MODELING FOR THE DEVELOPMENT OF HEAVY DUTY REFUELING PROTOCOLS

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ABSTRACT

The road transport sector is in need of new technologies to help it emit less greenhouse gases, as the world's emissions should be halved before 2030 and ultimately be part of a net-zero society. To that goal, hydrogen is envisioned to be used as the fuel powering road vehicles, in particular for heavy duty (HD) applications. To achieve the replacement of the current fossil fuel vehicle fleet, a network of hydrogen refueling stations (HRS) should be installed, with the ability to provide safe and rapid fillings to ensure the widest adoption of this clean technology worldwide. The FCH JU project PRHYDE aims to develop a dedicated HD refueling protocol for type III and IV tanks with 350, 500 and 700 bar nominal working pressures (NWP). For this purpose, the SOFIL code, modeling the physical variables in the tanks during filling, is used in the frame of the project. The current paper compares SOFIL to experimental data for HD type IV tanks.

Keywords: heavy duty, hydrogen, refueling, protocol, modeling

INTRODUCTION

Greenhouse gas emissions should be lowered in the next decade to help meet the emission targets. This can only be achieved, for the transport sector, with hydrogen as energy carrier, combined with fuel cells. To achieve mass adoption of this new technology, it needs to be safe, affordable and easy-to-use. This is the goal of refueling protocols, standardizing the process across different companies, systems and geographies. Existing LD (Light Duty) refueling protocols, such as the SAE J2601, provide table-based process requirements to ensure a safe filling. The PRHYDE project [1-3] is dedicated to help developing a HD (Heavy Duty) hydrogen refueling protocol. For this purpose, modeling tools, estimating the gas temperature and pressure evolution during fillings, are essential. In particular, SOFIL [4, 5] by Air Liquide and Hyfill by Engie, 0D-gas/1D-wall modeling software, are used in HD protocol development in PRHYDE. This paper is dedicated to their validation in real conditions.
Two different type IV tanks have been used for experimental validation. A first tank, with a volume of 165 L, will be used by Nikola in their vehicles, and was therefore tested in a variety of experimental conditions. The second tank, with a volume of 240 L, has been chosen by Toyota for their vehicles, and was tested by ZBT in different conditions.

RESULTS AND DISCUSSION

The first tank, 165 L type IV tank, was used for experimental testing. A thermocouple tree was placed inside the tank to measure the gas temperature at several locations, denoted as 'TinX' as shown in Figure 1. Thermocouples were also applied to the exterior of the tank, denoted as 'TsX'. The OTV (On Tank Valve) gas temperature is denoted as 'Totv', and the tank pressure 'Ptank' was recorded at the of the tank. Table 1 shows the different test conditions that have been run with the 165L type IV tank.

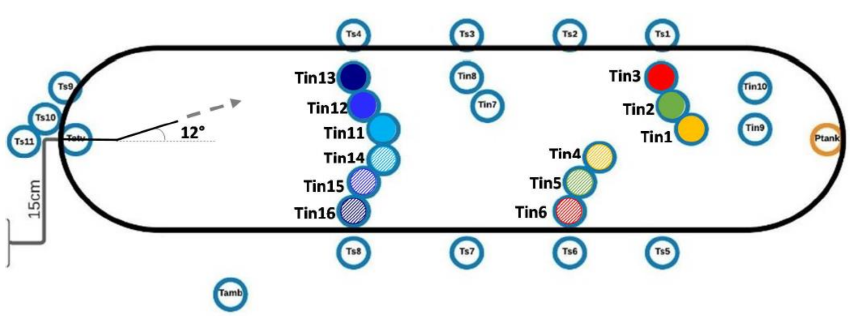

Fig. 1. Locations of thermocouples inside the 165L type IV tank during the testing.

Table 1. List of all tests for the 165L type IV tank.

Test number	Characteristics

#1 (ref)	Initial pressure 2 MPa. Ambient temperature 15 °C. Dispenser temperature -40 °C. Constant pressure ramp rate 8 MPa/min.
#2	Same as #1, but changing ambient temperature to 50 °C.
#3	Same as #1, but changing ambient temperature to 40 °C.
#4	Same as #1, but changing ambient temperature to -30 °C.
#5	Same as #1, but changing ambient temperature to -15 °C.
#6	Same as #1, but changing ambient temperature to 0 °C.
#7	Same as #1, but changing dispenser temperature to -33 °C.
#8	Same as #1, but changing dispenser temperature to -26 °C.
#9	Same as #1, but changing dispenser temperature to -17.5 °C.
#10	Same as #1, but changing initial pressure to 5 MPa.
#11	Same as #1, but changing initial pressure to 25 MPa.
#12	Same as #1, but changing the constant pressure ramp rate to 5 MPa/min.
#13	Same as #1, but changing the constant pressure ramp rate to 16 MPa/min.
#14	Same as #1, but changing the constant pressure ramp rate to 20 MPa/min.
#15	Same as #1, but changing the pressure ramp rate to 20 MPa/min for 3.85 minutes, then 1 MPa/min.
#16	Same as #1, but changing the pressure ramp rate to 20 MPa/min for 3.85 minutes, then 3 MPa/min.
#17	Same as #1, but changing the pressure ramp rate to 20 MPa/min for 3.33 minutes, then 1 MPa/min with pulse of 8 MPa/min for 10 seconds every 30 seconds.
#18	Same as #1, but changing ambient temperature to 40 °C and dispenser temperature to -17.5 °C.

