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Influence of fluid compositions and process parameters on allocation uncertainties

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1 INTRODUCTION

Current focus on cost-effective developments of new hydrocarbon fields aims at exploiting the capacity of existing production infrastructure to the maximum. Thus, many developments involve tie-backs where the satellite may have different fluid compositions compared to the mother field. This generates the need for a more in-depth understanding of how the fluid properties and the production process affect the allocation uncertainty for the involved fields.

In order to establish a foundation for industry best practice related to allocation uncertainty and risk-cost-benefit calculations, NORCE has initiated a joint industry project (JIP), which is supported by Wintershall Dea Norge, DNO Norge, and Lundin Energy Norway. In this paper, results from the ongoing work related to influence of fluid compositions and process parameters on allocation uncertainties are presented.

Many allocation systems are based on oil recovery factors (ORF) or component oil recovery factors (CORF) found by process simulations. Typical questions that are discussed among partners when developing allocation agreements and evaluating uncertainties are:

- Can a simplified multi-step process simulation be applied?
- How does component lumping affect the allocation uncertainty?
- Are all-in simulations (component tracking) required, or are stand-alone simulations preferable for allocation uncertainty evaluation?
- How will variations in fluid composition between each process simulation update affect the CORF uncertainties?
- What are the dominating uncertainty contributors to the CORF and ORF uncertainties?
- How does CORF uncertainties contribute to uncertainty in allocated values?

The objective of the work presented in this paper is to increase the understanding of how fluid composition and process modelling affect the allocation uncertainties, through studies of an example tie-in system involving tie-in of an oil-producer to a gas producing host.

A Monte Carlo simulation framework is used to study the effect of variations and uncertainties in production flow rates, measurement system, production process, fluid compositions on the uncertainty of allocated values. The process simulations are carried out in PVTsim Nova using a Matlab-implementation that enables multistage processing with component tracking to account for commingling effects. This allows for different process simulation approaches to be compared.

The case studies are carried out in two steps by first estimating how variations/uncertainties in fluid properties, process parameters and flow rates affect the component oil recovery factors. Secondly, it is examined how these variations in component oil recovery factors affect the uncertainties in allocated values.

2 NOTATION

Notation in allocation equations and uncertainty models:

HC:	Hydrocarbon (oil + gas).
M:	Mass (total for all components)
m_i:	Mass per component *i*
$calc$:	Calculated quantity from input measurements
$meas$:	Measured quantity
all:	Allocated quantity
ORF^A:	Oil recovery factor
$CORF_i^A$:	Component Oil recovery factor for component *i*
$C_{oil,i}$:	Oil mass fraction of component *i*
$C_{gas,i}$:	Gas mass fraction of component *i*

Notation in figures:

co:	Oil mass fraction of component *i*
cg:	Gas mass fraction of component *i*
Mo:	Oil mass (total for all components)
Mg:	Gas mass (total for all components)
mo:	Oil mass per component
mg:	Gas mass per component

Uncertainties are stated with k=2, ≈95 % confidence level.

3 SYSTEM DESCRIPTION

The cases studied in this paper consider tie-in of a new producer to an existing topside processing platform. The tie-in field (A) is an oil producer which is processed together with a mature gas producer (B). The production is allocated pro-rata, with a split between oil and gas based on CORFs that are updated regularly by process simulations. Figure 1 shows a schematic overview of the pro-rata allocation system.

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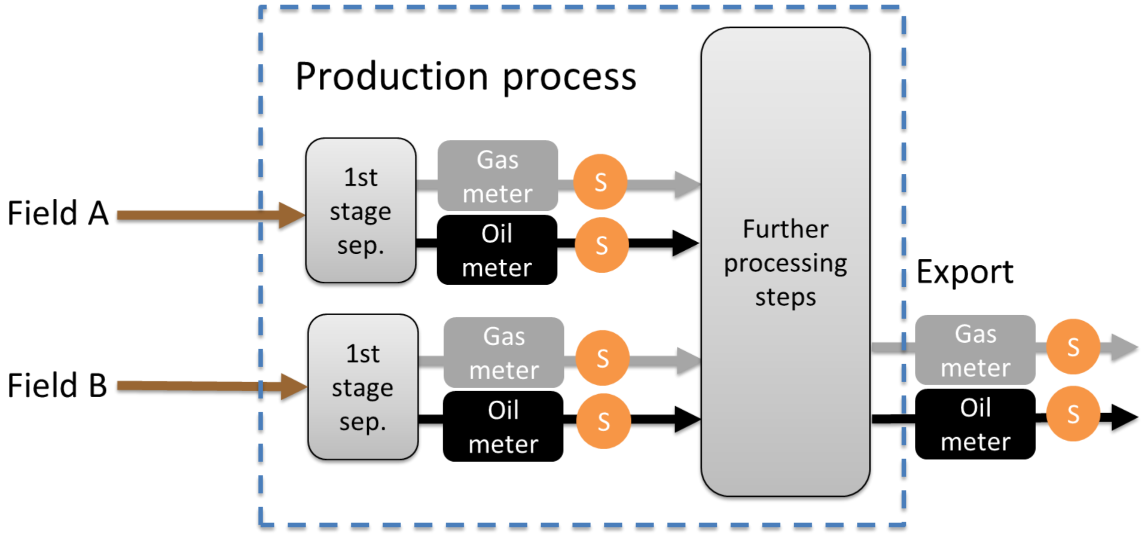

***Figure 1** Schematic overview of pro-rata allocation system. (S: fluid sampling)*

3.1 Base case description

For the base case a monthly allocation approach is considered, based on daily measurements of flow rates, average fluid composition over a month, and CORFs found from process simulations. It is assumed that the CORFs are updated monthly by running process simulations with average flow rates and compositions.

The production per component for the two producers is shown in Figure 2. The oil producer (A) has a higher fraction of heavy components, and the gas producer (B) has a higher fraction of lighter components. For the base case, the accumulated HC masses are quite similar for the two fields.

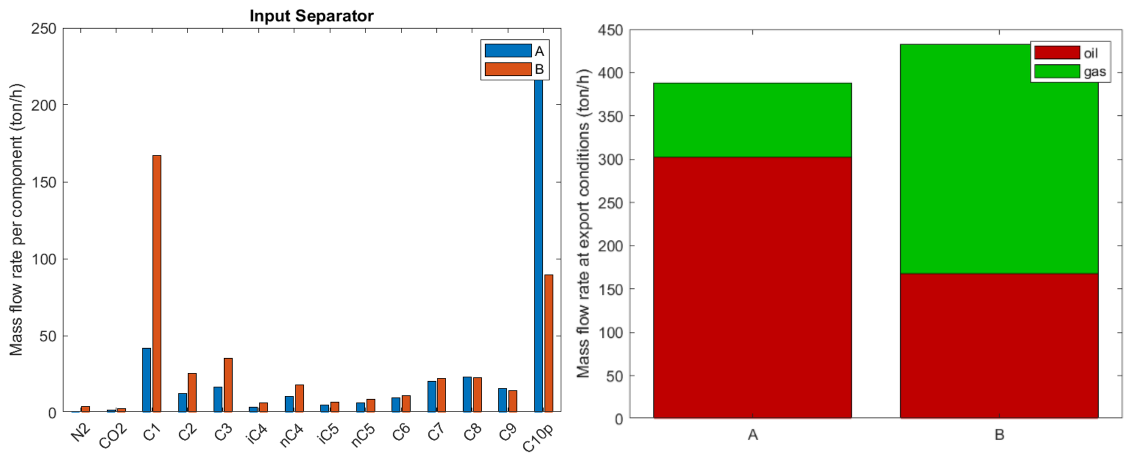

***Figure 2** Mass flow rate for stream A and B (a) per component and (b) for exported oil and gas.*

3.2 Process simulation and oil recovery factors

The process simulation provides information about the distribution of hydrocarbons in the oil and gas phases at the various processing steps. A sketch of the process model studied in this paper is shown in Figure 3. This model has been implemented in HYSYS. For allocation purposes, we are interested in how much of the hydrocarbon components in the input fields production that ends up in the oil and gas phases at export conditions. This can be quantified using *oil recovery factors* (ORF) or *component oil recovery factors* (CORF) found by process simulations. Thus, the allocation uncertainty calculations are divided into two steps:

1) Calculate CORF (and/or ORF) for the streams, and associated uncertainties
2) Calculate allocated values, and associated uncertainties, using the CORF/ORFs from step 1

