COMBUSTION TECHNOLOGIES WITH LOW POLLUTING EMISSIONS LEVEL – LOW SWIRL COMBUSTION

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Abstract: The paper presents the most important aspects regarding the low swirl combustion system (LSC), the design of the low swirl burner (LSB), the development and technological transfer stages from the lab-testing burner to the burners used in the high power gas turbines. The development of this low swirl combustion technology was required by the bigger and bigger constraints on the burning equipments that use fossil fuels, regarding the reduction of pollutant emissions. The low swirl combustion technology is an easy and cheap way to ensure the efficient combustion of the fossil fuels with a low level of pollutant emissions.

Keywords: lean premixed technologies, low swirl combustion, low swirl burner, low swirl injector, dry low NO_x methods

1. INTRODUCTION

In the last half of the last century, the researchers have carried out considerable efforts towards the development of several efficient and clean combustion systems, namely with a low level of pollutant emissions. By increasing the combustion efficiency, an important saving of fuel consumption and, at the same time, an associated reduction in CO_2 emissions was achieved. The most important issue to be solved by the researchers is the accomplishment of the two challenges at once, namely the efficiency increment and the pollution reduction. Sadly, for the most part, the price paid for the pollution reduction is exactly the decrement of the energy efficiency. A high thermic efficiency usually features a high combustion temperature, with a constant flame, but mostly, this leads to a high level of NO_x emissions.

There are combustion technologies that can block the emerging of NO_x compounds, for example oxy-fuel combustion (replaces the combustion air), that leads to a high temperature combustion, with a constant flame. This technology has the advantage of a high thermic efficiency, a low NO_x emission, and the possibility of seizing the carbon dioxide resulting form the combustion. The big disadvantage of this technology is the high price of the necessary oxygen.

Another example is the cooling flame combustion technology [1] which, because of the temperature reduction, can cause issues regarding the combustion instability and that causes an incomplete combustion of the fuel and, at the same time, a growth in the CO emissions [2]. Even more, by using staged combustion technology, a substantial reduction in NO_x can be achieved by creating the low fuel and oxygen combustion areas, which leads to the decrease of the combustion intensity, and, sadly, which also leads to the decrease of the thermic efficiency of the whole process [2].

The fluid bed combustion technology [3], having the advantage of using the solid fuels with low thermic power and of low NO_x emissions, is not able to exceed the problem of relatively low combustion efficiency, caused by

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the low temperature of the combustion [2]. The lean premixed–LP technologies were embraced by the gas turbine producers under the generic name of dry low NO_x method-DLN, a technology embraced in order to comply with the environmental requirements [4]. However, in order to comply with the very strict requirements regarding the ultra-low emission level standards, the DLN burners must work at the lowest limit of the combustion stability outer cover, whereat the noise, the combustion instability and the decrease of the flame may affect the engine's performance [4].

The burning technology with premixed fusion that operates with the unique concept of low swirl combustion-LSC is a promising answer for these problems. This technology was initially developed in the Lawrence Berkeley National Laboratory on a small burner of about 15 kW for fundamental research use, so that the complete understanding of the operating principle was reached [4, 5]. This concept is based on the use of the aerodynamic spreading properties of the premixed fusion flame [6]. This is a simple, robust and rapidly adjustable technology for the gas turbines' burners in order to reach the emission targets without significant altering the system's configuration, the efficiency and the costs [4]. The low swirl combustion technology was also adapted for the gas turbines. The tests conducted on the prototype low swirl injectors–LSI for the 10 MW engines have showed that this is a promising actual cost solution, by replacing the traditional injectors, in order to let the current DLN turbines to reach the emission target of <5ppm (with 15% O_2) for NO_x and CO [4].

2. LOW SWIRL COMBUSTION PRINCIPLES AND THE HISTORY OF THE TECHNOLOGICAL TRANSFER

The swirl flow burners were essential in the premixed and no premixed systems because of the benefic influence on the flame stability, the combustion intensity and on the performances of the burner. Until now, the gas turnines' burners and the industrial systems have used high swirl burners-HSB, on which the rotating movement generated by the injector (or by the burner) is strong enough to produce a completely developed internal recirculation area at the burner's inlet [4]. For the conventional no premixed combustion, the role of the recirculating large area, known under the name of toroidal vortex core, is to induce the air-fuel turbulent mixture. In the DLN premixed systems, the reticulating area ensures a stable heat source needed for ignition continuity of the fresh reacting substances [4].

