SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 15 – 18 2022

The evolution of slug capturing

Jan G Norstrom[1*], Jørn Kjølaas [2]

[1] LedaFlow Technologies DA/Managing Director, Norway, *jan@ledaflow.com
[2] SINTEF/Senior Research Scientist, Multiphase Flow Laboratory, Norway

Abstract

The energy sector aim is to achieve a net zero carbon footprint in the petroleum industry by reducing the carbon emissions associated with oil and gas production. A key element for this endeavour is to re-use existing infrastructure using tie-back solutions, reducing the need for building new installations. Tiebacks involve transporting unprocessed fluids as a multiphase flow over long distances, which brings some challenges. One notable challenge is the risk of slugging, which can lead to severe operational difficulties due to the intermittency of gas and liquid flows. Indeed, liquid slugs tend to grow as they travel over long distances, so if the transport lines are very long, extremely long slugs may arrive at the end terminal, requiring very large receiving facilities. Those slugs are also exerting forces on risers in deep-water development than can cause a riser rupture. Over a decade, considerable effort has been made into the research and development of "Slug Capturing", which is a rigorous modelling approach for predicting the generation and evolution of slugs in long pipelines. In this work we present a review of the evolution of the LedaFlow Slug Capturing model, from its inception to its current state.

Keywords

Multiphase flow; Slug capturing; NetZero

Introduction

LedaFlow was launched in 2001/2002 as a research project between ConocoPhillips and TotalEnergies, in partnership with SINTEF. The objective of the LedaFlow JIP was the development of more refined models for multiphase flow, based on a more complete and detailed treatment of the underlying flow physics. In 2010, KONGSBERG was chosen as the commercialization partner. Thanks to this stable industry partnership over the past 20 years, LedaFlow has evolved into a leading multiphase simulator. We will share and discuss how we have worked with industry partners to evolve technology over several years across several R&D initiatives for improvements to slug capturing technology.

The longest tiebacks for oil fields are up to ~60km long. Sometimes maximum tieback distance is shorter due to technical complications like e.g., unfavorable terrain, water depth or fluid composition causing slugging, wax or hydrates. Slugging is a critical phenomenon that must be predicted accurately. With reference to Figure 1, imagine how an area may be developed if it is possible to simulate and develop a 100km tie back for oil.

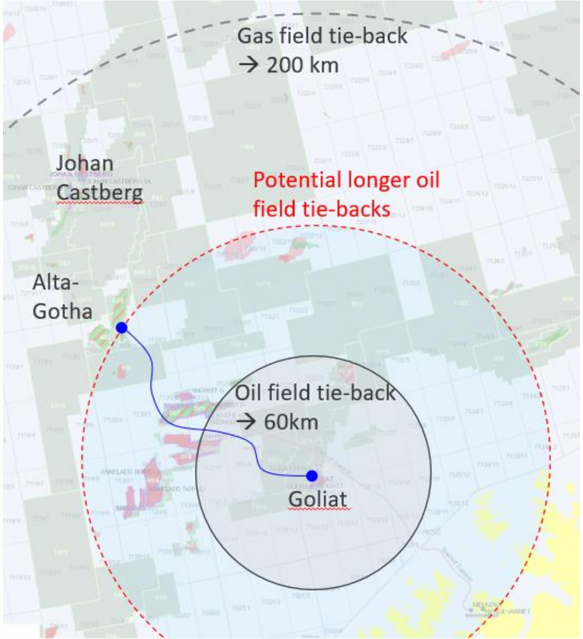

Figure 1. Map of the Barents Sea showing a maximum oil tieback distance of 60km vs. hypothetical 100km if new technology is evolved.

The capability of the industry decides how the maps will look in the future. More tiebacks mean less platforms, and less logistic supply-, anchor handling vessels and tank boats etc. Therefore, the environmental footprint would be significantly lower if one is able to double the distance.

This poster will discuss how we have advanced our slug capturing technology over years via working with oil companies as end users for new technology. Confidence in the simulation results is key for their decision processes for developing and operating tiebacks.

Methodology – Design and commercialization

Developments of advanced multiphase simulators are costly as they require several disciplines of science. It is traditional science using experimental physics and theoretical models to describe the phenomenon of multiphase flow, followed by the numerical implementation in simulator software. One may think the latter is the easy part, but to solve the models numerically researchers find themselves inventing new numerical methods for the purpose – All to design a multiphase simulator. Once you have all this sorted out you can go back to the experimental data to compare simulator vs. experiments and improve the models. In addition, one needs to investigate computational speed with a strategy for bringing down the simulation time. This requires deep knowledge of computer science as a discipline as well as physics, mathematics and chemistry that adds to the complexity of creating a commercial product.