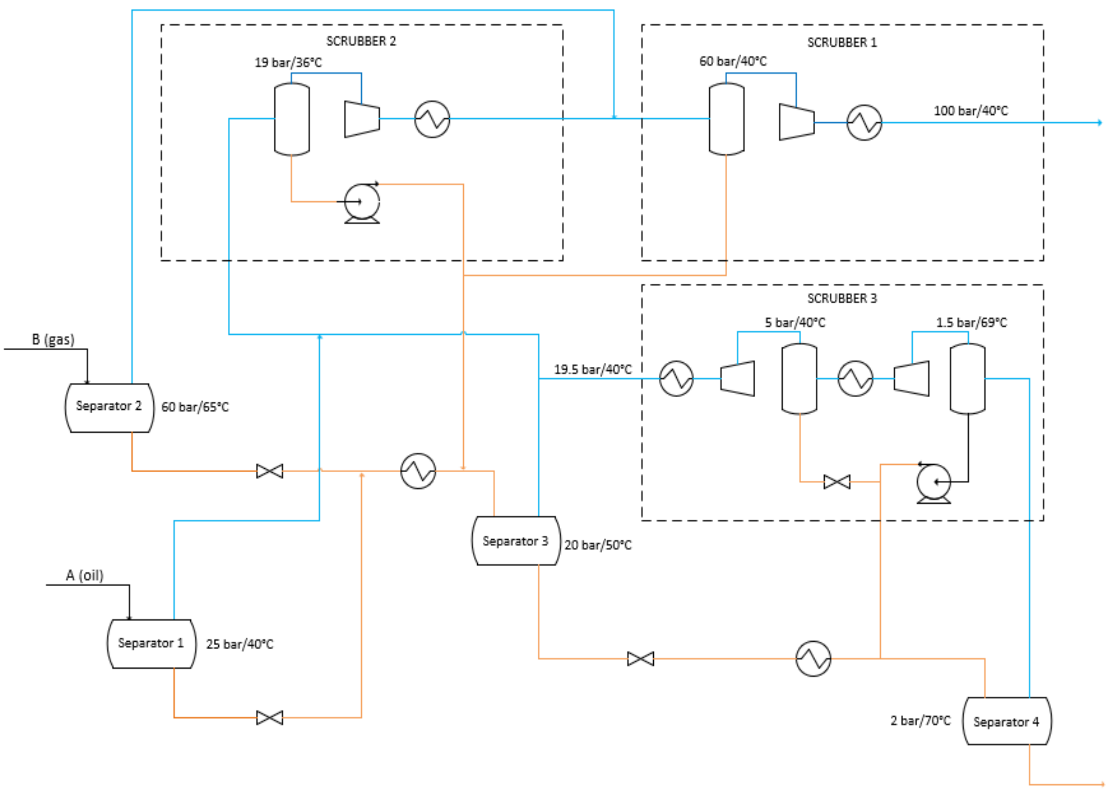

Figure 3 Sketch of the process model as implemented in HYSYS.

The ORF (*oil recovery factor*) for field A is related to the oil, gas and hydrocarbon total masses as:

$$ORF^A = \frac{M_o^{A,out}}{M_{HC}^{A,in}} \tag{3-1}$$

where $M_o^{A,out}$ is field *A* total oil mass flow at exports conditions, $M_{HC}^{A,in}$ is field *A* total hydrocarbon mass flow.

The CORFs (component oil recovery factors*)* for field A is related to the oil, gas and hydrocarbon compositions as:

$$CORF_i^A = \frac{m_{o,i}^{A,out}}{m_{HC,i}^{A,in}} = \frac{C_{o,i}^{A,out} M_o^{A,out}}{C_{HC,i}^{A,in} M_{HC}^{A,in}} \quad (3\text{-}2)$$

where $m_{o,i}^{A,out}$ is field *A* and component *i* oil mass flow at exports conditions, $m_{HC,i}^{A,in}$ is field *A* and component *i* total hydrocarbon mass flow, $C_{o,i}^{A,out}$ is field *A* and component *i* oil mass fraction at export conditions, $C_{HC,i}^{A,in}$ is field *A* and component *i* total hydrocarbon mass fraction.

Similar equations can be set up for field B. Note that $C_{o,i}^{A,out}$ and $M_o^{A,out}$ are the oil mass fractions per component and total oil mass flow at export conditions, obtained from export sampling and flow measurement, whereas $C_{HC,i}^{A,in}$ and $M_{HC}^{A,in} (= M_g^{A,in} + M_o^{A,in})$ typically are obtained at inlet conditions (for instance from inlet/test-separator flow measurement and sampling). Thus, $C_{HC,i}^{A,in}$ and $M_{HC}^{A,in}$ and corresponding uncertainties are input data to the process simulations, whereas $C_{o,i}^{A,out}$ and $M_o^{A,out}$ are output data from the process simulation.

By including variations in the process input parameters and the process itself, the uncertainties in CORFs and other output parameters can be calculated from the corresponding variation in output data.

3.3 Allocation equations

Component-by-component allocation equations for oil and gas based on component oil recovery factors (CORFs) from process simulations are presented below. Here *field* denotes any of the involved fields. Notation *calc* is used when field oil and gas mass are calculated and not measured directly. The index *i* indicates the different components (C1, C2, C3 etc.)

The hydrocarbon mass per component from each field is input to allocation equations, and found from measured oil and gas flow rates multiplied by oil and gas composition as found from sampling at inlet separator outlets:

$$m_{HC,i}^{field} = m_{oil}^{field,meas} C_{oil,i}^{field} + m_{gas}^{field,meas} C_{gas,i}^{field} \quad (3\text{-}3)$$

The oil mass per component for each field is calculated as the field hydrocarbon mass per component multiplied by the CORF:

$$m_{oil,i}^{field,calc} = m_{HC,i}^{field} \cdot CORF_i^{field}$$

The oil mass per component allocated to a field is then found by pro-rata allocation: (3-4)

$$m_{oil,i}^{field,all} = m_{oil,i}^{export} \cdot \frac{m_{oil,i}^{field,calc}}{m_{oil,i}^{A,calc} + m_{oil,i}^{B,calc}}$$

Similarly for gas allocation:

$$m_{gas,i}^{field,calc} = m_{HC,i}^{field}(1 - CORF_i^{field})$$

$$m_{gas,i}^{field,all} = m_{gas,i}^{export} \cdot \frac{m_{gas,i}^{field,calc}}{m_{gas,i}^{A,calc} + m_{gas,i}^{B,calc}} \tag{3-5}$$

4 CASE UNCERTAINTY CONSIDERATIONS

4.1 Uncertainty in measured flow rates

Uncertainties in export flow rates are set according to regulations from the Norwegian Petroleum Directorate, i.e. 0.3 % for oil volume flow rate and 1.0 % for gas mass flow rate (k=2). If the export station is equipped with a flow proportional sampling system, the uncertainty in oil density is considered negligible compared to the volume rate uncertainty. Thus, the oil mass rate uncertainty is also set to 0.3 %. Table 1 gives an overview of the input uncertainties applied in the study.

Table 1 Overview input uncertainties (k=2)

Measurement station	Parameter	Base Uncertainty
Export	Oil mass rate	0.3 %
	Gas mass rate	1.0 %
	CORF	From process simulations
	ORF	From process simulations
Inlet separators	Oil mass rate	1.0 %
	Gas mass rate	1.5 %

4.2 Uncertainty in fluid compositions

As seen from equation (3-3), the inlet mass flow and mass fractions per component are needed for component-based allocation methods. The gas and oil compositions are normally found from fluid sampling at separator outlets. The combined hydrocarbon composition is typically found by recombining the gas and oil compositions according to the measured gas and oil flow rates. The uncertainty of the oil and gas composition depend on the laboratory analysis uncertainty and the representativity of the samples. The uncertainty in the combined hydrocarbon composition is also affected by the uncertainties in oil and gas flow rates.

There is very limited information openly available for evaluating and quantifying uncertainty contributions from the sampling and laboratory analysis. Important questions with no clear answers in the literature are how representativity uncertainty due to the sampling grab process can be quantified, if this uncertainty is best expressed in relative or absolute form, and how laboratory analysis uncertainties of unstable samples from inlet separators can be evaluated.

Due to the lack of an established approach, in this work we estimate the uncertainty contributions from laboratory analysis of fluid samples on NORSOK I-106 [1] for light components in gas, ASTM D1945 reproducibility [2] for light components in oil, ASTM D-5134 reproducibility [3] for C4 – C9 and ASTM D-2892 reproducibility [4] for C10+. This is summarized in Table 2 and Table 3.

Table 2 Gas stream - Absolute uncertainties (k=2) in mass fraction of laboratory analysis applied in this work, with reference to the uncertainty source. Set as equal to reproducibility for ASTM D-5134 and ASTM D-2892 standards.

			Comments
N2 CO2 C1 C2 C3	NORSOK I-106		NORSOK I-106 table F.0 gives component uncertainty as a function of component molar mass for different mass fraction ranges.
iC4	ASTM D-5134	0.13 (x)^0.85	x refers to the mass percentage of the component. For components in the C6, C7, C8 and C9 groups, the ASTM D-5134 gives different uncertainties for specific components. For this example case, uncertainties for a selection of these components are used.
nC4		0.17 (x)^0.85	
iC5		0.17 (x)^0.67	
nC5		0.14 (x)^0.67	
C6		0.12 (x)^0.67	
C7		0.16 (x)^0.50	
C8		0.094 (x)^0.50	
C9		0.073 (x)^0.50	
C10+	ASTM D-2892	1.3	Depends on composition and boiling points of the elements in the C10+ group. An assumption of some C10 (if any) and negligible heavier components in gas phase and thus 1.3 % used.

Table 3 Oil stream - Absolute uncertainties (k=2) in mass fraction of laboratory analysis applied in this work, with reference to the uncertainty source. Set as equal to reproducibility for ASTM D-5134 and ASTM D-2892 standards

			Comments
N2 CO2 C1 C2 C3	ASTM D1945		ASTM D1945 chapter 10.1.2 gives component reproducibility as for different molar fraction ranges.
iC4	ASTM D-5134	0.13 (x)^0.85	x refers to the mass percentage of the component. For components in the C6, C7, C8 and C9 groups, the ASTM D-5134 gives different uncertainties for specific components. For this example case, uncertainties for a selection of these components are used.
nC4		0.17 (x)^0.85	
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C7		0.16 (x)^0.50	
C8		0.094 (x)^0.50	
C9		0.073 (x)^0.50	
C10+	ASTM D-2892	2.0	Depends on composition and boiling points of the elements in the C10+ group. An assumption of most of heavier components and thus 2.0 % used

The fluid composition uncertainties also depend on how representative the samples are for

- The fluid flowing through the pipe during sampling (i.e. grab representativity)
- The fluid flowing through the pipe between sampling events (i.e. time representativity)

The sample representativity in time (e.g. how much the composition changes in the period between two sampling events) is case-specific and is discussed in section 5.2 In this analysis it is assumed that the grab representativity gives negligible uncertainty contribution.

