



Assessing the pressure losses during hydrogen transport in the current natural gas infrastructure using numerical modelling

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Introduction

- The UK government aims to shift to a hydrogen-based energy infrastructure by 2050 [1-3].
- The use of green hydrogen as an energy vector has been proposed to reduce the country's carbon emissions [4,10,11].
- Research has been conducted on the use of natural gas - hydrogen mixtures in the gas network to improve thermal efficiency and reduce natural gas consumption [5-9].
- The use of hydrogen has two notable points [12-14]
 - Highly inflammable – low ignition energy (0.019mJ)
 - Wide flammability range (4-75%)

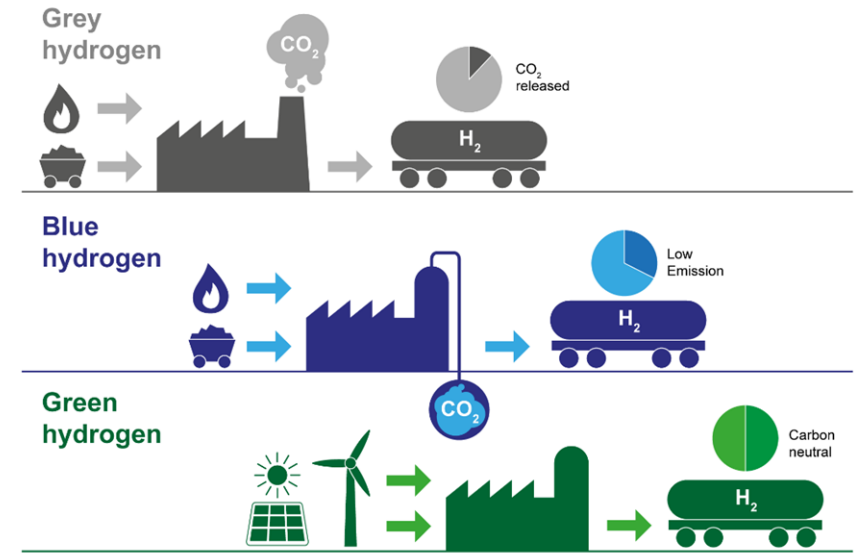


Fig 1. Schematic for different hydrogen production methods



Introduction (Cont.)

- Current research focus is on long distance (national scale) transport of hydrogen in mixtures with natural gas (~30% Hydrogen/Natural gas) [21-24]
- Little research done to observe pure hydrogen flow in the natural gas infrastructure [16-18]
 - Important to focus on transport at local and domestic scale
 - Consider the potential for the formation of micro-grids
- Important to understand the shift in risk profile at a domestic level when the main fuel is replaced



Aim and Objectives

- Aim of this study is to compare the flow of Hydrogen and Methane at various levels of the transport network and understand the different conditions required for the transport of hydrogen in the natural gas network
 - Mathematical and computational modelling tools used to compare gas flow performance based on pressure loss over a fixed distance
 - Two pipe materials compared – X52 Steel, and Medium Density Polyethylene (MDPE)
 - Gas flow compared over a fixed length of pipe (100m) for varying pipe diameters
 - Gas velocity – 30m/s (BS 6891:2015; BS 6400:2006)



Methodological Approach

- Hybrid methodology with the use of mathematical modelling and numerical modelling
 - Mathematical modelling carried out using the Darcy-Weisbach and Colebrook-White equations
- Numerical modelling carried out using ANSYS Fluent (k- ϵ turbulence model)

Table 1. Pipe sizing for MDPE and X52 steel pipes based on EN 12201-2 and ASME/ANSI B 36.10, respectively

Nominal Diameter (mm)	MDPE – Inner diameter (mm)	MDPE – Outer diameter (mm)	Steel – Inner diameter (mm)	Steel – Outer diameter (mm)
10	9.46	11.64	9.23	13.7
20	18.92	23.28	18.846	26.67
100	101.2	125	102.26	114.3
500	494.8	560	533.6	559
914	915.6	1000	939.6	965
1000	1006.6	1100	996.94	1016



