A NOVEL SOLUTION FOR QUENCHING IN LNG

Terry Lou, John Sabey and Tommie Jackson, ProSep, USA, present a novel solution for quenching in LNG for contaminant removal and Btu upgrade.

A proprietary inline mixer has proven to effectively treat natural gas at the origin or receival of LNG to provide appropriate Btu heating value and remove BTEX contaminants. The high-efficiency mixer allows for a liquid hydrocarbon stream to be blended (quenching) into natural gas directly to adjust the Btu heating value and remove BTEX contaminants. The inline mixer was subsequently deployed at a gas treating facility supplying feed to a 15 million tpy LNG plant along the US Gulf Coast. Full scale deployment results are expected to provide a platform for several other LNG applications for ProSep's high-efficiency inline mixer, including: boil-off gas (BOG) reliquefaction;[1] LNG quenching;[2] pentane quenching; propane quenching; and mixed refrigerant (MR) quenching.

Transition fuel needs treatment prior to use

Natural gas globally is forecast to be a significant source of power for the next few decades, and LNG is a key means to supply natural gas for this purpose. The pathway to produce LNG and reevaporate it to natural gas is, however, quite complex and involves electrical, chemical and mechanical methods. Two key challenges are: the removal of toxic and process contaminants, including benzene, toluene, ethyl-benzene and xylene (BTEX); and upgrading the Btu content of natural gas and integrate it into the regional natural gas supply infrastructure.[3]

Both challenges mentioned above can be overcome by the deployment of a high-efficiency inline mixer design: the Annular Injection Mixer (AIM™). The high-efficiency AIM mixer achieves efficient mixing of injected fluid with multiphase, gaseous or liquid dominant feed flows with low pressure drop over broad operating turndown range. Momentum transfer creates injected fluid dispersion with high mass-transfer properties, while the annular injection ring along the pipe wall creates a homogeneous downstream process fluid (Figure 1).

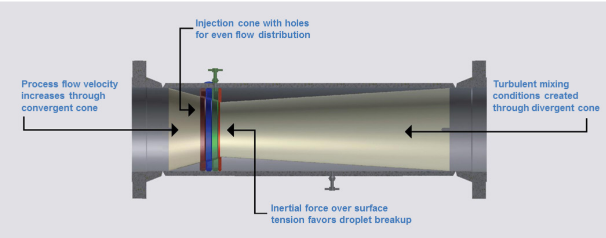

Figure 1. Illustration of an Annular Injection Mixer (AIM™) design (natural gas flows from left to right).

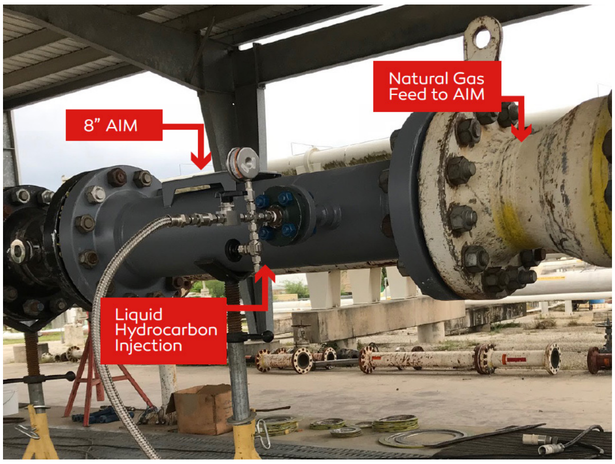

Figure 2. A flow loop test setup with an 8 in. AIM inline mixer injecting liquid hydrocarbon into a stream of natural gas.

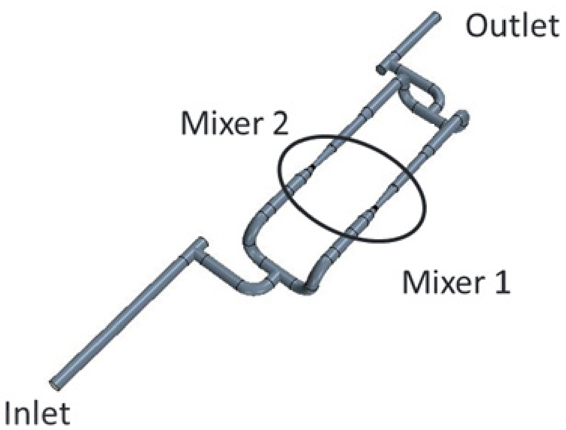

Figure 3. 3D geometry model of AIM mixers.

