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Turbulent flame acceleration: The transition from deflagration to detonation

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The transition from deflagration to detonation gets very important in safety analysis of accidents, where combustible gases are released. Whereas the necessary precautions can be taken against the pressure waves generated by a deflagration, the shock waves of detonation would have catastrophic consequences. Therefore it is very interesting to know, how such a transition takes place and if it can be prevented by suitable measures. Such a measure could be for example the mixing of the combustible gas with an inert component.

It can be seen in many experiments, that the transition from deflagration to detonation can occur at relative low flame speeds, if there is a high degree of turbulence in the gas. The physical background for this phenomenon was not yet understood up to now. A model for the investigation of the stability of a deflagration, which was developed in this work, shows, that the generation of a strong shock wave has its cause in an instability of the deflagration. This strong shock wave initiates the transition to detonation. The developed model is a feedback circuit, which describes the interaction between the flame and the pressure disturbances, which are sent out by the flame (fig. 1). The mathematical description of the feedback circuit of fig. 1 contains the computation of weak shock waves by a change of heat addition of a deflagration and the dependance of the burning rate on the temperature, pressure and turbulences. The feedback circuit can be devided into a direct and indirect branch.

The indirect branch, which describes the feedback of a change in the turbulence degree on the burning rate can be neglected for the stability analysis, because it is too slowly for the spontaneous generation of a strong shock wave. Fig. 2 shows the result of this computation for 20 % Vol H_2 in air, where a stability parameter which was defined in this work, is plotted versus the relation of the burning velocity to the critical burning velocitiy. The deflagration gets instable and builds up a strong shock wave, if the burning velocity exeeds the stability limit, which lies near by the critical burning velocity for the H_2 combustion. The critical burning velocity only depends on the mixture compositon and the initial state.

In a first experiment this spontaneous generation of a strong shock wave in front of the deflagration could be demonstrated. The measurements were made in a 6 m long tube. The flame path along the tube was registrated by an optoelectronical system consisting of glass fibres, photodiodes and an electronic measuring system, which was controlled by a computer.

The result of this measurement is plotted in fig. 3. At 2 meters a shock wave is generated in front of the flame, whereby the flame accelerates spontaneously to a velocity,

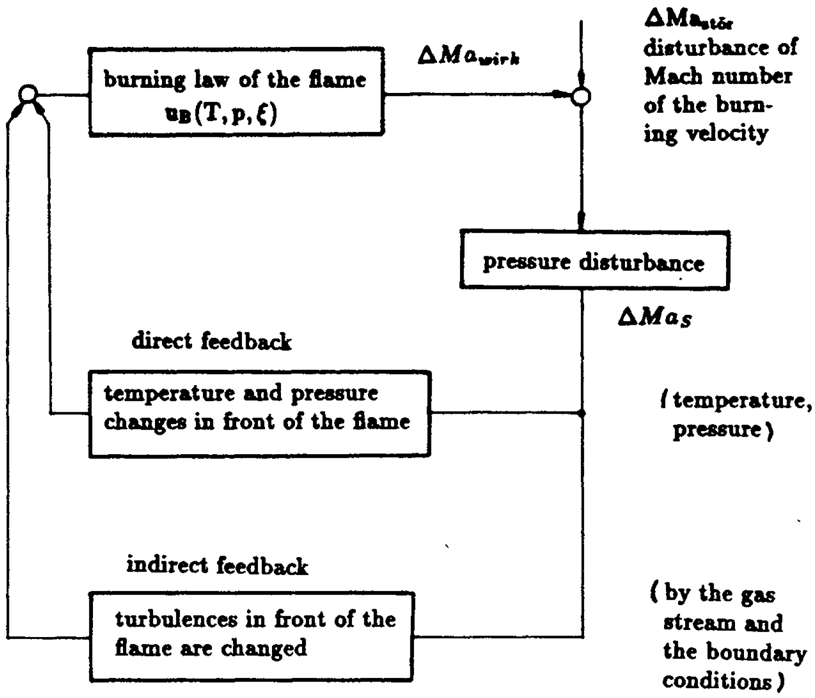

Fig. 1 : *Feedback circuit for the description of the interaction between a deflagration and a pressure disturbance.*

which is in the detonation velocity range. This experiment clearly indicates the instability of the deflagration, which was predicted theoretically.

