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Technical Paper
Production Allocation Deployment from Concept to Operation

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1 Introduction

Over the past 30 years, the nature of oil and gas field developments has changed from a single operator with a dedicated pipeline, to multiple fields each with differing ownerships, and multiple product streams, processed in a common plant.

Allocation of exports to field production impacts revenue for owners, such that some may be heavily exposed to measurement uncertainty by the metering and allocation methods used, whereas others with interests in multiple fields may have a relatively low exposure.

This paper describes each stage of deployment of the PAS (Production Allocation System) for a 200kbpd oil development from concept through to operation. The primary objective is equitable mass allocation of Crude Oil, Condensate and LPG export products to the field owners, and for regulatory compliance in accordance with project Basis of Design for metering and allocation which states:

"The facility design will fundamentally accommodate the metering systems required to transfer fiscal custody, and to allocate volumes, and operating costs associated with the products streams. The metering system will provide the required level of accuracy, reliability, and operability that is commensurate with the principle requirement for the meter".

2 Overview

2.1 Requirement

Once the plant process design was complete the operator considered product allocation. Initially the development was for four fields (two Gas Condensate, two Crude Oil) and an external Wet Gas feed, for allocation to LPG, Condensate, and Crude Oil export. Later this reduced to one Gas Condensate field, and two Crude Oil fields all with multiple owners with unitisation into two groups.

The initial allocation requirement was limited to allocation of products to fields, including gas lift to the crude oil field, and fuel gas. At various stages during the project flare allocation, out of specification recycle, and plant material balance including water, were added to the project. Allocation of the field product allocation to wells is done with a separate system.

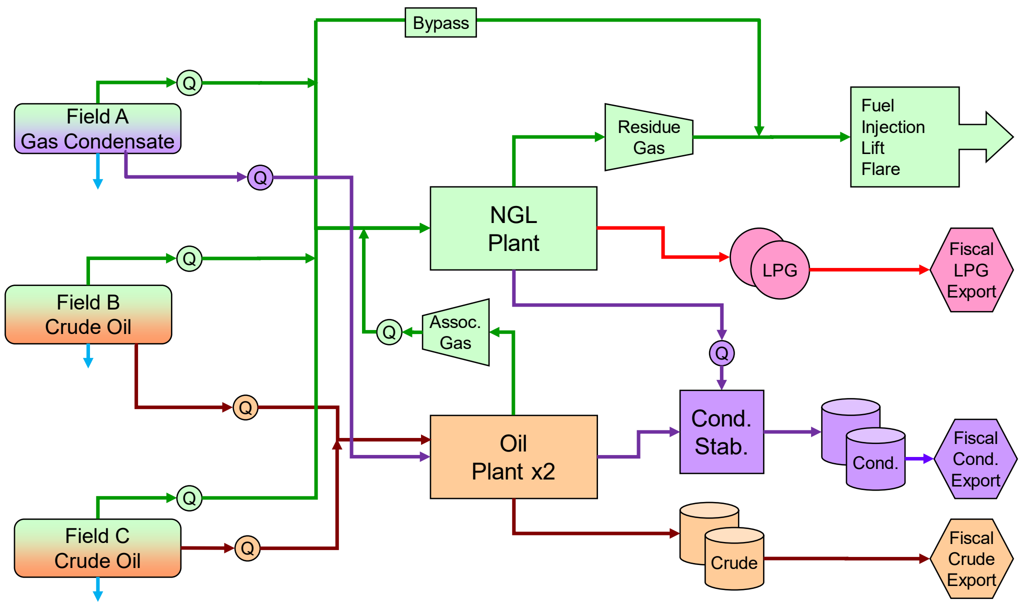
An allocation uncertainty analysis was required so field owners could assess their exposure in each field, and total exposure of all their interests. This was required for a number of HMB (Heat and Mass Balance) scenarios. At a later stage in the project measurement and composition deviation exposure was examined.

Involvement in the project at a very early stage of the project ensured that all measurement and allocation options could be considered without compromise. The main constraint was the requirement for mass allocation.

