



## Hot surface ignition of oxygen–ethanol hydrothermal flames



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### ABSTRACT

In this work we present the hot surface ignition of turbulent diffusion oxygen–ethanol hydrothermal flames. For this purpose up to 520 W electric are dissipated through a heating wire. The mean wire temperature and the electrical energy it releases at ignition are reported by measuring the voltage drop across its resistance. The wire temperatures – up to 385 °C – are compared to the auto-ignition temperatures reported in literature and the ignition map of our system is drawn. In case the reactants are injected at room temperature, the hot surface enables ignition for ethanol contents in the aqueous fuel stream above 30 wt.%. In the end, potential applications of the ignition system in the scope of supercritical water oxidation and hydrothermal spallation drilling are highlighted.

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### 1. Introduction

A significant part of the energy available on earth is stored in the underground: either in the form of fossil fuels, radioactive minerals or heat. In order to access it, drilling is required and currently allows to gather a consequent share of the energy consumed by EU countries [1]. Spallation rock drilling is an alternative technology that could prove economic viability over conventional drilling, especially at depth where hard polycrystalline rocks are encountered. It uses the low thermal conductivities of these rocks and the resulting differential expansion induced by local heating, to break them in disc-like fragments (spalls) [2].

However, to sustain the borehole and excavate the cuttings from a great depth, a water-based drilling fluid is necessary. In an evaluation of deep drilling systems, Maurer et al. [3] classified spallation drilling with low potential due to the inoperability of flame jets in water filled boreholes.

Since 1985, flames burning in supercritical water ( $T \geq 374$  °C,  $P \geq 221$  bar) are reported in the literature [4]. Such flames burn at high temperatures [5] and could be used to provide the intense heat flux required for spallation [2].

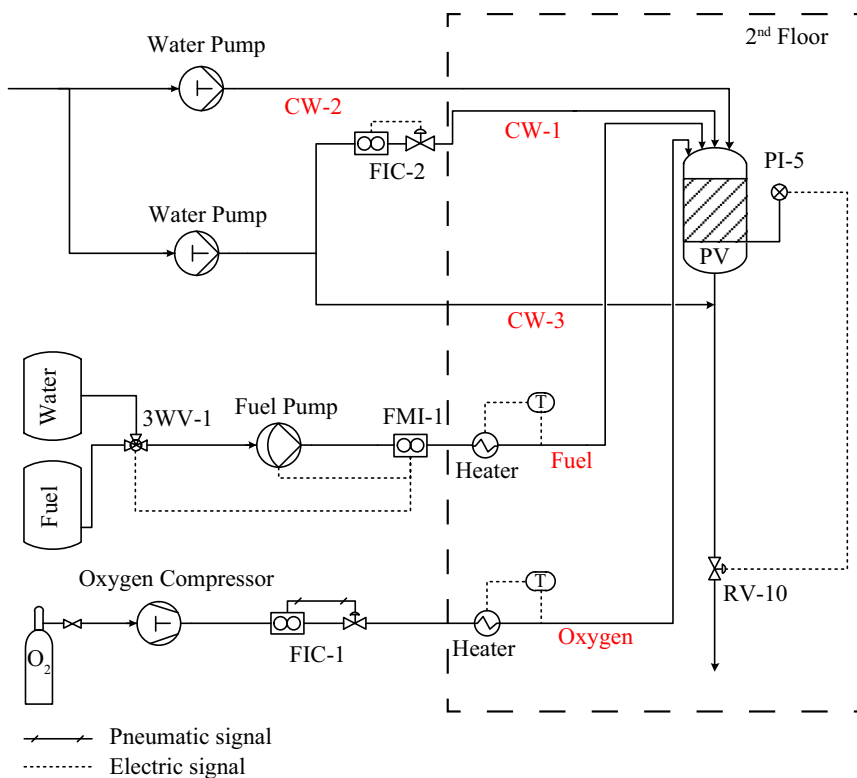
To assess exhaustively the potential of these flames for drilling, further efforts are needed. Most experimental facilities [2,6,7] built to study hydrothermal flames rely on the auto-ignition of the

mixture which requires preheating of the components above its self-ignition point, i.e. at temperatures ranging from 350 °C to 510 °C, depending on the fluid dynamics, the mixture composition, the oxidizer, the pressure, etc. This is cumbersome and does not promote the development of the drilling technology due to the important equipment expenses and operating costs.

A further motivation for this work is the potential to reduce the costs of supercritical water oxidation (SCWO) facilities, used industrially to treat waste water [8–10]. A benefit of SCWO over conventional waste destruction processes is the zero-emission of dioxins, NO<sub>x</sub> and other harmful products as a result of the relatively low reaction temperature [10]. Moreover, compared to conventional combustion which often requires a drying process beforehand, the wet destruction of aqueous waste is favorable. Despite these intrinsic advantages over other waste destruction processes, SCWO is hindered by corrosion problems, plugging and high running costs [10–14]. The running costs and corrosion problems are related to the direct proximity of a highly corrosive fluid with the equipment. In addition to corrosion, heating and cooling cycles, as a result of the preheating necessary to start the waste oxidation, induce extreme requirements on the material. This often results in leakages and galling of the high-pressure fittings.

