Current Projects

1. Unified Modeling of Multiphase Pipe Flows (Including Gas/Liquid, Oil/Water and Gas/Oil/Water Flows)

***Status: Ongoing***

TUFFP developed the unified model for three-phase pipe flow, in which the predictions of both flow pattern transition and hydrodynamic flow behavior are incorporated into a single model based on slug dynamics. It has been shown that this is an effective and successful approach for multiphase flow modeling. The objective of this study is to improve the TUFFP unified model for the prediction of flow behavior during production and transportation of gas, oil, and water through wellbores and pipelines at different inclination angles (-90° to 90° from horizontal). Closure relationships in the model are detached from the original code and made modular. This allows the incorporation of better and new closure relationships whenever they are available. Currently, the calculation methods and numerical schemes of the code are being improved.

1. Unified Model Verification and Improvement Project (TUVIP)

***Status: Ongoing***

The ultimate goal of the TUFFP unified model and software is to provide the predictions of multiphase flow behavior on field-scale with high accuracy and confidence. The unified model utilizes closure relationships mostly developed based on laboratory and flow loop experiments. There is a lack of comparison with field-scale data. The main objective of this project is to verify and validate the TUFFP model against a broad dataset of experimental and field data. This project is the combination of two previous projects approved by company members, namely, the *Steady-State Multiphase Flow Database Development* and *Field Scale Multiphase Flow Database*.

This effort will enable us to determine the best available closure relationships. These closures will be set as the default options in the TUFFP Unified model. It is expected to improve the overall accuracy of the TUFFP Unified model. This effort also gives TUFFP researchers a unique opportunity to analyze special conditions such as dense gas regions, high pressure, high temperature, etc. This will help identify the upscaling gaps by inferring the potentially dominant mechanisms under conditions almost impossible to reach in laboratory and flow loop conditions.

The current TUFFP data bank will be expanded with field data. This requires the participation of member companies by providing available field data. TUFFP will respect any restrictions that the provider requests. The identity of the data will be concealed. The data collected will not be shared with any other company unless we have the permission of the provider. Only the analyses and conclusions from the given data will be provided to TUFFP members.

As new data becomes available, it will be incorporated into the databank, and the TUFFP Unified model will be further improved.

1. Pressure and Inclination Effects on Low Liquid Loading Two-phase Flow in Near-Horizontal Pipes

***Status: Ongoing***

Low liquid loading is a common phenomenon in horizontal and slightly inclined gas pipelines. It affects pipeline and downstream facilities' design and operational procedures, making the investigation of this kind of flow very important. Several studies have been conducted in the past utilizing small scale facilities with small diameters and low operating pressures. Recently, TUFFP built the new High Pressure-Large Diameter facility with an ID of 6-in, and maximum operating pressure of 500 psia for scale-up purposes.

The current project is a continuation of the previous study to slightly inclined pipes. The main objective of this new phase is the acquisition of more detailed entrainment data. The axial visualization system will be calibrated in an attempt to determine the droplet size in the system. Moreover, an image processing software will be developed to determine the droplet size distribution for the acquired videos. Additionally, a new transverse isokinetic sampler will be constructed, as suggested by member companies. The same system will be used in the future to install a Pitot tube as used in the past by Kawajl et al. (1987) and Hamad and He (2010). This will be the first attempt by TUFFP to measure the velocity profile at elevated pressures.

