWR can enhance the anti-corrosion and anti-plugging of TWRs and to avoid the demerits of TWRs. The feasibility of DGSWR has been proved in previous research [11].

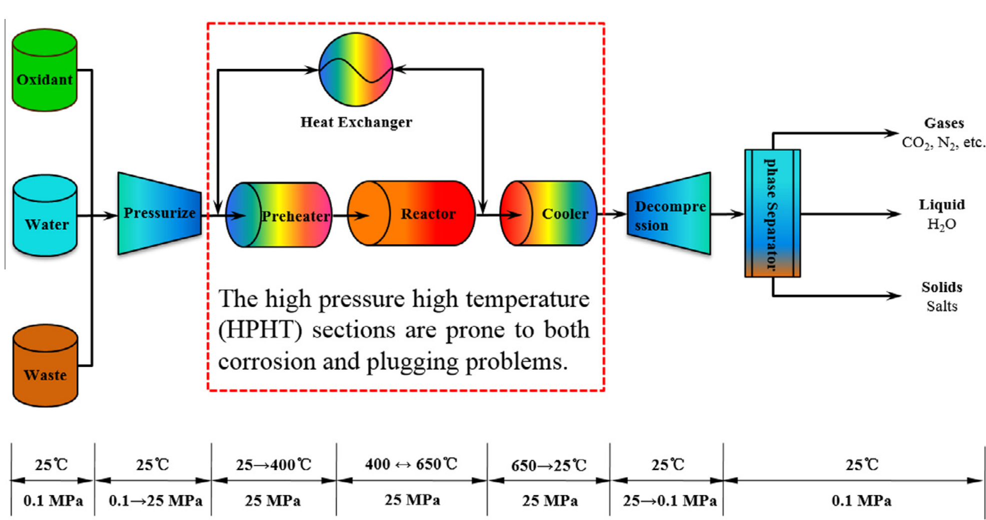

Fig. 1. Typical SCWO process. Adapted from literatures [8,9].