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Technical Paper

Streamlining Selection and Surveillance: An end-to-end Lifecycle Tool for Well Test Optimisation

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1 Abstract

A multi-module and evolving cloud-based well test equipment selection, surveillance and monitoring tool has been developed to ensure optimum field specific selection of well testing equipment for field life-cycle operability which can be utilised for real time monitoring on accuracy and performance of installed MPFMs during operations. The tool consists of three modules each used at different project phases, namely early sizing and selection (FEL 0/1), verification (FEL 2/3), commissioning and surveillance (Operation).

This paper covers the methodology of the tool to demonstrate fit for purpose selection catered for full field life reliability for well test equipment by ensuring calculations from process simulations or Heat and Material balance taking into consideration full field life scenarios and cases as well as well counts. Results of each case and simulation is then analysed via a two-phase flow map, GVF vs WLR plots as well as flow regime predictions. Apart from that, another module serves the purpose of creating and monitoring well test performances to ensure deviations are monitored and mitigation plans can be made to ensure improved acceptance rates and confidence with well testing facilities, which is always questioned.

Fourteen project cases had been evaluated utilising this tool and the evaluation results from tool usage has demonstrated incorrect and not fit for purpose selection to last for full field life as per intension, reverification during FEED stage proved vital in correcting the selection as well as setting the baseline for health checks during operation and surveillance provided rectification plans with assured results. All in all, the simplicity of tool usage as well as being hosted in a sustainable cloud-based environment, contributed towards significant cost savings in manhours to expedite tedious manual calculations and perform flow regime predictions in order to develop the optimum operating envelope for the field life of the wells. In addition, during operations, this tool has proven to demonstrate higher well tests acceptance rate due to the ability to carry out real time surveillance which enabled well test engineers to carry out tuning or rectification on well test parameters to improve accuracy of measurements.

Results depicted in Table 1 showcases tool strengths in selection, verification, and monitoring of well test equipment. The tool, namely “PETRONAS Well Test Equipment Selection and Surveillance Tool (P-WEST©)”, will facilitate third party testing and verification by Operators, removes tedious manual calculations of each well stream and case to select equipment which would satisfy all cases of a well prediction. It also provides real time well data monitoring and recommendations to resolve issues with well test equipment specific to field requirements and reservoir characteristics. Its current deployment has managed to resolve issues at hand with realised cost savings- however there is room for further development as well as potential commercialisation in the future to resolve pain points and eventually, becoming a virtual advisor.

2 Introduction

Metering and measurement practitioners across the globe suffer from problems which stems from the pre-development stage up to the operational phase when it comes to well testing and measurement in the Oil and Gas industry (Goswami,2015). Amongst others, high operational cost for additional well test verification, additional cost requiring third party verification, consultancy towards mid to late field life, well test acceptance and compliance percentages, equipment operating envelope not able to cater for full field life, production rates not within the operating envelope and the accuracy of the data but most importantly the inability to select the right equipment based on fluid properties as well as monitoring performances of procured units. In the past and present day, too much reliance is on design consultants as well as technology provider pushing their agenda on a single design fits all conditions raises the concerns. Detailed well by well calculations and full field life simulations are not diligently performed as it is viewed as a tedious process, whereby this foresight has led to bigger issues when equipments are in operations.

Realising the issue at hand, a multi-module cloud-based well test equipment selection, surveillance, and monitoring tool namely P-WEST© was developed to ensure optimum field specific selection of well testing equipment for field life-cycle operability as well as use case for real time monitoring on accuracy and performance of installed test equipment's during operations. This tool automates tedious calculations and is vendor agnostic, it's able to depict and analyse reference vs measured data for pre and post commissioning activities as well as well test campaigns for assurance purposes transferring the risk to equipment suppliers instead of the facility owner.