Methodological Approach – Mathematical modelling

- Mathematical modelling carried out using the Darcy-Weisbach and Colebrook-White equations
- Commonly used equations for measuring turbulent flow
- Key focus on mechanical factors and turbulence affecting gas transport

$$\frac{\Delta P}{L} = f_D \cdot \frac{\rho}{2} \cdot \frac{v^2}{D} \longrightarrow \text{Darcy-Weisbach Equation}$$

$$\frac{1}{\sqrt{f_D}} = -2 \cdot \log \left(\frac{2.51}{Re \sqrt{f_D}} + \frac{\varepsilon}{3.7D} \right) \longrightarrow \text{Colebrook-White Equation}$$

Methodological Approach – Fidelity Study

- Numerical modelling carried out using ANSYS Fluent (k-ε turbulence model)
- Fidelity study used for the simulations to understand the effect of the cell size used in the problem domain on the accuracy and computation time of the simulation.
- Pipe diameter 0.1m; pipe length 100m; and gas flow velocity of 30m/s was selected
- Different element sizes selected for each model while ensuring a comparable number of elements

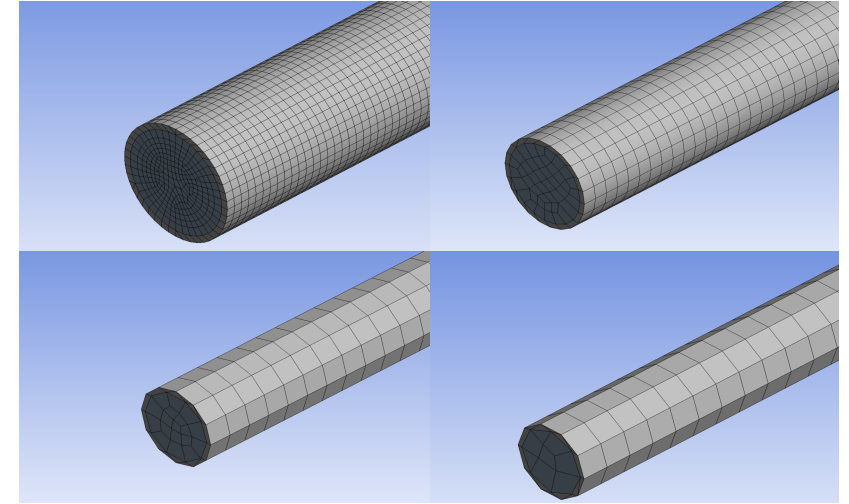


Fig 2. Different mesh fidelities for modelling hydrogen flow in steel and MDPE pipes

Table 2. Results of fidelity study highlighting the relationship between the number of elements, computation time, and error

Element size (m)	Number of Elements	Number of cores	Number of iterations	Computation Time (s)	Pressure loss (Pa)
0.5	3959963	8	624	1949.30	873.29
1.0	426589	8	306	60.724	888.21
2.0	108256	8	129	3.685	926.29
2.5	58581	8	156	1.625	939.62

Key Findings – Mathematical Modelling

- The change in velocity resulted in changes in the turbulence (Reynold's number) of the gas and the friction factor.
- The different pipe diameters influenced the relative roughness of the pipe materials, also influencing the estimation of friction factor.
- Hydrogen must be transported at approximately 2.5-2.7 times the velocity of methane to create comparable flow conditions.
- Suggestive of higher energy requirement to pump hydrogen to replicate flow properties of methane

