39th North Sea Flow Measurement Workshop 2021

Setting up a fit for purpose well testing environment in PETRONAS

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1. INTRODUCTION

Let's face it. Well testing can be tough. This paper will chronicle the challenges that has been plaguing well testing activities, especially so when utilizing MPFMs. A catalogue of pain points unearthed by a collaborative effort not limited to metering practitioners, production technologists and planners alike. Complex as it may be, these pain points are identified, compiled and will be described comprehensively as part of the problem statement.

Field potential optimizations are often complicated in an oil field with large number of wells, as gas and water production increasing, both can affect each well optimization due to many reasons (lower reservoir pressure, increasing gas-oil ratio, backpressure from produced gas and water, etc.). Achieving optimum production for the total field requires good understanding on the well performance and flow characteristic as accurately as possible. Accurate well data can help operations to effectively plan well activities such as choke optimization and gas lift optimization. Without good and accurate data, the efficiency of optimization programs will not be significant – resulting in lower revenue return on investment made for these activities.

After going through these, the paper will then showcase what has been done to remedy, and resolve these issues. These will involve the efforts being put in using current available technology and being agile to adapt with new way of doing things with the intent of establishing a robust tool for selection of the well test equipment, tailored to PETRONAS wells, the establishment of a digital twin for baseline data, and an efficient system of making PVT data available as input parameter where and when it is required for the various makes of MPFM in our fields.

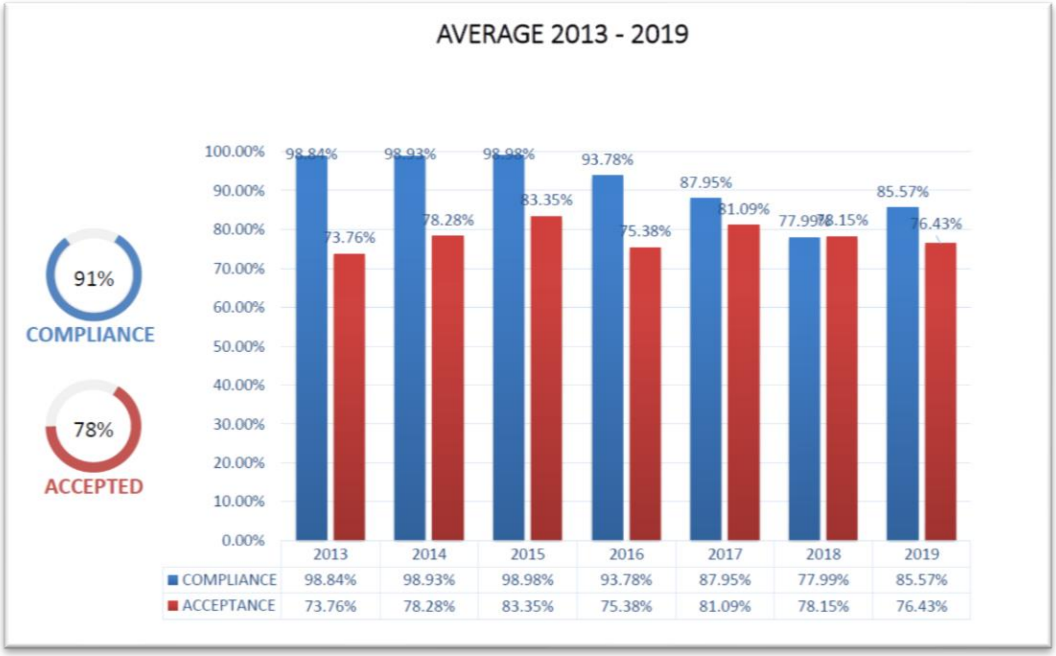
By the time the paper concludes, it is expected that the methods that was used to effectively resolve the issues has been clearly communicated to the audience and that the sharing of the experiences will provide an insight and can be used as a guide for fellow measurement practitioners in the energy industry.

2. WELL TEST PAIN POINTS

Since MPFMs came about, we have encountered many challenges in achieving an optimized / desirable well test results over the years

The focus is always on optimizing the assets in view of yielding superior results, i.e. a good reconciliation factor, well test results that is agreed by the subsurface and measurement teams

Previously our well test acceptance numbers are at about 78-80%, as can be seen in Figure 1. There is plenty of room for improvement here. In my analysis of the historical data sets, the MPFMs came up with the most numbers of technical issues. (Figure 2)



	2013	2014	2015	2016	2017	2018	2019
🟦 COMPLIANCE	98.84%	98.93%	98.98%	93.78%	87.95%	77.99%	85.57%
🟥 ACCEPTANCE	73.76%	78.28%	83.35%	75.38%	81.09%	78.15%	76.43%