2.2 Process

Figure 1, Allocation Measurement Overview shows the main plant equipment and allocation measurements. This includes the Oil Plant Associated Gas liquid-vapour exchange and NGL plant Condensate vapour-liquid exchange. Fuel gas, and gas lift are allocated as well as flare gas allocation which was added at a later stage. Gas injection is not allocated.

Figure 1 Allocation Measurement Overview

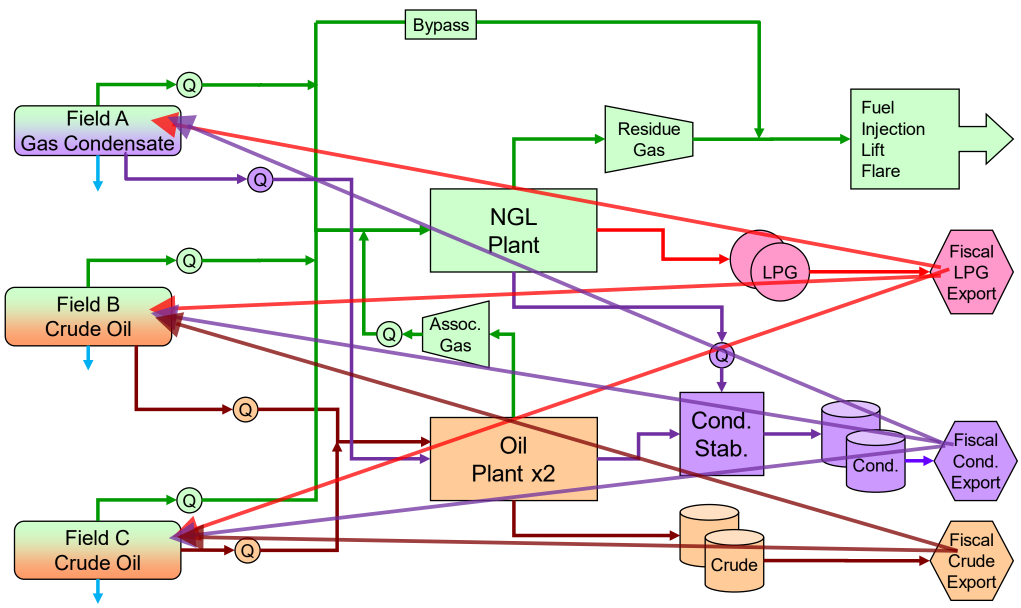


It was observed in the process design that no streams are recycled to the reception facilities. This is favourable as the allocation measurement at each slugcatcher is not contaminated by recycled fluids thereby simplifying the allocation.

The main Allocation Pathways for LPG, Condensate, & Crude Oil are shown in Figure 2, not including fuel gas, gas lift, flare gas, and out of specification recycle.

Out of specification LPG is recycled via an LPG Re-run sphere for reprocessing in the NGL plant, or regassified for gas injection. Out of specification Condensate, and Crude Oil, plus other waste oil from water treatment, and other sources is recycled to a Crude-Condensate re-run tank for reprocessing in the oil plant.

Figure 2 Allocation Pathways for LPG, Condensate, & Crude Oil



3 Concept

3.1 Product Allocation Method

At the early design phase the feasibility of a number of allocation methods for the proposed plant design were considered including Mass Component, Multi Stage Flash, and Process Simulation, described in Table 1, Allocation Methods.