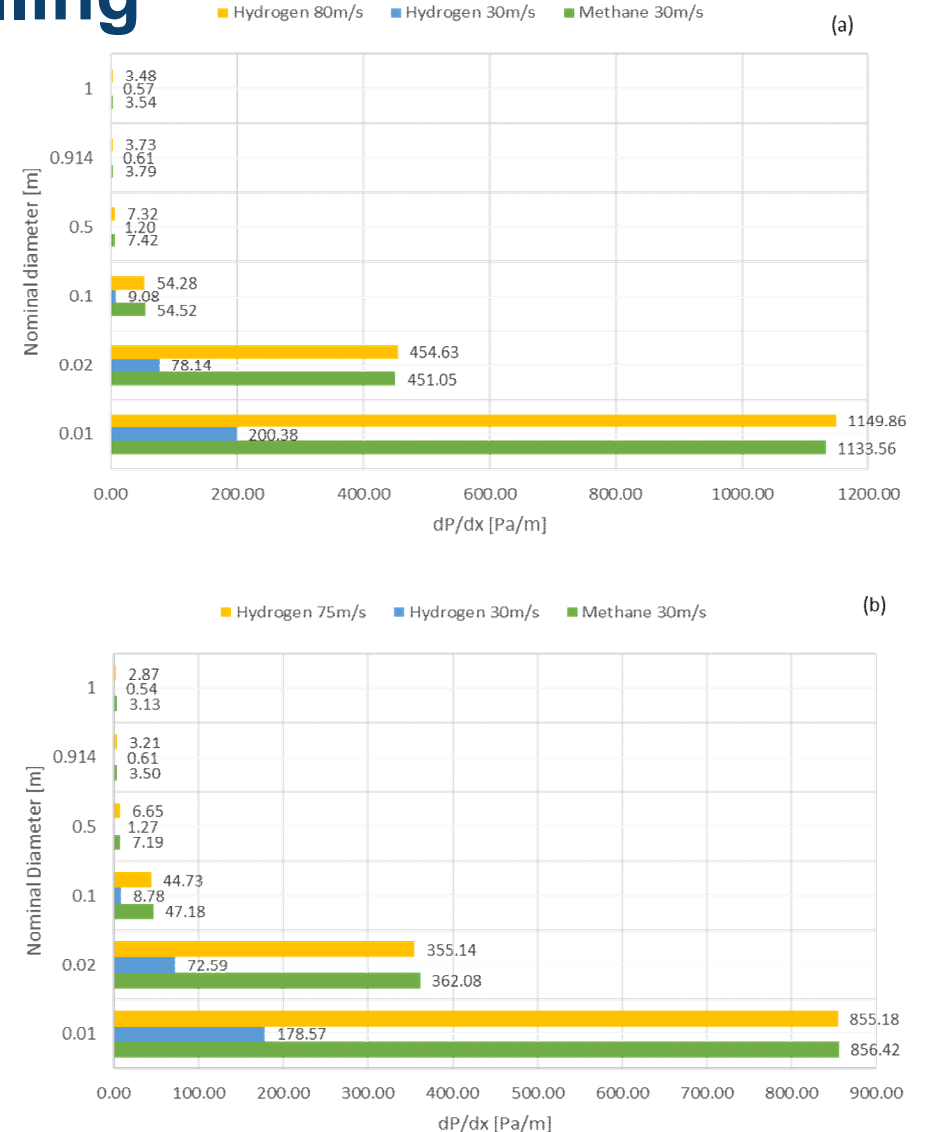


Fig 3. Estimation of pressure loss using the Darcy-Weisbach equation for methane and hydrogen gas flow in (a) Steel and (b) MDPE Pipes of different nominal diameters (0.01m-1m)



Key Findings – Comparing models

- 5-20% error between mathematical and computational model results.
- Inaccuracy in computational model for the prediction of pressure loss for lower diameters (0.01m; 0.02m)
 - Transitional flow in 0.01m pipe ($2300 < Re < 4000$)
 - Low turbulent flow in 0.02m pipe (Re is ~ 5000)
- Compared to MDPE pipes, computational models for steel pipe underpredict pressure losses in hydrogen flow compared to mathematical model
 - Influenced by higher pipe roughness combined with gas diffusion and advection at high velocity