1. Gas-Liquid Slugging Study in Large Diameter (6-in. ID) Pipes at High Operating Pressures

***Status: Ongoing***

This project can be considered as part of TUFFP’s pipe diameter and pressure upscaling efforts. Flow pattern transitions may shift significantly at elevated pressures when compared to low pressures. The influence of high-pressure conditions on slug characteristics has not been investigated yet. The objectives of this project are to determine the operating envelope for slug flow and investigate the slug characteristics (length, frequency, translational velocity, holdup, pressure drop) at elevated pressures. The 6-in. ID high-pressure flow facility is being upgraded for this effort. The facility modifications include the installation of an additional pump and separation skid, new oil export header, and additional instrumentations. The new oil export header will provide the capability to use the flow loop in both clockwise and counter-clockwise directions. Therefore, future experiments can be performed at 2° upward and downward inclinations. In this phase, one more pump and separator, a legacy of the TUHOP 3” facility, will also be incorporated to increase the maximum *vSL* up to 0.88 m/s. Additional instruments are proposed while preserving the existing instruments. One constant temperature anemometry (CTA) set (8 sensors) for wall shear stress measurement is planned to be installed along the pipe perimeter. The wall shear stress measurement will provide useful data for corrosion/erosion/fatigue management and hydrodynamic model development. A flow direction sensor (FDS) will be installed to complement CTA.

1. Multiphase Flow Measurement Technologies

***Status: Ongoing***

Multiphase flow measurements are complex due not only to the nature of the flow but also to the uncertainty of diverse measurement techniques employed by different researchers. Moreover, techniques that are suitable for low pressures or small diameter pipes are not suitable for higher pressures or larger pipes; for instance, intrusive methods are difficult to implement in field applications.

Proposal: This project proposes to review and further develop different principles to measure various aspects of multiphase flow, such as:

* Non-intrusive measurement of entrainment fraction
* Radial (local) variations in droplet sizes in dispersed flows
* Monitoring solids in multiphase flows
* Online (vs. offline) versions of the above

Business Alignment: The application of these kinds of technologies is endless. Member companies can use potential products in different manners, including: improve and calibrate multiphase flow meters, troubleshoot facilities with separation issues, and develop diagnostic tools that can be connected to e-field technologies. The idea is to start by defining the different parameters that should be measured and establish the state-of-the-art of these technologies. This activity can be carried out by a Master’s student guided by the TUFFP staff. The outcome of this initial project can be utilized to develop a route map for multiphase metering development. This should be a continuous activity for TUFFP, which will improve the measurement capabilities of the group, and it has the potential to deliver new technology to the member companies.

1. Mitigation of Corrosion in Stratified Water-Oil-Gas Multiphase Flow

***Status: Ongoing***

Stratified multiphase flow of water-oil-gas is common in oil and gas pipelines, especially in oversized pipes and at low flow rates during turn down operations. The extent of water wetting of internal pipe walls, due to the presence of a continuous water film flowing at the bottom of the pipe, significantly impacts the magnitude and severity of internal corrosion; therefore, pipe integrity. Internal wall water-wettability decreases when the turbulence in the liquid phase is sufficiently high to disperse and entrain the water film into the oil phase. As a result, corrosion decreases significantly, and, in some cases, ceases to exist, when the water is entirely dispersed and entrained in the oil phase. The objective of the proposed experimental and modeling investigation is to develop a tool that determines the minimum velocity (i.e., turbulence intensity) that is sufficient enough to disperse the water film in the continuous hydrocarbon medium, hence minimize/eliminate wall wettability and subsequent corrosion in oil-water-gas stratified flow. Details of the proposed approach can be found in Daas *et al.* (2014).

Daas, M.A., Espedal M., Aydin T.B., Pereyra E., and Sarica, C.: “Modelling of water dispersion in stratified oil-water-gas flow,” 19th International Corrosion Congress, Jeju, Korea, Nov. 2-6, 2014.

1. Two-Phase Induced Vibration in Pipe Fittings

***Status: Ongoing***

Two physical aspects should be considered as potential sources of flow-induced vibration in two-phase flow through pipe fittings: (1) the agreement between the frequency of momentum/pressure fluctuations and the piping’s natural frequency, and (2) the collision of liquid slug onto a structural surface transmitting a large excitation force. The induced two-phase flow excitation frequency depends on the flow pattern, void fraction, and volumetric flux. Such fluctuations can be in the order of several Hz for internal two-phase flow. Usually, a piping system consists of combinations of vertical, horizontal, and inclined pipes, and it is expected that frequency vibration induced by two-phase flow then decreases into the order of few Hz (slug flow).

