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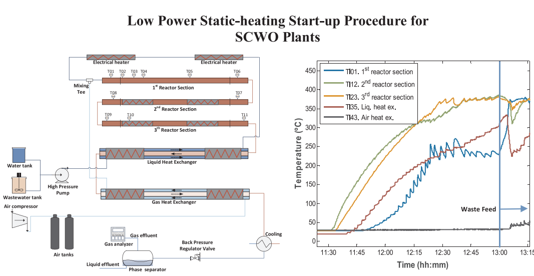
Low power static-heating start-up procedure for supercritical water oxidation plants

J.M. Benjumea[a,b,*], J. Sánchez-Oneto[a,b], J.R. Portela[a,b], F.J. Jiménez-Espadafor[a,b], E.J. Martínez de la Ossa[a,b]

[a] Department of Chemical Engineering and Food Technologies, Faculty of Sciences, Agro-Food International Excellence Campus CeiA3, University of Cádiz, 11510 Puerto Real, Spain

[b] Energetic Engineering Department, Higher Technical School of Engineering, University of Seville, 41092 Seville, Spain

GRAPHICAL ABSTRACT



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ABSTRACT

One of the factors against the upscaling of SCW plants is the enormous amount of energy demanded during the start-up phase to reach the stationary state and the autothermic operation phase.

This work proposes a new strategy with a lower energy cost and, consequently, with a smaller initial investment. It consists on statically heating up different sections in an SCWO plant by means of electric heaters distributed throughout the plant. A constant temperature of 400 °C can be reached in a plant containing a mixture of water and ethanol at near critical pressure. Then, when the feed and the oxidant are pumped, the oxidation reactions starts. Such reaction, in turn, releases the heat required for autothermal operation. The experiments that have been carried out have confirmed that the Low Power Static-heating Start-up Procedure (LPSSP) proposed would mean a saving of 46.4% in power consumption when compared to a conventional start-up procedure.

1. Introduction

SCWO technology is widely implemented at different universities and research centres, both at laboratory and pilot plant scales. However, only a few companies have dared to bring up this technology to industrial scale and built actually operative plants. Some of those companies, such as Hanwha, SCFI, Innoveox, General Atomics or SuperWater Solutions have developed commercial plants that are currently operating. On the other hand, some others have stopped working due to different issues [1]. This is why, we are still to face some technological challenges that enable a better understanding of the process if we are to improve the performance of industrial plants. Despite recent advances in some relevant aspect, such as the control of corrosion [2–6], the treatment of salts [7,8], the use of optimized reactors [9–11]

* Corresponding author at: Department of Chemical Engineering and Food Technologies, Faculty of Sciences Agro-food International Excellence Campus CeiA3, University of Cádiz, 11510 Puerto Real, Spain.

E-mail address: josemanuel.benjumea@uca.es (J.M. Benjumea).

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or the increased knowledge on new reaction mechanisms [12–15], there are still some difficulties associated to the development of this technology at an industrial scale that are still to be overcome. The extreme operating conditions with regards to temperature and pressure, as well as the enormous demand of energy to reach such operating conditions, have a negative impact on the economic viability of this technology.

Several economic assessments on the performance of SCWO plants have already been published. Different cases and different plant sizes have been studied, but no definite results have been reached yet. Modell and Svanström [16] worked out the total cost for a SCWO plant at around 100–170 €/dry t at 10% solid. Griffith and Raymond [17], estimated the total cost of a plant to process up to 9.8 dry t/day of sludge at around 190 €/dry t solids processed. O'Regan et al. [18] calculated the cost corresponding to the treatment of more than a 24 dry t/h plant being in the range of 174–197 €/dry t of sewage sludge depending of the solid concentration. Marulanda and Bolaños [19] analysed the cost of a SCWO plant for the treatment of PCB contaminated oil which resulted in a total cost of 62 €/L. Vadillo et al. [20] worked out a total cost of 230 €/t for a 1 t/h SCWO plant. In view of such a diversity of results, both in relation to installation investments as well as to running costs, it is hard to come to an unanimous conclusion. Nevertheless, all researchers agree on the large initial investment required, together with the great amount of energy that is necessary to deliver for the process to reach the supercritical phase, which directly affects its operating costs.

The size of the facilities seems to be a key factor with regards to the economic viability of these plants. In this sense, and particularly for large scale plants, the stage before the supercritical conditions are reached, i.e. the start-up, seems to be one of the main problems. This stage requires a large amount of energy to reach the necessary temperature level where the oxidation process starts. Moreover, the external energy supply must be maintained to finally achieve autothermal operation, where the hot effluent is capable of heating the feeds (wastewater and oxidant) that circulate along the system in a continuous mode. Therefore, an industrial SCWO plant requires both a powerful heating equipment and a considerable and punctual energy supply during such start-up stage.

