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# Up to date experimental facility for testing low-NOx burners

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## 1. Introduction

Burners for combustion of gas and liquid fuels (e.g. natural gas and fuel oil, respectively) belong to the most important equipment in process and power industries and elsewhere. Efficient research and development is not possible without an experimental facility. During recent period the experimental research and burner's development has been strongly supported by sophisticated approach based especially on CFD (Computational Fluid Dynamics) modelling.

The paper analyses the above described approach including the importance of know-how. Differences between experiments aimed at research and development and testing of industrial burners are described and discussed. We take into account experimental testing facility as a whole as well as importance of the key apparatus – combustion chamber. From the point of view of potential industrial applications it is necessary to consider operational regimes which are close to those from the real operation.

Everything is demonstrated through recently built, up to date experimental facility which enables testing of burners with duty up to 1.8 MW, which is convenient both for research and development as well as for testing and improving industrial burners.

## 2. Introduction

Nowadays, in time of dynamic development of computer simulations and demand to reduce costs of research and development of products, it is possible to see effort to reduce number of real experiments. It concerns first of all experiments, that are demanding on investments in the research facility and/or operating costs (fuel, water, chemicals). There are many cases, where it is not possible to substitute the real experiment by computer simulation completely. One of these many cases is the research and development on the field of combustion and construction of different burners with stepwise fuel and combustion air supply or internal flue gas recirculation.

The experiment on the field of combustion of gaseous and liquid fuels is possible to split to the two basic categories. The first category contains experiments, which are done by groups developing new burners or enhancing their performance. The second category includes different experiments in the field of applied or industrial research. Each of these categories has specific requirements on the planning of experiments and the equipment of the testing facility. In dependence on the purpose of the tests, different burner testing facilities are built, which differ by their sizes of the combustion chambers, by fuels and by measuring instrumentation. Industrial burner testing facilities typically consist of several combustion chambers with different size, which cover large heat duty range, and they have fuel management, which allows the combustion of different fuels and their mixtures (Baukal, 2004). In contrast to that, experimental units used by research institutions can typically accommodate only burners with small heat duty and they are limited by availability of different fuels. The main advantage of experimental units is in their measuring instrumentation and well educated personnel, which has large range of theoretical and practical knowledge. In case it is required to carry out multiple tests for the purpose of empirical modelling or as a support (validation) for CFD modelling (e.g. of nitrogen oxides formation) (Kermes et al., 2004), it is necessary to use large experimental unit with high heat load or industrial testing facility. Low-NOx burners have complicated geometry and the manufacturing of small-scale prototypes with small heat duties is very difficult. It is however very difficult to find experimental units with burner duties greater than 1MW and possibility to fire different fuels.

## 3. Main equipment and technological circuits

The main devices and technological circuits of media in experimental units and industrial burner testing facilities are combustion chambers, combustion air preheaters, systems of flue gas exhaustion and fuel and combustion air supply systems. In case of liquid fuel combustion it is necessary to provide also compressed air or steam for atomization, possibly for preheating of heavy fuel oils. When the facility includes water cooled combustion chamber, it is necessary to have a water circuit for extraction of heat from the cooling water.

### 3.1 Combustion chambers

The central piece of equipment of experimental units and industrial burner testing facilities is clearly the combustion chamber or combustion chambers used for burner testing. There are several possible designs, either fully insulated (adiabatic) combustion chamber or water cooled combustion chamber, possibly with partial insulation on the flame side.

The first group of combustion chambers that are fully insulated and where it is possible to neglect heat loses, finds its application in cases, when combustion chamber is only a hot flue gas generator. The flue gas is heat carrying medium, that is required for subsequent exploitation in the main process performed by the facility, and radiative heat transfer from flame is not desirable. Thus the control of combustion chamber operating conditions is subordinated to the higher priority of obtaining required flue gas parameters for the main process.

The second group, which is widespread among research institutions and burner manufacturers, consists of water cooled combustions chambers. They are either horizontal or vertical. The cooling of the combustion chamber allows to simulate conditions similar to conditions in the heating furnaces of the process industry. It is usually possible to reach heat absorption rates between 45 and 70% of released heat, depending on the thermal load of the combustion chamber and possible partial insulation. In the manufacturing of the combustion chamber, it is necessary to carefully select the final treatment of the internal surface. In cases, when it is not possible to paint the surface with special warmish, that has low reflectivity, it is better to keep it without any surface conditioning.

