

2.4 Incomplete Combustion

For hydrogen there are two lean propagation limits, upward and downward. At the lean upward propagation limit (~4.5%), flames will propagate upward. At lean downward propagation limits (~8%), flames will propagate both upward and downward throughout the volume. Hence, the extent of flame propagation (or combustion completeness) for combustion at lean flammability limits is dependent on the hydrogen concentration. If the hydrogen concentration is above the upward propagation limits but below the downward propagation limits, combustion will be incomplete.

Incomplete burning occurs for hydrogen concentrations below ~8% which is the downward propagation limit (see Figure 2-8 and Figure 2-9). Concentrations that are above the downward propagation limit lead to fairly complete combustion. The effect of steam addition is also shown in these figures. There is close agreement between these sets of deflagration data despite a significant disparity in geometric scale of the vessel used in each experiment (i.e., 0.002 m³ and 2048 m³, respectively) [Reference 29, 44, 65]. In both cases, it is evident that the addition of steam has an effect on the completeness of combustion, shifting the required hydrogen concentration to a higher value as more steam is added.

Steam affects the combustion completeness, flame velocity, heat capacity, and emissivity of the combustible gas mixture which, in turn, affects the resultant system pressure rise. Figure 2-10 and Figure 2-11 illustrate this reduction in combustion pressure as a result of increasing the relative concentration of steam for two different size systems (6.3 m³ and 2048 m³ sphere) [Reference 24, 44]. Both sets of data were taken with initial hydrogen concentrations of 8%. This concentration was chosen to represent a condition that undergoes complete combustion in dry air. It was also selected to provide a common point of reference for comparing these two sets of tests. The pressure rise ratio is reduced by about 50% in the large apparatus and by even a greater factor in the smaller apparatus. In each case, combustion was only about 38% complete for the highest steam addition test.

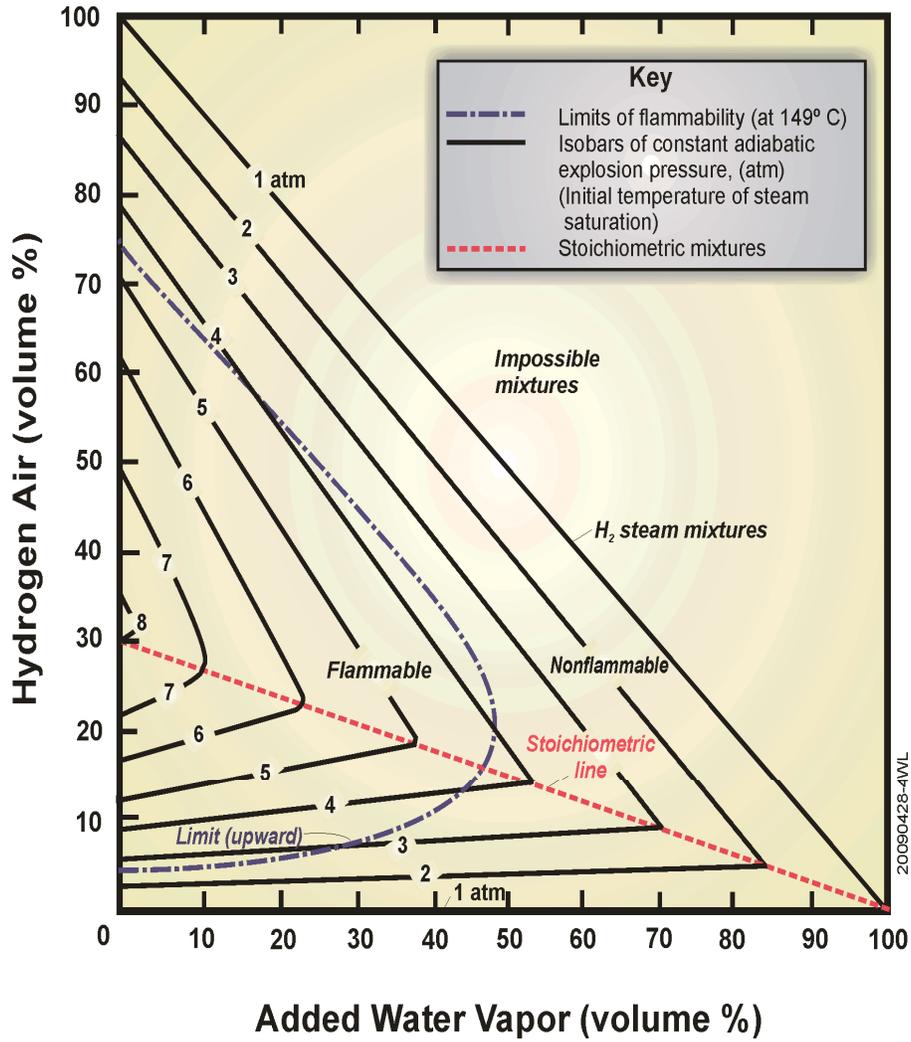


Figure 2-4 Flammability Domain for upward Propagation for H₂-Air- H₂O vapor mixtures. [Reference 19]

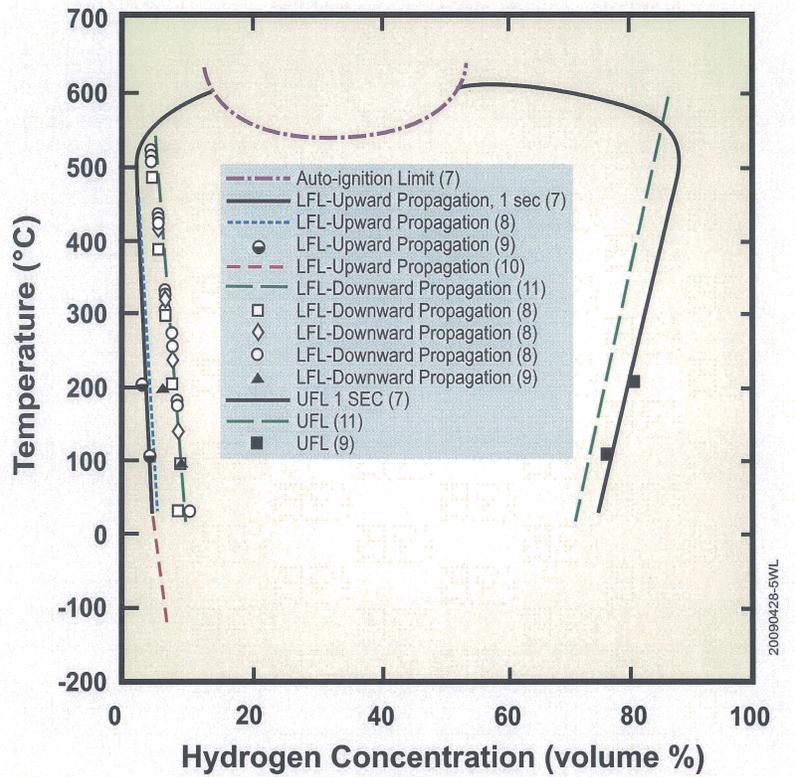


Figure 2-5 Comparison of Lower Flammability Limits (LFL) and Upper Flammability Limits (UFL) of hydrogen-air-mixtures as a function of initial temperature [Reference 53]