Karlsruhe Institute of Technology

Mixed Fuel Vacuum Burner-Reactor

Review and Evaluation of Concept and Recommendations

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1. Preliminary remarks

On the recommandation of Dr. Hans. P. Rheinheimer Prof. Bockhorn has been asked to survey a concept for a Mixed Fuel Vacuum Burner-Reactor, which has been developed in the recent past by Ing. Jorge de la Sovera. After receiving scarce material describing the development a first short statement about the invention by Prof. Bockhorn was as follows:

As far as is apparent from the difficult to read and less precise indications, this procedure is a two-stage combustion in swirl combustion chambers. Because of the applied swirl, it shows a good mixing of reactants and air in the primary combustion chamber as well as in the secondary combustion chamber, which is fed with secondary air. Additionally, regarding to the documentary the combustion is intended to be performed under vacuum (i.e. reduced pressure). The documentation gives no clear indication, how and to what level this vacuum should be created.

In principle the multi-stage combustion of residues is not a new technology. However, the particular exemplification could be a promising version of a two-stage process. Therefore, it remains to be seen, whether the intended patent applications will come into complete effect.

I have not been able to make a specific evaluation of this process – even after a repeated and thoroughly review of the documentation entrusted to me - since clear and precise data concerning this process are not available (e. g. measurements, whereby patent application have been substantiated, mass and energy balances, flue gas composition etc.).

However, I am quite happy to assess more accurately this process if appropriated documents, e.g. patent specifications, measurement results of test series with prototypes, procedure schemes and device schemes etc. will be available for me. [1]

After this it has been determined to commission Prof. Bockhorn to evaluate the proposed process in more detail and to develop conclusions for the further treatment of the provided development. For that, a number of short descriptions, photographs, videos and pieces of text have been delivered to Prof. Bockhorn, all of them describing in more or less detail the process under discussion and different as well as modified completions of the process. More recently, an US patent application publication has been issued [2], which has been also handed to Prof. Bockhorn. On the basis of these documents the proposed Mixed Fuel Vacuum Burner-Reactor process is evaluated.

2. Technical description of the Mixed Fuel Vacuum Burner-Reactor process

The Mixed Fuel Vacuum Burner-Reactor process has been designed for completely and free of residues burning low grade fuels such as glycerine, water containing alcohols, waste oils, soy-oil, industrial fuel oil or combinations of these. The combustion of low-grade fuels of that kind requires high temperatures, over-all excess air and comparatively long residence times at high temperatures. The proposed development meets these demands by a staged combustion process combining an intensively swirled primary flame with an equally well swirled secondary flame.

The primary flame is generated with the help of a kind of injector-burner within a primary combustion chamber. The injector acting as a kind water-jet pump is driven by air compressed at a level of 10 to 20 bars. Due to the pumping effect the injector sucks primary gaseous fuels which are provided with the help of a manifold mounted at the upstream end of the injector. Air jet and gaseous fuels are intensively mixed and discharged into the primary combustion chamber where an inverse diffusion flame is established. The primary combustion chamber exhibits an internal conical shape and is equipped with blades or fins to create a macroscopic vortex and swirl, so that the primary flame is stabilized in a rotating flow field. The swirl homogenizes more or less the primary flame, so that the temperature at the outlet of the primary combustion chamber is approximately uniform.

The primary combustion chamber is restricted at the downstream end. This restriction accelerates the flow leaving the primary combustion chamber and creating again reduced pressure, so that secondary fuel can be injected at the restriction. The secondary fuel is injected in counter-direction of the swirl of the primary flame and in counter-direction of the mean flow, so that intensive mixing between the hot gases from the primary flame and the secondary fuel takes place. This secondary fuels consist of the above mentioned low grade fuels or mixtures of these, the chemical energy of which is to be converted into thermal energy.

