1. Introduction

Combustion accompanies human beings since the very beginning. The combustion process itself is all the time almost the same, but our knowledge and understanding of combustion changed from its very primitive use ages ago to very special, advanced technological applications in present days. Unfortunately, even now we still cannot say that our knowledge and understanding of the process is complete. Its complexity causes that even with the use of modern research tools there are still several problems and topics that have solutions beyond our availability. In addition, huge progress in technology development requires new, more advanced applications of combustion process for which better understanding of the process is strongly needed. This is why combustion researches concentrate not only on just physics of the process, but most of them are related to its special applications such as: Diesel engines particulate matters, air-planes engines, power generation, incinerating plants or combustion-generated pollutants (for example dioxin and \( \text{CO}_2 \)) reduction. It means that researches in this discipline are necessary not only for the science itself, but also for engineering and its application to our society [Ikeda Y., Mazurkiewicz D., 2000, 2001, 2002; Hunicz J., Mazurkiewicz D., Niewczas A., 2002]. As interesting research subject, the phenomenon is complex and its researches in various fields have been carried out all over the world. There are several questions to be answered and solutions to be found.

In the last decade laser diagnostic techniques [Chigier (Ed.), 1991] became the most popular and promising tool in combustion process researches - such new techniques as Phase Doppler Anemometry (PDA) or Particle Image Velocimetry (PIV) allowed making an important progress in the researches [Taylor (Ed.), 1993]. With the use of lasers, new combustion experiments become possible and new information together with better understanding of the process available. Several previous borders are widely opened now, but as a result of this - some new and unexpected problems appeared too. It seems that for most of them, solutions can be found within Computer Science (CS) tools. It can be expected that the next huge step in combustion researches can be made with the use of Discovery Science (DS) tools and techniques, especially after a huge boom of neural networks and fuzzy logic technologies during the last two decades.

This is why - the aim of this paper is to discuss how to access combustion essentials in terms of CS tools, to extract knowledge and discovery dominant relations in combustion physical and chemical reactions and scale factors, for example in industrial combustors? What should be the CS algorithms and methods of combustion parameters optimization and its systems \textit{in situ} control? What should be the rules generated using expert knowledge? Do we have enough knowledge to apply these technologies or any further researches will be necessary?
2. Combustion laser diagnostics and its experimental data

For better understanding of combustion process characteristics and especially its dynamics, laser measurement techniques have been used in various fields including: internal combustion engines, gas turbines, furnaces, power generation and so on. Some typical research topics are related to: analysis of fluid dynamic mechanisms for different geometries, limitation and applicability of measurement systems, spatial spray structure and its time-dependent motion analysis, investigations on droplet and air behaviour together with their interactions, etc. In our case different research topics of the combustion process are investigated [Ikeda Y., Nakajima T., Kurihara N., 1996, 1997].

Let us take into consideration two examples, which will be later examined – gasoline injector spray for self-ignition 4-stroke engine and 0.1 MW class oil burner for industrial furnaces. Typical experiments on air assist injectors are related to unsteady spray investigations (Fig. 1) and are important in the technology of gasoline injectors used in engines for automobiles. Fuel spray formation by gasoline injectors have been used in internal combustion engines in order to improve engine performance and reduce exhaust emission. Understanding of mixture formation requires data such as: each fuel droplet velocity, diameter, evaporation rate, mass flux, entrained air, drag coefficient, spray shape, penetration and others [Lefebvre, 1989; Ikeda et al, 1996].

The shape of spray and individual droplet detailed dynamics can be measured with very high temporal resolution, up to 40 kHz at a certain location [Ikeda et al, 1997]. Such a high temporal resolution measurement is necessary because of specific characteristics of the process. In combustion time scale for physical phenomena is $10^{-3} - 10^{-6}$ sec and time scale for chemical reaction is equal to about $10^{-6} - 10^{-10}$ sec. Time scales of the process and measurement time resolutions cause additional problems resulting in limitations of data acquisition area. On the other hand – steady flow of heavy oil spray is analysed when gas type burners for industrial furnaces are investigated. The performance of spray combustion in oil burner is associated with fuel atomisation, fuel droplet dispersion, evaporation and so on. One of purposes is for example to investigate the relation between droplet dynamics and spray combustion characteristics near a burner where recirculating flow holds the flame [Kawahara et al, 1996].

Problems, which appear during experiments, are almost the same for all researches of this kind. For example, a gasoline injector spray has been measured with the use of PIV technique to understand its instantaneous spatial spray structure [Ikeda et al, 1996]. But the data size of each image was equal to about 1 MB for each, single laser shot. In this case, at least one thousand images were needed just for statistical analysis. It means, that several GB datasets had to be stored only for one, single experimental operation. Similarly during typical PDA experiments there are 264 points and 5 measured parameters in each of them. Each of these parameters has 10,000 measured values just during one operation. It means, that single operation dataset includes more than 13 million of different values. It makes the process of data analysis and interpretation more complicated and time-consuming.