Fig 4. Comparing mathematical model (DW equation) to computational model (k-e model) based on pressure losses observed for (a) Methane with velocity 30m/s; (b) Hydrogen with velocity 30m/s; and (c) Hydrogen with velocity 80m/s in a steel pipe

Key Findings – Comparing pipe material

- The absolute roughness of the pipe is a key variable in the determination of the friction factor which in turn influences the estimation of pressure loss.
- Pipe roughness influences the acceleration of gas and the dissipation of energy during gas flow
- MDPE being smoother than steel, has lower dP/dx values for all diameters
 - Relatively lower velocity required for hydrogen transport to replicate flow characteristics of methane
 - Explains the use of this material for domestic distribution of gas

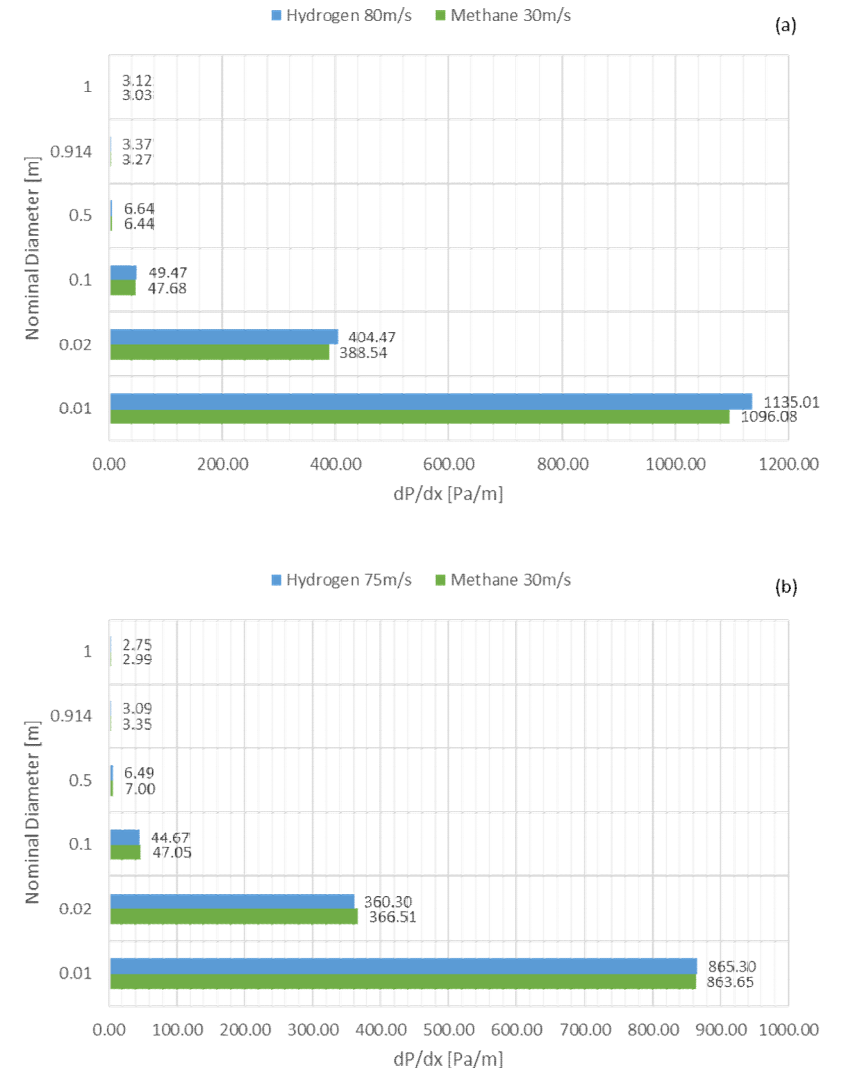


Fig 5. Comparison of gas flow and pressure loss in hydrogen (80m/s, 75m/s) and methane (30m/s) in (a) steel pipes; and (b) MDPE pipes