The restriction forms the transition from the primary combustion chamber to the secondary combustion chamber and leads into the secondary combustion chamber leaving a free annulus between the downstream end of the primary combustion chamber and the secondary combustion chamber. Secondary air is entrained through this annulus into the secondary combustion chamber, sufficient to completely burn the secondary fuel. The secondary combustion chamber is likewise equipped with blades to generate a macroscopic swirl of the flow in the secondary combustion chamber.

A cross section of the Mixed Fuel Vacuum Burner-Reactor is given in Fig. 1.

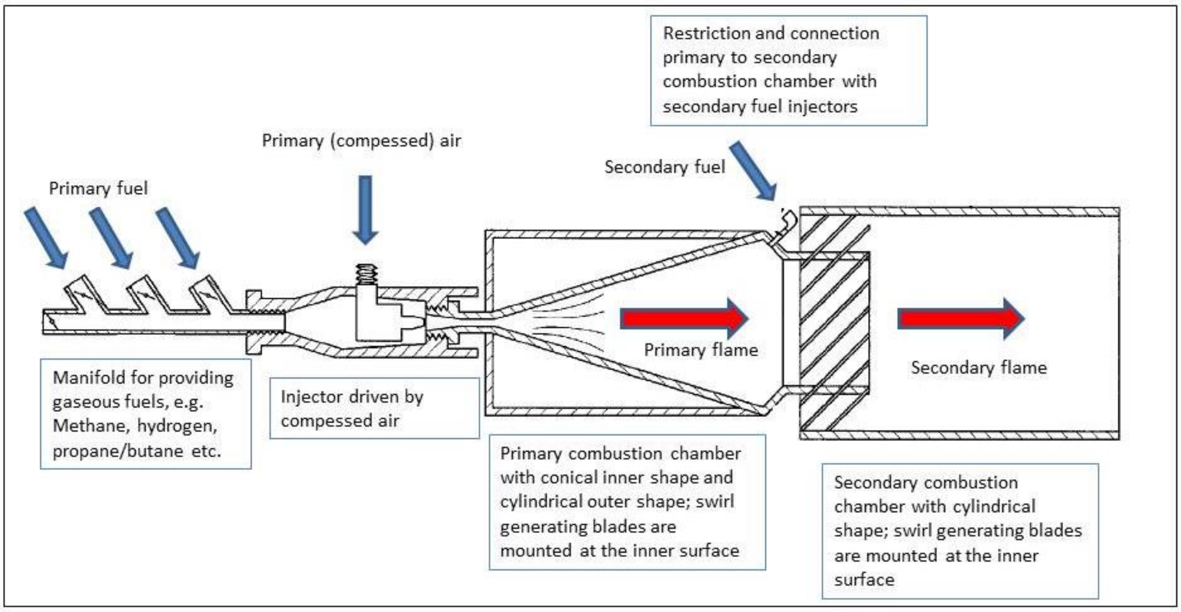

Fig. 1: Cross section of the Mixed Fuel Vacuum Burner-Reactor adapted from [2].

The operating principle of the Mixed Fuel Vacuum Burner-Reactor is obvious from Fig. 1. The gaseous primary fuels are ingested from the fuel providing manifold (most left) into the vacuum chamber of the injector (left) and mixed with the primary combustion air, which simultaneously drives the injector. The mixture is released into the primary combustion chamber (right) where an inverse diffusion flame (inverse: inner jet air, outer jet fuel) is stabilized. The flow in the primary combustion chamber is moved into rotation by swirl generating blades and thereby homogenized. At the downstream end of the primary combustion chamber a restriction is provided to accelerate again the flow, so that secondary fuel through (mostly cooled) injectors can be fed into the hot gases. The transition piece of the primary combustion chamber is smaller in diameter than the cylindrical secondary combustion chamber, so that an open annulus exists between primary and secondary combustion chamber. This annulus serves as inlet for secondary air necessary for complete combustion of the secondary fuel. The flow in the secondary combustion chamber again is set into rotation by structures or blades mounted at the inner surface of the secondary combustion chamber. The complete burnout of the secondary fuels occurs in the secondary combustion chamber.