**Fig. 1.** Typical spray spatial observations in case of air assist injector
Experimental database size is not the only problem of combustion process experiments with the use of laser diagnostics. Also the data structure makes the analysis more complicated [Ikeda Y., Mazurkiewicz D., 2001]. On effective fuel injection an influence have for example such phenomena as: injection itself, collisions, evaporations, agglomerations, mixing, ignition, flame propagation, etc. In addition combustion flow is a mixture of gases, solids and liquids that properties also have to be taken into consideration.

From the industrial point of view very important for the combustion process is good understanding of turbulent motion, which is unsteady and 3D. But unfortunately, as a result of rapid mixing - this motion is random and irregular. Such a list of problems accruing when combustion process is analysed can be extended almost to infinity. Does it mean, that so many different problems make researches on combustion impossible? Of course they are possible and necessary, but complicated. In addition, these problems cause the necessity to search for new solutions beyond typical combustion research methods. First references shows that such solution can be found with the use of Data Mining (DM), Knowledge Discovery in Databases (KDD) and other similar CS tools.

3. DS in combustion researches

Investigations of combustion process are complex and involve interactions between many different scientific disciplines. Observed phenomena understanding, practical datasets analysis, theoretical modeling, formulation and combustion problems solving requires support from mathematical and analytical methods. Described above several problems of which combustion complexity consists, makes it evident that its experiments have to be extended by some additional interactions with numerical and theoretical research methods. This problem was deeply described by Roy [Roy (Ed.), 1998], who proved that there is no experimental technique that would be able to provide all information necessary to explain or predict the occurrence of combustion instabilities, which typically appear in several, sometimes completely different fields or systems.

Progress in Computer Science (CS) allows now to analyse and explain physical phenomena, such as combustion is. But not only explanations and data analysis for better understanding of the process is needed. In some cases predictions are also necessary. All this can be done with high accuracy or reliability, when CS tools are applied. But unfortunately, only relatively small group of combustion researches is involved in the process analysis with the use of CS. Some of these few applications are:

- Algorithm for detecting laminar flow and turbulence [Nogawa et al, 1997], which makes possible to obtain not only qualitative, but also quantitative information about the flow field.
- 3D vortices extraction in turbulent fluid flow [Zhong et al, 1998], during which the classification study of fluid motion together with vortex structure detection in the boundary layers of turbulent flows were done.
- Artificial Neural Networks (ANN) were used for combustion process prediction and description. The target of these investigations was to make a temporal evolution model of reduced combustion chemical system with the use of ANN [Blasco et al, 1998]. Two different networks were used for this topic. The first one was used for prediction, representing the temporal evolution of the reactive chemical species. The second one was used for modeling of some relationships, there is - temperature and density of the mixture as a function of the chemical composition of the system.
- ANN were also used in another project [Blasco et al, 1999] for some simulation of methane-air combustion.
- Homma and Chen [Homma and Chen, 1999] made combustion process optimization by genetic algorithms. They have obtained some NOx emission reduction as a result of post-flame process optimization.

All of above described examples come from very new references. Results are valuable for better understanding of combustion process, but most of them are just preliminary and concern only on basic research topics. Data analysis, optimization and control needs more advanced CS applications. But what is the reason that only few examples of such applications are available? Why they are so basic in comparison to other disciplines? First of all combustion is too complex. CS commercial software available on the market is not suitable for this process analysis, which should be done in interactions with several scientific disciplines. It is necessary to prepare special CS algorithms only for combustion process analysis. Such an algorithm should be readjusted to specific characteristics of the process. It should include several CS tools and sub-algorithms for separate, parallel and serial support of combustion process sub-topics analysis. This way, as the first step, separate research objects should build for each sub-topic of the combustion. As was described before – combustion is a very complex and determined by many different parameters which has different time scale and data structure. This is why first of all its understanding and splitting into
several basic sub-topics is necessary. According to chosen research topics, converting into future, for example Data Mining problems should be done. In addition - proper experimental equipment should be also designed in consideration of limitation and applicability of measurement methods, accessibility to the measurement point, enough data number, enough resolution, suitable data format, uncertainty and error estimation of the measurements. For each of these sub-topics all given and measured variables together with uncertain parameters and dominant factors should be described. This step is equal to problem understanding and problem viewing in typical data analysis or process modeling with the use of CS. From each experiment designed for such research objects, separate datasets will be obtained. Each of them should be described, including the structure, missing values, data uncertainty, data storage and its resolution. It is especially necessary in the case of combustion data, which are discrete and have some characteristic time and spatial resolution. All these sub-datasets will create new combustion database. The database will include raw data, which preparation with the use of CS tools is necessary. In the case of combustion this step should include especially - data visualization, reduction, decomposition, missing values estimation, transformation, cleaning, etc. Preparing the raw data typically includes all necessary activities to construct of initial raw data the final database. This final combustion process database will be fed into further modeling methods.