Based on this new knowledge about the physical background of the transition from deflagration to detonation a deflagration to detonation transition (DDT) - limit was defined. This DDT -limit separates combustible mixtures for which a DDT is impossible from those for which a DDT can not be excluded under certain geometrical conditions. In a combustible mixture, where the burning velocity can not exeed the stability limit of fig. 2, a DDT is impossible. This DDT - limit was measured in H_2- air-steam mixtures in the explosion tube, which was already mentioned before. Turbulence promotors were built into the tube to get the very high burning rates, which are necessary for these experiments. The flame or rather detonation velocities for stoichiometric H_2-air mixtures, which were diluted by different parts of steam, are shown in fig. 4. Whereas the flame moves as a deflagration in the mixture with 35 % Vol steam the explosion front is a kind of detonation in the mixture with 33 % Vol steam. In this mixture the DDT -limit was exeeded, whereas in the mixture with a little higher steam concentration this limit can not be reached because of quenching effects in the flame.

The same experiments were made with other H_2-air-steam mixtures. The derived DDT - limit is shown in fig. 5 as a drawn through line. With this diagram it is possible to decide if a hydrogen-air-steam mixture can undergo a transition from deflagration to detonation or if this is impossible.

The results of this work are important for the whole combustion and explosion research. The stability analysis and the definition of a DDT -limit is valid generally. The special results for the hydrogen combustion will be also important for safety aspects in a future hydrogen technology.

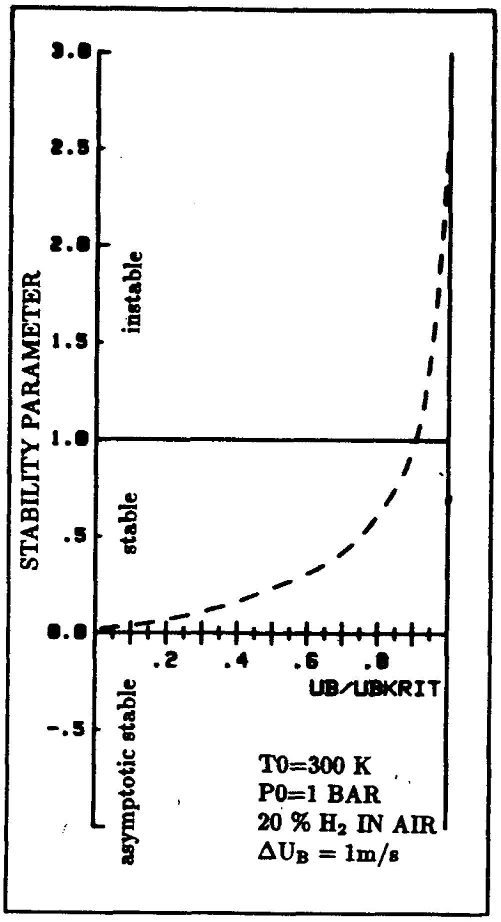

Fig. 2 : *Stability diagram for the direct branch of the feedback circuit of fig. 1.*