Figure 1: Well test historical data

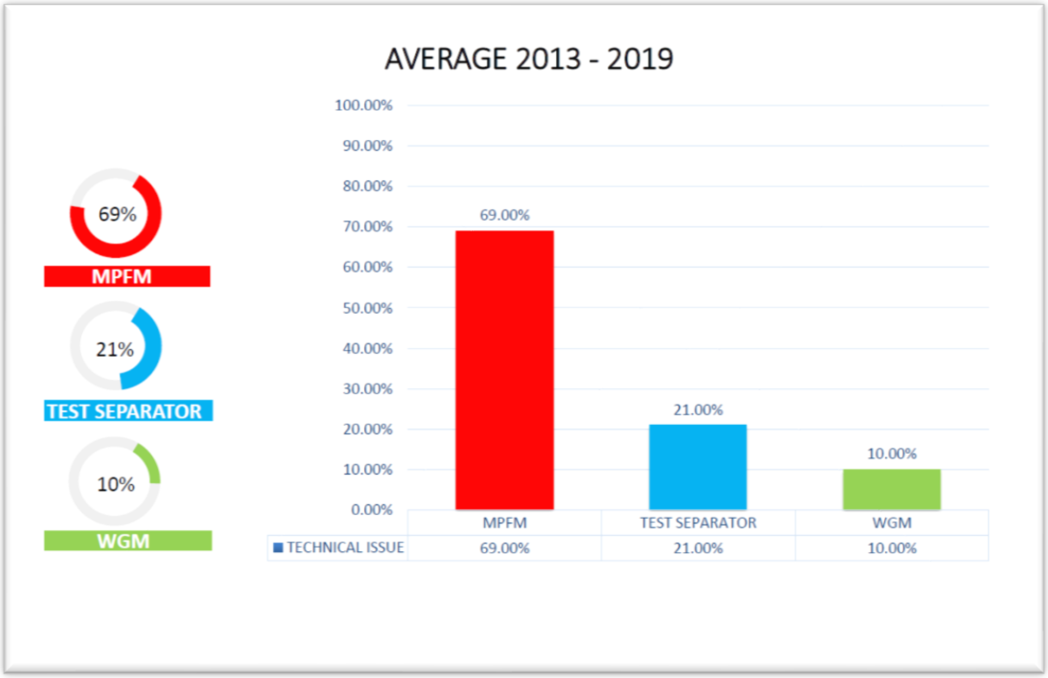
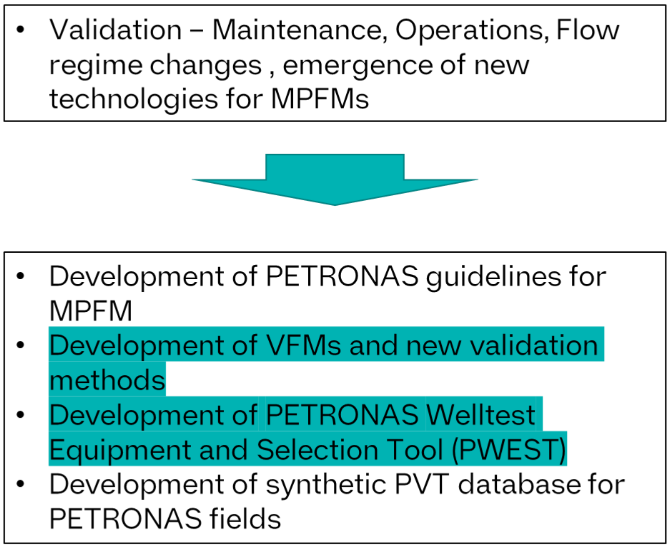


Figure 2: Technical Issues by equipment



- Validation – Maintenance, Operations, Flow regime changes , emergence of new technologies for MPFMs

- Development of PETRONAS guidelines for MPFM
- Development of VFMs and new validation methods
- Development of PETRONAS Welltest Equipment and Selection Tool (PWEST)
- Development of synthetic PVT database for PETRONAS fields

Figure 3: Well test improvement programs

In this paper we will be discussing 2 of the initiatives that has been initiated, and currently on going that will address a huge chunk of the issues that have been impacting the business

3 VFM development (Initiative 1)

In this section, the methodology used to carry out the experiments and achieve the project objectives will be explained. There are six subsections:

1- Overall VFM workflow
2- Data-driven VFM workflow
3- Physics VFM workflow based on Turbulent Flux transient multiphase flow simulator
4- The Combiner algorithm
5- Performance metrics
6- Overview of the pilot experiments

3.1 Overall VFM workflow

The general diagram of an online VFM system is shown below.

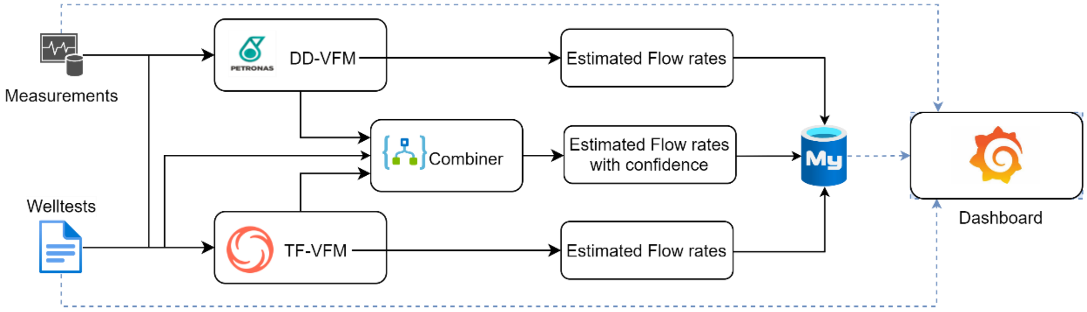


Figure 1: System diagram

The measurements from PI and the well test reference reports are fed to individual VFMs and the outputs are stored into database. The combiner uses the outputs from individual VFMs and calculates its flow rate estimates along with confidence level indicator. All the data is stored into the SQL database and visualized in Grafana dashboards.

The system is flexible such that more than one VFM model can be running for the same asset. The combiner is also flexible as it accepts one or more models to run the combining algorithm and can handle missing values properly.