Statement of Theory and Definitions

The key to well testing is selection and sizing which can be done during the Front-End Loading or FEL phase. It is to eliminate inappropriate selection during project FEL 1-2 stage and to have ability to validate selection at FEL 3 stage to avoid wrong investment nullifying extra expenditure and unnecessary design changes.

Although the selection of well test equipment is important in the operation of the well, in the current practice to select a well test equipment, a well operator can only rely on the manufacturer of the well test equipment to recommend a well test equipment. However, these practices might lead to inaccurate selection as the simulation done by the manufacturer might not cater to all flow cases of a full filed life cycle. Therefore, there is a need for a system and method that addresses the problems.

At its current representation, the tool has three modules developed are explained below.

Module 1, namely "Well Test Selection & Sizing", performs selection and sizing of fit for purpose well test equipment for individual field. Module is utilised during FEL 0/1 stage where information is limited with only available composition data, PVT data, fluid characterisation to name a few. At this stage, an additional PVT simulation and/or fluid characterisation is required to attain input for tool simulation.

Module 2, namely "Well Test Equipment Verification". verifies the selection of well test equipment used during FEL 2/3 stage when Process Simulation data is available with full field like cases, scenarios per well.

Module 3, namely "Surveillance and Routine Well Testing". measures the health and performance of well test equipment in operations. Module is deployed at assets with existing well test facilities installed.

Module 4, namely "Commissioning and Well Test", compares test deviations between Factory Acceptance Test and actual commissioning or first hydrocarbon.

When deciding or determining a right testing equipment, the critical parameters to observe and compute on the surface apart from the pressure temperature and volume are the Gas Volume Fraction (GVF), Water Liquid Ratio (WLR), Lockhart Martinelli Coefficient (X_{lm}) and superficial velocity of the fluids. GVF is defined as the fraction of gas volume flow rate compared to the total volume flow rate (i.e. the sum of the gas and liquid volume flow rates). It is calculated as

$$GVF\ (\%) = Qg / (Qg + Ql) \quad \ldots (1)$$

where:-

Qg = Gas flow rate in Volume @ Actual Condition (m3/sec or ft3/sec)

Ql = Liquid flow rate in Volume @ Actual Condition (m3/sec or ft3/sec)

The gas volume flowing is the volume of the humid gas at flow conditions. That is, the gas volume flow rate is the gas phase and the liquid vapour component. The liquid volume flow rate is the volume of the "free liquid" flow rate at flow conditions. Water to liquid ratio is simply the amount of water content part of the total liquid content.

$$WLR = Qw / (Qw + Qo) \quad \ldots (2)$$

Qw = Water flow rate in Volume at Actual Condition (m3/sec or ft3/sec)

Qo = Condensate flow rate in Volume at Actual Condition (m3/sec or ft3/sec)

Xlm or Lockhart Martinelli Coefficient is a dimensionless number used to express the liquid fraction of a wet gas stream, and is given as

Xlm = sqrt (Inertia of Liquid Flowing Alone / Inertia of Gas Flowing Alone)

$$Xlm = (ml / mg) * \mathrm{sqrt}\ (\rho l / \rho g) \quad \ldots (3)$$

$$Xlm = (Ql / Qg) * \mathrm{sqrt}\ (\rho l / \rho g)$$

Where

ρg = Gas Density (kg/m3 or lbm/ft3)

ρl = Liquid Density (kg/m3 or lbm/ft3)

mg = Gas flow rate in mass (kg/sec or lbm/sec)

ml = Liquid mass flow rate (kg/sec or lbm/sec)

Qg = Gas flow rate in Volume @ Actual Condition (m3/sec or ft3/sec)

Ql = Liquid mass flow Volume @ Actual Condition (m3/sec or ft3/sec)

The gas mass or volume flow rate indicates the total gaseous phase (i.e., it includes liquid vapour) mass or volume flow rate. The gas density is the density of the overall gas and liquid vapour phase mix i.e. and includes the effect of any liquid component's mass saturated in the gas.