The AIM injection mixer consists of three critical elements: the inlet convergent cone; the injection cone; and the divergent cone. The inlet convergent cone is where the process feed flow is accelerated; the injection cone is where the additives are introduced into the main feed process stream; and the divergent cone is where the additive is dispersed, broken into tiny droplets, and turbulently mixed with the feed process stream.

Proven performance

Thermal treatment and use of static mixers are some of the available options to address the challenge of BTEX removal from natural gas prior to liquefaction at the LNG plant. Those two options are both expensive and only partially effective. Utilisation of the AIM mixer for injecting a liquid low-chain hydrocarbon into a natural gas stream containing BTEX contaminants showed remarkable effectiveness to remove the contaminants.

The key to remove the contaminants was the complete and rapid vaporisation of the liquid hydrocarbon when injected into the natural gas upstream of the LNG plant. The AIM inline mixer achieved this successfully as shown via a flow loop test (Figure 2) and was supported by computational fluid dynamics (CFD) studies.

Multiple gas chromatography (GC) sample ports are installed at a certain distance downstream of the AIM mixer to evaluate the dispersion/homogeneity of the liquid hydrocarbon. Process conditions are scaled accordingly as below for the testing:

- Natural gas feed flowrate: 13.7 million ft^3/d – 50 million ft^3/d.
- Liquid hydrocarbon injection flowrate: 0.17 – 2.3 gal./min.
- Natural gas operating pressure: 750 psig.
- Natural gas operating temperature: 70°F.

Results indicate complete liquid hydrocarbon dispersion is achieved within 5 m from the injection port. The actual mole concentration of the liquid hydrocarbon measured onsite from GC quickly matches up the level of stoichiometric equilibrium liquid hydrocarbon mole concentration after injecting into the AIM mixer, indicating superior heat transfer efficiency between natural gas and liquid hydrocarbon along with complete vaporisation within a short distance after injection. This is further proved by the observation of no free liquids in sight glasses installed along the pipe at a certain distance downstream of AIM mixer.

Liquid hydrocarbon vaporisation and blending with feed natural gas flow through the AIM mixer is comprehensively studied using CFD analysis. Figure 3 illustrates the 3D geometry model of AIM mixers installed in an existing pipeline set up from a commercial CFD software package.

Two identical AIM mixers are installed to handle the entire turndown ratio of feed natural gas flowrate requested. Each AIM mixer is equipped with two injection rings to cover the broad range of liquid hydrocarbon injection rate and ensure homogeneous mixing of liquid hydrocarbon with feed natural gas flow. As shown in Figure 4, the feed natural gas enters the AIM mixer and the velocity of gas increases due to a reduced open area along the convergent cone. The liquid hydrocarbon is injected through a small nozzle integrated in the AIM mixer and is homogeneously distributed over the circumference of the injection cone. The liquid hydrocarbon is then directed to the surface of the

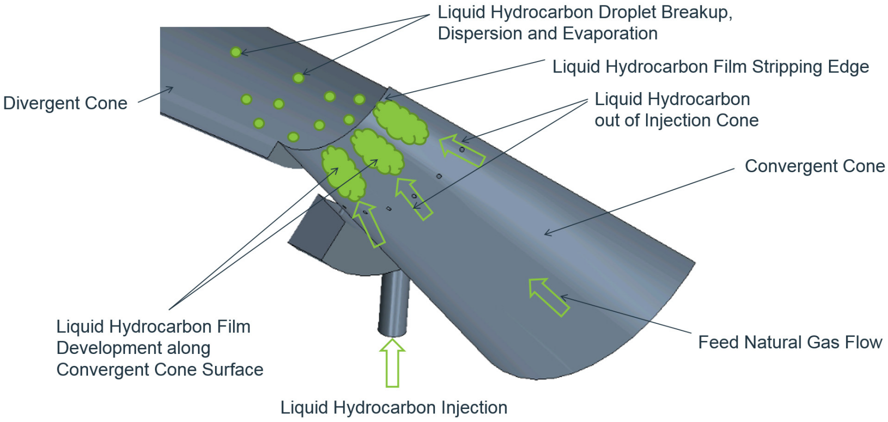

Figure 4. Liquid hydrocarbon injection and vaporisation process in AIM mixer.