These two-phase flow-induced vibration phenomena are currently studied using TUFFP’s 2-in. gas-liquid flow loop facility with some modifications. Force sensors, accelerometers, and pressure transducers are mounted into the elbow to measure the momentum fluctuation and the forces and vibrations (amplitudes and frequencies) on the anchors.

1. Effect of Medium Oil Viscosity on Two-Phase Oil-Gas Flow Behavior in Inclined Pipes

***Status: Ongoing***

Previous experimental studies have shown different behaviors between low viscosity oils (20 cP < *μO*) and high viscosity oils (*μO* > 200 cP) for two-phase gas-liquid flow. Few experimental studies for medium oil viscosity (20 cP < *μO* < 200 cP) have been published in the literature. Thus, there is a need for experimental investigation for medium viscosities to characterize the two-phase flow behavior for the entire range of possible viscosities. Furthermore, current two-phase flow models are based on experimental data with low and high viscosity liquids. Therefore, existing mechanistic models need to be verified with medium liquid viscosity experimental results.

The objective of this project is to perform an experimental and modeling study of oil-gas two-phase flow in ±90° inclined pipe to investigate the effects of medium viscosity oil (33 cP < *μO* < 129 cP) on two-phase flow parameters such as flow pattern, pressure drop, liquid holdup, and slug characteristics.

New Projects

1. Simplified Transient Multiphase Flow Modeling

***Status: To Start in 2021***

Prediction of transient multiphase flow behavior in wellbores, flow lines, and risers is one of the most complex problems in the petroleum production system. Different commercial software packages are available on the market, but running them is time-consuming and sometimes not an easy task. A simplified transient flow simulator can provide significant value. In the past, TUFFP proposed a simplified transient model based on the drift-flux approach. The developed simulator was relatively fast, simple, and user-friendly, permitting it to be used as a screening tool. This new project aims to expand this effort with a more robust implementation of the simulator, allowing the development and implementation of new concepts and model capabilities. New capabilities will include: the gas compressibility to store energy in the pipe, more complex pressure gradient models, the ability to solve complex pipe systems, etc. Model validation will be performed using synthetic, experimental and field data.

1. Two-Phase Induced Vibration in Pipes

***Status: To Start in 2021***

The most important parameter in the evaluation of pipeline vibration induced by two-phase flow is flow pattern. Depending on the flow pattern, the two-phase flow local fluctuations of phase fraction, density, local velocities, pressure field, and momentum flux could generate periodic forces or vibrations with different modes of amplitudes and frequencies on pipes and risers. Such a phenomenon can potentially cause fretting-wear or fatigue or resonance when the predominant frequency coincides with the piping system's natural frequency. This two-phase flow-induced vibration phenomenon and its interaction piping system's natural frequency can be studied using TUFFP’s 3-in. gas/oil/water flow loop facility.

The figure below shows a schematic where the pipeline anchors or supports can be modified to test different anchor’s schemes such as anchors located on the pipeline’s extremes, anchors located close to the pipe entrance, and the outlet of the pipe is in cantilever. With different anchor schemes, the different behaviors and degrees of coupling between these two dynamic systems can be studied.



1. Oil-Water Flow Patterns Transitions in Large Diameter Horizontal and Near-Horizontal Pipelines

***Status: To Start in 2021***

Oil-water flow in pipes is commonly seen in the oil industry; therefore, oil-water flow pattern predictions are necessary for optimizing the injection of corrosion inhibitors and other production chemicals. Moreover, predicting flow pattern in pipes is crucial for calculating pressure drop (correctly) along the pipe and for optimum pipeline design and maintenance. Despite the great importance of oil-water flow pattern predictions, few studies are available in the literature, especially for pipe diameters above 6-in. The available, informative data for oil-water flow, which can be used to draw a reliable conclusion about flow pattern transitions in oil-water flow, are mainly for 2-inch ID pipes. Systematic and updated data in large pipe diameter (6-in or above) are needed for horizontal and near-horizontal configurations. Many available studies have not covered all flow pattern classifications, and some lack a denser test matrix (Oddie *et al.* 2003). For example, stratified, wavy stratified, and stratified with mixing interface must be identified separately. The available oil-water flow pattern models need to be verified by using data from a large pipe diameter. Several correlations and models may be improved using these data.