Superficial Gas Velocity is the average gas velocity of the flow if the gas flow component of the wet gas flowed alone in the pipe while superficial liquid velocity is the average liquid velocity of the flow if that liquid flow component of the wet gas flowed alone in the pipe.

Gas Superficial Velocity, Usg = mg / (ρg *A) ………………………………………………………………………………..(4)

mg = Gas flow rate in mass (kg/sec or lbm/sec)

ρg = Gas Density (kg/m3 or lbm/ft3)

A = Cross Sectional Area of Piping at inlet of test equipment

Liquid Superficial Velocity, Usl = ml / (ρl *A) ……………………………………………………………………………….(5)

ml = Liquid flow rate in mass (kg/sec or lbm/sec)

ρl = Liquid Density (kg/m3 or lbm/ft3)

Description and Application of Equipment and Processes

Figure 1 depicts the architecture of selection which illustrates the system for selecting a well test equipment and for monitoring performance of the well test equipment. The system comprises an input module, a stage coordinator a computational module, a database, and an output module.

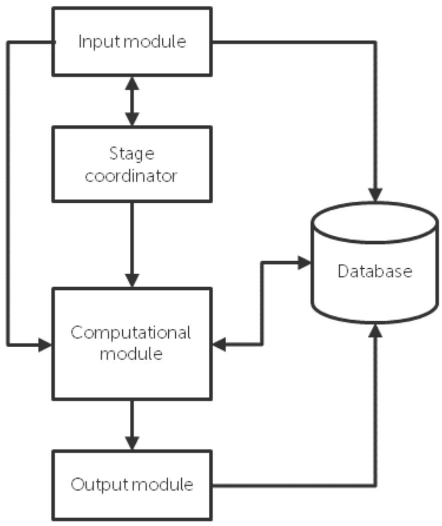

Fig. 1—System overall architecture block diagram of system for selecting a well test equipment and for monitoring performance of the well test equipment.

The input module is configured to obtain information regarding the oil or gas wells and computational parameters required to compute gas volume fraction or GVF, a Lockhart-Martinelli parameter or XLM, Water to liquid ratio or WLR, liquid volumetric flowrate, gas volumetric flowrate, water volumetric flow rates for each well stream, and simulation conditions. The information regarding the oil or gas well includes, but is not limited to, the name of the oil or gas well, a current implementation stage of the oil or gas well, pipe size, and pipe orientation. On the other hand, the computational parameters includes, but is not limited to, composition data, PVT data, and fluid characterisation data. The information regarding the oil or gas well and computational parameters may be obtained from user input or other sources. The input module is connected to the computational module to forward the information regarding the oil or gas well and computational parameters to the computational module for its further action.

The input module is further connected to the stage coordinator, while the stage coordinator is also connected to the computational module. The stage coordinator is configured to determine the information regarding the oil or gas well and computational parameters required by the input module and computational module according to the current implementation stage of the oil or gas well. Furthermore, the stage coordinator is further configured to determine whether the input module should obtain the information regarding the oil or gas well and computational parameters from the user input or other sources and whether the computational module should obtain the computational parameters from the input module, or an existing data stored in the database according to the current implementation stage of the oil or gas well.

There are four current implementation stages of the oil or gas well and they are known as the selection stage, verification stage, commissioning stage, and monitoring stage. The selection stage (Module 1) is one of pre-planning stages where available information regarding the oil or gas well and/or computational parameters are limited. For example, only composition data and PVT data are available. Therefore, in addition to the available composition data and PVT data, additional PVT simulation and/or fluid characterisation is required for the system to select a fit for purpose well test equipment. Hence, for the selection stage, the stage coordinator instructs the input module to obtain the additional PVT simulation and/or fluid characterisation from a flow assurance center and/or information regarding fluid phase of the oil or gas facility.