Table 1 Allocation Methods

Mass Component	– The mass flow and molecular composition of each hydrocarbon liquid or gas stream required for allocation is used to find the mass flow of each stream by molecular component; – The field input quantities to the NGL Plant and Oil Plant are found separately by component including Associated Gas from the Oil Plant processed in the NGL Plant; – Oil Plant and NGL Plant input quantities for each field are adjusted in proportion to the quantity of product output from each plant by mass component to find the mass allocation to each field group.
Multi-stage Shrinkage & Recovery	– Analysis of hydrocarbons for the field input to the CPF is used to find liquid shrinkage factors and gas liquid recovery factors for each product output; – Liquids and gas field input measurements to the CPF are multiplied by the factors to find the mass of the product input for each field group; – The input quantities for each field are adjusted in proportion to the mass of each product output to find the mass allocation to each field group.
Process Simulation	– A process simulation of the CPF is used to find mass field factors for the Crude Oil, Condensate and LPG product outputs. A suite of process models is created for each operating scenario forecast; – The previous daily average flow rates and the molecular composition of each stream is entered into the chosen process model scenario and the simulation is run to find product allocation factors; – The allocation factors are multiplied by the previous daily mass of Crude Oil, Condensate and LPG product to find the mass allocation to each field.

3.2 Product Allocation Methods Selection

The three methods of allocation were assessed based on a number of weighted critiera shown in Table 2, Product Allocation Method Comparision.

All three methods are simplified by having no recycled fluid contamination in the reception facilities Slugcatcher measurements. Any recylce adds considerable complexity requiring multiple iterations to allocate the recycled fluids.

Table 2 Product Allocation Method Comparision

Criteria	Mass Component	Multistage Flash	Process Simulation
Number of plant measurements by meters[1]	Medium 16 Hydrocarbon Gas 14 Hydrocarbon Liq. 3 Produced Water	Low 9 Hydrocarbon Gas 14 Hydrocarbon Liq. 3 Produced Water	High 16 Hydrocarbon Gas 14 Hydrocarbon Liq. 3 Produced Water 30+ Instruments
Material balance	Good	Poor	Moderate
Redundancy	Good	Poor	Good
Field flow sensitivity	Low	Medium	High
Plant sensitivity	Low	High	Medium
Composition sensitivity	Low	High	Medium
Computation	Medium	Low	High
Data entry	Medium	Low	High
Data processing	Medium	Low	High
Process support	Medium	Medium	High
Allocation bias risk	Low	High	Moderate
Overall rating[2]	28	21	17

1. Not including flare meters or paralleled meters
2. Rating: Good/Low=3, Moderate/Medium=2, Poor/High=1

3.2.1 Process Simulation

Uses mass correction factors on the measurement and additional pressure and temperature measurements at points throughout the plant.

PSM (Process Simulation Models) work by using EoS (Equations of State) to determine fluid properties at locations throughout the process by iteration on the plant material balance. A Process Engineer is required to run the PSM which must be regulary updated with composition to ensure the validity of the factors.

3.2.2 Multistage Flash

Requires the least number of measurements and, is dependant on stable operating conditions such that small changes in pressure will affect the factors used. This is particularly a concern when allocating Crude Oil and Condensate where the Condensate factors have large influence on the allocation. Multistage flash analysis in the laboratory is relatively time consuming.

3.2.3 Mass Component

Allocation is an arithmetic method that prorates hydrocarbon components (C numbers, or psuedo components) at each measurement location to stock, and export of LPG, Condensate and Crude Oil mass quantities.

Pressurised samples for component analysis are required for each measurement location daily and when operating conditions change. Analysis of pseudo components from boiling point ranges in the laboratory can be very time consuming. The alternative is a chromatograph which can find the composition for each C (Carbon) number to simulate psuedo components, or allocation can be done based on the C number components.

3.2.4 Selection

Mass Component allocation was selected based on Table 2, Product Allocation Method Comparision, which had the highest criteria rating of 28.

4 Allocation System Design

4.1 Production Allocation System

The Production Allocation System Schematic in Figure 3 shows the main plant equipment with all the allocation instrumentation identified by yellow circles. Refer to the legend in the top left of the schematic for the instrument function identifier and colour coding for the fluid lines. Instruments and other information are also identified with labels with the fluid colour coding.

This is the final design incorporating all changes made throughout the project design and construction including changes since commissioning and acceptance.

Prior to award of the EPC contract for construction a simpler design was used for evaluation of the measurement uncertainty and input bias errors investigation, with a composition to C10 and six psuedo components was used. Many of the checks and balances required for the final design were not needed at this stage. For example lift gas and separator gas flow rates where chosen to ensure there was no possibility of negative components.