Conclusions

- Based on the mathematical and computational modelling, the primary observation is that **hydrogen must be pumped at a much higher velocity (~2.5-2.7 times) than methane** to replicate similar flow conditions.
- The velocity of hydrogen required to replicate the **pressure loss of methane was lower in MDPE pipes (75m/s) compared to steel pipes (80m/s)**.
- X52 steel being rougher than MDPE, showed larger pressure losses for both gases, and all the different pipe diameters considered.
- Based on the computational models, **hydrogen had 2-31% lower pressure loss** when transported in MDPE pipes at high velocity (75m/s) for different pipe diameters (0.01m-1m).
- Based on the mathematical models, **hydrogen had 9-34% lower pressure loss** when transported in MDPE pipes at high velocity (75m/s) for different pipe diameters (0.01m-1m).



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Figure 3

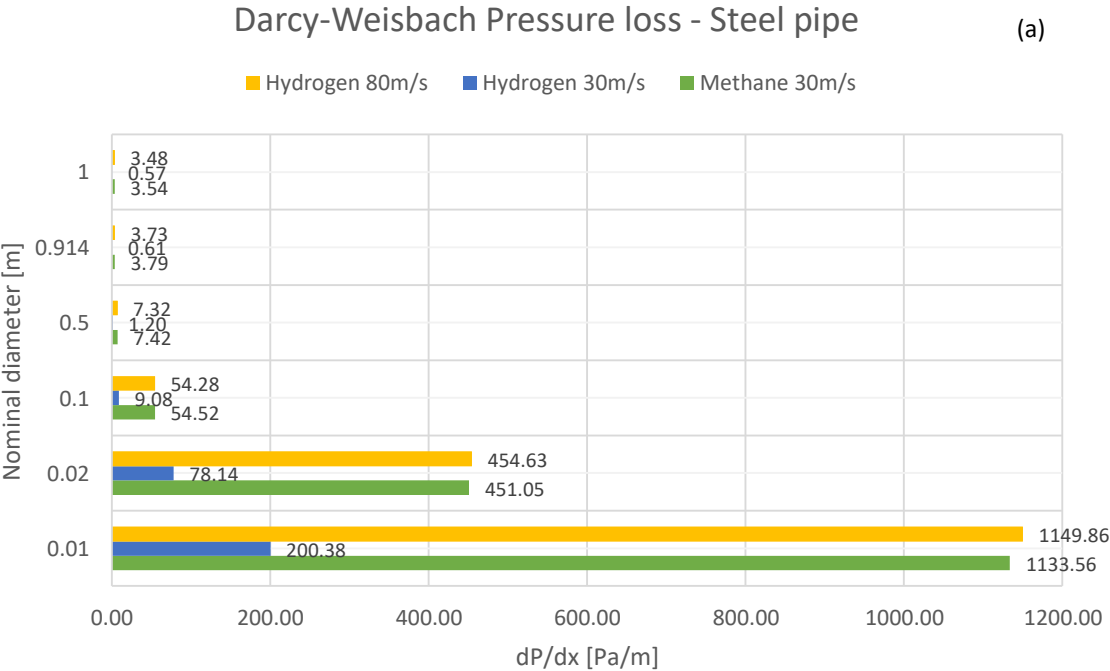
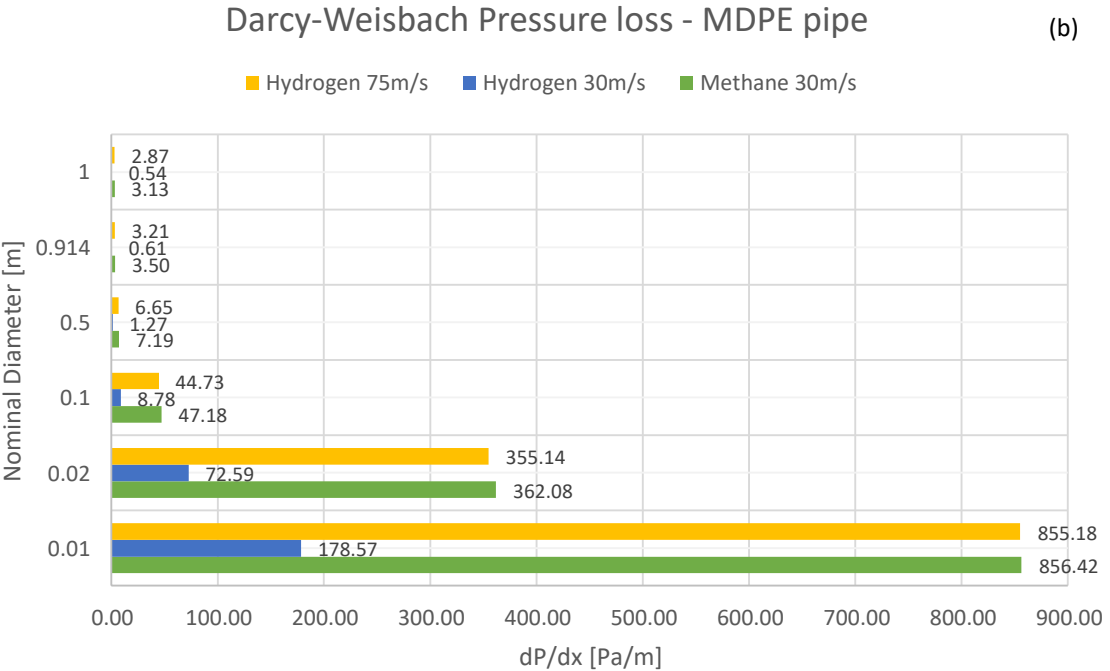




