Computational Fluid Dynamic Modeling of Methane-Hydrogen Mixture Transportation in Pipelines

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INTRUDUCTION

Replacing fossil fuels and natural gas with alternative fuels like hydrogen have been suggested and thoroughly examined for years. However, because of the vast property difference between hydrogen fuel and traditional energy sources, hydrogen conversion in large scale requires huge investments. Instead of jumping directly from the current energy system to a pure hydrogen energy society, several intermediate steps must be considered for practical reasons. Blending hydrogen to methane is one of the most important intermediate steps.

Running hydrogen blended methane in existing natural gas pipelines can reduce carbon emissions. Methane-hydrogen gas has been served as an alternative fuel in many existing applications that commonly use fossil fuels. End-use applications like engines and burners can switch from petrol to methane-hydrogen mixture with a few modifications.

Computational fluid dynamic (CFD) modeling is a numerical method for solving fluid flow related differential equations with assistance of iterative computer capability. In this research, a 3D steady-state CFD model has been built to study energy efficiency of methane-hydrogen fuel transportation in a straight horizontal pipe flow using the same setup described in Cadorin et al. (2010). Additional models built on top of the reference model were constructed for testing variables such as 1) hydrogen concentration, 2) pipe surface roughness of common pipe materials, and 3) pipe diameter.

METHOD

The first set of experiments involves with altering the volume percentage of hydrogen in the methane-hydrogen gas mixture transporting in a six-meter horizontal pipe. Six methane-hydrogen concentration volume ratios (100/0, 90/10, 75/25, 50/50, 25/75, 0/100) were tested.

The next set of CFD models studied the effect of pipe surface roughness to the energy transport efficiency in a horizontal pipe. Internal pipe surface roughness varies significantly among pipes of different materials. Common pipe materials for transporting natural gas and biogas such as Cast-Iron steel, Stainless Steel, and polyethylene (PE) were tested in the study.

In the last set of experiments, pipe diameter was the testing variable. Four different diameter pipes (100 mm, 150 mm, 200 mm, and 250 mm) were modeled in two sets of study: 1) with fixed mass flow rate of 32.6 kg/s, and 2) with fixed inlet average velocity of 48.8 m/s.

Governing Equation

$$EST = \frac{(\Delta p/\rho)}{LHV} \cdot \frac{1}{L}$$

The pressure drop along with other variables were used to calculate the energy specific troll (EST), which represents the energy necessary for transporting gases in a unit length. The higher the EST value, the lower the heating value the mixture of the gas.

RESULTS

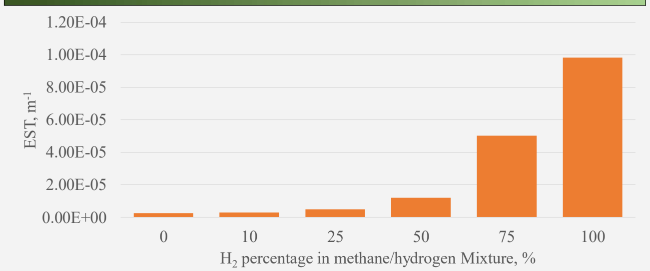

Figure 1. H_2 Concentration Test EST vs hydrogen percentage in Methane/Hydrogen mixture

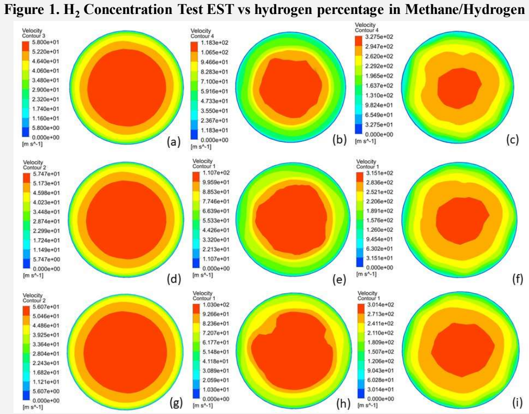

Figure 2. Velocity contour of (a) 90%/10% methane/hydrogen in cast iron pipe, (b) 50%/50% methane/hydrogen in cast iron pipe, (c) 10%/90% methane/hydrogen in cast iron pipe, (d) 90%/10% methane/hydrogen in stainless steel pipe, (e) 50%/50% methane/hydrogen in stainless steel pipe, (f) 10%/90% methane/hydrogen in stainless steel pipe, (g) 90%/10% methane/hydrogen in PE pipe, (h) 50%/50% methane/hydrogen in PE pipe, and (i) 10%/90% methane/hydrogen in PE pipe

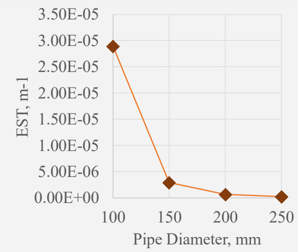

Figure 3. Pipe Diameter Test EST vs pipe diameter at constant gas mass flow rate = 32.6 kg/s

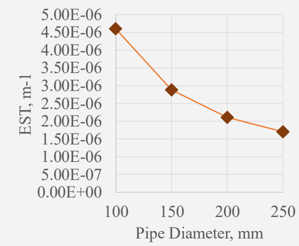

Figure 4. Pipe Diameter Test EST vs pipe diameter at constant average inlet velocity = 48.8 m/s

CONCLUSIONS

- The results of the hydrogen concentration study suggest that high hydrogen concentration (greater than 25% and 50%) is less energy efficient in pipeline transportation.
- PE or PE coated pipes are 33-40% more energy efficient in transportation than stainless-steel pipes, which are 17-31% more energy efficient than cast iron pipes.
- Due to fewer gas interactions with wall surfaces than smaller diameter pipes, larger diameter pipes reduce the energy required for transporting gas.

Future studies include incorporating real natural gas pipeline temperature, pressure, and mass flow rate in the model. The simulation results will be valuable in designing conversions from natural gas to methane/hydrogen mixture using existing pipeline system.

ACKNOWLEDGEMENT

All CFD models are created in ANSYS FLUENT Student Version

REFERENCES

Cadorin M, et al.; Numerical analyses of high Reynolds number flow of high pressure fuel gas through rough pipes; INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 35 7568-7579 2010