In Ref. [5] it was found that uncertainty in operating conditions and fluid compositions were the main uncertainty contributors to the oil shrinkage and gas expansion factors (and thereby also to the component recovery factors). Thus, the choice of equation-of-state and the uncertainties in component properties (e.g. molecular weights of pseudo-components) had a minor influence on the uncertainties. In this study we have therefore neglected these in the uncertainty analysis.

The calculated uncertainties of separate oil and gas compositions of field A and B at inlet separator conditions are shown in Figure 4 assuming negligible variation/uncertainty due to representativity in input composition and in Figure 5 assuming a variation/uncertainty due to representativity in input composition of 0.5 weight% (absolute). When a negligible variation/uncertainty due to representativity is assumed, the composition uncertainties varies between roughly 1 % and 10 % for oil components and between 0.5 % and 10 % for gas components, close to the composition uncertainty referred to in Ref. [5]. When a 0.5 weight% (absolute) uncertainty due to representativity is taken into account however, the component uncertainties are significantly higher.

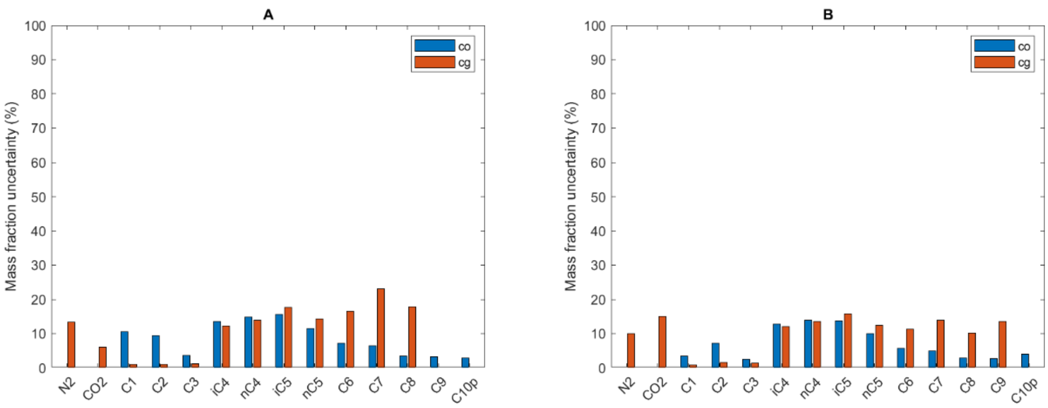

Figure 4 Uncertainty in composition (oil and gas mass fractions) for fluid A and B at inlet separator conditions. The uncertainties shown here are estimated assuming a negligible variation/uncertainty due to representativity in input composition (thus only laboratory analysis uncertainty according to Table 2). Uncertainties in components with mass fraction less than 0.01% are set to zero.

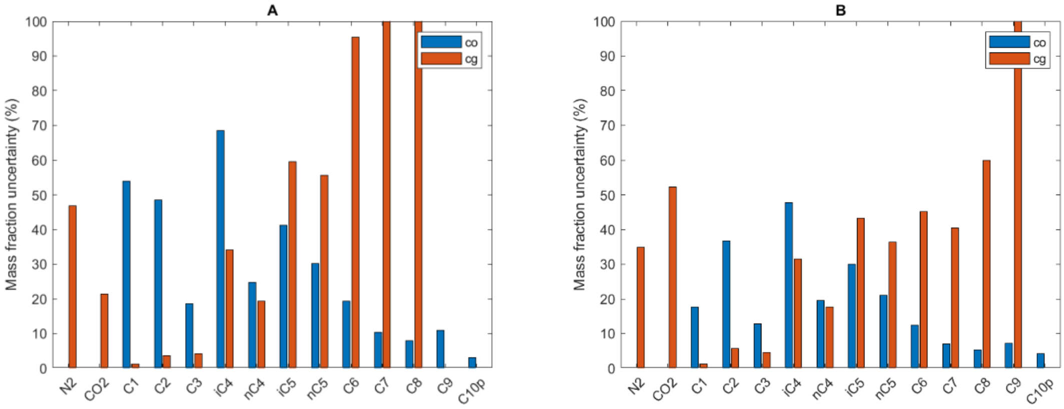

Figure 5 Uncertainty in composition (oil and gas mass fractions) for fluid A and B at inlet separator conditions. The uncertainties shown here are estimated assuming a <u>variation/uncertainty due to representativity in input composition of 0.5 weight% absolute</u> (in addition to laboratory analysis uncertainty according to Table 2). Uncertainties in components with mass fraction less than 0.01% are set to zero.

4.3 Uncertainty analysis of process simulations

The ORFs and CORFs uncertainties may be found by Monte Carlo simulations of a process model. The uncertainties in these parameters are calculated based on the expected **variation** in input parameters between each update of the process simulations.

The input parameters to the process simulations, i.e. flow rates, separator pressures and temperatures, fluid compositions, etc. are all assigned a probability density function based on assumed measurement uncertainty and variation. The resulting distribution of the ORFs and CORFs gives their respective uncertainties. The variation in fluid compositions, flow rates and process parameters between each update for the cases studied in this work is as shown in Table 4.

As process simulations are time-consuming and labor intensive, it would be convenient if simplified estimations of CORF/ORF uncertainties can be carried out instead of full process simulations using e.g. HYSYS. This is the one of the objectives studied in this paper.

Table 4 Variations in flow and process parameters between each update of oil recovery factors. Variations and representativities given in the table are used as expanded uncertainties (k=2) into the Monte Carlo simulations.

Flow variations / representativity of streams between simulations			
Input oil rate	5 %		
Input gas rate	5 %		
Composition (mass fraction) input streams	0.5 wt%		
Composition (mass fraction) export streams	Negligible		
Process variations			
	1st stage	**2nd stage**	**3rd stage**
Separator pressure variation	1 bar	0.5 bar	0.1 bar
Separator temperature variation	3 °C	3 °C	3 °C
Scrubber pressure variation	1 bar	1 bar	0.1 bar
Scrubber temperature variation	3 °C	3 °C	3 °C

5 RESULTS AND DISCUSSION

Here we first show how process simulation simplifications affect ORF and CORFs and their associated uncertainties. We then show how uncertainties in fluid composition and process parameters affect component oil recovery factors (CORF). Finally, we investigate how uncertainties in ORF and CORFs affect allocation uncertainty for different case variations.

5.1 Process simulation simplifications

A simplified simulation model of the process is shown in Figure 6. The process is here represented by a series of stream splitting, commingling and flash operations at specified temperature and pressure conditions. According to Stockton [5], such a simplified simulation approach gives comparable results to a detailed process simulation that includes all process components (heaters, coolers, scrubbers, separators, compressors etc.). A simplified process model is easier to set-up, and the simulation time is also shorter. Thus, the first thing to consider is:

Q1. Can a simplified multi-step process simulation be applied?

We have implemented the simplified model in Figure 6 by combining PVTsim Nova and Matlab. The flash operations at the process elements' (separators and scrubbers) temperature and pressures are done in PVTsim, whereas stream splitting and commingling are carried out in Matlab. The overall iterative process is controlled in Matlab.

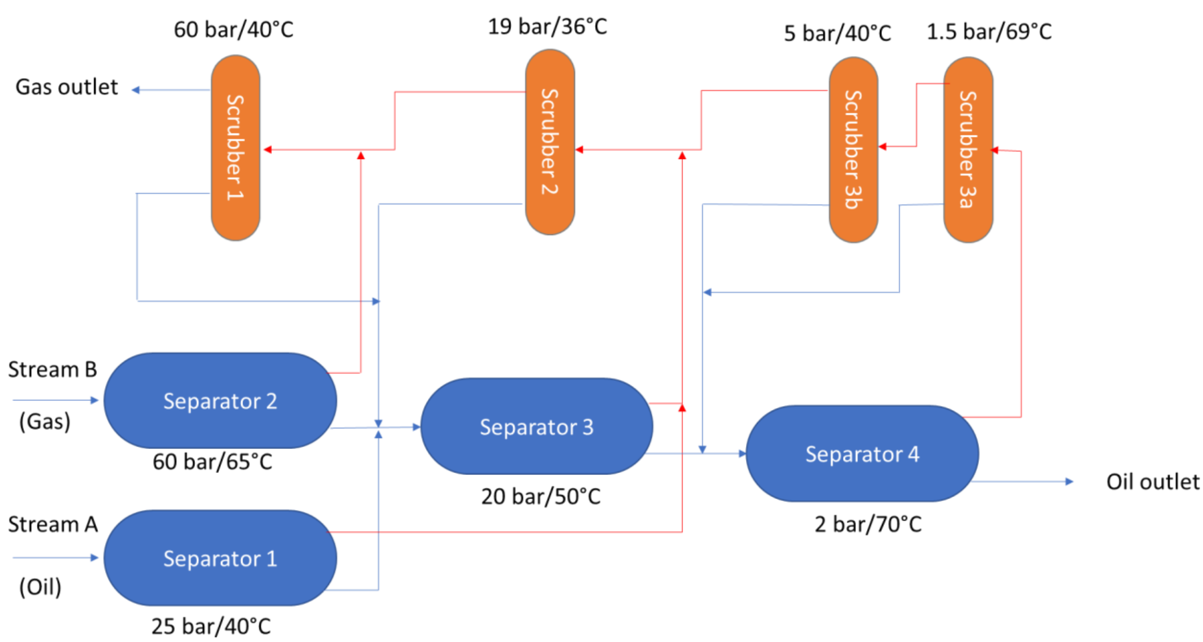

Figure 6 Simplified simulation model of the three-stage process with example pressure and temperature used for case studies.

