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# Temperature Sensitive Paints for Ultra High Speed Acquisition and the Development towards the Determination of Flight Temperatures

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## Abstract

Surface-mounted temperature sensors like thermocouples or thin film gauges are commonly used in high enthalpy impulse facilities with the goal of the precise determination of the surface heat flux into wind tunnel models. The High Enthalpy Shock Tunnel Göttingen, HEG, is one of the major European hypersonic test facilities of this kind. The test time in such facilities in general and for experiments in HEG in special is typically in the ms range, which requires measurement techniques with high acquisition rates and high precision and resolution at the same time, because the precise determination of the surface heat flux is mandatory for experiments in high enthalpy impulse facilities [1]. Thermocouples and thin film gauges guarantee fast response times in the order of a few microseconds and therefore a high temporal resolution. But the spatial resolution is limited and can only be increased by increasing the number of sensors installed in a wind tunnel model. Additionally, it is challenging to attach sensors on complex or sharp-edged models. A very promising but experimentally challenging non-intrusive option is the use of the temperature-sensitive paint technique (TSP). The application of TSP enables the measurement of spatially resolved surface temperatures which allow for the subsequent calculation of surface heat fluxes. The development of this technique with a special focus on high repetition rates due to the typical measurement times of ms will be reviewed in this paper and the application possibilities will be outlined. Selected applications in HEG over the last decade will be discussed and the newest development of the TSP towards high temperatures which are encountered in flight will be presented and results of an application will be shown.

**Keywords**: *Hypersonic Flow, Temperature Sensitive Paint, High Temperature High Enthalpy Testing, High Enthalpy Shock Tunnel Göttingen, HEG,*

As the test time in impulse driven high energy facilities in general and for experiments in HEG in special is typically in the ms or sub-ms range measurement techniques require high acquisition rates in the order of MHz [1] and high precision and resolution at the same time. The development of TSP towards this requirements is not straight forward and special prerequisites needed will be described in the paper.

A TSP typically consists of a polymer binder, luminescent molecules called luminophores and a solvent. An example would be the use of  a mixture of Dichlorotris(1,10-phenanthroline) ruthenium (Ru(phen)) serving as luminophore dissolved in the polyamide AQ Nylon (P-70) and ethanol. The binder has to be oxygen impermeable in chemically reacting hypersonic flows to prevent recombination processes in the boundary layer and on the surface. In addition, the impermeability is mandatory to prevent any pressure dependence of the TSP. The paint is illuminated by light emitting diodes (LEDs) having a specific wavelength in order to excite the luminophores of the paint, while a light sensitive device detects the luminescence signals emitted from the TSP. The luminophores are exited to higher electronic states by the absorption of photons. The return to the ground state occurs through different mechanisms, either non-radiative relaxations or radiative decay [3]. One of those is the deactivation by the emission of a photon (photoluminescence). The other predominant mechanism is the thermal quenching which is a

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radiation-less process due to particle collisions. This process is temperature dependent, which means a rise in temperature increases the probability of radiation-less transitions. As a result, there are less emissions and thus the luminescence of the paint decreases. The energy loss due to the radiation-less transitions causes a shift in the wavelength: the spectrum of the excitation light source (LED) differs from the detected emission spectrum of the TSP. The maximum in wavelength of the emitted luminescence radiation is increased in comparison to the excitation wavelength. The difference in wavelength between both maxima is defined as the Stokes shift. A large Stokes shift is advantageous, because it facilitates the mandatory separation of luminescent emission from excitation radiation before the detection. For this purpose, a filter is placed in front of the detector to suppress light of shorter and longer wavelengths.

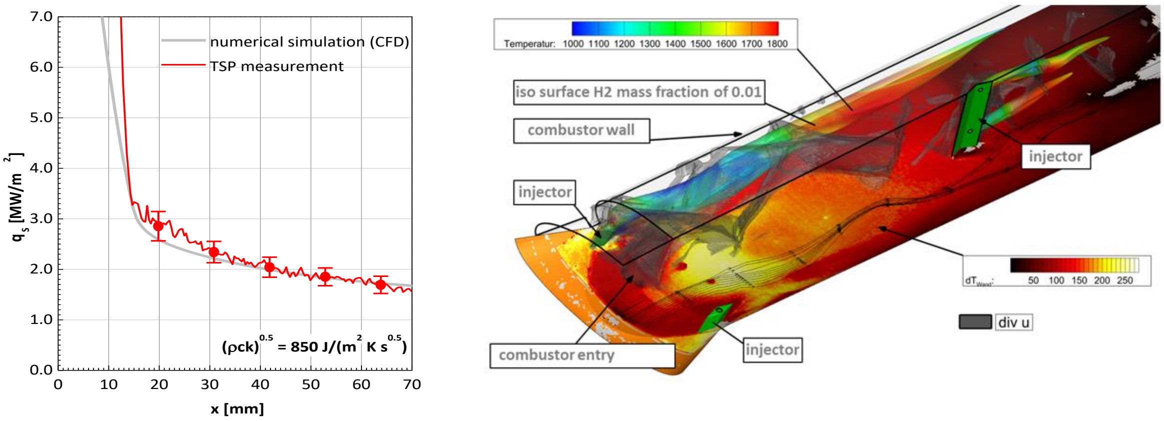


**Fig 1.** Comparison between experimental TSP data obtained for surface wall heat flux and the numerical reconstruction on a blunted cone in high enthalpy hypersonic flow (left) and experimental TSP wall surface heat flux of an internal combustion chamber flow overlaid with a numerical simulation (right)

The applications of the technique to external and internal high temperature hypersonic flows in HEG during the last decade [4,5,6,7,8,9,10,11] will be presented in this paper. The possibilities offered by this measurement technique will be given by examples ranging from blunted coned flow at 13 MJ/kg specific total enthalpy to the internal flow of a hydrogen combustor at 3 MJ/kg total specific enthalpy with a full three dimensional reconstruction of the wall heat flux during combustion [11]. The two examples are illustrated in figure 1.

Special focus of the paper will be the review of the current development status of the TSP technique towards high temperatures. Due to the experimental nature of high enthalpy testing and the short measurement times intrinsic to the experiments, the temperature rise of wind tunnel model walls during a test is typically less than 100°C. New testing applications, which allow to preheat the wind tunnel models to obtain wall temperatures over 600° C, need the new TSP techniques. Here, the luminophores will have to withstand much harsher environment and will, once ready, also be applied during flight testing. The measurement technique for flight, which need different prerequisites, will be discussed.

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