Each sample point is identified with an X in the yellow circle and associated with a mole fraction composition which is converted to a mass fraction composition for input to the allocation model.

4.2 Instrumentation

Instrumentation, sampling, analysis, and data processing requirements were defined at this stage to include all measurements including vapour liquid exchanges. The advantage of involvement at such an early stage meant all the allocation requirements were taken into account such that all fluids were accounted for before the plant design was finalised.

The Basis of Design called for redundancy with all measurement, with degraded performance being tolerated. This was achieved in various ways including dual path Ultrasonic gas, measurement, including flares gas meters, where failure of one beam does not stop the measurement function.

With Liquid flow measurement, including fuel gas, redundancy was achieved with duplicate parallel Coriolis meters with a single meter capable of the maximum flow capacity. This had the advantage of derating normal flow to prevent gas breakout at the slugcatcher hydrocarbon liquid legs.

A high level Instrument Requirements Specification was prepared for input to detailed design at a later stage.

Table 3, Allocation Measurement Class, shows four classes of measurement that are defined for compliance with the OIML standards listed. This does not include flare measurement and some other quantities derived from valve position, slugcarcher level, and plant conditions.

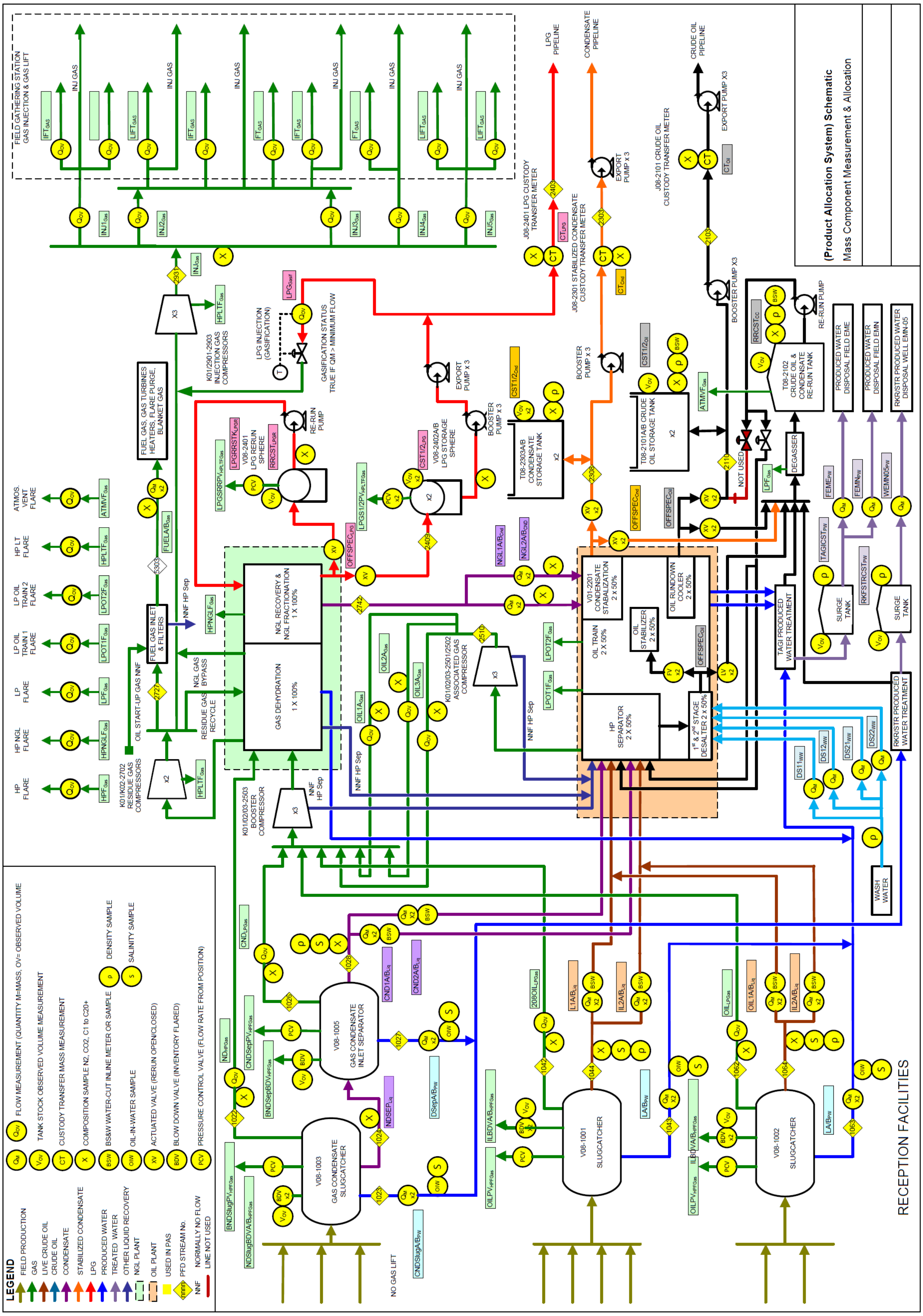
The uncertainties shown in the table are used for selection of instrumentation and input to the allocation uncertainty modelling.

