SAE J2601 – The Worldwide Standard for Hydrogen Fueling Stations

A short summary and explanation of some important terms

from

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About the Wenger Engineering GmbH

Wenger Engineering GmbH is a R&D service provider for thermodynamics, fluid mechanics and process engineering. The focus of the projects has been in the field of hydrogen technology since the formation of the company. In about 150 projects for companies such as Daimler, Toyota, Honda, Bosch, Linde, Shell or Hexagon, the team of Wenger Engineering GmbH has successfully worked on topics like hydrogen storage (700 bar, LH2, chemical storage, components), fueling stations technology, standardization, hydrogen purity, fuel cell system technology etc.

A worldwide known project is the SAE J2601. In this standardization committee, Wenger Engineering GmbH was in charge of all simulations. In addition, Wenger Engineering GmbH has implemented numerous projects to optimize fueling of fuel cell buses, trains and other hydrogen-powered vehicles.

This little e-book should help you to understand the extensive and complex SAE J2601 even better and to know Wenger Engineering GmbH as an additional helper at your side if necessary.

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Hydrogen Fueling – Why does the world need the SAE J2601?

The most important question beforehand: Why does the world need a standard that regulates hydrogen fueling down to the smallest detail? Why is the document almost 270 pages thick? Why aren't a few key points sufficient to regulate fueling?

Let's start with thermodynamics. Hydrogen for fuel cell vehicles is fueled to a standard pressure of 700 bar (70MPa). The 700 bar is based on the temperature of 15°C, whereby a "standard densitiy" of 40,22 kg/m^3 is reached. In a tank with an internal volume of 100 liters, about 4 kg of hydrogen has space. That correspons to a range of 400 km.

However, the fill level of a gas can't be measured with a level sensor as with gasonline. It is measured with the calculation of the densitiy of pressure and temperature. So far, so clear.

Now thermodynmics comes into play:

When gas is compressed, it heats up. When it relaxes, it cools down. The result of which is that the gas in the vehicle tank is significantly warmer than it was delivered from the filling station. Without active measures, these temperatures would be above 100°C when fueling in the desired time of a few minutes.

The current maximum permitted tank temperature is 85°C. The result of which is that active measures must be taken to prevent exceeding the permissible temperature. This is done by actively pre-cooling the gas down to -40 °C.

We have a conflict of objectives:

You want to a) fuel as quickly as possible (3 minutes), b) not exceed the maximum permissible temperature (85°C), c) reach the highest possible fill level (>95%) and d) not overfill the tank at the same time (>100%).

The filling station as a "brain" of fueling has some parameters under control: fueling speed, pre-cooling temperature, final pressure. However, it also has no control over many relevant parameters: type, size and geometry of the tank system, initial conditions of the hydrogen in the tank, pressure drop on the vehicle side.

If we look at all the parameters influencing the final teamperature and the final pressure (and thus the filling level), we notice that the variance is constant with the same parameters on the filling station side. In addition, at the filling station side a certain control accuracy of all parameters can't be undercut and also a priori undefined variables play a role.

To compensate for these numerous uncertainties, the **SAE J2601 panel** chose the "table-based approach". This approach provides a set of tables telling a filling station builder under what conditions he has to comply with fueling speed, pre-cooling capacity etc..

Those tables have been created in elaborate simulations, taking into account all aspects of security consideration as well as performance goals.

Performance Goals of the SAE J2601

The goal of every fueling is that the customer has a final fill level (State of Charge, SoC) between 95% and 100%. More than 100% wouldn't be allowed for security reasons, less than 95% would unnecessarily reduce the range.

The standard density at 70MPa and 15°C corresponds to a pressure of 87,5MPa and a temperature of 85°C – this is the highest permissible pressure. The result of which is that the temperature must not be higher that 85°C for performance reasons as well, as otherwise the target SoC can't be reached.

The target fueling time is 180 seconds, which is three minutes. To equally fill different size tank systems, we fuel with an "Average Pressure Ramp Rate". This constant rate or pressure rise allows a variable mass flow to automatically fill both small and large tanks systems at the same speed.

Thus, if the target pressure is 70MPa and the initial pressure is 2MPa, the APRR is 22,67 MPa/min. This may be higher in reality due to a higher target pressure or lower due to other restrictions (e.g. too high a temperature). The tables in the appendix to SAE J2601 provide information on a case-by-case basis.

Table-Based-Approach vs. MC Formula

The current revision of the SAE J2601 features an alternative fueling methodology – the MC Method or MC Formula. This approach was invented by Honda and developed in detail together with Wenger Engineering GmbH.

The **goal of the MC Formula** is to have a simpler, easy-to-use approach that allows filling station builders to be more agile. The basic idea is that with every fueling a certain mass (m) with a certain heat capacity (c) is transferred into the tank system. This results in a certain enthalpy, which is decisive for the temperature rise.

The MC Method is very interesting in principle, but due to numerous "exceptions" over the years it has become increasingly complex and controversial in the European legal area in its original form due to the strong dependence on the mass flow measurement (SIL 2 to IEC 61508).

[If you have any questions about the MC Method, please contact us directly,

mail@wenger-engineering.com]

Hot Case vs. Cold Case

On Page 44 of the SAE J2601, a table shows the “Hot Case” and “Cold Case” assumptions. These are the “upper” and “lower” constraints for creating the tables.