The verification stage (Module 2) is a stage further along the pre-planning stages. At the verification stage, most of the information such as heat and material balance and processes simulation data are available with full field life cases and scenarios. For this stage, the stage coordinator instructs the input module to obtain all computational parameters from the user input, wherein the computational parameters include the heat and material data as well the field life cases and scenarios such as the mass flows and densities of fluids for computation and output results.

The monitoring stage (Module 3) is when the offshore facility is fully operational. For the monitoring stage, the stage coordinator instructs the input module to obtain the computational parameters, which is data measured by the well test equipment during the periodic well testing, from the user input. Optionally, the stage coordinator may instruct the input module to obtain the computational parameters directly from the well test equipment. Additionally, the stage coordinator instructs the computational module to obtain the to obtain the information regarding the oil or gas well and data of the performance of the well test equipment installed at the facility from the database.

The commissioning stage (Module 4) is the stage where the well testing equipment design is accepted and tested. In the commissioning stage, verification of the commissioning test is performed to determine whether project specification requirements are fulfilled. During the commissioning stage, the stage coordinator instructs the input module to obtain the computational parameters, which is data measured by the well test equipment during the commissioning test, from the user input. Optionally, the stage coordinator may instruct the input module to obtain the computational parameters directly from the well test equipment. Additionally, the stage coordinator instructs the computational module to obtain the information regarding the oil or gas well and Factory Acceptance Test (FAT) data from the database. FAT data refers to specification information regarding the well test equipment that is obtained from a simulation by the manufacturer of the well test equipment. The FAT data includes GVF, water liquid ratio or WLR, liquid flowrate, and gas flowrate of the well test equipment.

The output module is configured to choose the suitable well test equipment according to the computed GVF and XLM received from the computational module and according to fluid phase of the oil or gas well if the current implementation stage of the oil or gas well is in the selection or verification stage. Moreover, the output module is configured to generate a selection report containing the reasons for the selection of the well test equipment. The selection report includes tabulated results of the computation by the computational module, graphs of fluid flow rate in a two-phase flow map, a graph of GVF against WLR, and a flow regime prediction map.

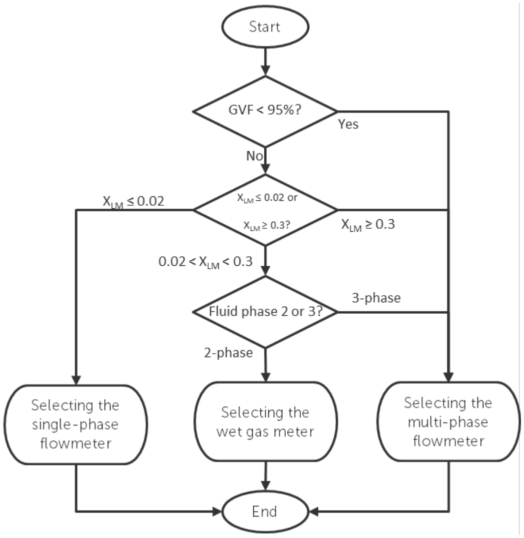

Fig. 2—Flowchart of selection decisions for well test equipment

Figure 2 shows a flowchart of sub-steps of choosing the most suitable well test equipment by the output module of the method in Figure 1. Firstly, the output module determines if GVF is less than 95 per cent as in decision. If GVF is less than 95 per cent, the output module chooses the MPFM as the well test equipment.

On the other hand, if GVF is more than 95 per cent, the output module further determines whether XLM is less than or equal to 0.02 or greater than or equal to 0.3 as in decision. If XLM is greater than or equal to 0.3, the output module chooses the MPFM as the well test equipment.

If XLM is less than or equal to 0.02 the output module chooses the single-phase flowmeter as the well test equipment. Otherwise, if XLM is between 0.02 and 0.3, the output module further determines whether the fluid phase is 2-phase or 3-phase as in decision.