Figure 2 shows the evolution of gas temperature and pressure in the first test case with the 165 L tank.

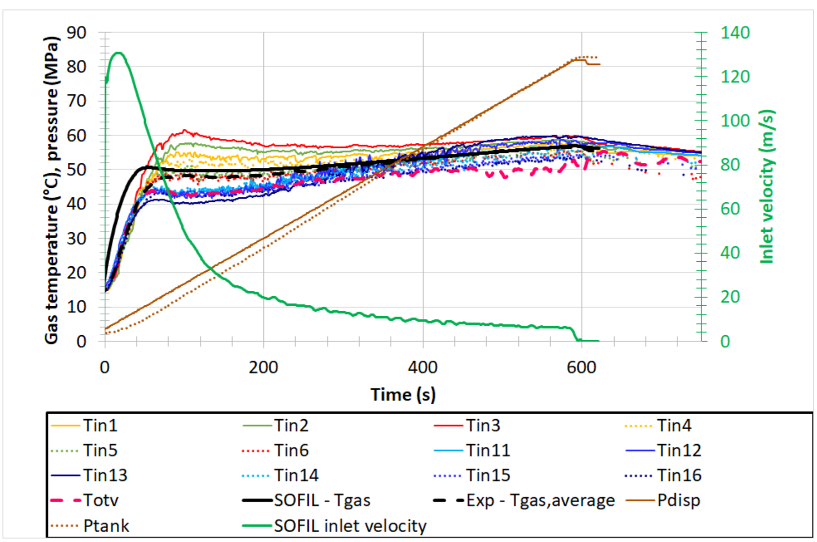

Fig. 2. Comparison of SOFIL model prediction with experimental data from 165 L tank testing. Case #1: Initial pressure 2 MPa, ambient temperature 15 °C, dispenser temperature setpoint -40 °C, pressure ramp rate 8 MPa/min, with a 165 L type IV tank.

The second tank is also a type IV tank, with a 240 L volume. Another thermocouple tree was placed inside to measure the gas temperature at several locations, as shown in Figure 3. Similar to the first set of tests, for the 240 L tank the tests varied the dispenser temperature (from -40 °C to ambient) and the pressure ramp rate (from 1 MPa/min to 16 MPa/min). Figure 4 shows the evolution of gas temperature and pressure in the reference test case with the 240 L tank.

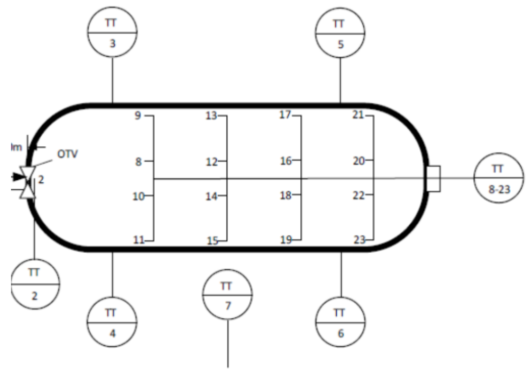

Fig. 3. Locations of thermocouples inside the 240 L type IV tank for testing.

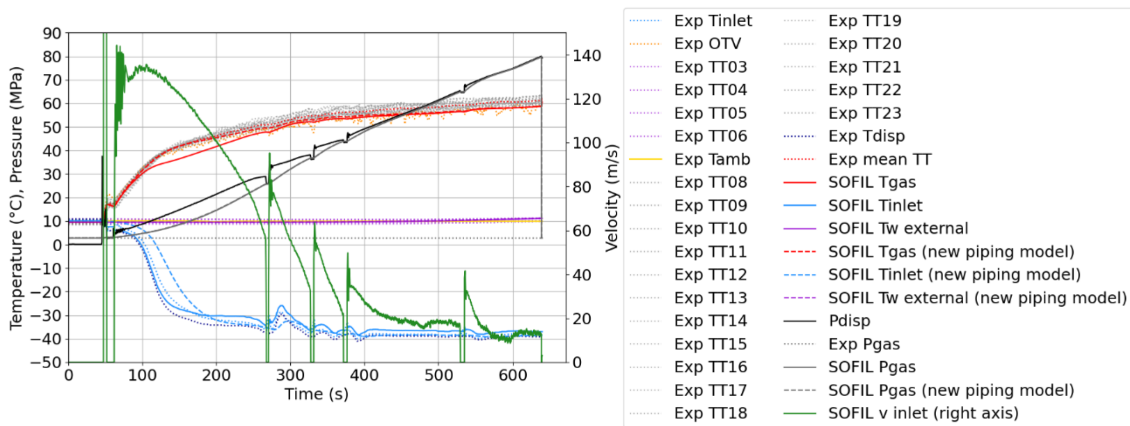

Fig. 4. Comparison of SOFIL model prediction with experimental data from 240 L tank testing. Initial pressure 2 MPa, ambient temperature 10 °C, dispenser temperature set point -40 °C, pressure ramp rate 8 MPa/min, with a 240 L type IV tank.

CONCLUSIONS

The modeling software used in the project is able to correctly estimate the gas temperature during the fillings. The validated software will be used to look into dynamic methods for the HD protocol.

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