Figure 7 compares the results of the simplified process simulations with HYSYS simulations. Some small differences are observed in the estimated masses, but the overall agreement is good. As the intention with the process simulations in this work is to study variations (uncertainties) in CORFs rather than to find the exact CORF values, we consider that the CORFs obtained with the simplified simulations are sufficiently close to the "true" CORFs obtained in HYSYS. However, a dedicated process simulator such as HYSYS should be used to avoid any systematic errors when calculating the exact CORF values used for allocation as the accumulated errors over the lifetime can be large.

Similar agreement between HYSYS and the Matlab/PVTsim simulations has also been observed for other processes and other fluids (not reported here). Thus, we conclude that **a simplified multi-stage process simulation is sufficient for CORF uncertainty estimation**.

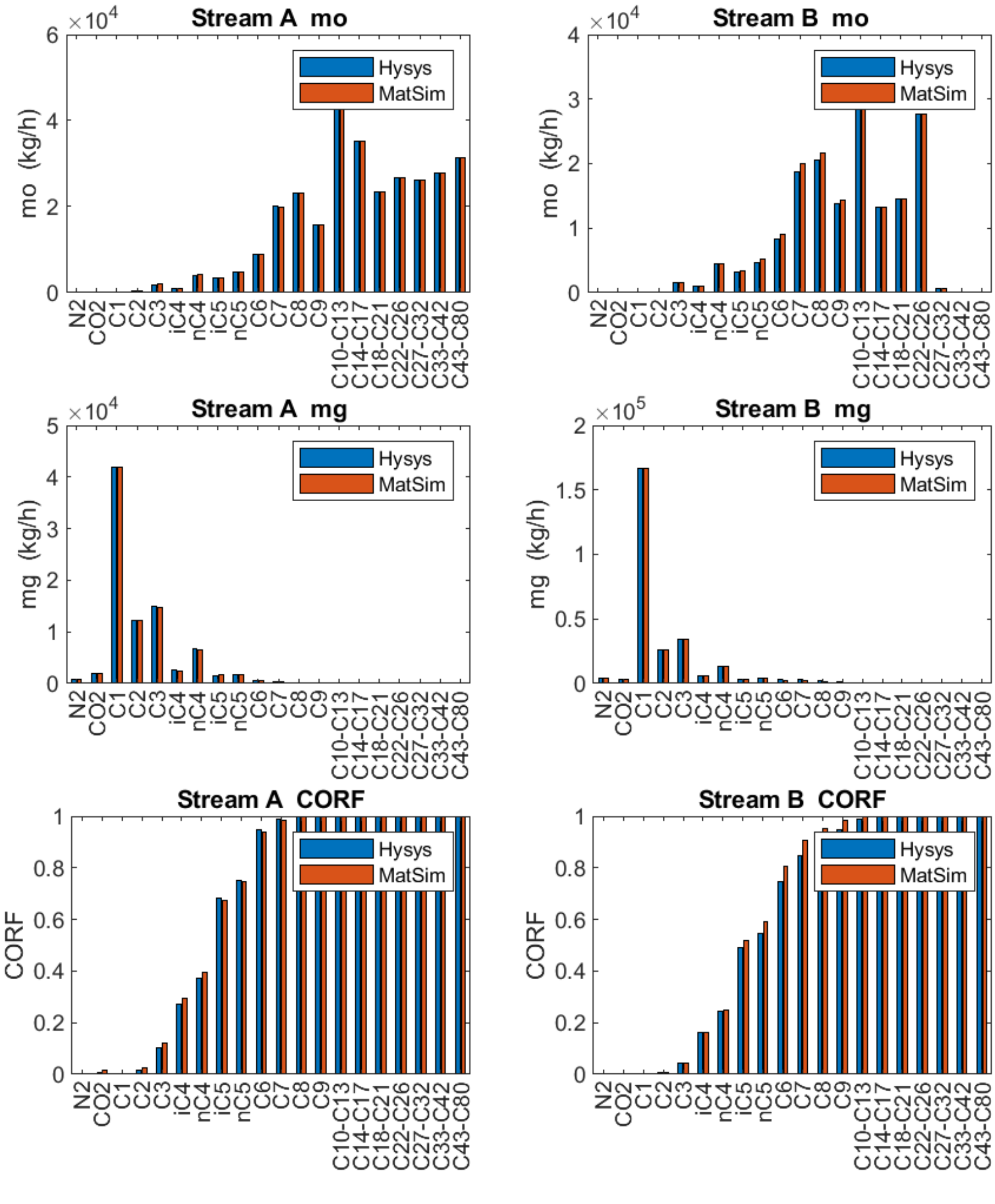

Figure 7 Comparison between HYSYS and simplified process model

The results shown in Figure 7 were obtained using a fluid composition with a large number of pseudo-components. Often, it will be desirable to stop the grouping of pseudo-components at a much lower carbon number, for instance at C10+. Hence, that all components from C10 and above are lumped together in one single pseudo-component. In order to study the effect of this, we aim to answer the following question:

Q2. How does component lumping affect the allocation uncertainty?

Figure 8 shows oil and gas mass flow per component for field A and field B calculated using two different lumping schemes. The lumping scheme referred to as *full* is the same as used in Figure 7. The other lumping scheme is referred to as *C10p* and stops the lumping with a C10+ pseudo component. To be able to compare the mass flows of the heavier components (C10 and above) the full lumping scheme mass flow per component for C10-C80 has been added together in Figure 8. Some minor differences are observed. The largest relative differences are in how the mid-range components (C4-C8) splits between gas and oil. The observed differences could be significant in terms of allocated value, but they are considered acceptable for evaluating the allocation uncertainty.

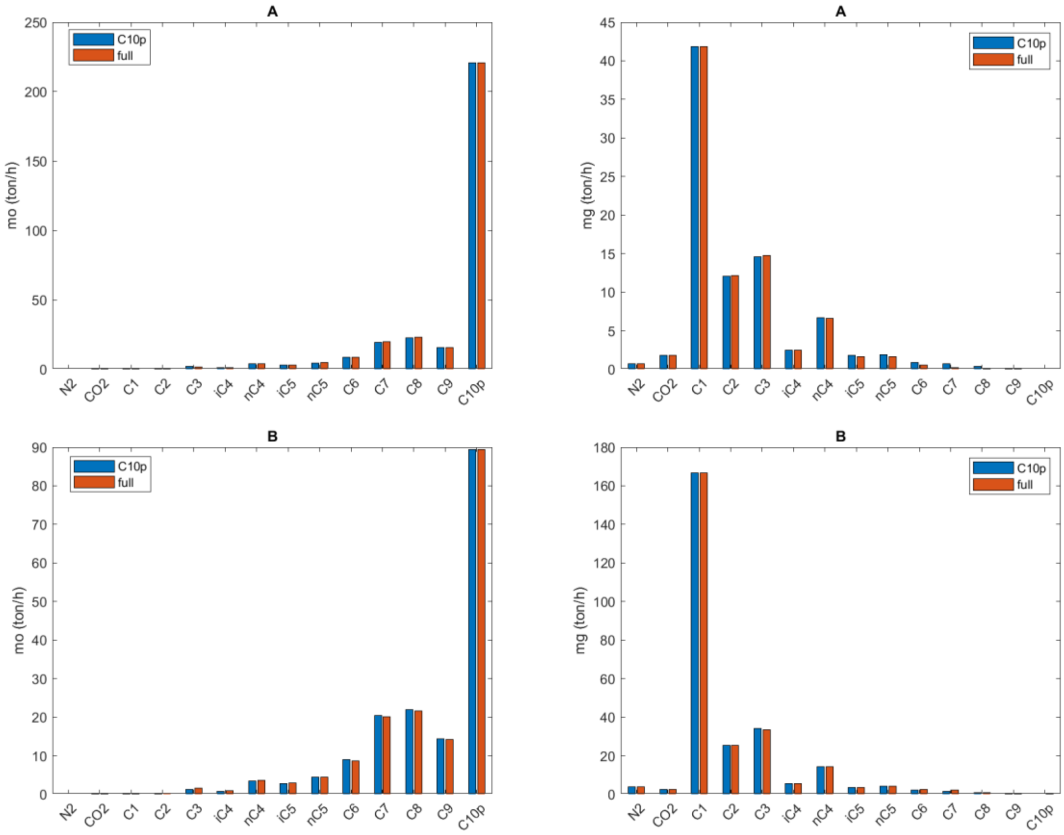

Figure 8 Gas and oil mass per component at export conditions calculated using all-in simulations with two different lumping schemes. C10p: PVTsim simulations with lumping

scheme stopping at C10+. Full: PVTsim simulations with lumping scheme as showed in Figure 7, with C10-C80 groups combined after simulation

Based on the observations we conclude that even if the degree of lumping affects the simulated distribution between phases slightly**, a large number of pseudo-components is not needed to evaluate the allocation uncertainty.** A possible further work is to investigate the effect of further lumping, for instance down to C6+.

Q3. How does the choice between all-in simulations (component tracking) and stand-alone simulations affect ORF and CORF uncertainties?

In order to answer this question, Oil Recovery and Component Oil Recovery factors and their uncertainties have been calculated for the base case for two different uses of process simulation model:

- All in: Stream A and B are commingled and simulated through the process model. Component tracking is used in order to determine which resulting oil and gas products that originate from stream A and stream B. Commingling effects between the different streams are taken into account through an all-in simulation.
- Stand-alone: Stream A and stream B are simulated separately through the process model, and commingling effects between the streams are therefore not taken into account.

