Specification of Wet Gas Measurement Equipment for Fiscal Allocation

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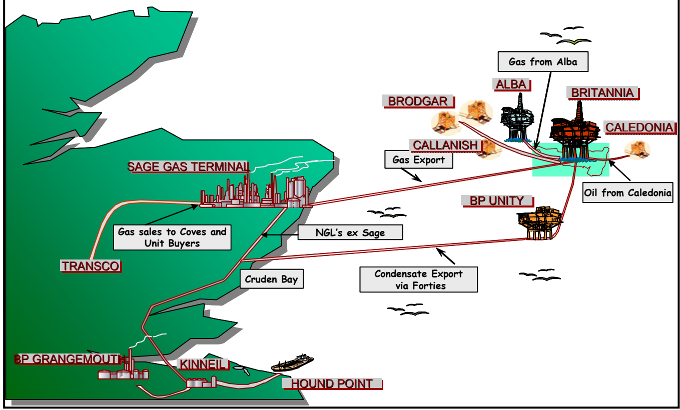
1 INTRODUCTION

In the UK North Sea new developments are increasingly utilising existing infrastructure for processing and transportation of hydrocarbons. Utilising existing infrastructure for such developments brings challenges as to how to cost-effectively allocate the produced hydrocarbons (as well as water, fuel usage, and emissions) back to each field – particularly where these fields are under different ownership.

When a new field is to be accepted by a host, it is necessary to define a functional specification for the measurement equipment. This is usually documented as part of the allocation agreement. The question that needs to be addressed is: "What is an acceptable measurement specification?". The ultimate answer will be one which meets standards set by relevant Government authorities and is acceptable to all parties who approve the allocation agreement. One approach, often used, is to apply standard guidelines derived from industry best practice, e.g. 1% uncertainty for a gas fiscal flow measurement. This approach has the advantage of being simple to apply, but may involve some measurements being made with an unnecessary degree of accuracy. Another approach is to undertake modelling of uncertainty in the measurement system to establish the criticality of each measurement (See for example [1]). Scheers and Wolff ([2]) point out the need to consider the whole measurement system through to allocated revenue and propose that the optimum uncertainty of each measurement should be established by evaluating the trade-off between measurement costs and the losses and risks of uncertainty in the measurement. In this paper an extension of these approaches is applied to the Britannia facilities in which uncertainty modelling was applied to the propagation of uncertainty through the whole measurement and allocation system and was used to establish the impact on each company or field's revenue stream.