The utilization of an igniter could reduce the surface of material in contact with the highly corrosive working fluid – as no preheating units are required – and permit reliable ignition of hydrothermal flames. Up to date, forced ignition systems are not common in the scope of high pressure combustion: In 1981, Chen et al. [15] used NiCr wires charged with a capacitor to initiate

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**Fig. 1.** Process and instrumentation diagram of the experimental facility. The cooling water (CW-1, CW-2) and the oxygen plus the fuel network lead to the pressure vessel (PV). The cooling water (CW-3) quenches the effluent stream before the back pressure regulator (RV-10).

decomposition waves in liquid ethylene oxide at high pressure – up to 250 bar. In 1995, Steinle et al. [16] used of a thin NiCr wire electrically heated and determined its temperature at ignition from its temperature-dependent resistance. Augustine et al. [17] used a high voltage spark plug to ignite a supercritical  $H_2/O_2$  mixture in an aqueous environment at 100 bar.

Finally, in a recent study from our laboratory [18], a heating coil has been used to support the ignition of turbulent diffusion hydrothermal flames at 260 bar, reducing therefore the need for preheating. Using the hot surface igniter, preheating temperatures around 370 °C for an aqueous mixture containing only 12.5 wt.% ethanol ( $P_c \approx 200$  bar,  $T_c \approx 350$  °C [19]) were reported. At ignition, wire temperatures up to 850 °C for mixtures containing up to 17.5 wt.% in the fuel stream were reported.

Nevertheless, supercritical injection of the reactants was required to ignite turbulent diffusion flames under high pressure. This considerably hinders the development of spallation drilling and SCWO until an improved mechanism is developed to further reduce this preheating demand.

In this work we present the hot surface ignition of oxygen–ethanol flames of different concentrations in an aqueous environment pressurized dynamically to 260 bar. The mixtures are injected in the combustion chamber at near-room temperatures and at ignition, energies up to 200 J are dissipated through the electrical resistance. This results in a wire temperature around 360 °C.

## 2. Experimental facility

The experimental facility used in this study occupies a space of 70 m<sup>3</sup> on two floors (Fig. 1). It consists of four main fluid networks leading to a pressure vessel (PV). Two high pressure plunger pumps ensure redundancy of the cooling water, a triple head metering membrane pump pressurizes the fuel – an aqueous ethanol mixture

( $w_{EtOH}$  wt.%) – as two gas boosters pressurize the oxygen. Two electrical heaters serve to preheat the fuel and the oxygen streams to the desired temperature ( $T_{heaters}$ ) before their mixing and subsequent ignition by the hot surface igniter. The vessel pressure is adjusted to 260 bar by throttling a triple stem needle valve (RV-10). The effluent stream leaving the pressure vessel is mixed with the water provided by one water pump (CW-3) to cool the mixture well below its flash point before the back pressure regulator (RV-10). Further details of the experimental facility is presented by Stathopoulos [7].

The wall-cooled hydrothermal burner (WCHB-4) is a pressure vessel of 4<sup>th</sup> generation (Fig. 2(a)) built at ETH-Zurich and tailored for the study of turbulent diffusion hydrothermal flames. A concise review of the previous designs (WCHB-1,2,3) is presented by Augustine [5]. The new vessel has a volume of 5.83 L and its pressure bearing walls are designed to sustain 650 bar at a temperature of 500 °C. It consists of a main volume ( $\varnothing = 100$  mm) surrounded by a cooling jacket ( $\varnothing = 140$  mm). Both are separated by a cylinder perforated with 12 holes to balance the pressure.

The combustion chamber (Fig. 2(a)) is composed of two concentric tubes. The bore of the inner one ( $\varnothing = 10$  mm) discharges the hydrothermal flame in the main volume of the pressure vessel and the intermediate space permits to cool down its internal wall with 475 kg/h of deionized water – initially at 20 °C (CW-1). In its main volume, a class 1 K-Type thermocouple ( $\varnothing = 3$  mm) is positioned to measure the feed temperature ( $T_{feed}$ ).

The fuel injection nozzle (Fig. 2(b)) is responsible for the mixing of the reactants and plays therefore a crucial role in the following experiments. Its design is based on the know-how of our laboratory with SCWO processes [6,7,20,21] and is a combination of a coaxial and a radial nozzle where the fuel is injected at an angle with respect to the oxygen flow. As the coaxial nozzle retards ignition, the radial can produce chugging phenomena for injection angles of 90° [21].

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