What does that mean in concrete terms? In the “Hot Case” all assumptions regarding the warm-up of a tank during fueling are mentioned:

- A single-vessel system heats up more than a multi-tank system.
- A Type IV container (plastic liner) heats up more than a type III container (metal liner).
- A tank system with high pressure loss in the pipes heats up more than a tank system with low pressure loss.
- A tank system that has stood in the blazing sun for a long time before fueling has a higher temperature at the beginning than a tank system in a vehicle that has just come from a cool underground car park.
- etc.

These assumptions were all „stacked” to a so-called “**Hot Case**” in which the tank must not exceed the permissible temperature.

You can say, that a vehicle should not exceed the allowable temperature even if it has the largest conceivable volume + a one container system at the same time + a Type IV-container at the same time + the highest conceivable pressure loss at the same time + a long standing in the sun at the same time + at the same time… About 8 – 10 influencing factors have to be considered in the Worst Case in order to not exceed the maximum allowable temperature.

Sounds crazy? Maybe. Maybe not. After all, it is hydrogen at 700bar and so many things can happen in real life, that it is better that the standard regulates this.

In the „**Cold Case**“ on the other hand, all assumptions are considered, which warm up a tank as little as possible during fueling. This consideration is necessary to prevent overfilling by too low a temperature (with a simultaneously defined final pressure). The assumptions are among others:

- The more containers in one system, the less it heats up.
- An aluminium liner heats up less than a plastic liner due to its high thermal conductivity and heat capacity.
- A tank system with “infinitesimal” pressure loss heats up less than one with high pressure loss.
- A tank system that has been standing in the shade for a long time or in a (cooled) underground car park has a lower starting temperature than the ambient temperature.
- A tank system that has been deprived of hydrogen at a high take-off rate by a (fast) trip has cooled down “actively” and is therefore colder than the environment.

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- etc.

A **combination of those cases** was calculated in the way that the three possible error cases

- overheating
- overfilling
- filling with too high mass flow

are prevented. At the same time, the maximum possible fill level is reached, that is permitted without data interface. In practice, the fill level will be somewhere between the minimum and the maximum possible because the actual temperatures reached will be somewhere between the two “Worst Cases”.

Questions?

You want to plan and build a hydrogen filling station?

Do one thing: work with specialists. Work with people having experience. We have often experienced people saying „It can’t be that difficult. We’ve already done X, Y or Z – everything is easy.” In a first approximation that might be true.

Everything is solvable.

It is not a rocket science. But the reality is: The devil is in the detail. Safety technology and reliability are crucial. It may be that the fueling station also works somehow. But does it meet the requirements? Does it take into account all eventualities? Is everything implemented correctly and in compliance with standards? Believe me, the way is farther than you think.

Talk to professionals. For example with the co-authors of the SAE J2601. Talk to Wenger Engineering GmbH:

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We are looking forward to working together with you!

WENGER
Engineering GmbH

Project examples hydrogen technology: system and product development, simulation

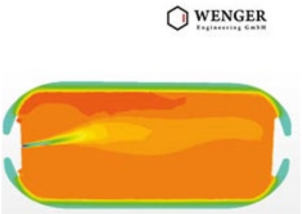
Development and conception of a hydrogen infrastructure for commercial vehicles

The aim of the project was the development and conception of several hydrogen refuelling stations for commercial vehicles in Lower Saxony (Germany) as well as the required hydrogen production from renewable energies and the acquisition of potential customers and project partners (maintenance service providers etc.). The result was an overall concept which the customer will implement as soon as some (political) boundary conditions change positive direction.

Scenario comparison of different hydrogen production and use cases

The aim of the project was to present solutions to reduce investment and operating costs in different production and use scenarios to a consortium of politicians, energy suppliers and potential users of hydrogen. Moreover, the goal was to identify the CO2 savings potential. The result was a study with profound scenario analyses and practical technological approaches.

Optimisation of hydrogen tank by simulation



The aim of the project was to better understand and optimize a 700-bar hydrogen tank using CFD simulation. The main focus was on local temperatures during refuelling and cooling during fast defueling.

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Testimonials

“Wenger Engineering GmbH from Germany is the industry **accepted thermodynamics expert**. The algorithm they developed **is used at every hydrogen fueling station in the world today**.”

Chris MCWhinney, CEO, Millenium Reign LLC, Dayton, Ohio (USA)

“I just wanted to personally thank you for a job well done on the simulation work. We learned a lot through this process and I can honestly say that **without Wenger’s simulation tool and the expertise of the Wenger Engineering team, we could not have achieved our goal**. I hope we have the opportunity to work together on future projects.”

Steve Mathison, Principal Engineer, Honda R&D Americas, Inc, USA

“Wenger Engineering GmbH has real **expert knowledge in the fields of hydrogen infrastructure and fuel cell vehicles**. This helped us to make significant progress.”

Sybille Riepe, CEO, motum GmbH

“Wenger Engineering has greatly assisted me in the development of the **MC Formula hydrogen fueling protocol**. They have a high degree of expertise in modeling and programming. This expertise assisted me in both the research and development process and also the final production process. During the R&D phase, hundreds of computer fueling simulations were conducted to find the best control approach. And during the production phase, thousands of fueling simulations were utilized to generate the final map of coefficients which are core to the MC Formula control. Wenger Engineering’s programming expertise was essential in the development of the MATLAB based MC Formula Validation Calculator. The Wenger Engineering team is focused on customer satisfaction and they are a pleasure to work with.”

Steve Mathison, Principal Engineer, Honda R&D Americas, Inc, USA

☞ More information on the MC Formula Validation Calculator can be found at: https://www.wenger-engineering.de/mc-formula-validation-calculator-login/