Figure 9 show that the commingling effects (all-in) between field A and B result in that less of the hydrocarbon mass ends up in the oil phase after the process than if each field was produced individually (stand-alone). Although the difference in ORFs seems small, this adds up to a difference in oil mass flow of about 3 t/h for the studied case. Most of this as a reduction in oil to field A. For C3-C5 both fields get lower CORFs with all-in simulations. From C6 and above, field A still "loses" oil to the gas phase, whereas field B will produce more oil in a commingled process than if it was to produce individually. Thus, commingling effects lead to a lighter oil for field A and a heavier oil for field B. Note that these effects are specific for the considered case and process set-up with dedicated inlet separators for each field, and other commingling effects might be observed for other set-ups, fluids, flow rates and process conditions.

The uncertainties in CORFs calculated from stand-alone simulations and all-in simulations are similar. A slightly higher uncertainty for field A and a slightly lower uncertainty for field B is obtained when using stand-alone simulations as compared to all-in simulations (cf. Figure 10). However, the differences are small, and we therefore conclude that for the studied case **stand-alone simulations and all-in simulations give comparable uncertainty contributions to CORFs and ORFs. However, all-in simulations may be quicker and easier to carry out as coefficients for all streams are calculated in one simulation.** The cases studied further in this paper are therefore based on all-in simulations.

Note that focus here is on how the choice of all-in or stand-alone process model affects CORF uncertainty and later allocation uncertainty. If allocation based on stand-alone or all-in simulations should be used will depend also on other considerations, including commercial considerations and the complexity of the production process.

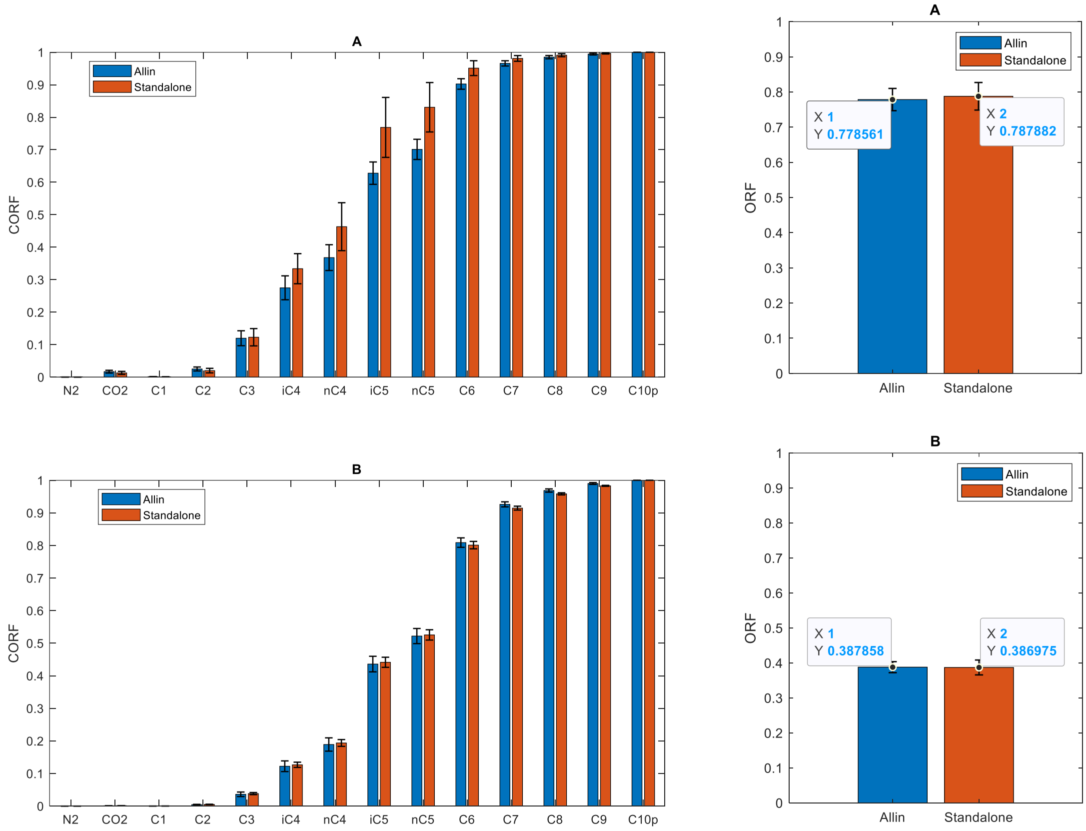

Figure 9 CORFs and ORFs (with uncertainty bars) for fluid A and B obtained from process simulations.

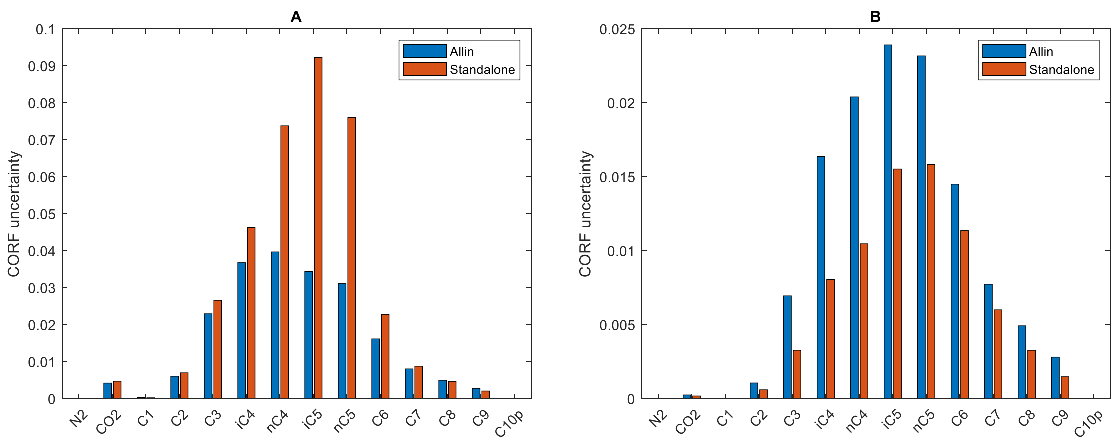

Figure 10 Absolute uncertainties (k=2) for CORFs fluid A and B obtained from all-in and stand-alone process simulations.

5.2 ORF/CORF uncertainties and sensitivities

The objective of this section is to investigate how uncertainties in fluid composition and process parameters affect the ORF and CORF.

Q4 How will variations in fluid composition between each process simulation update affect the CORF uncertainties?

Based on the findings in chapter 5.1, uncertainty analysis using simplified all-in process simulations (Matlab/PVTsim, C10+composition) are carried out. Simulations for two different cases regarding input composition representativity/variation between process simulations are performed.

- 0 wt% representativity: The composition is stable and sampled with high representativity, such that the composition variation between each process simulation is negligible compared to the analysis uncertainty. The composition uncertainty for this case is shown in Figure 4.
- 0.5 wt% representativity: There is a much higher variation in the composition in the time between sampling (as would be expected if more fields with different fluid composition produce through a shared riser), and/or process simulations are updated less frequently. The composition uncertainty for this case is shown in Figure 5.

The resulting CORF uncertainties (absolute values) for the two cases are shown in Figure 11. It is observed that the uncertainties for the two cases are very similar, and the increased representativity uncertainty only results in a small increase in CORF uncertainty. **Thus, the composition uncertainties do not influence the CORF uncertainty significantly for the studied fluids and process conditions.** Based on this observation, we state the next question:

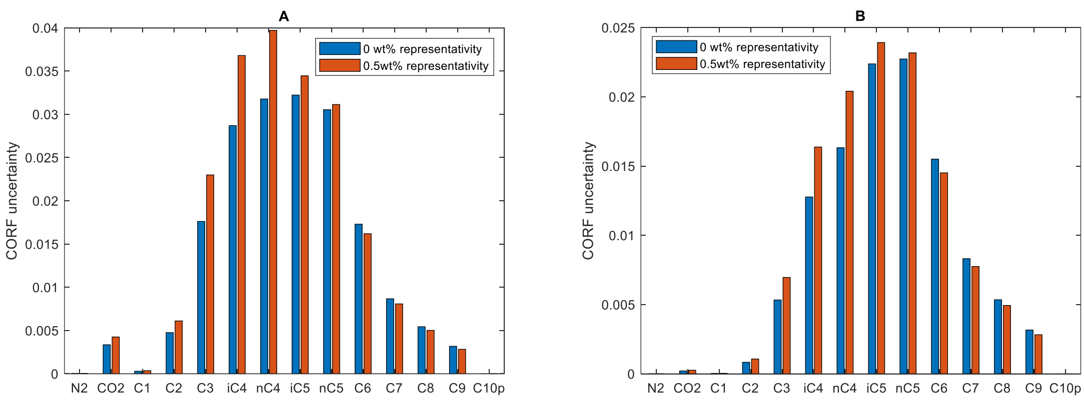

Figure 11 Uncertainties (absolute) in CORFs for fluid A and B obtained from process simulations for two different assumptions regarding input composition representativity/variation between process simulations.

Q5. What are the dominating uncertainty contributors to the CORF and ORF uncertainties?

In order to determine how uncertainties in fluid composition and process parameters affect the CORF and ORF uncertainties, a sensitivity analysis was carried out using the simplified process model (Matlab/PVTsim, all-in simulations, C10+composition). The variations as given in Table 4 were applied one at a time, and the results are shown in Figure 12 for ORF and Figure 13 for CORFs. The uncertainty bars show the uncertainties in CORF and ORF if the listed uncertainty parameter is the only contributing parameter.