Table 3 Allocation Measurement Class

Class	Description	Measurement	Measurement Range	Uncertainty
1	**Custody Transfer – Crude Oil, Condensate and LPG hydrocarbon liquid** shipped by pipeline to other facilities must conform to OIML R-117 Class 0.3A	Volume		≤ ±0.3%OMV
		Temperature		≤ ±0.3ºC
		Pressure	< 1Mpa ≥ 1Mpa < 4Mpa ≥ 4Mpa	≤ ±50kPa ≤ ±5%OMV ≤ ±200kPa
		Density		≤ ±1.0kg/m^3
		S&W[1]	≤ 0.5%wt/wt	≤ ±0.05%wt/wt
2	**Liquid – Hydrocarbon or Produced Water** shall be measured by mass to conform to OIML R-117 Class 1.0A	Mass		≤ ±1.0%OMV
		Temperature		≤ ±0.5ºC
		Pressure	< 1Mpa ≥1Mpa < 4Mpa ≥ 4Mpa	≤ ±50kPa ≤ ±5%OMV ≤ ±200kPa
		Density		≤ ±2.0kg/m^3
		S&W[1]	≤ 10%wt/wt > 10%wt/wt	≤ ±0.1%wt/wt ≤ ±1.0%wt/wt
		OIW[1] - Sample - (1-S&W)	≤ 1.0%wt/wt > 1.0%wt/wt	≤ ±0.1%wt/wt ≤ ±1.0%wt/wt
3	**Stock – Crude Oil, Condensate and LPG** stock shall conform to OIML R-71 tank calibration of < ±0.2%OMV and OIML R-85 level gauge uncertainty < ±2 mm	Volume		≤ ±0.3%OMV
		Temperature[2]		≤ ±0.5ºC
		Pressure[2] (LPG only)	< 1Mpa ≥ 1Mpa < 4Mpa ≥ 4Mpa	≤ ±50kPa ≤ ±5%OMV ≤ ±200kPa
		Density[2]		≤ ±1.0kg/m^3
		S&W[1] (Not LPG)	≤ 0.5%wt/wt	≤ ±0.05%wt/wt
4	**Gas –**shall be measured by Standard Volume to conform to OIML R-137 Class 1, In-service, restricted range and full range	Volume	≤10:1 turndown >10:1 turndown	≤ ±2%OMV ≤ ±4%OMV
		Temperature[2]		≤ ±0.5ºC
		Pressure[2]	< 1MPa ≥ 1MPa < 4Mpa ≥ 4MPa	≤ ±10kPa ≤ ±1%OMV ≤ ±40kPa
		Density[2]		≤ ±1%OMV

1. Equipment vendors specifications
2. Uncertainty of values not defined in OIML R-117 appropriate to standard of measurement

Figure 3 Production Allocation System Schematic



4.3 Sample Analysis

There was a concern that Mass Component Allocation method was unconventional for liquid hydrocarbon allocation, normally only being used for gas allocation.