If the fluid phase is 2-phase, it indicates that the oil or gas well is a Non-Associated Gas type of well. Therefore, the output module chooses the WGM as the well test equipment. On the other hand, if the fluid phase is 3-phase as in decision, it indicates that the oil or gas well is an oil producer facility with Associated Gas. Hence, the output module chooses MPFM as the well test equipment.

Figure 3 represents the surveillance and commissioning module flowchart where definition of parameters is based on existing design conditions. Defined project info is inputted such as well test configuration, line size inlet and number of wells. The existing facility test envelope is also developed prior to inputting well test results to establish a health check and diagnostic module for future well test results logging where the asset teams would key in well test results and compare or ensure equipment is able to measure the well flow.

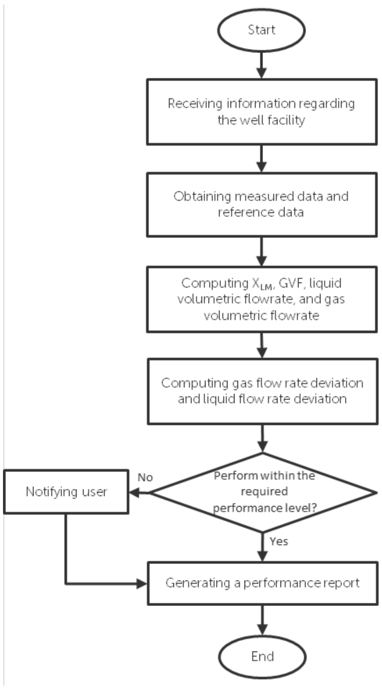

Fig. 3—Flowchart for surveillance (module 3 & 4)

Results & Discussion

Since the inception of the tool, the proposed framework was applied for 14 projects based on applicable modules and issues surfaced with solutions recommendations. Table A-1 depicts the summary of results.

Table A-1 results and recommendations from tool use cases.

Project	Module	Results & Recommendations
A	2	GVF for cases are ranging from 96-99 per cent with Xlm 0.02 < X < 0.3 which indicates applicability for WGM well test and metering.
B	2	Simulation results indicates the well streams are all above 99 per cent GVF which indicates applicability for WGM well test and metering. Flow regime and superficial velocity are also within the wet gas region. (wave flow with velocity approx. 15 m/s). Flow regime predicted to be in the wave flow going into the stratified flow towards the end of field life indicating wet gas region throughout field life.
C	2	GVF for cases are ranging from 99-100 per cent with Xlm 0.02 < X < 0.3 which indicates gas dominated flow. Flow Regime is predicted to be in wave flow throughout field design life.
D	2	GVF for cases is 99 per cent with Xlm of 0.043 which says its gas dominated flow. WGM is recommended based on the simulation.
E	2	GVF for cases are ranging from 99-100 per cent with Xlm 0.02 < X < 0.3 which says its gas dominated flow. Flow Regime is predicted to be in wave flow.

F	2	Based on the calculations from mass flows of gas and liquid, the GVF results for all cases range from approximately 36 -73 per cent. This indicates suitability to use MPFM as the GVF percentage is within the optimum range of MPFM performance. Flow regime is churn to slug flow. Intermittent flow is predicted based on superficial velocities calculation as well as inlet spool pipe cross section of MPFM. Partial separation type MPFM is recommended.
G	2	GVF for cases are ranging from 98-99 per cent with Xlm 0.02 < X < 0.3 which says its gas dominated flow. WGM is selected while flow Regime is predicted to be in wave flow.
H	2	GVF for case is 99 per cent with Xlm 0.006 which says its gas dominated flow. WGM is selected.
I	2	GVF for cases are ranging from 96-99 per cent with Xlm 0.02 < X < 0.3 which indicates applicability for WGM well test and metering. Flow regime predicted to be in the wave flow.
J	2	GVF for all cases are ranging from 97-99 per cent with Xlm (<0.09) which says its gas dominated flow and liquid does minimal effect to the gas flow. Flow regime predicted to be in the wave flow going into the stratified flow towards the end of field life indicating wet gas region throughout field life.
K	3	Tool developed baseline model and verified wells which were operating out of the MPFM design. Tool deployment has given the team confidence on measurement that are healthy and valid rather than guessing the figures.
L	3	Tool confirmed that portable MPFM unit selected for purchase for installation would not be suitable for the project due to high GVF. Operating envelope did not comply with design envelope hence tool recommended change from MPFM to WGM installation.
M	2	GVF for cases are ranging from 99-100 per cent with Xlm < 0.02 which says its gas dominated flow. Flow Regime is predicted to be in wave flow. Flow Regime is predicted to be in wave flow. Recommended pipe run to be horizontal as flow velocity to be at 15 m/sec (to keep the liquid suspended in the gas).
N	1	Verified PVT data simulation and tool recommended WGM as the well test equipment.