Qualification of multiphase predictive tools that one may use for industrial decision making i.e., billions of dollar investment decisions, needs more sophistication, qualification, and trust by the decision makers e.g., oil companies. This means that experimental data is not sufficient. Typical experiments use model fluid systems, which can have a different behavior than real fluid systems. The actual proof is thus delivered when predictions match actual field data. Therefore, multiphase flow simulators developed for decision making need to ensure a validation of the flow models against field data. In our example on slug capturing, initial comparisons of simulation results against field data showed that improvements were required. We will discuss how we worked and show how simulation results have improved.

Experimental Procedure – Design by evolution

To develop a multiphase simulator for decision making and qualify it, the following steps would apply:

1. Develop physical models based on lab experiments. You need access to both industrial scale and small-scale flow loops as infrastructure.
2. Implement models into the simulator, and. develop numerical schemes to solve the physical models.
3. Compare model results vs. experimental results. If ok move to 4. If too inaccurate move to 1. If too slow computation, move back to 2. Sometimes it is hard to separate between going back to step 1. or 2. as it is hard to understand whether the problem is numerical or is originating from physics assumptions.
4. Engage with potential users and develop R&D projects to qualify the simulator against an extensive set of actual field data. If the field data match the simulation results you are done. If the field data does not match one need to understand causes for the mismatch. This can be all from a simple software-bug to a fundamental problem in the physics model or in the numerical scheme. Potentially it can be due to inaccurate measurements from the field. Taking the industry perspective, one needs to move back to one of the previous stages in the process and redo those steps.

The time frame of moving between the different stages from research to commercial products takes years of effort. One can easily use 2-3 years in the first step before one are ready to implement the models and get first simulation results to compare vs. experimental results. Another 2-3 years may run for qualification. In such a process various models play together and each needs to be validated. You will see different levels of technical maturity. For example, once you have established the core multiphase "engine" additional functionality can be added such as sand transportation, wax or hydrate modules and slug capturing.

Results and Discussion

In 2005 the LedaFlow slug research was started. During 2007 the first results were available with a new physics-based model that simulated slugging. Slug Capturing was first time released as beta release in LedaFlow 1.0 in 2011. In 2012 the first paper on the slug capturing technology was presented at OTC [1]. Figure 2 below is the profile of the pipeline between two platforms. It has a gas rate of 52400mscfd, oil rate of 30500sbpd, and water rate of 31900sbpd. The field data is given as pressure deltas in Figure 3.

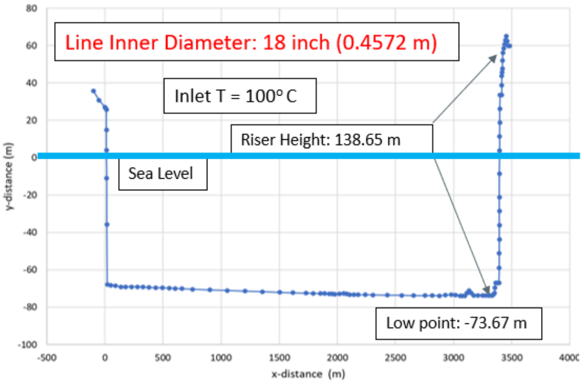

Figure 2. Pipeline profile from 70m depth to 60m above sea-level.

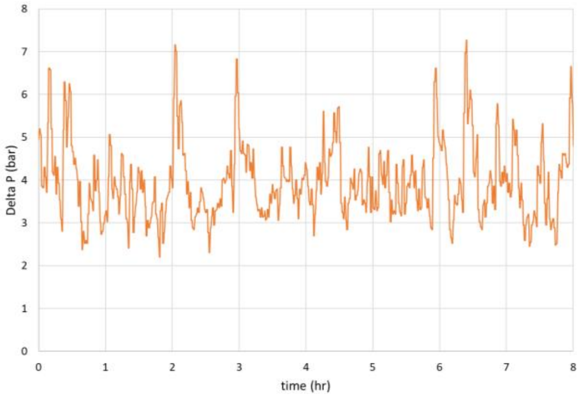

Figure 3. Field data pressure drop [bar] vs. time [h].

Figure 4 shows the field data compared to the unit cell model of LedaFlow. Note that slugs are not resolved in the unit-cell model but treated in an average manner. The estimated average pressure difference estimated by is close to the average of the slugs in the field data, but model is unable to predict the fluctuations.

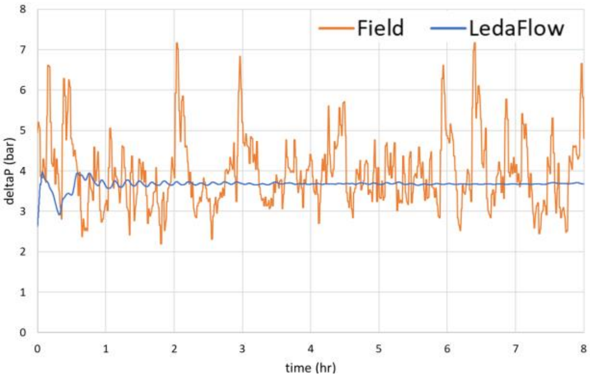

Figure 4. Field data compared to the LedaFlow unit cell model.