The next step of data analysis is its modeling. Several different modeling techniques can be used according to analysed data type, the sub-topic or expected final result. This is because each one has different purpose, structure or was acquiesced to give different information about each of sub-topics separately or about whole phenomena. Modeling requires the use of trial-and-errors method, this is why in some cases additional return to raw data preparation step will be necessary to reduce the modeling step error or increase modeling efficiency. The final step of combustion sub-topics analysis with CS is results validation. This step will help to compare all models and choose the best one for future use or further applications. This way better phenomena understanding will be obtained as a final result.

These are basic steps that should be taken into consideration when creating any algorithm for combustion process analysis with the use of CS tools. Several problems of combustion itself and its data analysis or modeling has an influence on the structure of the algorithm. This is why typical commercial software cannot be used for solving such complex problem as combustion researches are. Special software or additional algorithms have to be prepared for this kind of researches. The same as was done in the case of medical investigations of brain images or astronomical images processing.

Computer Science (CS) includes several tasks tools and topics, such as data cleaning and data reduction, prediction, classification, etc. In the case of combustion process most of them have to be applied parallel, according to basic sub-topic, researches target or data type. It causes additional complication, especially when our aim is to apply laser diagnostics and process modeling with some data analysis for process control, monitoring or optimization. It is strongly required to create some kind of combustion control. Researches and data analysis with the use of CS tools for better understanding of the combustion phenomena is just the beginning of very long way. Technology development requires on-line monitoring of the process together with its control or optimization. The whole laser diagnostics measurement together with data analysis and further decision making in process optimization should be considered as one integrated system.

The software, data analysis tools and algorithms together play important role in whole integrated process. It should help to regulate emission of pollutants, combustion intensity and flammability limits [Roy (Ed.), 1998] or allow making automated vortex structure detection. It is known that combustion control or optimization can be achieved through energy release control or optimization. At this moment we are able to control combustion chemistry, but fluid dynamics in situ controlling, optimization and/or monitoring is still a big challenge. For both - combustion and CS researchers, who together have to find proper ways. There is no doubt that especially in this case, CS tools and methods can help a lot.

As described above interactions with several research topics are necessary for combustion phenomena better understanding and development. These interactions require also better understanding of them process and its research problems in CS community. All the applications can be made only as a result of close combustion and CS communities cooperation. But is there any research filed comparable to combustion which previous experience with CS applications we can use? Answer for these questions can be found when analysing the history of brain or astronomical image analysis and processing systems. Both of these disciplines had several problems because of their researches complexity and difficulty to apply theoretical CS solutions in practice. No typical models or commercial software was possible to be used. And after several years of close cooperation with CS community they have established Astronomical Image Processing System (AIPS) and comparable brain image processing methods. For example the AIPS uses
several CS tools to reduce and analyse astronomical data. It includes very good and successful selection of individual programs for analysis and visualization of optical astronomy data. It seems that in the case of combustion researches we should follow the same way.

4. Conclusions and future work

Combustion phenomena have been taking place in various industrial applications such as internal combustion engines, furnaces, gas turbine, heater and so on. Combustion is complex and as a result its researches are very complicated, but also extremely wanted for social or environmental development. Progress done in laser diagnostics methods helped to achieve also a huge progress and new results in combustion process experiments. But the development and new problems that appeared when laser techniques were used, requires new solutions. These solutions are among CS tools and methods. CS application can help to make another huge step, especially in the case of process in situ control, monitoring or optimization. This is why investigations, which results are presented in this paper were done in order to apply CS approach to analyse combustion data, extract knowledge and understand the physics. Laser diagnostic data and its measurement limitations are considered and examined for making “problem understanding and viewing” map. It was found that experimental dataset was discrete and its resolution was not enough well suitable for ordinary CS tools. The map of thinking to establish the research direction could be one of subjects in DS research. The goal of our research is to develop algorithm and flow chart in order to implement it into practical combustion diagnostics. This paper describes the first step of our researches which aim was to identify the research frame structure with applications of CS tools. Future investigations researches will concentrate on next steps - there is each process deeper analysis according to algorithms described above. Final goal is to make modeling of knowledge extraction from combustion data, especially in real-time analysis.

It is also extremely necessary to find a proper tool among CS techniques to solve some of the combustion laser data analysis. For this purpose the author continues researches on neural networks and their scientific and industrial applications, also with links to other topics, including models and systems of “intelligent” real-time industrial control (Fig 2.).

Why are the neural networks so attractive compared with alternative techniques? Partly because they simplify the modelling process itself, and also because they enable comparably easy practical application also in real-time industrial systems, which are strongly related to investigated topic. From numerous practical applications published over the past decade there seems to be substantial evidence, that these techniques indeed posses an impressive ability [Mazurkiewicz D., 1999; Norgaard M. et al, 2000; Sohlberg B., 1998].

Fig. 2. Example model of computer based real-time control system
5. References


Dr Dariusz Mazurkiewicz
Technical University of Lublin
Ul. Nadbystrzycka 36, 20-816 Lublin
E-mail: d.mazurkiewicz@pollub.pl