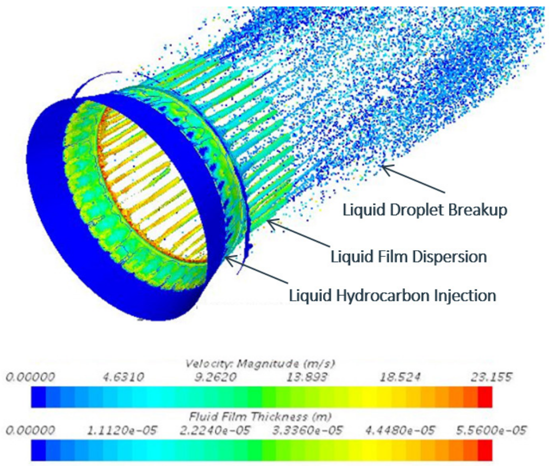

Figure 5. Computational fluid dynamics (CFD) visualisation of liquid hydrocarbon film behaviour and droplet breakup.

inlet convergent cone through multiple channels designed around the injection cone. A thin film of liquid hydrocarbon is developed smoothly along the surface of inlet convergent cone under extremely high level of momentum transferred from accelerating feed natural gas. The thin liquid hydrocarbon film then flows over the sharp edge where large turbulent flow eddies of the natural gas-liquid hydrocarbon flow mixture are generated. As a result, the liquid hydrocarbon film is stripped by highly turbulent natural gas flow and breaks up to small, micro-sized liquid droplets entering the divergent cone. The resulting high surface contact area provided by these liquid hydrocarbon droplets increases the quenching efficiency significantly and complete liquid hydrocarbon vaporisation is achieved rapidly within a short distance along the divergent cone.

The CFD study is used to simulate the entire process of liquid hydrocarbon injection, liquid hydrocarbon-natural gas interaction, liquid hydrocarbon film development, droplet breakup and vaporisation. The following process design parameters are used for the CFD simulation study.

- Natural gas feed flowrate: 250 million ft^3/d – 1500 million ft^3/d feed gas flowrate can be handled by 2 x AIM mixers. A total of 700 million ft^3/d with 350 million ft^3/d to each AIM mixer is used as feed gas flow condition for the CFD study.
- Liquid hydrocarbon injection flowrate: 0.75 – 60 gal./min. liquid hydrocarbon injection flow rate can be handled by 2 x AIM mixers with two separate injection segments installed on each AIM mixer. A total of 60 gal./min. with 30 gal./min. to each AIM mixer is used as liquid hydrocarbon injection flow rate for the CFD study.
- Natural gas operating pressure: a range of operating pressures 650 – 1250 psig can be handled by 2 x AIM mixers. 1250 psig is used as natural gas operating pressure for the CFD study.
- Natural gas operating temperature: 70°F.
- Liquid hydrocarbon injection temperature: 40°F.

Figure 5 represents the liquid film behaviour of the liquid hydrocarbon injection flow visualised from CFD analysis inside the AIM mixer. The colour shown from flow velocity and film thickness magnitude bar indicates even distribution of injected liquid hydrocarbon flow through multiple channels around the injection cone and homogeneous liquid film dispersion with uniform film thickness. Strong interaction between dispersed liquid hydrocarbon film and highly turbulent feed natural gas flow at the end edge of the convergent cone leads to millions of droplets generated from liquid film stripping and breakup. The distribution of droplet size is narrow with an average droplet size of 115 µm. Droplets that are relatively large in size are under secondary breakup to form more droplets that are smaller in size (the average droplet size is only 40 µm after the secondary droplet breakup). As a result, a high degree of mixing between liquid hydrocarbon and natural gas with a correspondingly large interfacial surface area provided by small liquid hydrocarbon droplets can be achieved in a short distance within the AIM mixer. Results from CFD analysis show complete liquid hydrocarbon evaporation within 4 m distance at pressure drop less than 2 psi across the AIM mixer, indicating superior mixing efficiency and enhanced liquid hydrocarbon quenching performance in natural gas before LNG liquefaction.

The successful AIM mixer design can be utilised in natural gas quality adjustment before the LNG liquefaction process, or after the LNG regasification process. The technology can be further applied to other applications where effective vaporisation of liquid flow with feed gas flow is required.

The inline AIM mixer was subsequently deployed at a gas treating facility supplying feed to a 15 million tpy LNG plant along the US Gulf Coast. Full scale deployment results are expected to provide a platform for several other LNG applications, including: BOG reliquefaction; LNG quenching; pentane quenching; propane quenching; and MR quenching. **LNG**

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