In Figure 5 we compare the field data vs. early version of slug capturing algorithm from 2012 in [1]. This is the early beta released version of slug capturing.

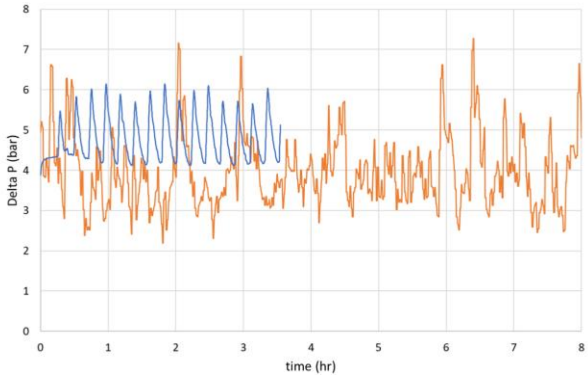

Figure 5. LedaFlow slug capturing 2012 in [1] compared to field data. Here 8-hour field data only compared with ~4 hour simulated data.

This is a first early version of the software and a starting point to iterate development and evolve LedaFlow. At the time it was clear that we needed to work both with the numerical schemes and as well as the physics model behind the technology. This resulted in Ledaflow 2.4 R&D version (never released officially) in 2018 shown in Figure 6. It was a major step forward, but the simulator stopped slugging after 5 hours.

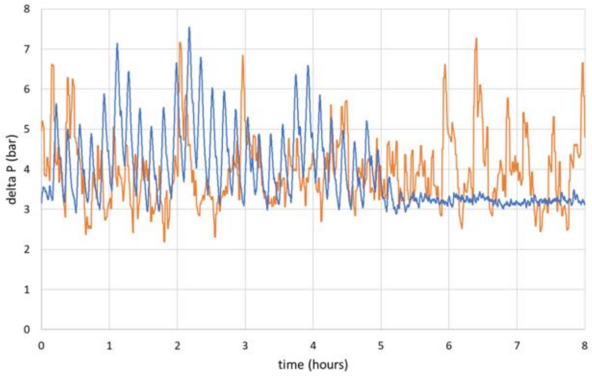

Figure 6. R&D version with new solver based on LedaFlow 2.4 from 2018 vs. field data.

At the time we were able to increase accuracy and one can see by eye that pattern is much closer to the field data. The improvements were due to both improvements in the physic representation of the model as well as some improvements to the numerical scheme. The evolution of the models continued with our numerical solver technology, and it was first with LedaFlow 2.7 in 2021 that a breakthrough came in the numerical scheme that made the release of single pipeline slug capturing based on the new numerical schemes. The new explicit solver worked more accurately than our implicit solver to resolve the integration required by the simulator. There were several new inventions that made this solver very accurate, and it was able to resolve the physical models better. Some improvements were made since 2.7 and in Figure 7 we compare the field data vs. LedaFlow 2.8 released in 2018.

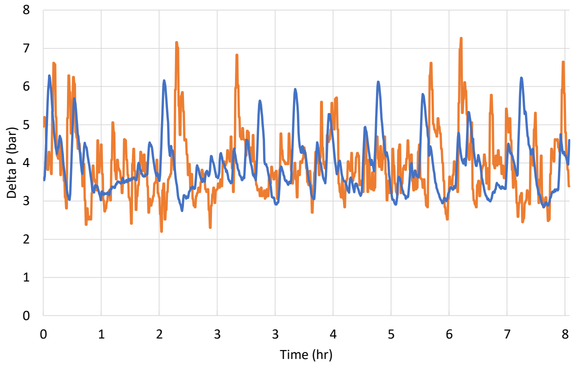

Figure 7. LedaFlow slug capturing from 2022.

The new solver technology is only available for single pipelines although the results are so encouraging that we follow up with additional R&D for the technology to support pipeline networks. At the same time, we have a proven concept, and we can start to explore computational speed-ups and look for better computer parallelization. We also see that once we have reached the accuracy shown in Figure 7 it is easier to make small adjustments by digging into experimental data and then improving the models further.

Conclusions

Development of advanced accurate physics-based simulator tools is an effort that takes years of research to accomplish. The development is based on scientific methods, and one must have control of the parameters and how the models behave. These are important aspects for the trust required in decision making.

Acknowledgments

Thank you to all oil companies that have supported LedaFlow development by donating field data and a big thank you to ConocoPhillips and TotalEnergies that made us able to use field data, and for their scientific contributions and testing of the software models over a period of 20 years.

Responsibility Notice

The authors are the only responsible for the paper content.

References

[1] Simulation of Slug Flow in Oil and Gas Pipelines Using a New Transient Simulator, T.J. Danielson et.al, OTC-23353-MS, Offshore Technology Conference, 2012