Figure 1 – Britannia Facilities and Satellites



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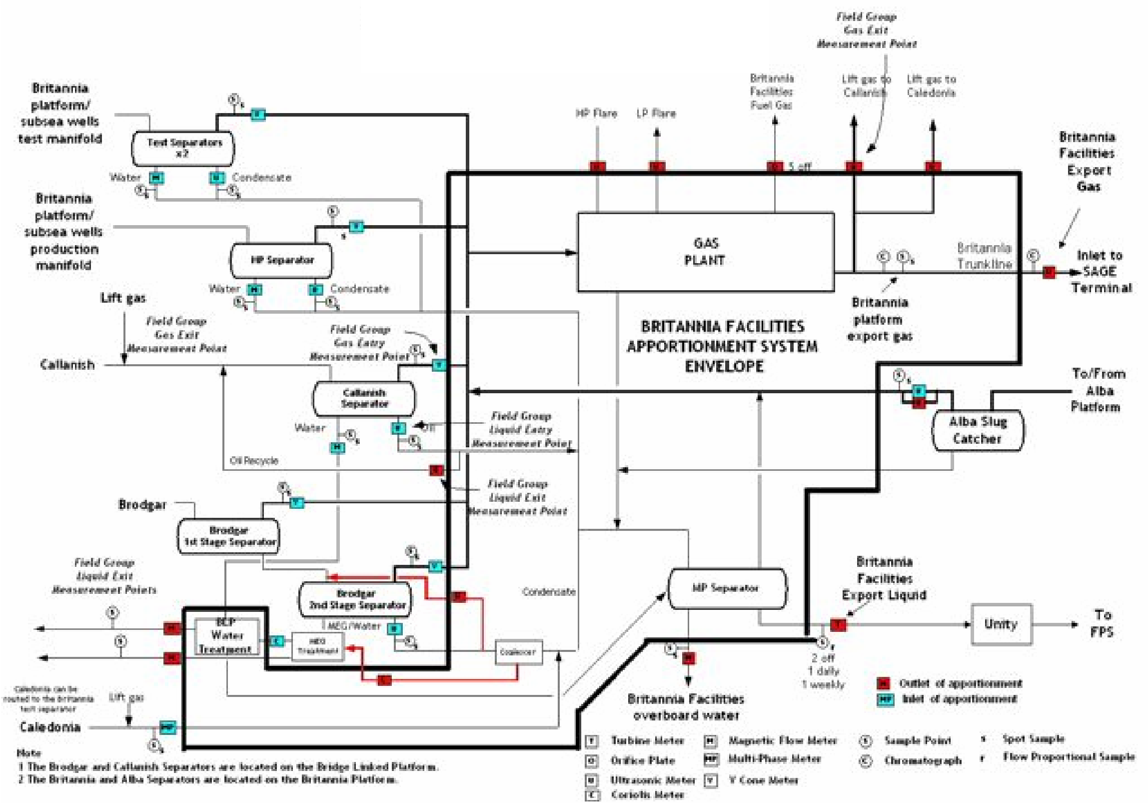
The Britannia platform was constructed to develop the lower cretaceous Britannia gas-condensate field over a thirty year field life. Following initial processing on the Britannia platform, liquids are exported to the BP Operated Forties Pipeline System (FPS) and processed onshore at Kinneil along with oils from many other North Sea fields. Similarly gas separated offshore is exported via a dedicated pipeline to the Scottish mainland at St Fergus where it is commingled with gas from other fields and processed in the ExxonMobil Operated SAGE terminal. First gas was in 1998. Since then additional facilities have been installed on the Britannia platform to accept gas from the neighbouring Alba oil field and to process hydrocarbons from Caledonia, a black oil field developed as a sub-sea satellite (see Figure 1). In 2004, UK Government approval was obtained for the development over Britannia facilities of two further sub-sea satellites: Brodgar – a gas-condensate field – and Callanish – a black oil field. Additional facilities will be installed to achieve first production by January 2007. With Britannia's long field life and its current transition from a single asset operation to a processing hub, it is ideally placed to secure further satellite business. As part of the preparations for accepting Callanish and Brodgar, the Britannia Coventurers[4] have put in place an allocation agreement to accommodate the new fields and define a fair and equitable method of allocating all products back to each source field. The allocation agreement includes the specification of the measurement systems to be used in the allocation.

The allocation system requires a set of measurements of each field's inputs to the allocation envelope (see Figure 2) and measurements at each output from the envelope. Both gas and liquids from the Britannia platform are commingled with hydrocarbons from other facilities in their respective offtake systems (FPS and SAGE – see Figure 1). The allocation algorithm thus involves two stages, apportionment of products leaving the platform and then allocation of the final sales product streams. The three revenue generating hydrocarbon product streams are: sales gas, natural gas liquids and stabilised crude oil. The total revenue generated on a day will be a function of the measured flow and composition of each of these streams and the prevailing product prices. How this value is allocated back to individual fields and field owners will however depend upon the measured flows and compositions at all of the inputs.

[4] ConocoPhillips, Chevron and BP

Figure 2. Allocation Envelope



2 METHOD

A spreadsheet implementation of the allocation algorithm was developed and populated with typical anticipated daily flow rates and compositions at each input and output measurement point. It is beyond the scope of this paper to present the allocation algorithm but it is an empirical representation of the physical process equipment based on component liquid recovery factors ascertained through a suite of process simulations. Representative product prices for each of the three main revenue generating output streams were entered into the spreadsheet and from these the total day's revenue allocated between fields and field owners was determined. This information was saved as the base case.