3.2 Data-driven VFM workflow

Data-driven VFM (DD-VFM) is developed based on the concept of ensemble learning. This is as per the recommendation from previous literature on data driven VFM. The complete workflow of DD-VFM is shown below.

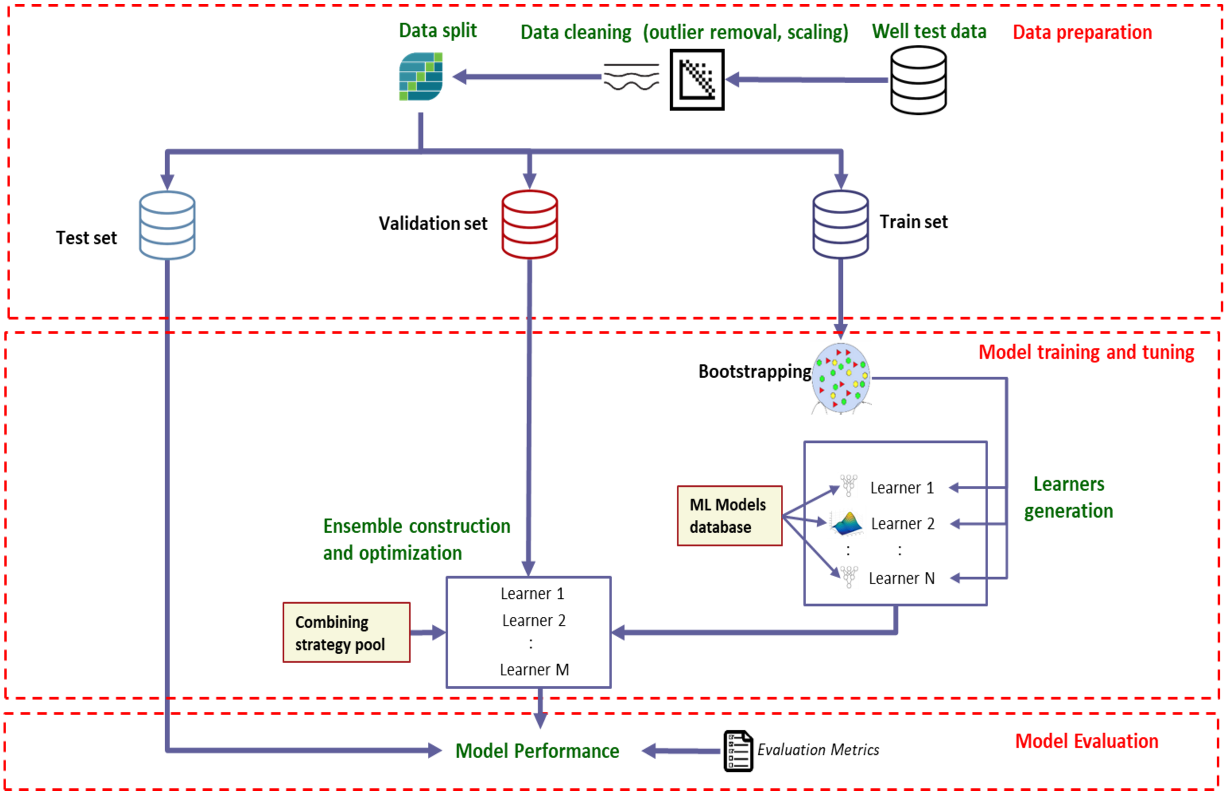


Figure 2: Data-driven VFM based on ensemble learning

Different algorithms are trained and the best performing algorithm is selected. Some of the algorithms implemented for this project are (including non-ensemble algorithms):

- Bagging
- Multi-layer Perceptron neural network (MLP)
- Support Vector Machine (SVM)
- Polynomial regression

Different DD-VFM models can be developed based on the available measurements. The models can be classified into three categories:

1- Subsurface models: Using the measurements from downhole until Upstream the choke
2- Surface models: using the measurements from upstream the choke to downstream the choke

3- Full models: using all measurements available from downhole to downstream the choke valve.