The experience with the operating of new burner testing facility (Fig. 1) that has horizontal water cooled combustion chamber with a maximum heat load approximately 1.8MW (internal diameter of 1 meter, length of 4m) shows that it is possible to reach heat absorption rate of about 50% of the heat input. At heat burner duty of 1.55MW, flue gas temperature is approx. 920°C, oxygen concentration ranges between 3 and 3.5% (in the wet flue gas) and the flame length between 2.5 and 3m.

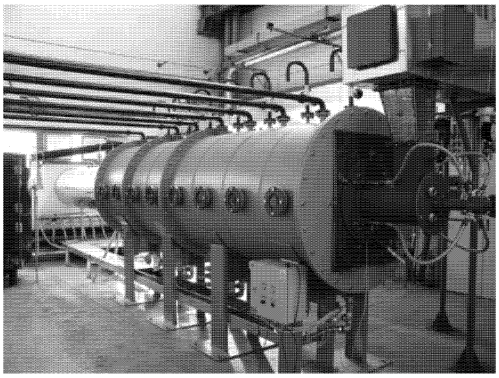

*Figure 1: Experimental water cooled combustion chamber*

In case that shell cooling is split up to more sections length-wise with respect to the chamber length, it is possible to evaluate intensity of the heat flux along the flame. The next positive effect of the splitting in several sections is an improved water circulation in the cooling shell, thus avoiding local boiling caused by poor water circulation. For low heat load up to about 3.5MW is a suitable length of the sections about 0.5m. The length of the sections in a combustion chamber is dictated by the size of the combustion chamber, but a sensible choice must be made to obtain a suitable number of sections. The number and size of inspection holes (windows) depends on the type of the type of unit. It is good to design at least one window per each section in experimental research units, because it enables detailed observation of the flame and installation of measuring instrumentation. In large industrial combustion chamber it is not common to have a high number of inspection holes, especially in water cooled combustion chambers. For observation of the flame and safety of operation, it is however advisable to place one or two inspection holes at opposite sides of the combustion chamber. The size and number of the inspection holes along the combustion chamber depends on their purpose.

### 3.2 Combustion air preheater

The utilization of the heat of flue gas for preheating of combustion air is mostly not possible due to process control considerations in both experimental units and burner testing facilities. The utilization of flue gas from a tested burner for preheating combustion air is very difficult from technical reasons and therefore air preheaters are built as separate units.

From the research point of view, the unavailability of combustion air preheating is not a critical deficiency of the experimental unit. The basic dependence between combustion air temperature and nitrogen oxides formation was described very well by a large number of researches. It is also very well known, that the increase of combustion air temperature leads to increase of the flame temperature and so to higher formation of nitrogen oxides usually. In case that air preheating is required, it is possible to use electrical preheating in very small experimental units; otherwise it is necessary to solve the preheating similarly to industrial testing facility that means by independent air preheater.

Combustion air preheating is required very often in industrial applications. The reason is simple – decreasing the fuel costs, because increasing air temperature by 20°C it is possible to save about 1% of the fuel costs. In case that a burner will be installed on a unit with air preheating, it is very useful to test it with preheated air to find real formation of nitrogen oxides. For standard applications, maximum air temperature about 450°C should be sufficient. There are several different technical solutions of the air preheater design. The basic design is a combustion chamber with block burner and U-tube heat exchanger. Another possible design is a compact equipment, i.e. a co-axial heat exchanger with integrated combustion chamber placed inside (Stulir at al., 2003).

### 3.3 Control of pressure in the combustion chamber

Another very important parameter for burner design is pressure in the combustion chamber. It may range from overpressure of approx. 2000Pa downto underpressure of approx. 1000Pa and it is even possible to find applications that exceed this range. An industrial burner testing facility should be able to cover the above mentioned range or it should at least be able to guarantee sufficient reserve in comparison to produced burners. Small experimental units are built for a specific research purpose very often and the requirement of maximum overpressure and negative pressure comes out from the type of the research. Larger experimental units, that are similar to industrial testing facilities, have a reduced range of pressure control.