Oil-water flow patterns, holdup and pressure drop in the horizontal and near-horizontal pipelines (-2, 0 and +2 degree) will be investigated by

* Collecting detailed flow patterns, holdup, and pressure drop data from a 6 in. ID pipe,
* Detecting and classifying the oil-water flow sub-regimes starting from stratified, including smooth, wavy stratified, and stratified with mixing interface up to non-stratified.
* Evaluating the influence of pipe diameter and inclination angle on the oil-water flow patterns
* Validating all oil-water flow patterns, pressure drop, and holdup models and correlations.

The results from this work can benefit several current and future projects related to large diameter oil-water transportation pipelines, optimizing the process of injecting corrosion inhibitors, corrosion strategy, and other chemicals into oil-water pipelines and optimizing oil-water separator inlet design.

1. Maldistribution of Multiphase Flow at Manifolds and T-Junctions

***Status: To Start in 2021***

Multiphase flow through distributing manifolds and T-junctions is common, especially in complex production networks. Uneven split and maldistribution of oil/water/gas mixture at a manifold or T-junction have a negative impact on the backpressure on wells, production network hydraulics, and downstream receiving facilities. This phenomenon can lead to operational interruptions, line choking, and phase segregation with one line(s) filled with gas phase and another line(s) filled with a liquid phase. The proposed research will focus on reviewing related literature and carrying out experimental and modeling work to:

* 1. Better understand/quantify the main upstream and downstream conditions that promote and dominate this phenomenon.
	2. Develop representative correlation(s) that quantify the severity of the maldistribution and predict the distribution ratio.
1. Characterization of Developing Slug Flow

***Status: To Start in 2021***

Slug flow poses a unique modeling challenge due to dramatic spatial evolutions. For large diameter, long, and undulating pipelines, which are commonly encountered in the field, the flow may never be fully developed. Thus, there are needs for a physically robust, accurate, yet computationally fast model to predict developing slug flow characteristics (length, frequency, etc.) for various design and operational purposes in the field.

Slug tracking is a practical model to simulate developing slug flow in long pipelines as it allows simulation in a coarse grid (~100D), leading to relatively manageable computation time [1, 2]. The longstanding weakness of arbitrary slug initiation has been recently addressed with a mechanistic model [2]. This research proposal is tailored towards improving the state-of-the-art slug tracking model(s). However, the deliverables will generally be beneficial for an alternative modeling approach (e.g., slug capturing [3, 4]) and enable more physical insight through experiments. Below are three research opportunities where member companies can get benefits in this area by leveraging TUFFP capabilities.

**Opportunity 1 – Slug Flow with Taylor Bubble Birth**

Generally, slug tracking models are well-tested in cases where slug flow is generated due to the birth of a “slug precursor” in a locally stratified zone. However, slug flow may also be generated due to the birth of a “Taylor bubble precursor” in a locally bubbly flow region. This may be an important mechanism in liquid-rich wells, for example: due to flashing or gas lift injection. Most experiments in the literature only attempted to emulate the “slug initiation” case, in that stratified flow was established in the inlet, then slugs are generated by inducing instability (such as by changing the inclination) [5, 6]. A systematic study on slug flow generated by the birth of Taylor bubbles will greatly benefit the efforts to extend slug tracking applicability toward liquid-rich/ steeply inclined wells and risers.