Most conventional SCWO plants use some form of device, such as a heater or an oven to aid the feeding current to reach supercritical conditions.

First, therefore, the temperature in the whole plant increases as the heat is transferred from the feed circulating at a particular flowrate. Heat is transferred to the steel pipes and then to the different devices in the plant (reactor and heat exchangers). This is generally a slow process due to the high thermal inertia of this type of systems and also due to the fact that the energy is only delivered at the preheating area.

Only when the supercritical conditions are reached after the static heating, the feeding of the waste starts. The oxidation of the feed generates energy that is used to heat the air and liquid flows. At that moment, autothermic stage should be reached and the delivery of external energy drops drastically [21]. It could even go down to zero depending on the waste concentration in the feed and the heat generated in the reaction. Nevertheless, the amount of energy required to reach autothermic stage is extremely high and it grows higher as both the size of the plant and the start-up flowrate grow.

The pilot plant at Cadiz University [22–24] with an operating flowrate of 25 L/h is fitted with four power sources of 3 kW each, which makes a total power of 12 kW. By extrapolating this power demand to a 4 m^3/h plant, the resulting power demand would be close to 2MW. This would imply an enormous investment on an equipment capable to deliver such power and would hinder its economic and technical feasibility at an industrial scale. Our research group has patented a new start-up strategy [25] that consists on a slowly and statically heating up process that intends to reduce energy requirements to reach stationary state in SCWO plants. This new strategy (Low Power Static-heating Start-up Process, LPSSP) suggests that a close to autothermal state can be reached thanks to the oxidation reactions. This new strategy would not only reduce the power demand for the start-up phase, but also would cut down the initial investment on power supply equipment.

This work intends to demonstrate the energy and time saving achieved by LPSSP compared to a conventional start-up procedure. Not only LPSSP is useful for the oxidation of supercritical water, but it can also be applied to other technologies that require high operating temperatures, such as wet oxidation or hydrothermal liquefaction.

2. Materials and methods

The new start up protocol proposed, LPSSP, has been tested and verified at Cadiz University's pilot plant. The performance of this pilot plant has been explained in previously published studies [23,26,27] in which different types of wastewater [22,24] have been satisfactorily treated.

In order to implement a new start-up procedure at Cadiz University's pilot plant, additionally to the already installed heating devices – (1) at the feed preheating section (4 × 3 kW each) and at the (2) air inlet section (1 × 3 kW each line) – other low power heaters were installed at new places in the plant (reactor and heat exchangers). Fig. 1. shows the new low power heaters (250 W each) installed at the (3) second (2 × 250 W) and (4) third sections of the reactor (2 × 250 W), as well as in all the sections that are fitted with (5) liquid (8 × 250 W) and (6) air (4 × 250 W) heat exchangers. Instead of replacing the 3 kW heaters in the liquid preheating section by new 250 W heaters, we decided to limit their output and make them deliver the same power as the new heaters (250 W). This would allow to evenly heat the whole system while the fluid remained static.

The first requirement to start-up the plant with a static heating strategy, is to feed the plant with a water solution containing 4% ethanol (or any other cofuel) and to rise the pressure up to the operating level, i.e. 250 bar. After these conditions are reached, the feeding pump is stopped and the exit valves are shut to keep the whole plant full with the water and alcohol solution, i.e. with a static fluid at 250 bar. It is then when the heating process is started. Since the fluid remains motionless, the amount of power required to raise the temperature is considerably less than at a conventional start up where the fluid is continuously flowing in an open circuit. Furthermore, since there is no oxidant, there can be no reactions and since the solution is clean, no plugging or coking takes place in the system. Therefore, using less powerful heaters the temperature of the whole plant increases gradually until it reaches supercritical conditions (around 400 °C). At this point, the pump is started again to inject the oxidant. When the oxidant gets in contact with the ethanol, the immediate reaction rapidly raises the temperature in the whole system. No additional heating is necessary at the first section, since the temperature rises when the oxidant is added. This, together with the low power heaters that are required at the rest of the sections both in the reactor and the exchangers, would considerably reduce initial investments.

3. Results and discussion

In order to assess the performance of the new start-up strategy as above described, several experiments have been carried out where the plant has been started up by the conventional method and by LPSSP. The following section shows a comparison between both start-up procedures. It includes the temperature in the reactor and analyses some working parameters that may affect SCWO plants viability.

3.1. Conventional start-up process

Fig. 2 shows the time evolution of the temperature at different thermocouples in the system during a conventional start-up process at Cadiz University pilot plant. The feed circulates through the plant, but