Case Study Highlight (Project F)

Based on the calculations from mass flows of gas and liquid, the GVF results for all cases range from approximately 36 -73 per cent. This indicates suitability to use MPFM as the GVF percentage is within the optimum range of Multi-Purpose Flow Meter (MPFM) performance. Figure 4 represents the two-phase flow map output.

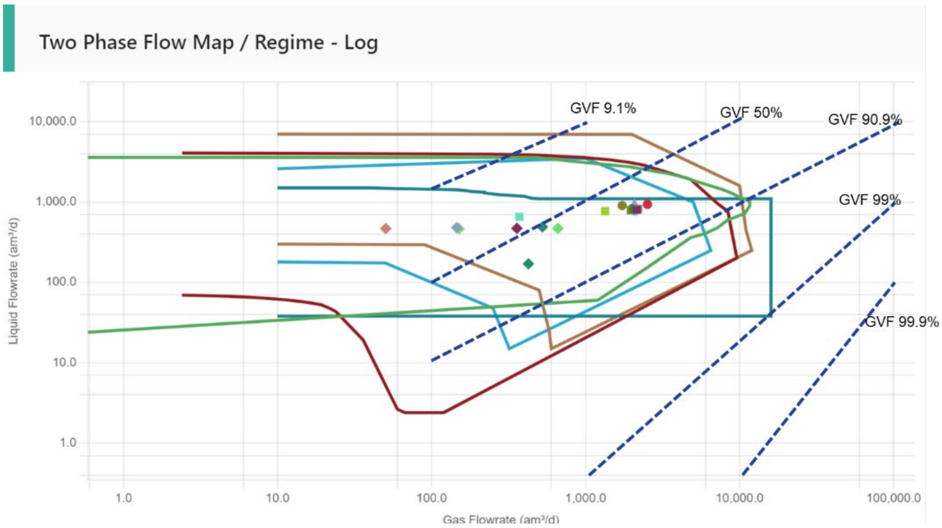

Fig. 4—Two phase flow map with GVF representation

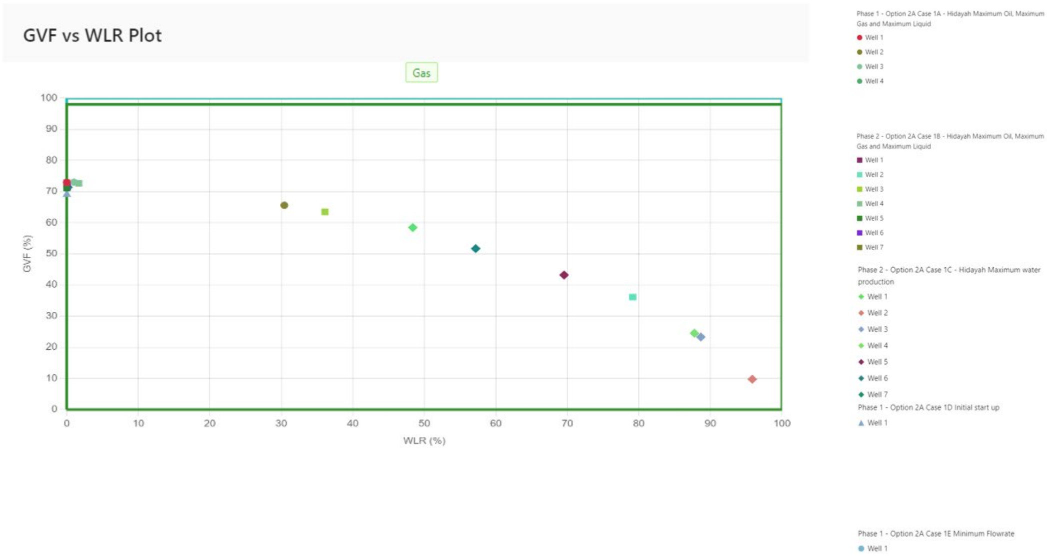

Fig. 5—GVF to WLR plot

Figure 5 represents another crucial plot as an output to determine the region of the fluid. Looking at wells from phase 1, the region is still gas dominant compared to condensate with ratio of 7:3. Hence, with the possibility of water injection planned for the future, the WLR and GVF may increase over time. In such a case, if the plot indicates movement towards the wet gas region, the in-line MPFMs would be disadvantageous (Handbook of Multiphase Flow Metering, 2005) and in most cases, partial separation type MPFM may be more suitable.

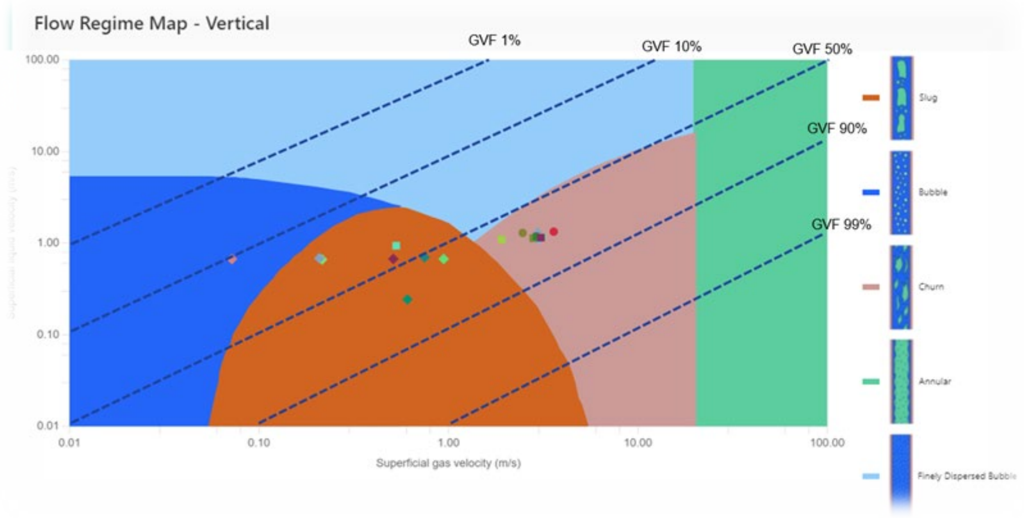

Fig. 6—Flow Regime Plot

The flow regime plot referred to in Figure 6 outputs the predicted flow regime of the well flow at the surface and is determined by the inlet piping orientation and cross section as well as the superficial gas and liquid calculations. This plot helps users determine the type of flow and helps with decision on mitigations. Intermittent flow is predicted based on superficial velocities calculation as well as inlet spool pipe cross section of MPFM. Intermitted flow is characterised by being non-continuous in the axial direction, and therefore exhibits locally unsteady behavior. Slug and annular flows are often the hardest flow regimes to measure. When the GVF increases to the upper limit of the measuring range of the meter, this will normally cause an increased measurement uncertainty. If the measurement uncertainties are obtained with an in-line type MPFM (without separation of the flow) and are not within acceptable limits for use in these high gas volume applications, a partial separation design may resolve this limitation in technology.