In Table 4, Stream Composition with Pseudo Components used in the early stages of the project is shown. The psuedo components were based on the expectation that component distillation temperature ranges would be used for allocation.

A preferred approach using C componets was considered. On investigation Liquid Analysis Chromatographs were found that can analyse C components to C36+, making this approach feasible. Based on the HMB it was decided to analyse components to C20+.

Table 4 Stream Composition with Pseudo Components

i	Compound	Formulae	Molecular Wt. kg/kmol
1	Nitrogen	N2	28.0134
2	Carbon Dioxide	CO2	44.010
3	Methane	C1	16.043
4	Ethane	C2	30.070
5	Propane	C3	44.097
6	i-Butane	iC4	58.123
7	n-Butane	nC4	58.123
8	i-Pentane	iC5	72.150
9	n-Pentane	nC5	72.150
10	n-Hexane	nC6	86.177
11	n-Heptane	nC7	100.204
12	n-Octane	nC8	114.231
13	n-Nonane	nC9	128.258
14	n-Decane	nC10	142.285
15	n-Undecane	nC11	156.312
16	Hydrogen Sulphide[1]	H2S	34.082
17	Water	H2O	18.0153
18	Pseudo1	P1-Stream[2]	Sample analysis[3]
19	Pseudo2	P2-Stream[2]	Sample analysis[3]
20	Pseudo3	P3-Stream[2]	Sample analysis[3]
21	Pseudo4	P4-Stream[2]	Sample analysis[3]
22	Pseudo5	P5-Stream[2]	Sample analysis[3]
23	Pseudo6	P6-Stream[2]	Sample analysis[3]

1. H2S is included for compatibility with project HMB
2. Pseudo components from the HMB for each allocation stream
3. Molecular Weight and Equivalent Standard Density from laboratory analysis of stream sample and calculation

Around 10 gas samples from plant gas allocation measurements are analysed in a Gas Chromatograph to find the gas composition at each gas allocation sample location. Approximately 15 pressurised liquid samples are analysed per day in a Liquid Analsys Chromatograph. The number and frequency of gas and liquid samples taken and analysed may vary due to time, and equipment constraints, and if the fluid composition is expected to change.

Pressurised liquid samples are first depressurised to separate the gas from the liquid. The gas volume is measured and then subsampled for analysis in a Gas Chromatograph. The liquid remaining in the sample is weighed and subsampled to analyse the composition. The sample gas mass and liquid mass and composition is then arithmetically recombined to obtain a full mass fraction composition for each liquid allocation sample location.

Liquid Analysis Chromatographs are fitted with carousel enabling samples to be analysed at rate of one sample per hour.

Gas and liquid sample results are uploaded via a LIMS system to a process historian, then daily hand-off to the PAS prior to running the previous days allocation.