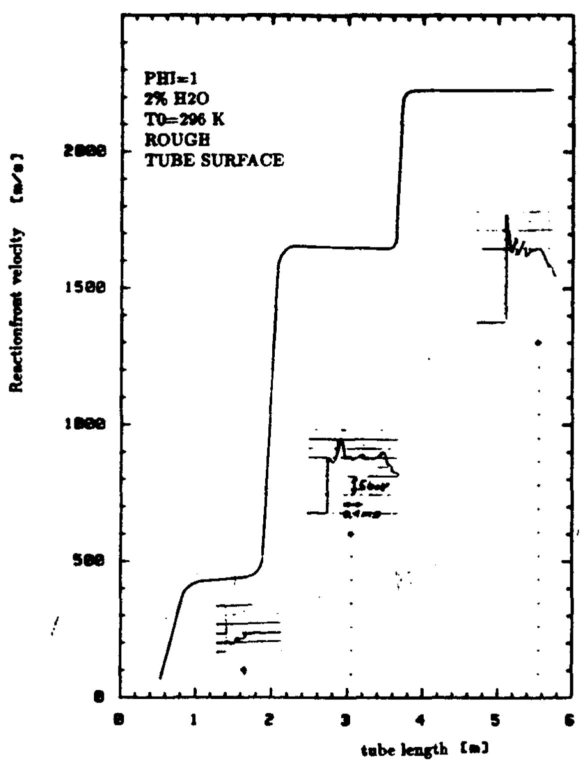

Fig. 3 : *Flame or rather detonation velocity versus the tube length in stoichiometric H_2-air.*

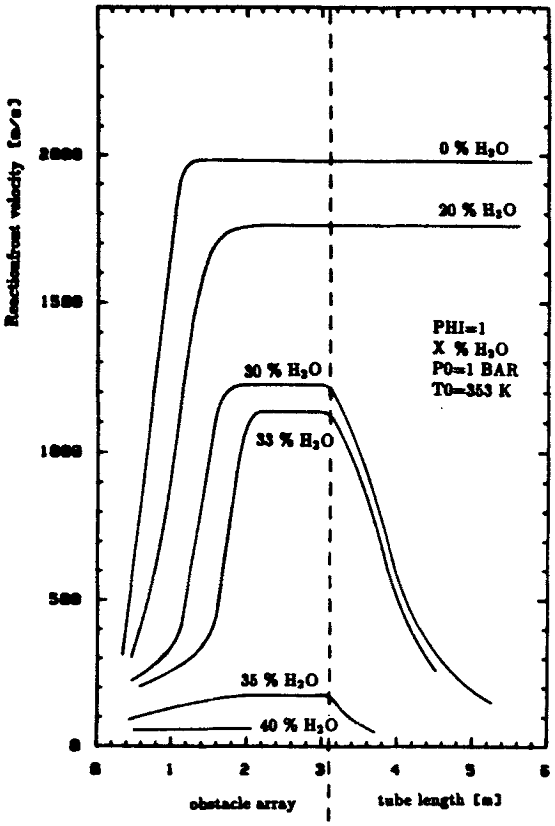

Fig. 4 : *Flame or rather detonation velocities for H_2- air-steam mixtures with a stoichiometric H_2-oxygen relation.*

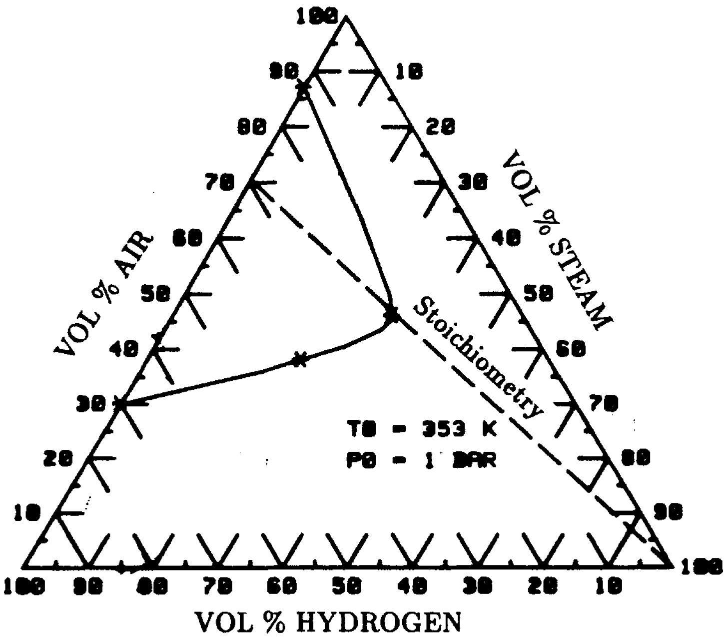

Fig. 5 : *DDT - limit in the triangle diagram for H_2-air- steam.*