Overpressure in the combustion chamber is created by throttling by means of orifice plates or flaps that are installed in the flue gas duct. Below-atmospheric pressure generation and control is more difficult than the generation of overpressure. It is not possible to use flue gas fan without cooling of flue gas that has typically very high temperature. That means it is necessary to consider flue gas temperatures higher than 700°C.

As a relatively advantageous way of negative pressure creation seems the use of ejectors using air as driving medium because, besides the creation of negative pressure in the combustion chamber, the flue gas stream is cooled at the same time. It is possible to use either compressed air, or air forced by high pressure fan. It however seems better to use air forced by high pressure fan equipped with frequency converter from the point of view of fine pressure regulation. In case it is required to test burners at atmospheric pressure or the underpressure is to be small, it is very useful to have a possibility to open the ejector to enable entrainment of air from surroundings; otherwise the amount of driving air would be very low, thus causing high temperature at the stack.

**3.4 Fuel management**

A characteristic difference between industrial burner testing facility and experimental unit used for research consists in range of the fuel management. Fuel management of the industrial testing facility has to be designed so that it would be able to satisfy the requirements on different fuels and mixtures related to different industrial applications. That means sufficient storage capacity for technical gases (hydrogen, nitrogen and so on) for creating of different mixtures simulating real fuels of the real plants (refinery gas, mining gas, off-gases etc.). Liquid fuel management should include heated storage tanks, source of compressed air and/or steam for atomization and feeding system with sufficient pressure and flow rate control.

The setting-up of fuel management in large experimental units is more difficult than in industrial testing facilities. Small experimental unit may be fed from pressure bottles, because the fuel consumption is low. Larger experimental units with heat load on the order of hundreds of kilowatts or units that are similar in size to small industrial testing facilities, is very difficult with gaseous fuels (with the exception of natural gas and LPG) because the storage of pressure bottles is an extremely difficult problem from the safety point of view. It is nevertheless possible to have some variability for liquid fuels. It is necessary to make a decision about the types of liquid fuels that should be combusted, because most liquid fuels have to be preheated before feeding into the burner. An acceptable compromise for larger experimental units seems to be a possibility to feed liquid fuels up to viscosity similar to viscosity of medium-heavy fuel oil for which suffices preheating by water at about 100°C.

## 4. Instrumentation and control

The biggest different between experimental units and industrial testing facilities consists (with possible exceptions) in instrumentation and control. This is given by the different purpose of the units. What should however connect all types of units is sufficient safety of operation that should not limit range of possible types of tests.

In burner testing, performed for burner development purposes, it is satisfactory to find out whether the burner works, has a stable flame and produces emissions below limits. Additionally, informative measurements of fuel burn-out along the length of the flame may be required. The equipment of the testing facility by measuring instrumentation and control system must then correspond to these requirements. Control valves are operated manually very often. The instrumentation for measurement of process values is reduced to a minimum that is necessary for the performance of the tests. Emphasis is put on simple operation of the testing facility. The limited accessories with measuring instrumentation are given by the fact that the costs must be covered by profits generated by sale of burners.

Regarding requirements on measurement instrumentation in large experimental units with high heat load, it is necessary to find reasonable compromise among accuracy, response time, durability and reliability of instrumentation. All instrumentation that is connected to the emergency shut down system must be highly reliable, with good durability. The response time and even accuracy of other instrumentation do not have such significance.

Experiences with the operation of a new experimental unit show that it is useful to split the instrumentation into two independent groups. The first group is created by the instrumentation closely connected to the safety control system of the experimental unit. The second group consists mainly of portable instrumentation where it is possible to use highly sensitive and accurate sensors that are more fault-prone. It is necessary to be aware that frequent failures and corresponding remedies are excessively demanding for operators and influence the course of experiments.

## 5. Conclusion

The construction of burner testing unit or facility for experimental research brings several difficulties that require compromises caused primarily by economic criteria. The search for a proper trade-off in the size (maximum heat load) of the combustion chamber and in the choice of connected accessories and instrumentation in experimental units is very difficult. The rebuilding or enlargement is rarely possible from various reasons.

A complete design of an experimental research unit with higher possible heat load should be solved so that it would be possible to utilize it also for other purposes than burner research (for example as heat source or flue gas generator for testing of other devices like off-gas cleaning units).

The principal point in the construction of experimental facility with high heat load is the instrumentation and control system, whose prime purpose is securing safety, without limiting the range of possible experiments.

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