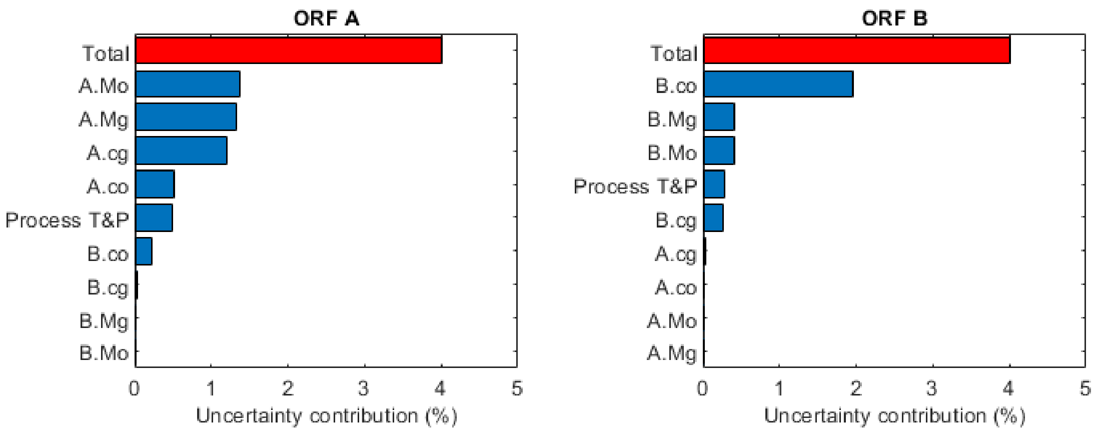

Figure 12 ORFs uncertainty contributions (cf. chapter 2 for notations.).

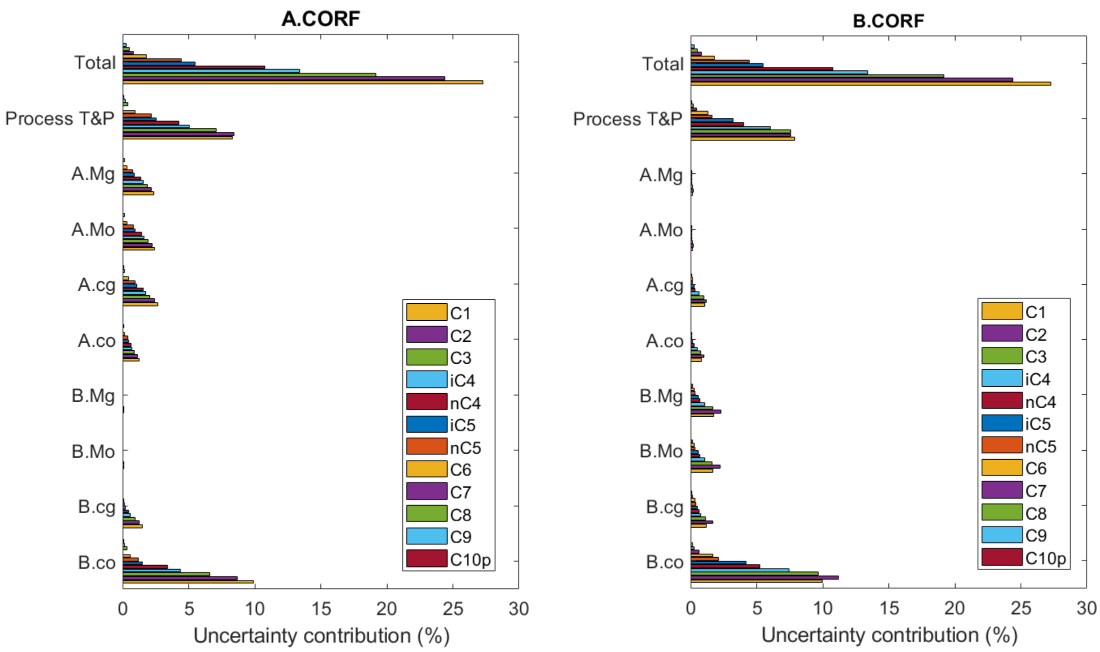

Figure 13 CORFs uncertainty contributions (cf. chapter 2 for notations.).

Process conditions: It is observed that uncertainties in temperature and pressure (labeled *Process T&P*) for the separators and scrubbers are the most important uncertainty contributors to the CORFs. For ORF on the other hand, process temperature and pressure only give a small uncertainty contribution.

Mass flow rates measured at inlet separators: For field A ORF, the measured mass flow rates for field A are the most important uncertainty contributions, whereas field B ORF uncertainty is dominated by uncertainty in field B oil composition and less affected by field B measured mass flow rates uncertainties. Both fields ORFs and CORFs are not affected by the other fields measured mass flow rates uncertainties, which may be explained by the dedicated inlet separators for each field.

Compositions (of liquid and gas part at the inlet separators): For field A, field A gas composition contributes more to the ORF uncertainty than field A oil composition. For field A CORF, field B oil composition is also a dominating uncertainty contribution for heavier components. For field B, it is the oil composition for field B that is the most significant uncertainty contribution both to ORF and CORFs.

For the studied case, variations in direct measurements (oil and gas masses and composition) give the most significant ORF uncertainty contributions, whereas variation in oil composition for field B and process pressures and temperatures give most significant CORF uncertainties. However, further work should be carried out to check whether this can be generalized.

It can be seen from Figure 12 and Figure 13 that the uncertainty contribution to CORFs and ORF uncertainties do not add up (squared) to the total CORF and ORF uncertainties. This is most likely due to higher order effects (coupling effects) in the process. According to ISO GUM [6], the standard GUM framework where combined uncertainties can be calculated based on uncertainties of input parameters and their sensitivities, does not hold when the measurement function is non-linear. This effect has not been studied further here.

5.3 Allocation uncertainties

The objective of this section is to investigate how process uncertainties (i.e. ORF and CORFs) affect allocation uncertainty for different case variations, or in other words:

Q6. How does CORF uncertainties contribute to uncertainty in allocated values

5.3.1 Base case

The allocation system for the base case is described in chapter 3, and the input uncertainties are listed in Table 1. The ORF and CORF uncertainties used in the following allocation uncertainty calculations are found from all-in process simulations as discussed in chapter 5.1 and 5.2.

Figure 14 shows the uncertainty (absolute values) in allocated oil and gas mass per component to field A and B. As expected, the uncertainty in oil is dominated by the heavy components, with an increasing contribution as the components become heavier. The uncertainty in gas composition is dominated by the lighter components, with a decreasing contribution with increasing carbon number.

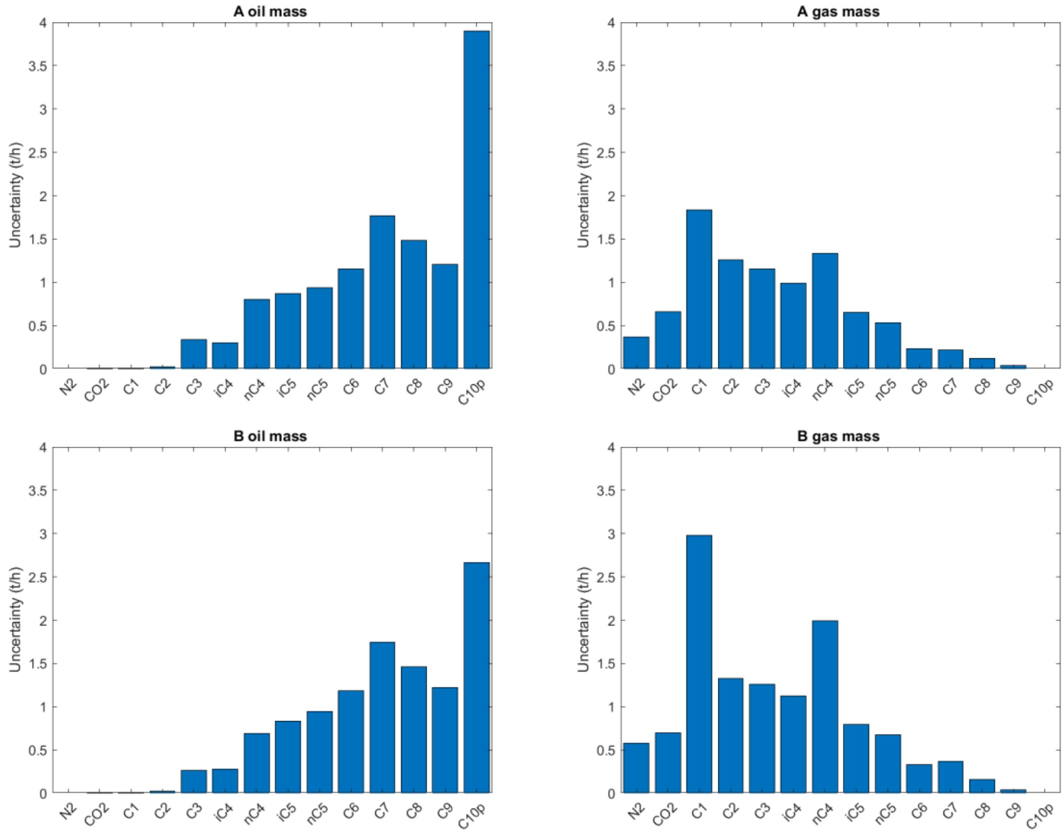

Figure 14 Uncertainty (relative and absolute) for allocated oil and gas per component

Figure 15 shows the uncertainty contribution of input measurements and CORFs to the oil and gas mass allocation uncertainties for each field. The figure shows that for the studied case, there are only small uncertainty contributions from CORFs to total allocated oil and gas mass. As a rule of thumb, if an uncertainty contribution is smaller than 1/3 of the total uncertainty, this contribution can be considered negligible, which is the case here. Note that this may be explained by the fluid compositions, rates and process model setup used for this specific case, and this result should not be generalized. In conclusion, for the studied case: **CORF/process variations contribute less to allocation uncertainties than direct measurement uncertainties**