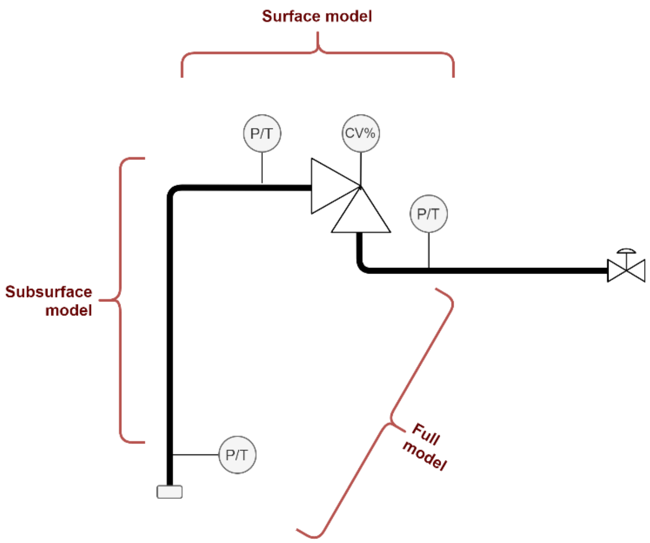


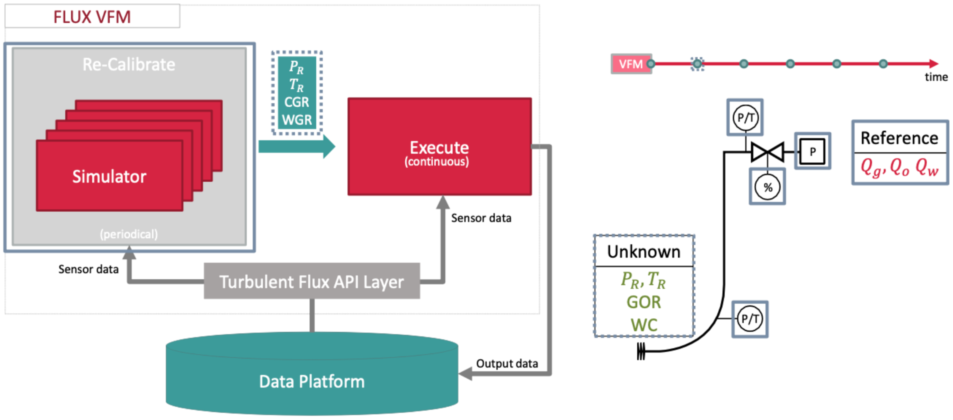
Figure 3: Possible ML models based on available measurements

3.3 Physics-based VFM workflow

Turbulent Flux transient multiphase flow simulator is used in this study to construct a physics based VFM (TF-VFM). TF-VFM goes into two general steps to work properly.

a. Physics and static tuning: the system in this step uses the static information about the well such as well geometry, PTV, and choke characteristics to tune physical and system parameters. This is typical done once at the beginning of the project and can be repeated if substantial changes occurred to the well.

Figure 4: TF-VFM initial calibration



b. Autonomous calibration: the system in this step uses an optimizer that runs periodically and corrects the system based on the measurements from the well. No reference flow rates are required to perform this step

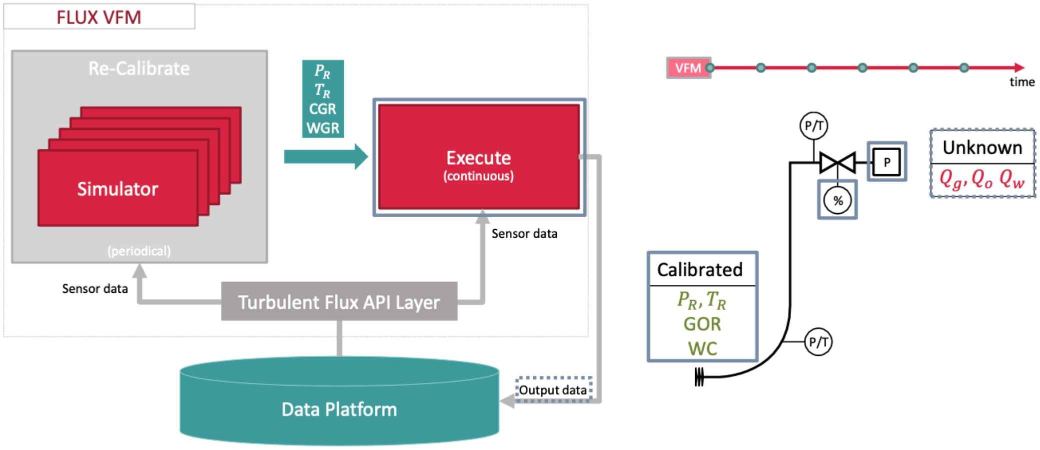


Figure 5: TF-VFM operational workflow

3.4 Combiner workflow

The combiner is an algorithm that aggregates estimations from different VFM models (be it data-driven or physics-driven) and finds the optimal flow rate estimates along with an indication of confidence level. The combiner tracks the performance of different models using the periodically updated and validated well tests. The contribution of individual model to the final estimate is dependent on its performance compared to historical well tests and the confidence decay factor which indicates the model relevance over time and concept drift.

The general combiner workflow is as shown below:

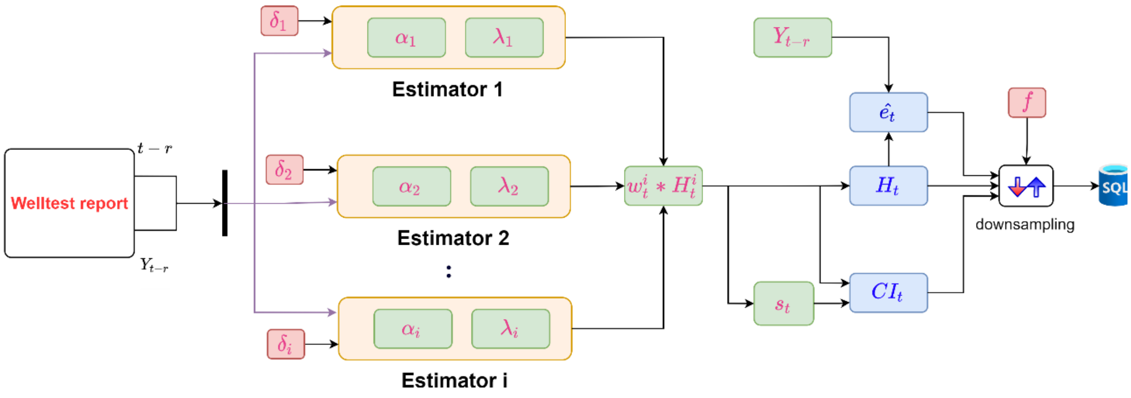


Figure 6: Combiner workflow

Confidence decay factor $\boldsymbol{\lambda}$ is calculated based on the time difference between the last estimator tuning and the current sample time. Decay coefficient δ is a constant selected based on the estimator behaviors and the well conditions, for example physics-based estimator can have small δ since it can have a wider operating envelope compared to data-driven estimators trained on small window of the operating envelope. Wells that are rapidly changing should also have a large δ since estimator's performance tend to degrade quickly over time due to the changing operating conditions and concept drift.