Case Study Highlight B (Project K)

Module 3 was deployed at existing facilities. In the case of project K, which has been already operational with asset teams having difficulties to match export metering figure with MPFM results. Furthermore, the subsurface team couldn't determine which well is not performing. With the help of the P-WEST tool, the team could identify which well operating out of the MPFM design envelope as shown in Figure 7. The health check assessment showed that 28 per cent of the well test results were beyond the measuring capability of the installed equipment which would ultimately lead to acceptance issues and higher errors in accuracy. The pilot exercise had given the asset team the confidence in reporting their well test acceptance and determine which figures to report for well test acceptance between well test equipment and export meter.

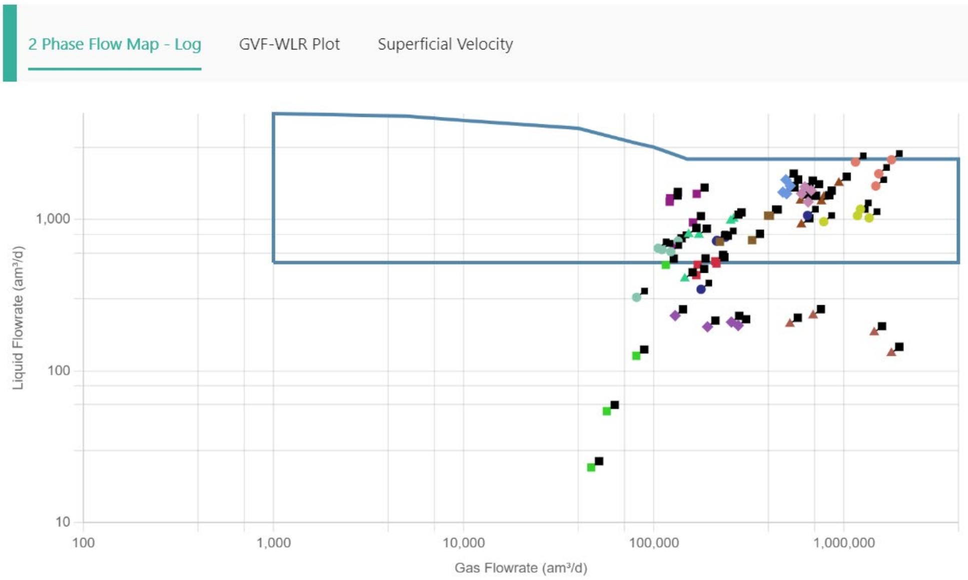

Fig. 7—Two phase flow map showing MPFM design envelope and well test results

Conclusion

The novelty of this tool is in the ability to integrate, perform and solve all critical issues arising from well testing, be it from predevelopment selection and sizing as well as towards equipment acceptance all the way to monitoring the facility in operation. In addition, the database can be progressively updated as technology evolution takes place, making it a future-proof solution which resided in a low carbon cloud environment. Significant strides have been made at this tool nascent stage with further development and continuous improvements in integration and compatibility with Virtual Flow Meter (VFM) tool (W. A. Adrie et al., 2022) which would act as a digital twin and correlate to a more confident model.

Further adoption across assets and tool continuous development would be necessary for tool success. As it stands, the framework presented has become a norm for adoption and embedded in organisational technical specifications as guidelines across all upstream projects with well testing requirements. In conclusion, the adoption of the tool has negated additional verification with baseline model from tools available, well test data capturing as well as deviation monitoring ensuring operating conditions are within design envelope, improved well test acceptance and lastly, significant value creations with in-house capability.

Acknowledgement

Our special thanks and acknowledgement towards the entire PETRONAS P-WEST team working on the development of the tool as well as the Group Digital Team for maturing it from an excel prototype into a copyrighted cloud-based tool and currently a Malaysian patent pending product.

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