The main inputs to the allocation algorithm are the measured values of flow rate and composition (expressed as percentage by weight of each of a series of hydrocarbon components and CO_2). Excluding recycle streams, there are 45 such inputs (e.g. Callanish C_2 weight percent or Britannia mass flow rate). A sensitivity analysis[5] was performed to establish the sensitivity of each field's and/or owner's allocated value to each of these 45 inputs. One of the inputs was varied by a small percentage, holding all other variables at their base values[6], and the value allocation re-calculated and compared to the base case.

[5] A Monte Carlo analysis could equally have been used to establish correlations between uncertainties in measurements and allocated values.

[6] Note – compositions were always re-normalised so that the total of the component weight percents equalled 100%.

By repeating this process for each of the input measurements one at a time it was then possible to plot the sensitivity of each field and/or field owner's value allocation to the uncertainty in the input measurement.

As some of the measurements on Britannia will be made with existing equipment whose uncertainty is already known, the next step was to establish the maximum measurement uncertainty in each other measurement which could be tolerated without any field / owner seeing an uncertainty in their allocated value greater than that which they would experience from the uncertainties in the measurement systems to be retained. This approach was applied twice: firstly, to consider random errors and secondly to consider systematic bias.

The measurement community place a great deal of emphasis on minimising systematic bias in measurement systems. Some degree of random uncertainty is usually tolerated on the basis that with a symmetrical probability distribution, over and under measurements will cancel out. In order to meet the fundamental criterion for all allocation systems of being fair and equitable, the allocation system mirrors the chemistry and physics of the plant. Since there are non-linearities in the plant behaviour, a symmetrical distribution for the uncertainty of an input measurement may lead to an asymmetric distribution in the resulting allocated revenue. (e.g. a +1% change in an input measurement may lead to a +0.1% change in the revenue allocated to a field, whereas a -1% change in the same input measurement may lead to a -0.15% change in the revenue allocated to the same field). A simplified example is to consider the pressure at which a separator operates. The lower the pressure the higher the proportion of gas to liquid recovered. The pressure in the separator will be a non-linear function of the flow rate through the plant upstream of the separator. If we consider the plant upstream to be a simple pipe, then we can apply Darcy's formula which states that the pressure (P) is related to the flow rate (Q) by the equation:

$$P = K\rho\, Q^2$$

Consider an uncertainty of $+/-\delta$ in the measurement of flow rate. When there is an error of $+\delta$ then:

$$P_+ = K\rho\,(Q+\delta)^2 = K\rho Q^2 + (2K\rho Q\delta + K\rho\delta^2)$$

Whereas, when there is an error of $-\delta$ then:

$$P_- = K\rho\,(Q-\delta)^2 = K\rho Q^2 - (2K\rho Q\delta - K\rho\delta^2)$$

The absolute value of the errors in the result therefore differ by $2K\rho\delta^2$ introducing an asymmetry which, whilst small relative to δ (assuming $\delta << 1$), may be amplified in further calculations.

When considering systematic bias, it was necessary therefore, not only to calculate the propagation of any systematic bias in each measurement, but also any systematic bias in the allocated value arising from the propagation of random errors through asymmetry in the allocation algorithm. The asymmetry found in the Britannia algorithm was slight, but since systematic bias in the measurement systems is expected to be very small, the bias introduced by random errors was a significant factor.

3 RESULTS

Given the potential commercial sensitivity of presenting actual results, the methodology will be illustrated numerically in this section using a hypothetical set of fields, but the same allocation algorithm. The discussion and conclusions in the following sections will however report the lessons learned when the method was applied to determine the functional specifications for flow and composition measurements at the inputs to the Britannia allocation envelope.

This example will consider three fields (Field A, Field B and Field C) owned by four companies (Company 1, Company 2, Company 3 and Company 4) in the equities shown in Table 1.