5 Allocation Uncertainty

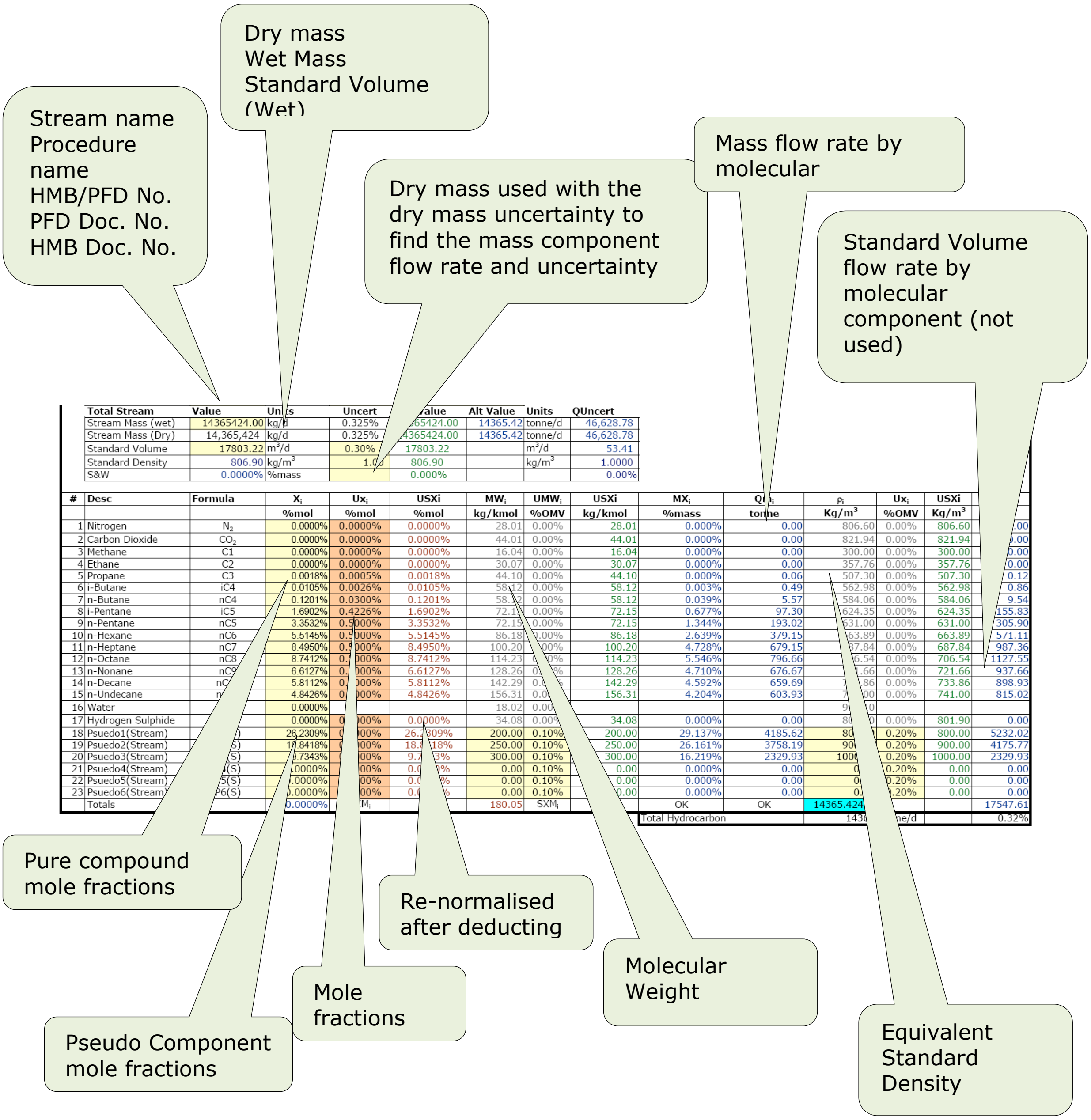
An allocation uncertainty analysis was required so field owners could assess their exposure in each field, and total exposure for all their interests. This was required for a number of HMB (Heat and Mass Balance) scenarios for Peak Liquid Summer, and Peak Oil Winter.

Due to the large number of inputs and strong dependancy within the Allocation, uncertainty was investigated using MCS (Monte Carlo Simulation). An Allocation Uncertainty Model was constructed and populated with the two HMB scenarios to find the Mass Allocation Uncertainty for each field, each field owner for each field, and field owners combined exposure for all fields. This included a sensitivity analysis to examine the impact of sample and deliberate measurement errors, and compositional errors on the bias and uncertainty of the allocated products.

Additional HMB scenarios were examined along with further uncertainty analysis and the results presented to the field owners.

In Figure 4, Allocation Measurement Point Input with Uncertainty example shows the flow rate, fluid properties, and stream mole and mass fraction composition, along with uncertainty for each value. Annotations show the inputs and the results required for input to the Allocation Uncertainty Model along with some check totals.