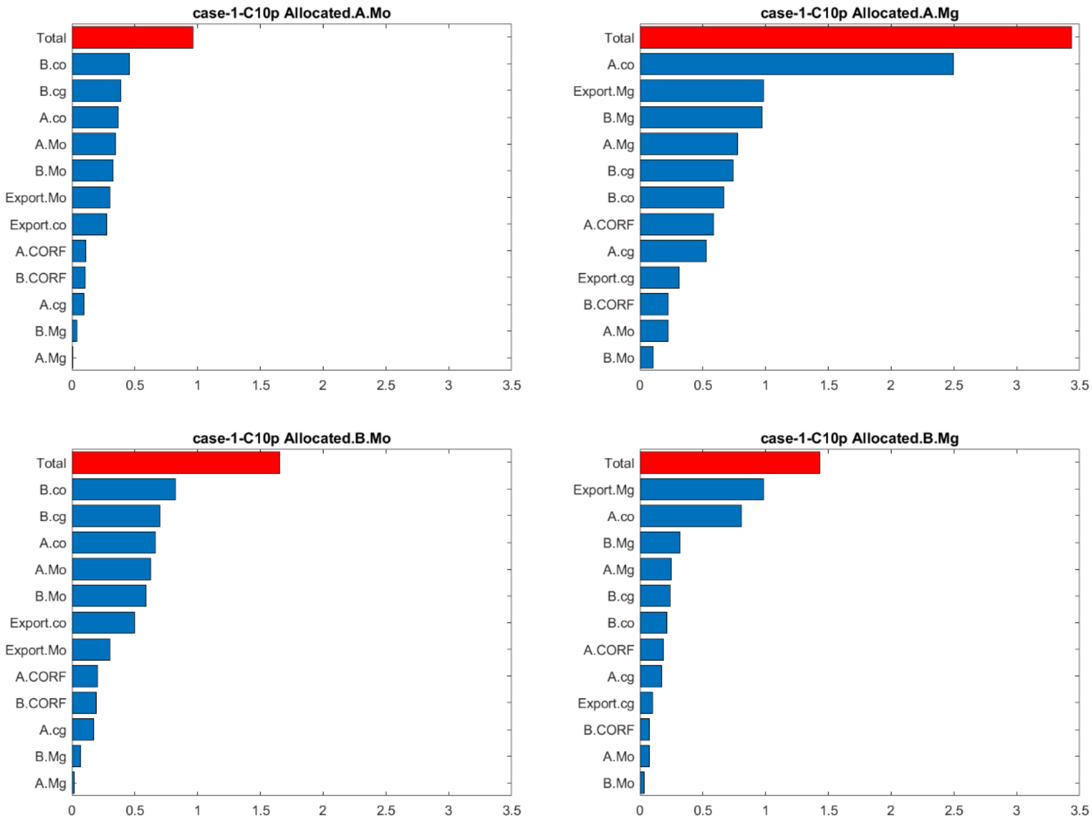

Figure 15 Uncertainty contribution to allocated oil and gas masses for the base case (relative uncertainties, k=2).

Uncertainty models derived from the allocation equations given in chapter 3.3 may be useful for explaining the different uncertainty contributions shown in Figure 15. As the oil phase is dominated by heavy components (which have CORF~1) and the gas phase by light components (which have CORF~0), allocation uncertainty models for C1 and C10+ components group may be used to explain effects for the total allocated oil and gas masses for field A:

$$\left(\frac{u\left(m^{A,all}_{Oil,c10+}\right)}{m^{A,all}_{Oil,c10+}}\right)^2 = \left(\frac{u\left(m^{export}_{oil,c10+}\right)}{m^{export}_{oil,c10+}}\right)^2 + \left(\frac{m^{B,calc}_{oil,c10+}}{m^{A,calc}_{oil,c10+} + m^{B,calc}_{oil,c10+}}\right)^2 \left[\left(\frac{u\left(m^{A}_{HC,c10+}\right)}{m^{A}_{HC,c10+}}\right)^2 + \left(\frac{u\left(CORF^{A}_{c10+}\right)}{CORF^{A}_{c10+}}\right)^2\right] + \left(\frac{m^{B,calc}_{oil,c10+}}{m^{A,calc}_{oil,c10+} + m^{B,calc}_{oil,c10+}}\right)^2 \left[\left(\frac{u\left(m^{B}_{HC,c10+}\right)}{m^{B}_{HC,c10+}}\right)^2 + \left(\frac{u\left(CORF^{B}_{c10+}\right)}{CORF^{B}_{c10+}}\right)^2\right] \tag{5-1}$$

(5-2)

$$\left(\frac{u\left(m_{gas,C1}^{A,all}\right)}{m_{gas,C1}^{A,all}}\right)^2 = \left(\frac{u\left(m_{gas,C1}^{export}\right)}{m_{gas,C1}^{export}}\right)^2 + \left(\frac{m_{gas,C1}^{B,calc}}{m_{gas,C1}^{A,calc} + m_{gas,C1}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC,C1}^{A}\right)}{m_{HC,C1}^{A}}\right)^2 + \left(\frac{-CORF_{C1}^{A}}{\left(1-CORF_{C1}^{A}\right)}\right)^2 \left(\frac{u\left(CORF_{C1}^{A}\right)}{CORF_{C1}^{A}}\right)^2\right] + \left(\frac{m_{gas,C1}^{B,calc}}{m_{gas,C1}^{A,calc} + m_{gas,C1}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC,C1}^{B}\right)}{m_{HC,C1}^{B}}\right)^2 + \left(\frac{-CORF_{C1}^{B}}{\left(1-CORF_{C1}^{B}\right)}\right)^2 \left(\frac{u\left(CORF_{C1}^{B}\right)}{CORF_{C1}^{B}}\right)^2\right]$$

In the models given above, two mechanisms will result in negligible contributions, indicated by colors:

- $CORF_{C1}^{field} \approx 0$ → sensitivity coefficient ≈ 0
- CORF relative uncertainty for C10+ ≈ 0

According to the uncertainty model given above, one would expect that CORF uncertainties have a negligible impact on total oil and gas allocated mass uncertainties, and this is in agreement with what is shown in Figure 15.

Due to the small uncertainty contributions from process simulations on allocation uncertainty, and the small uncertainty difference between all-in and stand-alone CORFs/ORFs (found in 5.1), it is expected that the choice of process simulation model will have a negligible effect on allocation uncertainties. Calculations using stand-alone CORFs confirm this.

5.3.2 Tie-in field with low production

In order to study a case where the tie-in field has a significantly lower production than the host field, field A production is reduced to 10% of the base case values. Figure 16 shows the uncertainty contributions to allocated oil and gas mass to field A and B. Compared to the base case where field A and B had comparable hydrocarbon production, the relative uncertainty in both oil and gas allocated to field A increases due the lower production. As field B now has a very large production compared to field A, field B allocation uncertainty approaches the export measurement uncertainties. These effects can also be derived from the uncertainty models presented in 5.3.1.

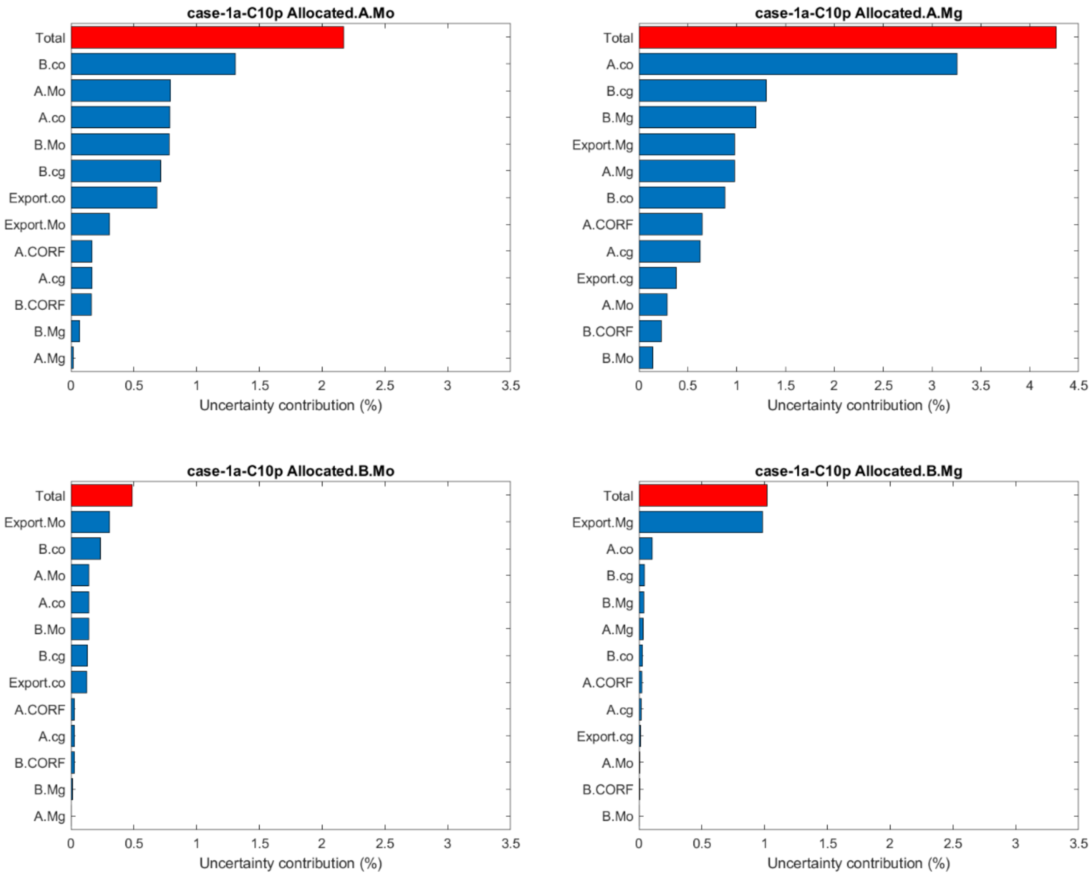

Figure 16 Reduced rates for field A: Uncertainty contributions to allocated oil and gas masses (relative uncertainties, k=2).