Table 1 – Field Ownership (Example)

	Company 1	Company 2	Company 3	Company 4
Field A	50%	20%	10%	20%
Field B	60%	40%	0%	0%
Field C	0%	20%	0%	80%

Under typical conditions the mass flow by component at the arrival separator for each field may be expected to be as shown in Table 2.

Table 2 – Typical Mass Flow by Component (Example)

	Field A		Field B		Field C	
Tonnes/day	Liquids	Gas	Liquids	Gas	Liquids	Gas
N_2	0.07	60.24	0.05	87.69	0.29	9.84
CO_2	1.40	251.37	2.85	131.54	1.11	6.30
C_1	12.55	4442.38	15.29	2718.49	21.95	312.33
C_2	6.78	690.86	29.63	350.77	24.97	88.52
C_3	10.24	411.10	77.60	328.85	56.99	69.66
iC_4	4.33	87.90	32.86	109.62	21.75	11.83
nC_4	11.58	183.67	92.18	131.54	59.27	24.63
iC_5	8.59	68.76	48.00	131.54	35.22	6.53
nC_5	13.34	87.63	73.32	175.39	51.07	7.54
C_6^+	562.07	337.35	1646.55	219.23	3,285.92	11.31
Total	630.95	6621.25	2018.33	4384.67	3558.53	548.50

These fields result in 32% of the inlet mass being exported from the platform as liquids and 68% as gas. The mass allocated to each field was calculated by the allocation algorithm to be as shown in Table 3.

Table 3 – Allocated Mass in base case (Example)

	Field A	Field B	Field C
Allocated mass of export liquids (Te)	1099.49	2939.08	4445.54
Allocated mass of export gas (Te)	10613.72	6509.49	1075.76

For the purpose of this example, the liquids have been assumed to realise £150/Tonne and the gas £100/Tonne. The allocation algorithm may thus be used to allocate the total revenue stream back to each field and company as shown in Table 4.

Table 4 – Allocated Revenue in Base Case (Example)

	Field A	Field B	Field C	**Total**
Company 1	£613,148	£655,087	£0	**£1,268,234**
Company 2	£245,259	£436,725	£154,881	**£836,865**
Company 3	£122,630	£0	£0	**£122,630**
Company 4	£245,259	£0	£619,525	**£864,784**
Total	**£1,226,295**	**£1091811**	**£774,406**	**£3,092,513**

If a 5% increase in the measurement of Field A gas C_1 is now introduced, the Field A component mass flow will be modified to that in Table 5.

Table 5 – Modified Field A Gas Composition Resulting from Measurement Uncertainty (Example)

Component	**Mass (Tonnes)**
N2	57.79
CO2	241.17
C1	4475.27
C2	662.84
C3	394.42
iC4	84.33
nC4	176.22
iC5	65.97
nC5	84.07
C6+	323.66
Total	6565.76