The realized versions of the burner/combustion chambers are of about 1 meter in length (each primary and secondary combustion chamber) and about 0.5 meter in diameter (secondary combustion chamber) as obvious from the delivered photographs. The thermal load of the process is in the order of magnitude of 60 to 350 kW for the gaseous fuels and of 70 to 900 kW for the liquid fuels, measured global temperatures in the secondary combustion chamber are about 1300^{o}C to 1500^{o}C [3].

2.1. Strengthes of the Mixed Fuel Vacuum Burner-Reactor process

As mentioned above the Mixed Fuel Vacuum Burner-Reactor process has been designed for disposing low grade fuels such as glycerine, water containing alcohols, waste oils, soy-oil, industrial fuel oil or combinations of these etc. Completely and free of residues burning of low-grade fuels of that kind requires high temperatures, over-all excess air and comparatively long residence times at high temperatures. Meeting these demands, the low grade fuels could be used advantageously for providing thermal energy. This is the promising idea of the proposed development.

The proposed development provides high temperatures with the help of a primary flame fed by methane, hydrogen (surplus hydrogen from electrolysis), or other gaseous fuels, the utilization of which for other purposes is not obvious. The primary flame is homogenized by means of an air jet with high momentum from the air injector and by applying swirl to the flow in the primary combustion chamber. Depending on the kind of secondary fuel the process can be operated - after heating the secondary combustion chamber – without that primary flame.

The low grade fuel is injected into the flow from the primary flame by injectors, the geometric arrangement of which can be adapted to the flow conditions. The direction of the injectors normally is in counter flow to the flow of the primary combustion chamber and in counter direction of the swirl, so that a complete vaporization and mixing of the liquid fuel with the hot combustion gases of the primary flame can be achieved.

The combustion of the low grade fuel is accomplished by the entrainment of secondary air into the secondary combustion chamber through the annulus between the secondary combustion chamber and the transfer section of the primary combustion chamber. The entrainment of the secondary air is also driven by the momentum of the flow in the primary combustion chamber, which is provided by the injected air, expansion through combustion and the acceleration of the primary flow by the constriction at the downstream end of the primary combustion chamber.

The flow in the secondary combustion chamber is set into rotation by blades or swirl generating structures mounted at the inner surface of the secondary combustion chamber. In this way the residence time in the hot region assumed to be high enough for complete burn-out of the low grade fuels. All of this guaranties the conditions, viz. sufficient high temperatures, excess of air, sufficient long residence time, for converting low grade fuels into harmless combustion products releasing thermal energy.

The Mixed Fuel Vacuum Burner-Reactor process resembles two stage or multi stage combustion processes for the combustion of gaseous or liquid fuels for proving thermal energy from low grade fuels or the combustion of production wastes. The unique feature of the proposed process is, that the entire combustion is driven by the momentum of the primary air. Therefore, it is crucial for the entire process to adjust the pressure and the flow rate of the primary air to contain sufficient momentum to absorb the primary fuel, to generate the macroscopic swirl in the primary combustion chamber, to be accelerated by the restriction at the downstream end of the primary combustion chamber, to absorb and entrain sufficient secondary air for complete combustion and to generate the macroscopic swirl in the secondary combustion chamber. In similar two stage combustion processes this is achieved by separately controlling primary and secondary air flow and to operate the primary combustion at fuel rich conditions, i.e. comparatively low temperatures and the secondary combustion at fuel lean conditions, i.e. equally well comparatively low temperatures.

2.2. Weaknesses of the Mixed Fuel Vacuum Burner-Reactor process

At present the design of the Mixed Fuel Vacuum Burner-Reactor process has been pursued on a semi-theoretical basis, where the criteria have been the proper functioning of the injector, burner and combustion chambers and the performance of the process has been justified by observing the flame occurrence and flame shapes and lengths and measuring global flame temperatures. For complete assessment of the process these qualitative criteria have to be replaced by quantitative criteria, i.e. the performance of the process has to be measured by burn-out functions based on measured flue gas concentrations, pollutants which can be formed during combustion should be measured (soot, NOx, unburned hydrocarbons etc).