The low swirl combustion has been recently developed. It is an excellent instrument for the laboratory research on the flame/swirl interactions [7]. The operating principle exploits the dissemination mode of the premixed mixture flame, which does not apply in the no premixed combustion case. The premixed flame exhausts the reacting substances thorough the self-supporting reaction, wave that is being disseminated at the flame speed, determined by the composition of the mixture, the thermodynamics conditions and the swirl intensity [4]. Opposite to this, the no premixed diffuse flame is not disseminating (is moving towards the reacting substances) because the combustion takes place only in the fuel-oxidizing jet mixing area. The low swirl combustion exploits a hydrokinetics phenomenon, called divergent flow. Even from its name, the divergent flow is an expanded jet flow. This occurs when the swirl intensity is deliberately lowered at the limit where the swirl almost doesn't get formed, this being the forerunner of the back flow generation and of the recirculation. That is the reason the LSC operating principle is fundamentally different from the high swirl combustion, which is typically for the gas DLN, where the powerful toroidal vortex is the essential element for the holding and continuous flame reignition [4].

The low swirl combustion can be implemented in two ways. The originally enforced burner uses low airstreams in order to create the swirl movement. The low swirl burner (LSB), developed for the heaters and for the gas turbines, uses swirl vanes, which represent its core, and that have two flow passing aisles. The reactants flow (the air-fuel mixture) passes through the openings in the center channel and through the surrounding vanes, thus determining the swirl. This configuration was designed for the low swirl flow generation that sustains a stabile or a floating flame, that being the main characteristic of the low swirl combustion method [8].

The vane burner development for swirl generation is the critical step for putting into practice the LSB concept. This is because the main flow decession and the swirl speed control are considered too complex and expensive. Sadly, the researches regarding the vane burners were focused on the rapid swirl achievement [9, 10]. The former knowledge is insufficient for designing a vane burner that could ensure the divergent field flow generation needed by the LSB. The LSB design, illustrated in the Figure 1 below, was reached after extended experiments took place [11].

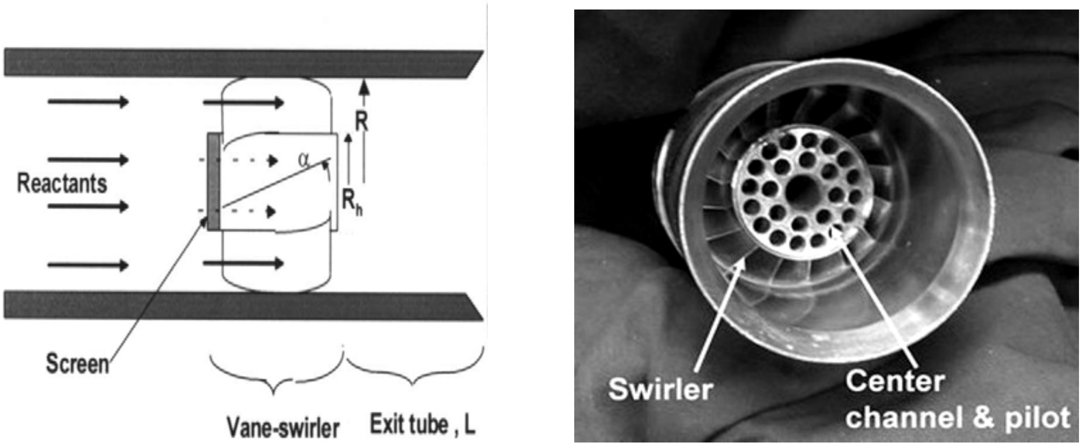

Fig. 1. Low-Swirl Burner - LSB [11].

The main characteristic that makes the difference between this burner and a conventional one is the center channel of the burner that has passing holes so that part of the reactants are able to pass and remain unswirled [12]. The originality of this design consists in the use of different degrees passing blocking screens in order to balance the pressure decrease beyond the central channel and the swirl vanes. These screens have the role to maintain an uniform distribution of the radial flow and to generate swirl [12, 13].

The LSB remains cold at touch because the flame is lifted and has no contact with the burner's body and so the latter doesn't heat. It was initially believed that the lifted flame is completely undesirable because in the conventional burners this ment an unstable flame behavior. This unique LSB divergent field flow allows the lifted flame to self-adjusts and to remain robust even in these limit conditions where the NOx emissions have reached the minimum possible [8]. All these are illustrated in the Figure 2.

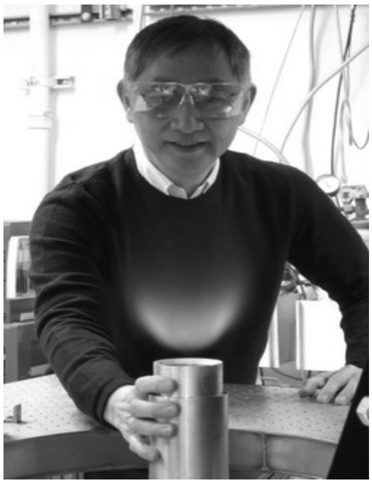

Fig. 2. The lifted flame of the LSB [8].