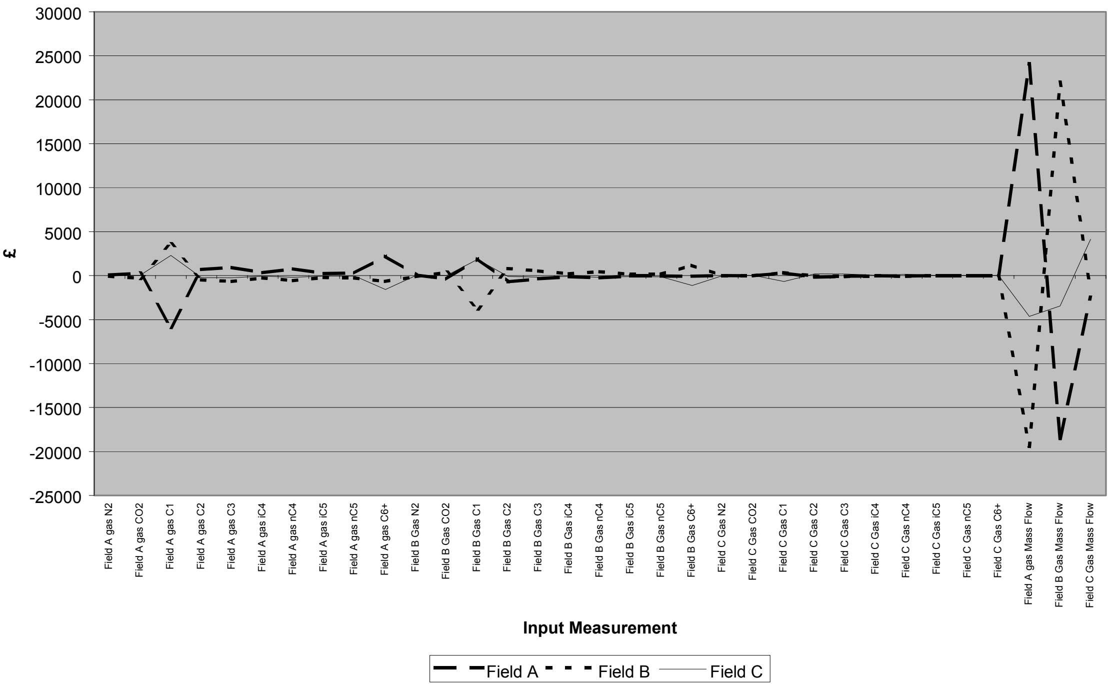
This revised composition was obtained by increasing the C1 mass by 5% from 4442.38 to 4664.49 and then normalising the gas composition to preserve mass. The change in measured composition leads to a revised revenue allocation as shown in Table 6.

Table 6 – Allocated Revenue following Increase in Field A C_1 (Example)

	Field A	Field B	Field C	**Total**
Company 1	£610,203	£657,237	£0	**£1,267,440**
Company 2	£244,081	£438,158	£155,342	**£837,582**
Company 3	£122,041	£0	£0	**£122,041**
Company 4	£244,081	£0	£621,369	**£865,451**
Total	**£1,220,406**	**£1,095,395**	**£776,712**	**£3,092,513**

It can be seen that Field A's allocated revenue is reduced by £5889 which is 0.5%. Field B and Field C receive an extra £5889 between them. If we apply a 5% change to each input variable in turn the impact on the allocation can be summarised in a graph as in Figure 3.

Figure 3 - Value Difference by Field for a 5% Change in Each Input



From this it is apparent that the allocation is most sensitive to the mass flow measurements for each field. Whilst the sensitivity to composition is less, the most important compositional measurements are the C_1 weight% for Fields A and B and C_6^+ weight% for Field A.

If the expected uncertainty of the mass flow measurements is +/-1% (symmetrical distribution) then we can calculate the maximum uncertainty which could be tolerated in measuring composition without increasing the uncertainty in the revenue allocated to a field. These define the functional specification (based on propagation of random errors) for each measurement. The lower (i.e. limiting) values are tabulated in Table 7.

Table 7 – Functional Specification based Limiting Factor Random Errors (Example)

Component	Maximum Uncertainty
Field A gas C1	4%
Field A gas C3	27%
Field A gas nC4	33%
Field A gas C6+	11%
Field B Gas C1	7%
Field B Gas C2	31%
Field B Gas C6+	21%

4 DISCUSSION

For the purposes of this discussion, the difference between the measured value used in the allocation algorithm and the actual prevailing physical conditions (if they could be known) will be referred to as a "measurement error". The measurement error will arise from uncertainty in the measurement equipment and timing differences. It is worth noting that timing differences can be a very significant source of measurement error in this context. For example, the use of onshore laboratory analysis of spot samples for compositional measurement often means that the results are not available when the allocation is run and so values from prior periods have to be utilised.

