Development of passive and active flow control methods for combustion process optimisation in diffusion flames.

Problems of clean and safe combustion methods are nowadays extremely important, particularly in Poland where most of industry and power plants is based on conventional combustion technologies. Any attempts aiming to minimise emissions and increase reliability of the combustion devices is always welcome both by specialists and by the general community. The objective of this project is to develop and apply efficient flow control methods for optimisation of turbulent diffusion flames. The project focuses on deeper understanding of multi-scale mixing processes, their modulation and intensification of interactions between large and small flow scales. These phenomena are still not fully understood and are now limiting the establishment of low-emissions and safe industrial devices (combustion chambers, burners, engines, cauldrons, etc.). A particular attention will be put on control of: (i) flame shapes; (ii) flame lifting dynamics/flame stability; (iii) pollution reduction; (iv) strongly unsteady processes including the flame initiation (ignition) and flame propagation, the phenomena that are crucial from the point of view of safety, reliability and environmental cleanliness. One of the novel elements of the project is the combination and simultaneous use of the passive and active flame control methods, which will allow alteration of the local and global characteristics of the mixing process. The key outcome of the project will be a better understanding of turbulent mixing/combustion phenomenon and guidance how it can be optimised, e.g., sustained, intensified or suppressed. The specific objectives of the project are the following: (i) to develop deeper physical knowledge on the fuel/oxidiser mixing process and its impact on the flame initiation, stabilisation, extinction and flame shaping phenomena, which are critical for the development of novel, efficient, and clean fuel use; (ii) to develop and verify knowledge based passive/active optimisation tools, which will enable efficient tuning of mutual interactions between the flow/flame scales along the whole energy spectrum. So that engineers will have increased predictive capability to produce innovative designs at lower cost.

Within the project we will apply both the passive and active flow control techniques, which will operate in a separate and combined variant. The former approach will rely on application of shaped fuel nozzles (rectangular, polygonal, fractal, etc.). It has been shown in the past that non-reactive jets issuing from non-symmetric and sharp edged nozzles characterize better mixing properties compared to their circular counterparts. We will verify to what extent this holds in reactive flows. Within the project we will try to find an optimal shape of the nozzle for varying fuel and oxidizer parameters (speed, composition, temperatures) and depending on assumed optimization criterions (e.g. maximum/minimum lift-off height of the flame, maximum/minimum flame surface area, the most uniform temperature, etc.). From the point of view of better flame control under a variety of different flow regimes, the active control approaches seem to be much more flexible. Active methods require energy input (excitation) whose type and level may be fixed (predetermined approach) or vary depending on instantaneous flow behaviour (interactive approach). In this project the active control will be obtained through a tuned excitation introduced to the flow through an axial, axial + flapping, axial + helical (azimuthal) forcing. Based on the non-reactive jet type flows it has been demonstrated that the use of this type of excitation can dramatically alter the flow behaviour/shape and can even split the main flow stream into several distinct branches. Within the project the active approach will be combined with the passive one and the parametric studies concerning varying forcing amplitudes, frequencies and phase shifts will be performed. The research will be carried out using advanced CFD (Computational Fluid Dynamics) methods and will be complemented by an experimental research. The simulations will be performed with the help of high-order numerical code SAILOR using direct and large eddy simulation methods (DNS/LES) with an advanced combustion model (Eulerian Field PDF). The experimental works will be performed on a research set-up equipped with a system for active flow modulation with a set of variable shape nozzles.

Ability to control strongly unsteady processes (e.g. ignition, flame stability, flame shape variability) is indirectly but largely dependent on the mixing process. The auto-ignition is conditioned by fuel/oxidiser mixing in high temperature regions, whereas the success of the spark is dependent on its localisation in the region of well-mixed ignitable mixtures. Thanks to the novel and precise mixing optimisation methods both the spark and auto-ignition processes will be efficiently controlled, which is crucial for efficiency and safety of many industrial devices. Ability of efficiently changing the flame shape is very tempting and the works in this direction offer new perspectives. The project results, if the assumed goals are reached, will open completely new horizons in steering not only the flame initiation and propagation phases or flame shapes, but also the whole combustion process.