Figure 4

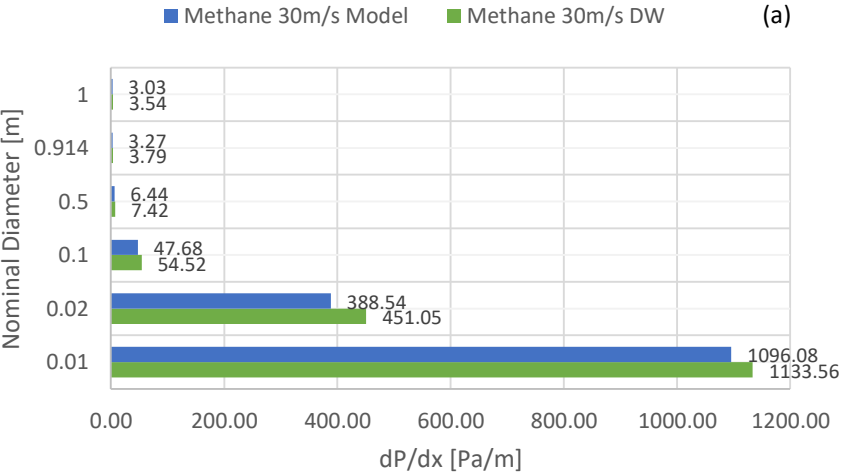
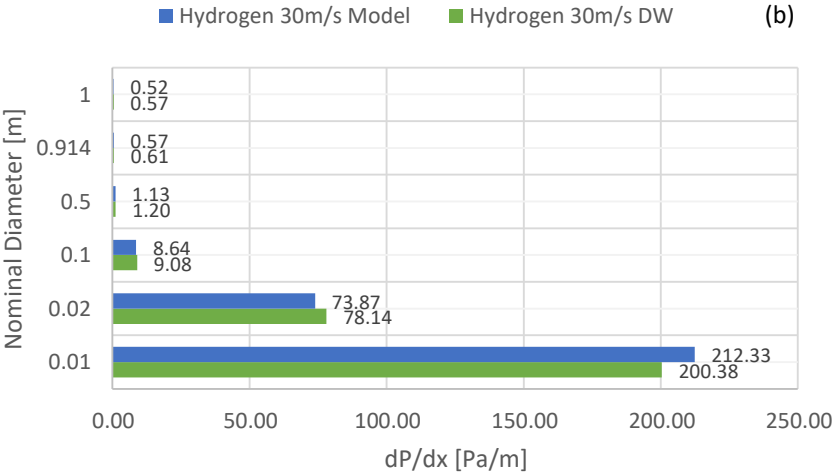
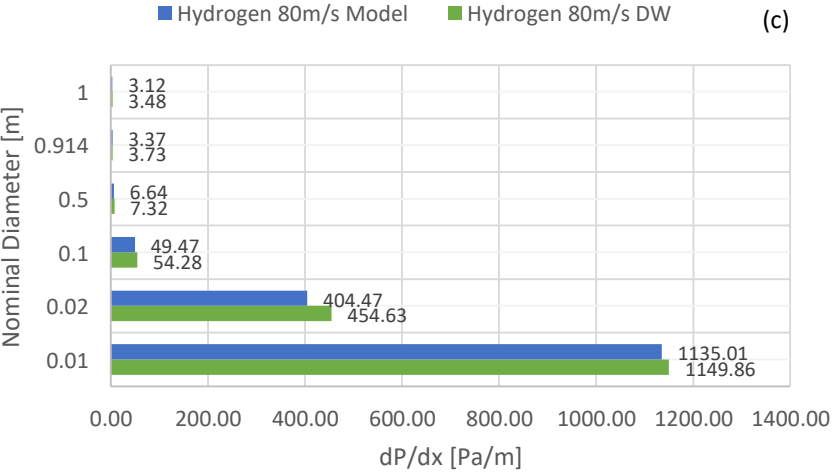


