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Introductory Remarks

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The Third International Workshop on Catalytic Combustion involved four sections, viz., (i) catalysts: development, performance and stability; (ii) monoliths and other supports: development and stability; (iii) mechanism and modelling; (iv) applications of catalytic combustion. One of the highlights of the workshop was the application of catalytic combustion in gas turbines to avoid emission of nitrogen oxides. Other important applications were the combustion of volatile or poisonous gases and the production of hydrogen within compact reformers for use in fuel cells.

The section on catalysts deals with catalysts for combustion at intermediate and at very elevated temperatures. Catalytic combustion of (saturated) hydrocarbons and especially of methane is difficult to control. Due to the low reactivity the oxidation of methane calls for a relatively high light-off temperature. When the catalytic reaction has been ignited, however, the elevated heat of reaction brings about that the temperature and, hence, the rate of the reaction rapidly rises to a level where usual supports and catalytically active materials sinter quickly.

Two different procedures can be conceived to perform catalytic combustion, viz., catalytic ignition of the homogeneous gas phase reaction, which can avoid very high temperatures of the catalyst, and catalytic combustion. In the second procedure the oxidation of the fuel, which is often methane, is performed completely catalytically. Unless the methane content, and hence the adiabatic temperature rise is low, the final temperature will be at a level where the homogeneous gas phase oxidation is rapid. The catalyst therefore must quench effectively free radicals to prevent the homogeneous gas phase oxidation to proceed. Furthermore the catalyst must be able to withstand fairly elevated temperatures. Utilization of catalytic combustion in gas turbines has stimulated much research on combustion catalysts. With complete catalytic combustion catalysts are required that are stable at temperatures characteristic for the inlet temperature of gas turbines, viz., 1200–1300°C. With radiant heaters the final temperature is also often high, but since the pressure is lower, the conditions for the catalyst are less severe. About eight contributions deal with catalysts of a very high thermal stability. McCarty (Catalytica, USA) overviews the stability of metals and metal oxides not only against sintering, but also against volatilization (in the presence of steam), which is extremely important at very elevated temperatures. Other lectures involve hexa-aluminates and different perovskites, most of which contain lanthanum, which are generally used as materials maintaining a surface area of about 10 m^2/g at temperatures as high as 1300°C.

For applications at intermediate temperatures palladium oxide exhibits according to many authors the most elevated activity. However, Lyubovski and Pfefferle present experimental evidence that with an α-alumina support metallic palladium is more active than palladium oxide in contrast to other authors who established that on γ-alumina palladium oxide is more active. In the section on mechanism and modelling Burch discusses results indicating that under non-stationary conditions the activity of palladium can vary strongly, which may account for the

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above discrepancy in the activity of metallic and oxidic palladium.

When the thermal energy released by the combustion can be removed sufficiently rapidly out of the catalyst structure, an intermediate temperature can be maintained. With a fluidized catalyst bed, fast transport of thermal energy can be achieved readily. Fluidized bed combustion therefore presents the possibility to provide thermal energy at a level of 500–600°C. Since a relatively large number of chemical plants need thermal energy at such temperature levels, which is now provided by molten metals or salts, fluidized bed combustion can be highly interesting. In a keynote lecture Ismagilov (Boreskov Institute of Catalysis, Russia) deals with the production of fluidized bed catalysts and provides many important practical details that do not appear in usual publications.

Remarkable with the short section on monoliths is a presentation about a reactor of a high thermal conductance. Within the reactor metal spheres are sintered together and the catalyst has been applied onto a thin ceramic porous layer of the support. The ceramic porous layer is prepared by pyrolysis of a layer of silicone rubber. The section also includes a survey dealing with the application of monoliths as catalyst supports concentrating on gas turbines.

Mathematical modelling is almost indispensable in the development of catalytic combustion devices. The difficult ignition and the rapid rise in temperature after light-off with catalytic combustion bring about that it is difficult to predict the temperature profile and, hence, the stability of the materials in combustion devices. Since development by trial and error can be extremely time consuming, mathematical modelling based on accurately measured kinetics can facilitate the development of devices considerably. The four lectures about modelling of catalytic combustion devices provide a very good survey of the present state of the art. The keynote lecture by Kolackowski (Bath University, England) surveys very competently different aspects of modelling of catalytic combustion. The lecture also deals with results of a European Union project in which modelling results based on kinetic measurements are validated by experimental data obtained on actual devices at pressures and space velocities representative for gas turbines and radiant heaters. In a poster this author presented together with Hayes a study on Nusselt and Sherwood numbers in monoliths.

The paper by Schmidt et al. (University of Minnesota, USA and Universität Stuttgart, Germany) contains results about oxidation of hydrocarbons using pure oxygen at high pressures and temperatures, which allows one to achieve a high rate of production in very small reactors. Synthesis gas and olefins can be produced by this procedure, which has attracted a lot of industrial interest. Other papers of this section deal with oxidation on palladium supported on oxidized glassy metals, on palladium–platinum alloys, which provide a higher sulfur resistance, and on the oxidation of palladium particles applied on a silicon wafer.

Sadamori (Osaka Gas, Japan) opens the section on applications of catalytic combustion with a keynote lecture on small scale catalytic combustors for natural gas focussing on radiant heaters and gas turbines. Kerzhentsev and Ismagilov published a lecture on fluidized bed combustion dealing with results obtained with large installations. With gas turbines catalytic oxidation presently involves mostly catalytic ignition of the homogeneous gas phase reaction. Four lectures discuss catalytic combustion within gas turbines. Highly interesting are two lectures by Dalla Betta (Catalytica, USA) and coworkers about research performed on gas turbines partly together with General Electric, USA. Especially the homogeneity of the distribution of combustible gas within the airflow appears to be highly important to avoid locally very high temperatures. According to the Oil and Gas Journal of April 1998 (pp. 76–80) the research presented at the Workshop has led to a flameless catalytic combustion process (Xonon, developed by Catalytica Combustion Systems, USA). The catalytic combustor has been installed on a Kawasaki M1A-13A engine. During 1100 h of operation and 220 cycles of start up and shut down, the emission of nitrogen oxides proved to be very low. The paper by Kuper et al. (GasUnie, Netherlands) mentions results obtained within the above project of the European Union on a high-pressure test rig.

Other applications dealt with are a compact reformer for the production of hydrogen for fuel cells, radiant heaters, and domestic heaters. For prevention of environmental pollution catalytic combustion can be very effective. Combustion of gasified biomass is important to avoid emission of nitrogen oxides and recycle carbon dioxide as mentioned by Johansson and Järås (KTH Royal Institute of Technology, Sweden). Trimm et al. discussed a very interesting catalytic combustion of methane and hydrogen sulfide. Finally Schneider et al. (University of Leipzig, Germany) deal with the oxidation of chlorinated hydrocarbons.