$$\lambda_i = 1 - \ |\Delta t| \delta_i \quad\quad range\ [0,1]$$

Accuracy contribution factor $\boldsymbol{\alpha_i}$ for estimator i is calculated from Mean Absolute Percent Error (MAPE) of the estimator and the last known reference point at time $t-r$ where r is the time of last known reference data available. α_i is normalized by the sum of errors of all estimators such that $\sum_{n=1}^{N} \alpha_n = 1$ where N is the number of estimators involved.

$$MAPE_i = \left| \frac{Y_{t-r} - H_{t-r}^{i}}{Y_{t-r}} \right|$$

$$acc_i = 1 - \frac{MAPE_i}{\sum_{n=1}^{N} MAPE_n}$$

$$\alpha_i = \frac{acc_i}{\sum_{n=1}^{N} acc_n}$$

Confidence Interval (CI) of the combined flow rate is calculated from the pair-wise sample standard deviation s_t.

$$s_t = \sqrt{\sum_{i=1}^{N} \frac{\left(H_t - H_t^i\right)^2}{N-1}}$$

$$CI_t = \widehat{H}_t \pm \frac{t * s_t}{\sqrt{N}}$$

Where $\widehat{H}_t$ represents the outcome of the combiner and t is the student's t-distribution score which is a parameter based on the confidence level and degrees of freedoms. If there are enough samples, normal distribution can be used instead.

Down sampling by f: the results are passed through a downsampler to produce estimates at the desired frequency f which should be slower than the estimators frequency to introduce a smoothing effect.

Figure below shows the detailed block diagram design and data flow of the combiner. Only two estimators (1 and i) are shown for simplicity.

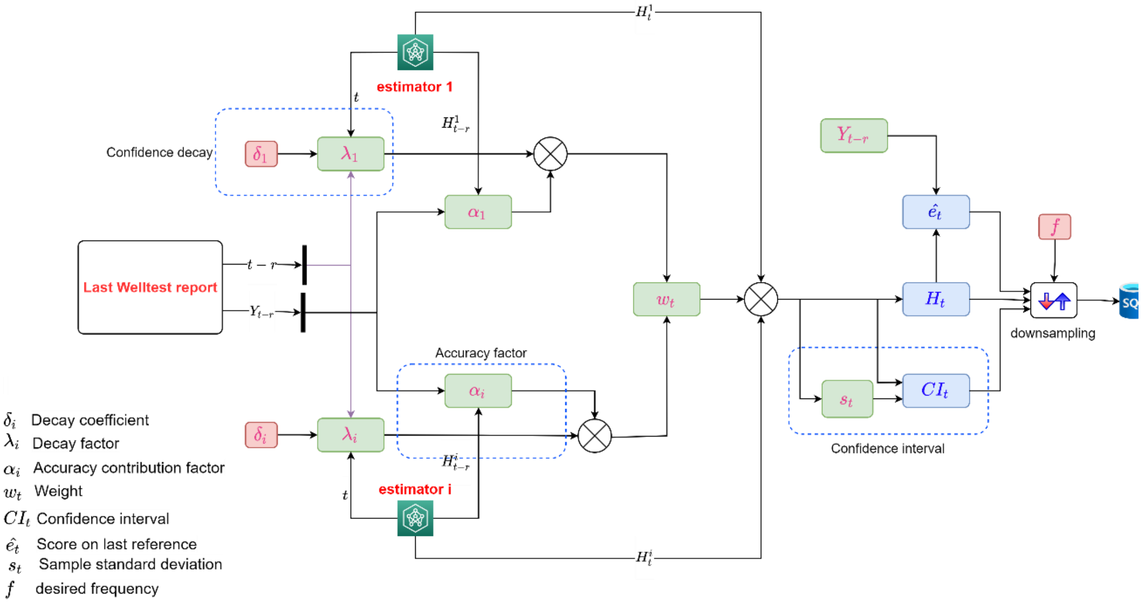


Figure 7: Combiner detailed algorithm

3.5 VFM performance evaluation

In order to evaluate the developed VFMs and confirm they will perform satisfactorily; an evaluation metric has to be devised. Following the published standards (such as API MPMS chapter 20.3), the metrics listed below are used to evaluate VFM performance. The main indicator will be the mean absolute percent error (MAPE).

Table 1: Model evaluation metrices

Evaluation Measure	**Equation**
Mean Absolute Percent Error	$MAPE = \dfrac{\sum \left\lvert \dfrac{Q_{meas} - Q_{calc}}{Q_{meas}} \right\rvert}{n} * 100\%$
Average flow rate deviation	$\overline{\Delta Q} = \dfrac{1}{n} \sum \lvert Q_{meas} - Q_{calc} \rvert$

In addition to quantitative performance measure, there are visual quality plots that are recommended by Norwegian Society for Oil and Gas Measurement and MPMS API Chapter 20.3. The performance plots used are:

Cumulative deviation plot: indicates the percentage of test points that are below certain deviation criteria. The error percent between actual and VFM estimate is calculated for each test sample. Then, the number of samples with error percent below certain deviation percentage (5%, 10%, 15%, etc.) are counted. The counts are then divided by the total number of test samples and plotted against deviation percentage.

