Report AFORSK: PLASMA BASED TOTAL TREATMENT OF WASTE

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Short Summary

. The project addressed the physical properties of thermal plasmas. It aimed at the synergy of experimental and theoretical analysis in order to explain the radiation transport under extreme conditions in modern plasma torches.
By application of a *thermal* plasma based system to a wide range of possible feedstocks which are CO_2 neutral, a clean syngas of high caloric value was produced simultaneously with a non-leachable vitrified lava. The results provided the advanced technology for clean electricity by processing waste and biomass. The driving force behind the project was to give priority to the environmental quality at affordable cost. Thus, the investigation of ways to increase the efficiency of the process turned out to be very important.
The major steps in the project were: the realisation of an efficient system for clean and efficient thermal plasma based waste treatment using a plasma torch and testing the combined system for various feedstocks, including oil shale and wood stocks. The economy of the system depends mostly on a crucial parameter to determine the future of this technology. The optimistic scenario holds the promise to provide 10 – 15 % of the energy needs for the EU.

Full Description of Results of the Project.

The thermal plasma emerges in a stationary discharge under a high pressure. Electric fields with varying frequencies ranging from the 0 (Direct Current) through high frequencies of the order of MHz to the optical spectra may be used to obtain the thermal plasma in large volumes. The sustainment implies the process providing for the energy transfer from an electric field into the plasma state. On the other hand, the generation requires continuos plasma production from a cold gas entering a discharge. A cold gas flows through a region of a tube where a discharge is sustained yielding an outward plasma flow. The devices employing this basic idea are termed plasma torches. They offer a wide range of important technological applications. Therefore, there are worldwide efforts to address the physics governing thermal plasmas. For historical reasons, Sweden has been underrepresented in this effort. Hence, the focus of this project was on the physics of thermal plasmas obtained by means of the Altering Currents.
Although the D.C. arc discharges were studied extensively for quite some time, only recently arc inductive discharges were addressed in some detail. The interest stems from the development of electrodless plasma torches. The lack of highly exposed electrodes benefits the purity of the plasma. This offers new options for chemical reactions in a plasma pyrolysis resulting in novel clean elements. The duration of the A.C. discharges in contrast to the D.C. is also significantly enhanced. Furthermore, these discharges do not require expensive thyristors for their operation. Yet, the performance remains to be sensitive due to the requirement of the consistency with power supplies. In general, the A.C. powered discharges are known to be more complex, less expensive and more subtle.
In more detail, there are two characteristic modes of A.C. arc burning in gas flows, which may be made of air, N_2, or inert gases (Fig. 1).

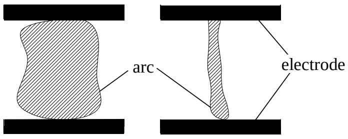

Fig 1. Diffuse (a) and contracted (b) modes of arc burning.

Diffuse mode emerges when an arc occupies a significant part of the discharge chamber volume. The discharge has a distinct turbulent character, caused by intensive jets emitted from electrodes. Evident fluctuations of the voltage and the pressure were reported. The plasma density is governed by the efficiency of the electrode vaporisation in contrast to the ionisation of the bulk working gas. Characteristic temperatures of the arc are in the range of 6 to 8 x 10^3 °K and the density is $n_e \sim (10^{14}\text{-}10^{15})$ cm^{-3}. Heat exchange with a surrounding gas is very efficient due to the enforced convection imposed by puffing of working gas through the arc. For diffuse discharges, the efficiency of energy transfer from the arc plasma to the surrounding working gas is extremely high of the order ranging from 70 to 90 %.

In order to obtain the contracted mode of operation the pressure of the working gas had to be amplified. Visually, the diameter of the arc column was strongly reduced reaching the diameter of hot spots governed by the electrode emission. Simultaneously, the current density in the arc and the value of the voltage have increased. In contrast to the diffuse mode, volumetric processes of the ionisation of the working gas determine the density of the current. Quantitatively, typical values of arc temperature are in the range of 10-20 x 10^3 °K and $n_e \sim (10^{16}\text{-}10^{18})$ cm^{-3}. The contracted arc column became evidently unstable oscillating around the quiescent position. The contraction was caused by the decrease of the metal diffusion into the bulk volume. It may be also due to the fact that with a rising pressure the gap between the energy embedded within in the arc versus the surrounding gas increased. Moreover, the higher pressure results in a shorter time for equipartition between the oscillatory (V-T) relaxation and the molecular recombination. These mechanisms lead to the energy compression in the vicinity of the axis of the arc column and subsequently to the enhanced heating of the plasma core. Therefore, the so-called overheat instability has been triggered resulting in the compression of the arc column in analogy to the phenomenon of the thermal contraction. The efficiency of the heat transfer to the surrounding gas is determined both by the electrode emission and the puffing of the working gas through the volume exposed to the meandering arc discharges.

Results offer means to produce dense hydrogen plasmas with densities up to 10^{21} cm^{-3} and temperatures up to 50 eV in the volume of about 1 cm^3 in a pulsed mode of operation. Given these parameters, plasmas resulting from the arc under pulsed conditions may benefit the start up for the thermonuclear burn in the inertial confinement scheme. It also constitutes a viable and powerful source of the Ultra Violet and the Soft X-Ray radiation with a high-energy yield.

Addressing technological applications it is important to keep in mind that the industrial processes and energy conversion plants have shown no or little care for environmental quality. The result is a huge accumulation of pollution and hazardous by-products, left as a heritage for the present and future generations. The driving force behind the present project was to give a high priority to the environmental quality at affordable cost. Recuperation of by-products or thermal energy from waste is not only motivated by cost saving, but also by resource saving considerations. Environmental awareness is more than staying within the lines of the existing regulations.

The bottom line was the paradigm that the plasma based remediation system is the *only* technology that prevents undesired pollution in the byproducts and end product (such as syngas or other gases). The two fold problem has been solved: recuperate clean energy from waste and renewables without pollution at affordable cost. The technique fulfils the objectives of sustainable development.

Today one of the main reasons that restrict use of plasma based methods is the complexity of plasma generators and the cost of electrical energy. Thus investigation of ways to increase the efficiency of the plasma treatment is very important. This has been accomplished in the studies carried out within the framework of the project.

The research and development of the project has been concentrated on the study of processes that are decisive for the efficiency of the process of decomposition of solid and liquid substances in thermal plasma flow, and on the economics of the resulting electricity and hydrogen production.

Several types of plasma jet have been compared – classical arc plasma torch with stabilization of discharge by flowing gas, inductively coupled plasma torch and plasma torches based on stabilization of arc by water. We have explored plasma torch technologies and potential facilities for industrial testing. The fine tuning and the selection of suitable plasma torches is of utmost importance, since it will affect the overall process in terms of energies, efficiency and environmental considerations as well as the capital and operating costs of the entire system. Important main torch selection criteria include: overall energy transfer efficiency, electrode lifetime, a cost and ease of replacement, temperature profile and plasma gas enthalpy, power supply and control system simplicity and cost, plasma gas requirement. A semi-wet pulsed plasma scrubber offers a simple solution to remove a range of pollutants simultaneously. When synthetic gas is transformed to electrical power, the price charged for power sold to the network appeared below 0.05 E/kWh (reference of the EU for power from renewable energy).

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