Any measurement error at the inputs to the allocation envelope will not alter the total quantity of each product stream produced at the outputs. A measurement error in the mass flow will result in a shift in the allocation between fields. A measurement error in a compositional component will result in changes to the other components for that stream (through the normalisation) and is most likely – due to the way the Britannia algorithm works – to result in a change in the ratio of liquids to gas allocated to that field. Depending on the relative product prices, this will typically have a smaller impact on the allocated revenues.

The methodology presented allows the sensitivity of each input measurement on the allocated revenue to be assessed. When applied to the Britannia allocation envelope it showed that the most critical measurements were the mass flows for the higher rate fields as would be expected. The next most critical measurements were the gas compositions of those fields – particularly the C_1 and C_6^+ fractions. It was found that the weight percentages for these two components need to be within $^{+}/-$ 6% (symmetrical uncertainty distribution) in order not to be the dominant factor on the allocation errors for a field[7].

Gas flow is measured at the arrival separators using V-cone meters. All differential pressure meters are known to over-read in the event of liquid carry-over [2]. With the expected conditions on Britannia this over-reading – if not compensated for – would be expected to be of order 0.5%. Using the methodology of Steven and Peters [2] it is expected that this can be compensated for, but it is estimated that there could still be a residual bias of 0.05%. It was found that a random measurement error of +/-6% in determining the C_1 and C_6^+ fractions would generate – through the non-linearity and asymmetry in the allocation algorithm – a systematic bias in the allocated revenues which is of the same order as the bias which may be expected to propagate from any residual bias (+/-.05%) in the flow measurement of gas off the arrival separators.

The figure of $^{+}/-$ 6% as a functional specification for measuring gas composition is not just an instrumentation specification. The transfer of the measurement into the allocation system must also be considered. The allocation algorithm will be run every twelve hours to enable allocation to be performed both on a gas-day (06:00-06:00) and on an oil day (18:00 – 18:00). Since gas is delivered into the UK National Transmission System and traded on the day, the allocation of gas has to be established quickly after the end of the day. Thus it is necessary to have a gas composition available for use in the allocation algorithm on each day which is within $^{+}/-$ 6% of the actual composition on that day. The functional specification for gas composition therefore implies a combination of measurement uncertainty and timeliness (coupled with what is known about the likely variability of the composition).

5 CONCLUSIONS

The methodology presented provides a means of applying a set of objective criteria to establish appropriate functional specifications for the measurement systems used to obtain the inputs to an allocation system. Attempting to establish functional specifications for the measurement systems in the absence of this kind of analysis runs the risk of introducing a level of uncertainty or bias in the allocated revenue which may prove unacceptable to some fields / owners. Alternatively it may lead to over-specifying parts of the system which have little impact on the final allocated revenues and introduce additional capital expenditure and operating costs.

It is not sufficient to look at the uncertainty of measurement equipment alone. The timely flow of information into the allocation system must also be considered. For example, using a flow-proportional sampling system gives a more representative compositional measurement than spot sampling. However if the flow proportional sample is collected

[7] Given the ownership positions in the fields using the Britannia facilities, the functional specification could have been derived based on company net positions. Since however the field owners may at some stage choose to trade equity in one or more of the fields, the methodology should be applied using field allocations of revenue. Given that much of the equity in satellite fields is owned by some of the Britannia owners, these owners will also want to see their overall company position across all fields.

over a seven day period then the gas allocation system would need to use the previous week's measured composition. Using daily spot sampling it would be possible to use a measurement taken on the day being allocated – albeit with a greater measurement uncertainty. If the expected day to day variability of the property being measured is greater than the measurement uncertainty of spot sampling, then it may be better to use spot sampling.

Since non-linearity in the process chemistry may introduce asymmetry in the allocation algorithm, it may be that random errors which might normally be considered acceptable to a metering / measurement engineer (given that they are symmetrical and cancel one another out) may not be acceptable in the context of the allocation as they may cause a systematic between fields' allocations.

6 ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Britannia co-venturers for this work and also the many colleagues who have discussed and reviewed aspects of it and ultimately shaped the methodology.

7 REFERENCES

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