5.3.3 Tie-in field with large variations in fluid composition

We here study a case where the tie-in field A has a large variation and uncertainty in fluid composition, e.g. due to commingling of several subsea wells with different compositions.

The larger variation and uncertainty in fluid A composition is represented by a higher representativity uncertainty, here set to 1 wt% for all components in fluid A. For field B, a representativity uncertainty of 0.5 wt% is used as in the base case. Figure 17 shows the uncertainty contributions to allocated oil and gas mass to field A and B. Compared to the base case, the **increased uncertainty in field A composition leads to increased uncertainties for both fields**, as expected due to the pro-rata allocation principle. The effect can also be derived from the uncertainty models presented in 5.3.1. Field A oil composition uncertainty is now the most dominant uncertainty contribution for both fields oil and gas mass allocation uncertainty.

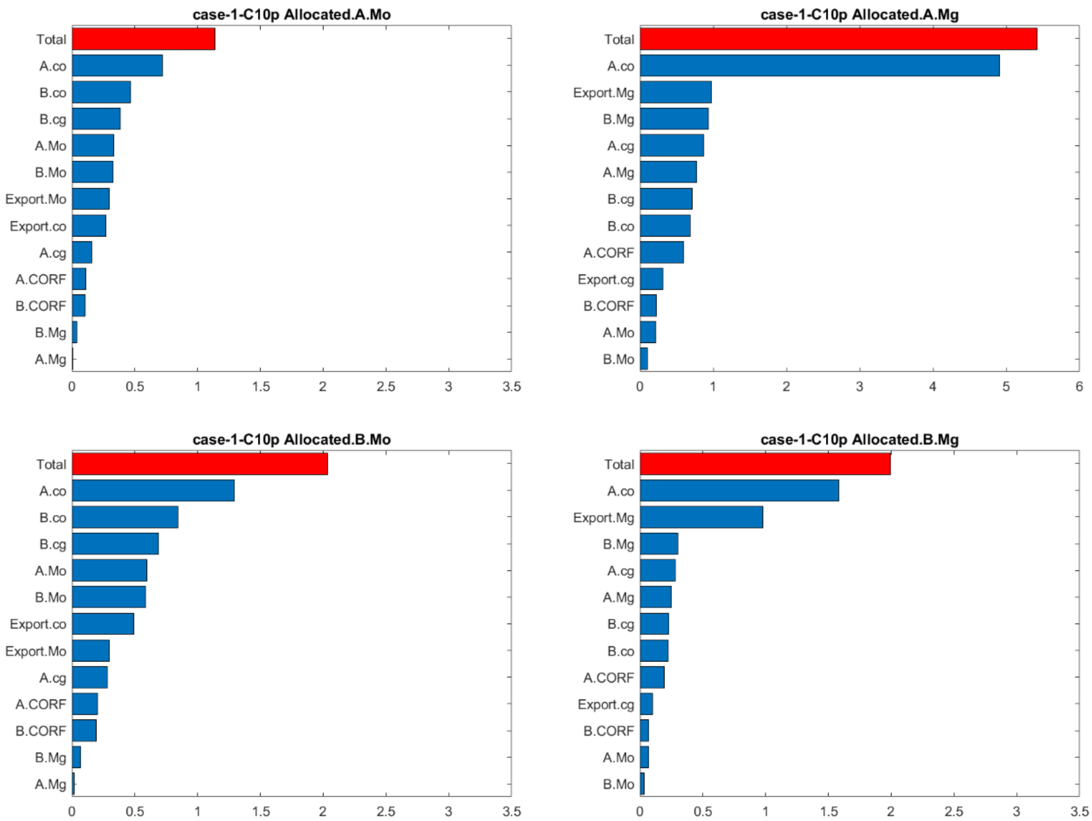

Figure 17 Increased fluid uncertainty for field A: Uncertainty contribution to allocated oil and gas masses (relative uncertainties, k=2).

5.3.4 Tie-in field measured by a multiphase flow meter

We here study a case where the tie-in field A is measured by a multiphase flow meter instead of a dedicated inlet separator. Field A measured oil and gas mass uncertainties are thus increased to 5 %. Other uncertainties are as for the base case. Figure 17 shows the uncertainty contributions to allocated oil and gas mass to field A and B. Compared to the base case, the **allocation uncertainties of both fields are increased**, as expected due to the pro-rata allocation principle. Field A oil and gas mass measurement are now dominating uncertainty contributions to oil and gas allocation uncertainty. For field B, gas export measurement uncertainty has a more significant uncertainty contribution to gas allocation uncertainty, as field B is mainly a gas producer and most of the export gas mass is allocated to field B.

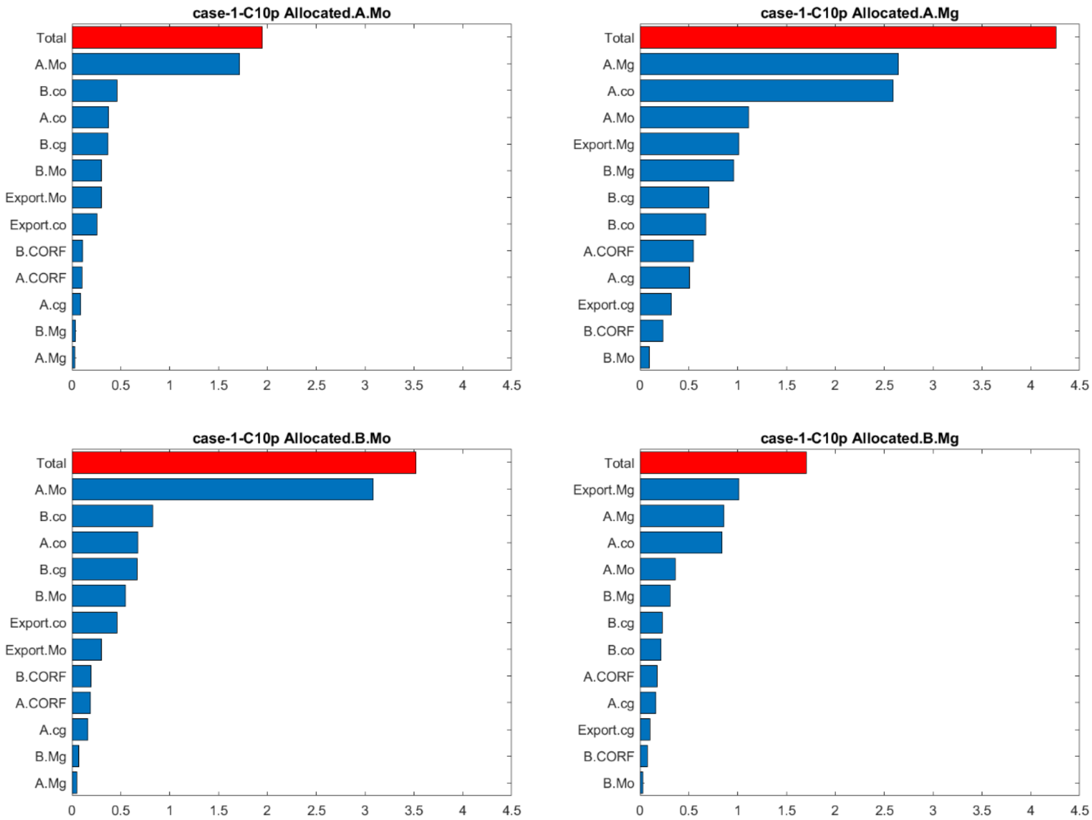

Figure 18 Increased measurement uncertainty for field A: Uncertainty contribution to allocated oil and gas masses (relative uncertainties, k=2).

6 CONCLUSION

Through studies of an example tie-in system involving tie-in of an oil-producer to a gas producing host, the work documented in this paper reflects an increased understanding of how fluid composition and process modelling affect the allocation uncertainties. The work is limited to specific examples, and additional studies should be carried out to investigate if the findings can be generalized.

We have shown that process model simplifications, degree of component lumping, and choice of all-in or stand-alone simulations have a small effect on ORF and CORF uncertainties for the studied cases:

- Agreement between HYSYS and the Matlab/PVTsim simulations is observed for a selection of processes and fluids. Thus, a simplified multi-stage process simulation is sufficient for ORF and CORF uncertainty estimation.
- A large number of pseudo-components is not needed to evaluate the allocation uncertainty.
- Stand-alone and all-in simulations give similar uncertainty values for CORFs and ORFs. However, all-in simulations may be quicker and easier to carry out as coefficients for all streams are calculated in one simulation.

We have investigated the uncertainty contributions to ORF and CORF uncertainties, and concluded that

- The composition uncertainties do not influence the CORF uncertainties significantly for the studied fluids and process conditions.
- For the studied case direct measurements (oil and gas masses and composition) give the most significant ORF uncertainty contributions, whereas oil composition for the gas field and process pressures and temperatures give most significant CORF uncertainties. However, further work should be carried out to check whether this can be generalized.

Finally, we show that for the studied cases, CORF/process variations contribute less to allocation uncertainties than direct measurement uncertainties. Composition uncertainties, on the other hand, have a significant effect on allocation uncertainties in some of the studied cases. As there is very limited information openly available for evaluating and quantifying uncertainty contributions from the sampling grab process and laboratory analysis of samples from inlet separators, we would like to encourage the oil and gas measurement community to evaluate and share findings related to this.

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