**Opportunity 2 – Slug Tail Velocity**

In slug tracking, a fixed, coarse grid is supplemented by a moving sub-grid which tracks the front and tail positions. This scheme allows direct implementation of slug flow closures (i.e., tail velocity, void-in-slugs). In developing flow, the velocities of the slug front (*UF*) and the tail (*UT*) are different. When the *UF* is greater than *UT*, then slug will grow and vice versa. These velocities dynamically respond to the local flow variables. The difference between *UF* and *UT* leads to a significant evolution of slug length and frequency over long pipelines. Thus, the prediction of these velocities is an essential element of a slug tracking model.

Several studies have observed that *UT* decreases as the length of the preceding slug increases [7, 8]. Generally, the mechanism behind this phenomenon is not well-understood (e.g., the effects of inclination, fluid properties, and phase velocities). A possible explanation for this is that when the preceding slug is short, the slug tail senses the velocity field in the wake (recirculation zone) near the front, leading to an increase in *UT.* Based on this hypothesis, the three-phase slug flow study is particularly interesting due to the complex phase and slip distribution in the slug body. The shape of the Taylor bubble nose may also influence the interaction between the slug tail and the wake zone. Additionally, it was observed that the behavior in small scale experiments does not scale up quantitatively to large-scale high-pressure data [2], although the general behavior is consistent.

**Opportunity 3 – Gas Entrainment across Slug Front**

In slug tracking, the slug front velocity (*UF*) is determined by a mass balance across the front. Therefore, we need to supply the closure for either void-in-slugs (*αGS*) or gas entrainment rate across the slug front (*qGE*). Most models use void-in-slugs correlations as they are simple and readily available. However, the *αGS* closures are inherently developed for steady-state fully-developed unit cell models. It is, therefore, more desirable to use the gas entrainment rate model (which is inherently transient) for slug tracking, as it will allow both *UF* and *αGS* to respond to the local flow conditions dynamically. Several works have been done using a mechanistic modeling approach for this topic [9, 10]. However, these models are limited to low viscosity fluids in near-horizontal conditions. Therefore, a fit-for-purpose model, which is both simple and physical, for gas entrainment, is still needed.

***Research Proposal***

The above-mentioned opportunities can be pursued in whole or in part, in phases or in parallel, as (and if) agreed by TUFFP members and investigators. As the investigation focuses on developing flow, it is desirable to use one of TUFFP large scale facilities (4-in ID or greater) with enough development length. The gas expansion should be minimized or properly accounted for.

For **opportunity 1**, the experimental setup shall allow the existence of bubbly flow at the inlet. Slug flow is then generated by injecting controlled amounts of gas through a sparging system to induce the birth of Taylor bubbles. It is also desirable to have steeply inclined flow experiments for this study.

For **opportunity 2**, the biggest knowledge gap is in three-phase cases. However, two-phase experimental data with variation in fluid properties/ inclination will also be immediately useful once available. These experiments will require a methodology to identify and track slugs and to measure front and tail velocities independently, in addition to typical slug characteristics measurement.

For **opportunity 3,** a direct measurement of gas entrainment rate (*qGE*) is challenging. Studies have reported gas entrainment measurement with stationary slug front (hydraulic jump) [11, 12], but they may not be directly applicable for slug flow (moving front). For slug flow, *qGE* may be roughly inferred from a mass balance across the front (see [2]). Of course, TUFFP investigators are encouraged to explore novel measurement methodologies as deemed appropriate.

The deliverables of this research line should include:

1. Slug characteristics evolution data (visual flow structure, length, frequency, body holdup, bubble zone holdup, front velocity, tail velocity, and slug fraction). Raw (time-series) data shall be made available for membership if requested. TUFFP investigators will determine the most suitable instrumentations to produce these data.
2. Benchmarking with existing slug tracking tools and documenting errors. Benchmarking with a steady-state model if the fully-developed state can be achieved is encouraged.
3. New model/ correlations of slug tail velocity or gas entrainment across slug front, if necessary.

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