Figure 4 – MDPE Pipes

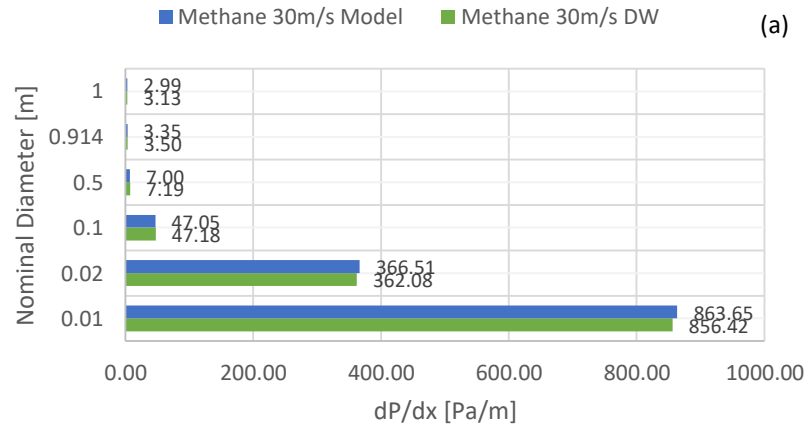
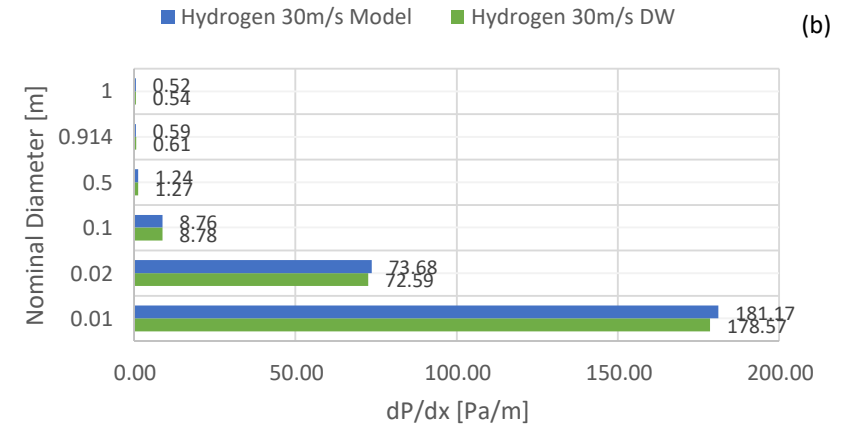
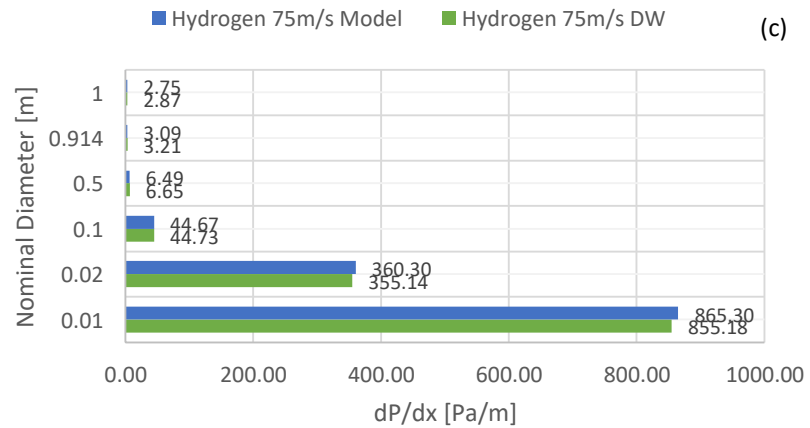