The US Department of Energy (DOE) Office of Science's Laboratory Technology Research has supported the LSB commercial development programme. The 2 inch diameter LSB was designed for domestic natural gas fired water heaters having a 15kW power and has succeeded in lowering the NO_x emissions from more than 120 ppm to under 10 ppm without compromising their efficiency [8]. An important discovery was the fact that this little LSB covers a large power range, from 15 kW to 600 kW, which indicates a multiplication rate of 40:1, fact unseen at another burner used in the low-NO_x technologies. This feature shows that the LSB can be scaled at bigger capacities for industrial use [8]. With the California Institute of Energy Efficiency and the DOE's Industrial Technology Program at the Office Energy Efficiency and Renewable Energy support, LSB was scaled at large capacities and successfully used in natural gas fired ovens and boilers. Maxon Corp. has introduced the first LSB for sale in 2003. Presently, this company has two production lines for LSBs that cover a range from 90kW to 35 kW, all of them emitting less than 9 ppm of NO_x (adjusted at 3% O_2). Subsequently, LSBs for gas turbines have been developed for electric energy supply [8]. DOE Distributed Energy Resources at the Office of Electricity helped Solar Turbines of San Diego, CA, to adjust the LSBs for small gas turbines, having an electrical power range from 5 to 7 MW. These gas turbines operate with pressures higher than 15 atm and temperatures over 400 °C. The first challenge was to apply the LSC method in these pressure and temperature conditions. The second challenge was designing the LSB for the gas turbines' combustion system. Because the vane burner was already a standard component of the high swirl combustion used in gas turbines, the decision was made to accelerate the development for the Solar turbines transition from the present burner, with high swirl, to the functioning in the LS (low swirl) mode. The transformation was successful so that the fuel low swirl injector was used-LSI, this representing a re-technologization of the fuel high swirl injector (HSI) from the SoLoNOx system. In this way, the NO_x emissions were lowered under the 5 ppm value (adjusted at 15% O_2) [8]. Figure 3 is presenting the graphic representation of the NO_x emissions for a fuel LSI assembly developed for a Solar T 70 gas turbine, which are 2.5 times lower than the SoLoNOx injectors (HSI) that use the high swirl combustion concept.

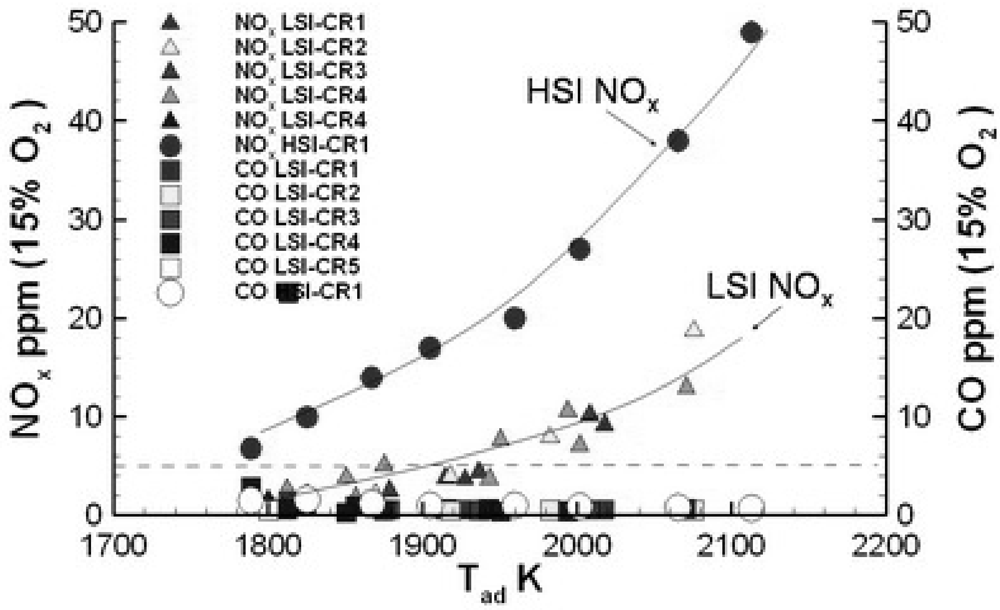

Fig. 3. NO_x and CO emissions for LSI use compared with HSI use at the Solar T 70 turbine [8].

4. CONCLUSIONS

The main characteristics of this very low emissions combustion technology, such as the lifted flame that doesn't allow the heating of the burner's body, the simple design, the extended use possibilities, the great flexibility regarding the fuels to be used (any type of gas fuel), the low re-technologization cost for the existing equipments, the burner's size multiplying potential without losing its characteristics and, not the least, almost zero emissions, legitimates the expectances regarding the emergence of clean (regarding the pollution) and efficient energy equipments.

The emergence and development of these low swirl burner's makes possible their use together with other low emission combustion technologies (staged combustion, no flame combustion) that can also ensure a high thermic efficiency thus answering the present constrains.

In Romania there are under operation gas turbines produced by Solar Turbines, San Diego, CA, that are equiped with SoLoNOx combustion systems that use high swirl injectors with a NO_x emission level that is in line with the present environmental regulations. It is expected that, once the new type of low emission level burners emerge, the limitations for new energy equipments acquisition will harden, respectively to be equipped with these performing combustion systems regarding the emissions and their efficiency.

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