Figure 4 Allocation Measurement Point Input with Uncertainty



6 Detail Design

6.1 Allocation Equations

When the project was approved and a contract awarded to an EPC contractor a detailed design of the allocation equations was developed as the specification for the software developer to design a Mass Component PAS (Production Allocation System) software. This work included a Three-day Allocation developed to test the allocation software to assist the software developers, the FAT, and later SAT.

6.2 Custody Transfer

Crude Oil, Condensate, and LPG exports products are measured with dedicated LACT units to fiscal standards in mass and standard volume.

6.3 Allocation Measurement and Processing

6.3.1 DCS Measurement

For plant allocation, the DCS system was used in place of dedicated flow computers for 70 allocation measurement locations. A document specified the DCS allocation measurement equations for implementation by the DCS vendor. This included real time FWA (Flow Weighted Average) for each stream updated every 5 minutes and uploaded to the process historian daily for further calculations and handed-off to the PAS daily.

6.3.2 Flare Gas Allocation

Allocation of Flare Gas to Fields requirement was added to the project scope which at first seemed to be an insurmountable problem given the large number of paths to the flares and as it was specified there should be no additional equipment.

Eventually a novel approach was determined to allocate flare quantities in real time based on the position slugcatcher and LPG sphere PCV's (Pressure Control Valve), the state of the Slugcatcher, BDV's (Blow Down Valve), Slugcatcher level, and other equipment flare valves.

A PCV flow rate curve was used which had a narrow pressure range. The BDV's had multistage pressure reducers downstream which have a specified flowrate during blowdown. An evaporation rate based on the Slugcatcher level change was used in addition to estimate the amount of vapour flared. The rate for each flare was then prorated to each vessel, normalised, and summed to determine the source gas allocated to each flare.

The flare rates were calculated in the DCS in real time every 5 seconds and uploaded to the process historian daily for further calculations, and hand-off to the PAS daily.

6.3.3 Plant Material Balance

A Plant Material Balance requirement was added to the project scope. The allocation system design was modified to determine the hydrocarbon liquid, gas, total hydrocarbon, water, and total plant mass balance. This was built up from each area of the plant to provide a diagnostic aid for location of the imbalance.

6.3.4 Stock Allocation

Changes were made to the stock allocation so the stock and export allocation could be determined for LPG, Condensate, and Crude Oil exports.

6.4 Instrument Design

The original instrument requirement specification was revisited to revise with more specific requirements to enable the EPC contractor to do the detailed design.

The detailed design and instrument construction was successfully implemented by the EPC contractor with only minor non-compliance

7 FAT

Partners requested a number of changes to stock allocation, flare allocation, and material balance. Specifications and models were revised, software modified, and tested at a FAT (Factory Acceptance Test).

FAT's for the Oil Plant, and Combined Oil and NGL plant were undertaken with the software developer culminating in a FAT with the field owners or their representatvies.

8 Commissioning and SAT

Commissioning followed by a SAT (Site Acceptance Test) was undertaken in two stages starting with the OIL SAT for the Crude Oil with the two Crude Oil fields. Six months later an NGL SAT with all fields producing, and all product exports was conducted.

Both SAT's were successfully signed off and the project entered the support phase with some further modifications to add Standard Volume Allocation of products that have not so far been implemented.

9 Operation

9.1 Allocation Metering System Audit

An Allocation Metering System Audit Inspection was a requirement of the partner's allocation agreement. This was done using Audit Criteria to objectively assess the flow measurement and stock instrumentation, sampling, laboratory analysis of samples, and data processing. The Audit examined aprroximately 70% of all measurement and other systems.

The inspection found the measurement systems to be operating in accordance with the requirements of the Measurement and Allocation, Philosophy and Methodology, with only minor exceptions.

9.2 Allocation System Performance

The plant has now been operating for over five years with a typical production allocation daily material balance of better than 0.5% of throughput.

Plant Material Balance has been a very effective diagnostic and has been primary means of monitoring the allocation system performance identifying most problems and enabling rapid solutions.

The excellent performance of this allocation system is due to involvement at an early stage such that all fluids movements are accounted for without compromise. The commitment of the operator to the allocation system was significant factor in the success of the project.