Error deviation plot which plots all errors as MAPE and draw horizontal lines to indicate the acceptable threshold (e.g., 10% or 20%).

3.6 Overview of the pilot experiments

The developed system was tested offline in Sumandak field and online in D28 field.

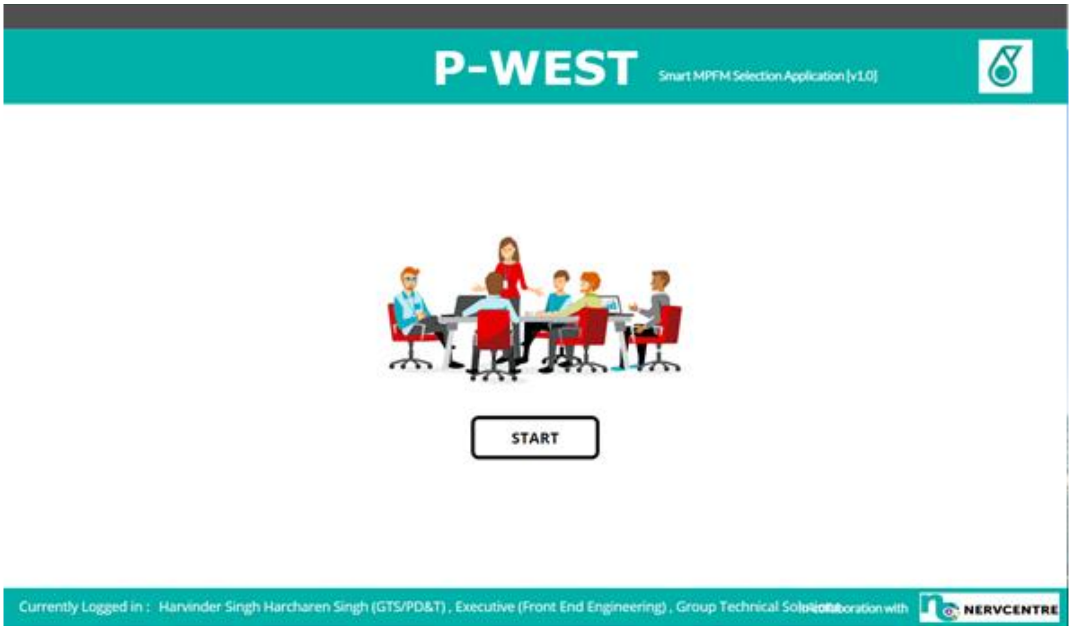
Table 2 summarizes the information of the both pilots.

Table 2: Summary of pilot experiments information

info\Pilot	Offline	Online
Field	Sumandak	D28
Wells		Well 101 and Well 102
Well testing equipment	Shared MPFM	Shared MPFM
Flow type	Multiphase (3 phases)	Multiphase (3 phases)
Training data	3 years	20 Sep 2020 – Oct 30 2020 (MRT)
Pilot period	-	1 Oct 2020 – 1 May 2021 (6 months)
Instrumentation	Downhole P/T, Upstream P/T, downstream P, WC, choke opening	Downhole P/T, Upstream and downstream P/T, Choke opening
Data source	Excel files	OSI Pi

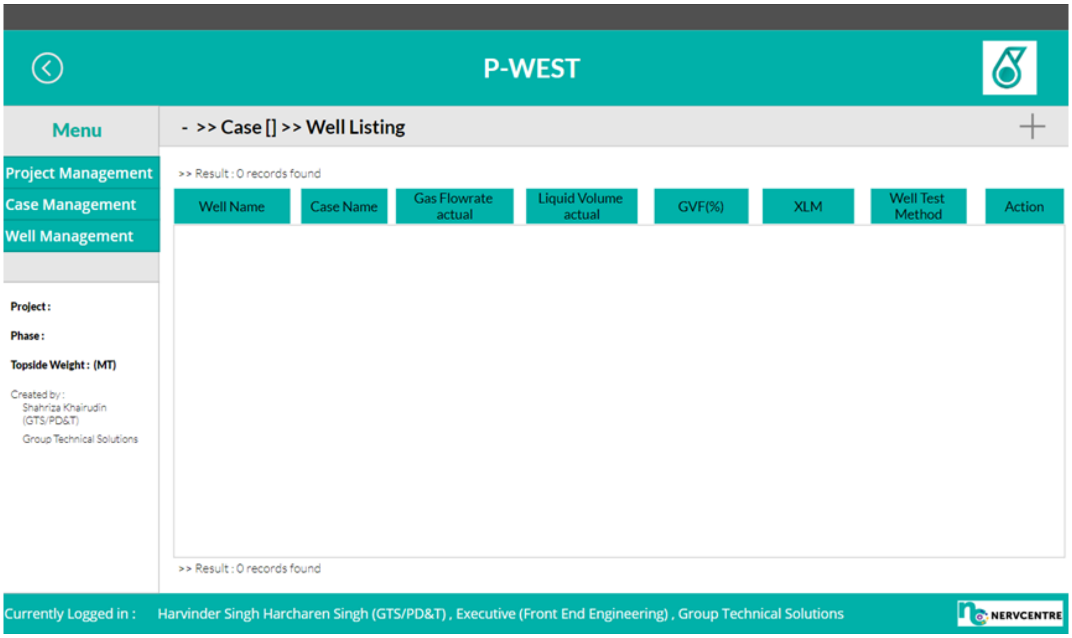
The pilot test results will be in the presentation slide.