For the complete and free of residues combustion of the low grade fuels temperature, mixing processes and residence time in the hot region of the combustion chambers must be controlled. This achieved by the global air to fuel ratio and the local velocity and temperature gradients in the combustion chambers. All those multiple and different parameters are controlled at present solely by the momentum (or kinetic energy) of the primary air and the fixed geometric dimensions of the burner and combustion chambers. For a clear and complete assessment of the operating conditions of the process the quantitative relation of all these parameters to the freely variable has to be constituted. For example, the size of the combustion chamber cannot be scaled up unlimited geometric similarly to adapt higher thermal loads because the flow field generated by the injector and the swirl follow other scaling laws. These scale up problems are documented for example by operating conditions where the flame length exceeds considerably the reactor length and the burnout is not completed at all at the downstream exit of the secondary combustion chamber, see e.g. Fig 2.

Fig.2: Operating conditions where the flame length exceeds the length of the combustion chamber [4].

A more specific and quantitative evaluation of this process is adversely affected by the lack of clear and precise data concerning this process, e. g. quantitative geometric dimensions, quantitative flow rates of air and fuels etc., which would enable calculating mass and energy balances.

The application of combustion devices in Germany (and in Europe) for any purpose is not possible without monitoring the efficiency and all the emissions from those combustion devices. Already in the approbation and design phase justified declaration of the emissions of a planned plant is necessary. At present this data is not available for the proposed Mixed Fuel Vacuum Burner-Reactor process.

In Germany (and supposedly in Europe) the market for some of the considered liquid fuels is limited. Glycerine and alcohols are absorbed from the Chemical and Pharmaceutical Industry and used oils are refined und recycled intensively. This situation may be different in countries outside of Europe.

3. Conclusions and Recommendations

The Mixed Fuel Vacuum Burner-Reactor process resembles a promising two stage or multiple stage combustion processes for the combustion of gaseous or liquid fuels for proving thermal energy from low grade fuels or the combustion of production wastes. The unique feature of the proposed process is mixing of fuel and combustion air in both stages driven by the momentum of the primary air.

The main purpose is to convert the chemical energy of cheap (waste) fuels into thermal energy, saving high grade fossil fuels and thereby working expenses for providing thermal energy. For estimating the perspectives of this process a detailed market analysis is necessary that gives the availability and prices for the low grade fuels under consideration for e.g. South America and possibly other countries. As mentioned in the previous section, in Germany (and supposedly in Europe) the market for some of the considered liquid fuels is limited and they are available for prices that are comparable to fossil fuels (or higher).

For a further step in developing the Mixed Fuel Vacuum Burner-Reactor process a detailed computational fluid dynamics (CFD) study is proposed, which clearly identifies the operation limits, performance of the process (by calculating burn-out) mixing of fuel and combustion air and flue gas concentrations etc. This study can be performed by using commercial CFD-programs employing sophisticated combustion models. CFD-studies of this kind are standard at Karlsruhe Institute of Technology.

On the basis of the results of the CFD-study an experimental program should be performed where the results of the CFD-study are verified and where a complete assessment of the process by quantitative criteria, i.e. measured performance, measured burn-out functions based on measured flue gas concentrations, measured pollutant concentrations etc. is possible.

References

[1] E-Mail of Dr. Hans P. Rheinheimer to Dr. Baccino and Ing. De la Sovera from 13.8.2014

[2] United States Patent Application US 2014/0234787 A1, 21. 8. 2014

[3] Video “Reactor-Video” received 25.8.2014

[4] Set of photographs received 16.8.2014

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(Prof. Dr. H. Bockhorn)