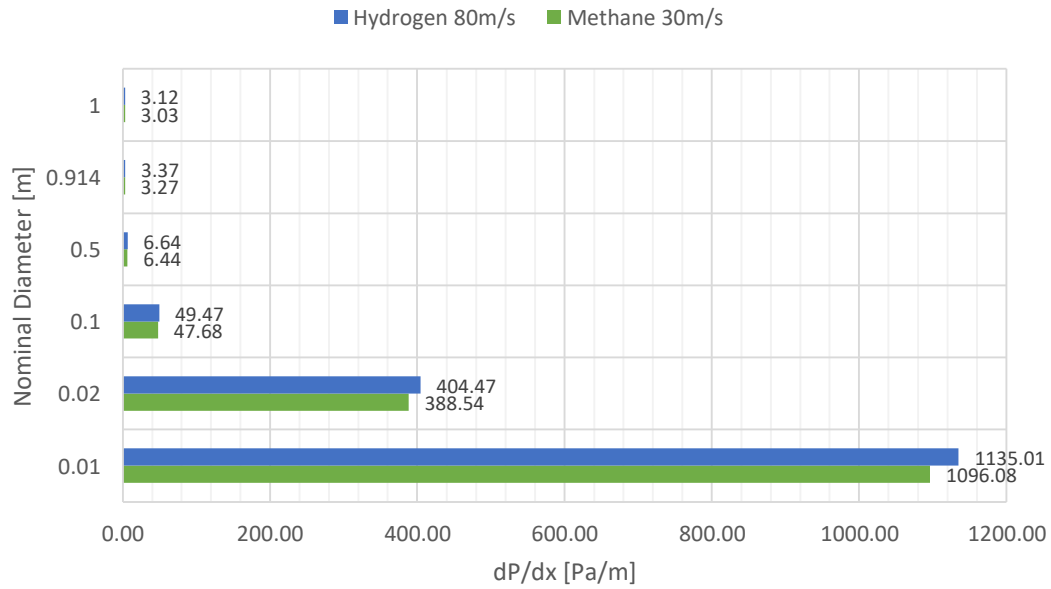


Figure 5

Comp. Model Gas flow performance - Steel pipe

(a)



Comp. Model Gas flow performance - MDPE pipe

(b)