4. PETRONAS WELL TEST SELECTION TOOL – Initiative 2



Currently Logged in : Harvinder Singh Harcharen Singh (GTS/PD&T) , Executive (Front End Engineering) , Group Technical Solutions In collaboration with

Selection of the right equipment is key to getting accurate well test results. This is motivation enough to develop this selection tool and guide responsible parties on the design and selection considerations to select the most appropriate and fit for purpose equipment based on lessons learnt and best practice.



- >> Case [] >> Well Listing

>> Result : 0 records found

Well Name	Case Name	Gas Flowrate actual	Liquid Volume actual	GVF(%)	XLM	Well Test Method	Action

>> Result : 0 records found

Project :

Phase :

Topside Weight : (MT)

Created by :
Shahriza Khairudin
(GTS/PD&T)
Group Technical Solutions

Currently Logged in : Harvinder Singh Harcharen Singh (GTS/PD&T) , Executive (Front End Engineering) , Group Technical Solutions

This software was developed to establish the design selection and operability of MPFMs based on technologies according to reservoir characteristic behavior by respecting to production profile, specific field requirement and up to RMP (Reservoir Management Plan) with emphasis given on the impact of changing PVT well effluent, reservoir drive mechanism, water /gas conning and flow regime

P WEST building blocks essentially covers 5 main areas

i. Fluid properties.

Fluid properties is one of the key critical parameters which influence the accuracy and type of MPFM to be used. Fluid properties will affect both the calculation of measurements and the prediction of flow regimes for the operating conditions of the incoming flow into the MPFM. In most instances or previous MPFM design consideration, the evaluation or incorporation of reliable accurate fluid data/properties were inadequate. Representative fluid phase envelope, as well as operating conditions i.e. range of Flowing Pressure and Temperature at inlet to MPFM with consideration of hydraulics between upstream of wellhead choke and piping. It is also crucial to determine density for each phase and how it changes at different Pressure and Temperature. The GLR and WLR range operating envelope and flowrates which helps us defines limit of max GVF and WLR Dynamic Viscosity and Viscosity to define EOS Attention to also be given towards :-wax, chemical injection and contaminants,

ii. Designing the MPFM would also require mapping out the production envelope plots such as:

- Plotting the MPFM envelope in the two-phase flow map.
- Plotting the MPFM envelope in the composition map
- Flow rate or production profile plot
- WLR-GVF plot
- Gas Flowrate Deviation Plot
- Liquid flowrate deviation plot
- Water to Liquid Ratio- and Gas Volume fraction deviation plot to dertemine how far the test points deviate
- And finally, the Cumulative plot to determine the flow regime of the reservoir

iii. Testing & Calibration

There are a few methods and options to perform this activity at a OEM factory, third party test facility, local workshop or even within a field in-situ. All options offer static and dynamic calibration but differ in its attributes such that factory acceptance testing offer least expensive solutions using model fluids via a purpose-built loop while independent test facilities would provide extended test matrix and reference instruments traceable to standards with use of representative of live process fluids. Field testing and collaboration limits us to baseline recordings and phase transition issues may arise.

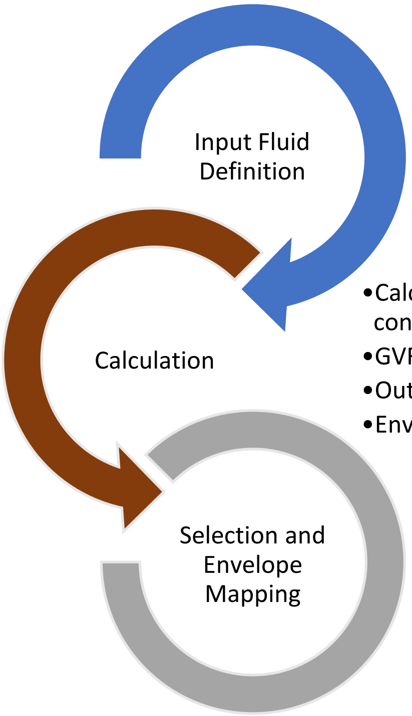
iv. Operation and maintenance

- PVT data availability at the MPFM location as required for optimal measurements.
- Ease of installation and removal of the meter.
- Have Access for maintenance
- A Bypass to prevent well shutdown during testing and service.
- Facilities and access for flow rate monitoring
- Header to local test separator or connection to transportable test equipment
- Injection point(s) for tracers.
- Power and communication lines to the meter computer
- Provision to collect multiphase fluid samples.
- Tie-In provision and space consideration
- Remote Operations

v. Validation options

- Reconciliation factor
- Baseline monitoring
- Self-checking / self-diagnostics capabilities / redundancy
- having Two meters in series
- Mobile test unit
- Tracer technology
- VFM
- Injection
- Sampling
- Geo-chemical fingerprinting

The 5 building blocks are then defined by workflow and user personas. A number of cases are simulated based on the process data input along with the sensitivities P WEST will output the best fit well test envelope and map that to the database of MPFM options.



- Well Fluid Characterization
- Well Stream Pressure, Temperature, Mass rates and Densities for each stream (Vapor, Liquid and Water)

- Calculates Gas and Liquid mass flowrate at actual condition.
- GVF determined
- Outputs Lockhart Martinelli value
- Envelope options

- Automates best fit well test equipment based on vendor envelopes.
- Tool Outputs best fit technology (i.e., GLCC,, In-Line, Partial Separation, Magnetic Resonance)

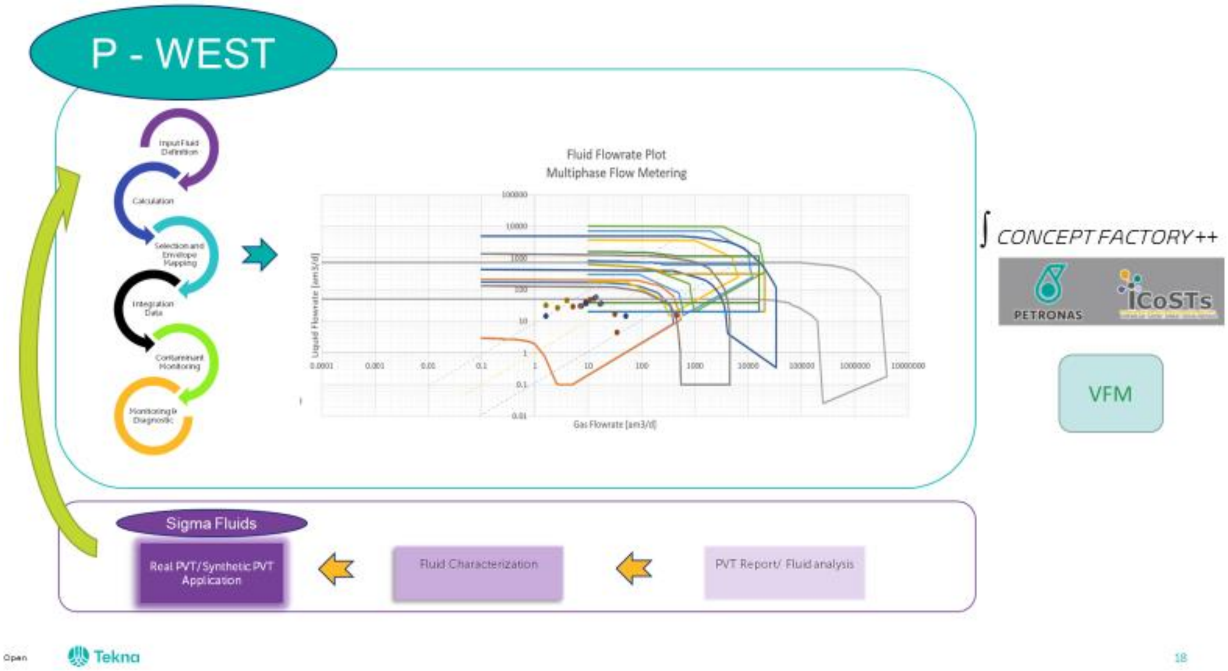
The nature of the workflow will also allow P WEST users to evaluate/ troubleshoot the currently installed MPFM units as well by superimposing the current installations versus the suggested options

Appraised projects and provided consultancy.

Deployed tool to verify current MPFM and recommended Piping ID change as well as enhanced Sampling point (WC) Methodology to rectify issues)

Recommendation on venturi size change to improve accuracy and reduce uncertainties of measurements

Verified the MPFM applicability is correct, developed Envelope based on HMB data for Team to use as basis to validate with OEM envelope



P - WEST

Input Fluid Definition

Calculation

Selection and Envelope Mapping

Integration Data

Contaminant Monitoring

Monitoring & Diagnostic

Fluid Flowrate Plot
Multiphase Flow Metering

CONCEPT FACTORY++

PETRONAS

iCoSTs

VFM

Sigma Fluids

Real PVT/Synthetic PVT Application

Fluid Characterization

PVT Report/ Fluid analysis

Open

Tekna

18

The current well test setup will be further enhanced by having tools that will fit in nicely in the whole well test ecosystem. Choices for validation are now broader as we incorporate advanced digital tools. Our aforementioned VFM, and P WEST will also be part of this.

5. CONCLUSION

Based on pilot implementation results, the VFM will be able to validate well test equipment at selected fields and location, and further enhancements to the VFM to make it more robust is one of our priorities, along with other initiatives such as the development of the synthetic PVT database

With P-WEST we are now able to independently select our well test equipment with added confidence that the probability of equipment failure will be significantly reduced. The ability to conduct a retroactive investigation to determine the root cause of failed equipment will also assist in mitigating the issues

Together these solutions – PWEST, VFMs, will enable the setting up of a fit for purpose well test environment in PETRONAS along with a few more currently on going initiatives such as the synthetic PVT database.

6. REFERENCES

- PETRONAS TRLC Presentation pack for TRL 4
- PETRONAS TRLC Presentation pack for TRL 6
- NGOFM Handbook of Multiphase Flow Metering, Rev 2
- PETRONAS Production Guidelines for Upstream Activities Volume 7
- Virtual Flow Metering Final Report
- PETRONAS Guideline for MPFM, Rev 1
- PETRONAS Technical Specification for MPFMs
- API Manual of Petroleum Measurement Standards Chapter 20.3 Measurement of Multiphase Flow

A special thanks to my fellow colleagues for your contribution and dedication

Tareq Aziz Hasan/ M Azmin, PETRONAS

Halvard Ellingsen, Johan Henriksson; Turbulent Flux – ***VFM team***

Norsham Nordin/ Zalina Ali/ Harvinder Singh/ Adhi Naharindra/ Azrul Hisham Othman

M Syukri Suhaili; PETRONAS – ***PWEST team***

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