VOCON – Recondensation

1   LIST OF MEMOS AND REPORTS:

Memos

Recondensation of VOC. Parameter study on recovery rates and power requirements for "worst case scenario", 1998-06-08

Recondensation of VOC. Selection and design of heat exchangers for VOC condensation, 1998-09-02

Freeze out of CO_2 and Process evaluation for NMVOC condensation, 1999-03-12

NMVOC Recondensation – Case Study, 1999-12-09

Reports

Effects and measures related to water content in VOC/inert gas mixtures, SINTEF Energy Research, Report no TR F4830, 1999-01-27

(NMVOC recondensation – Memos from the VOCON project, SINTEF Energy Research, Report no ?? ?????, 1999-??-??)

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2 SUMMARY FROM MEMOS AND REPORTS

2.1 Memo *Recondensation of VOC. Parameter study on recovery rates and power requirements for "worst case scenario"*

A calculation basis for the parameter study is established based on earlier measurements of VOC emissions at Statfjord and Gullfaks A. These measurements represents values for a "worst case" scenario where no procedures have been used to reduce the VOC generation. The measured fraction of HC gas and the measured volumetric flowrate have been represented by linear fit.

Accumulated recovery rates by use of compression and cooling have been calculated and presented. The calculations have been performed at a temperature range of –100 to 0 ^{0}C and at a pressure range of 3 to 20 bar(a). The inert gas will be saturated with water before the loading starts, but has at this stage been assumed to be dry. Consequences and measures related to water must be closer looked upon. The freezing point of CO_2 will approximately be in the range of –85 to –80 ^{0}C. This is not considered in the calculations.

For calculating power requirements for recovering VOC's by compression and cooling a two-stage refrigeration plant with propylene as refrigerant is used. Compressor efficiencies are selected based on information from screw compressor manufactures. Pressure drop in heat exchangers are verified by a design program (M-TASC from HTFS) for shell- and tube types. Process calculations are performed by use of PRO/II with PROVISION from SimSci.
The power requirement calculations are at this stage restricted pressures of 5 and 7 bar(a) at a temperature of –43 ^{0}C in the end separator.
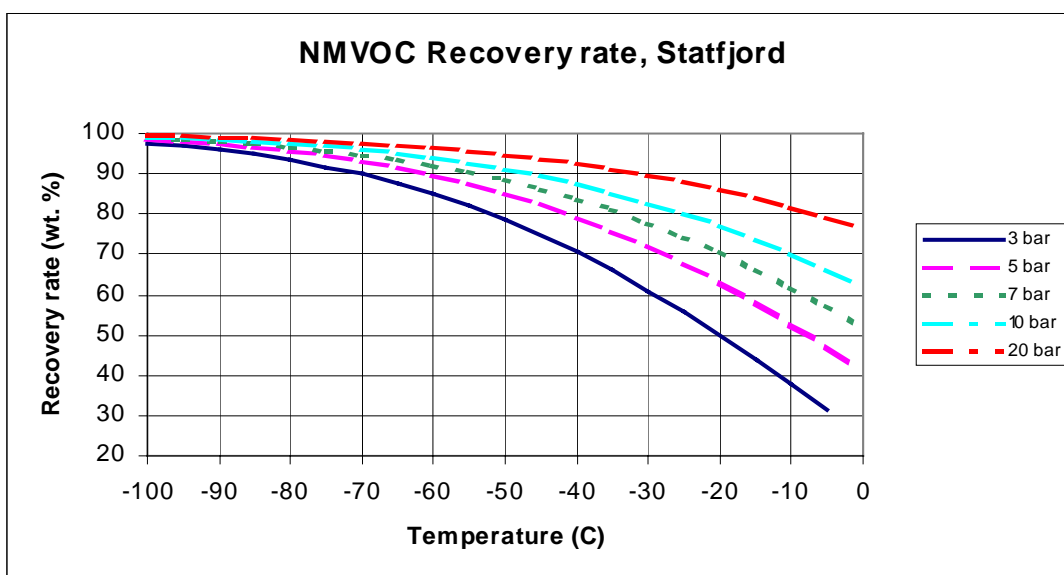
Accumulated NMVOC recovery as a function of end pressure and temperature, Statfjord

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2.2 Memo *Recondensation of VOC. Selection and design of heat exchangers for VOC condensation*

Different types of shell-and-tube and plate-frame heat exchangers have been evaluated for VOC recondensation. A plate heat exchanger may have blockage problems due to ice or hydrate formation, and most of the water will have to be removed if plate exchangers should be used. In a plate exchanger integral condensation will be achieved. This will also be the case for *tube*-side condensation in a shell-and-tube exchanger. The problem of blockage will not be as great for a shell-and-tube exchanger.

Maldistribution will be a problem for the second stage condenser, both for shell-and-tube and for traditional plate exchangers. The high temperature stage and the low temperature stage could be combined in one unit, and the VOC gas-inertgas mixture could flow continuously from inlet of high temperature stage to outlet of low temperature stage, removing the problem of maldistrubution. This could be achieved with the Barriquand Platular plate heat exchanger.

A rough approximation of the design of both shell-and-tube and plate-and-frame heat exchangers has been carried out. Both can be used to condense the VOC gas, but the effects of water should be studied more closely, especially for the plate exchanger where the risk of blockage is greater.

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2.3 Memo *Freeze out of CO₂. Process evaluation for NMVOC condensation*

2.3.1 Freeze out of CO₂

The CO_2 freezing point temperature is determined for eight different VOC compositions at different pressures. Four of the compositions are based on measurements of VOC emissions at Statfjord and Gullfaks A for different values of inert gas fractions (1-α) and the rest are correspondingly determined compositions in the remaining gas after condensation (cooling to –43 ^{0}C at VOC pressure 7.5 bar). It is found that the CO_2 freezing point basically depends on the α-value and it is also increasing with increasing pressure.
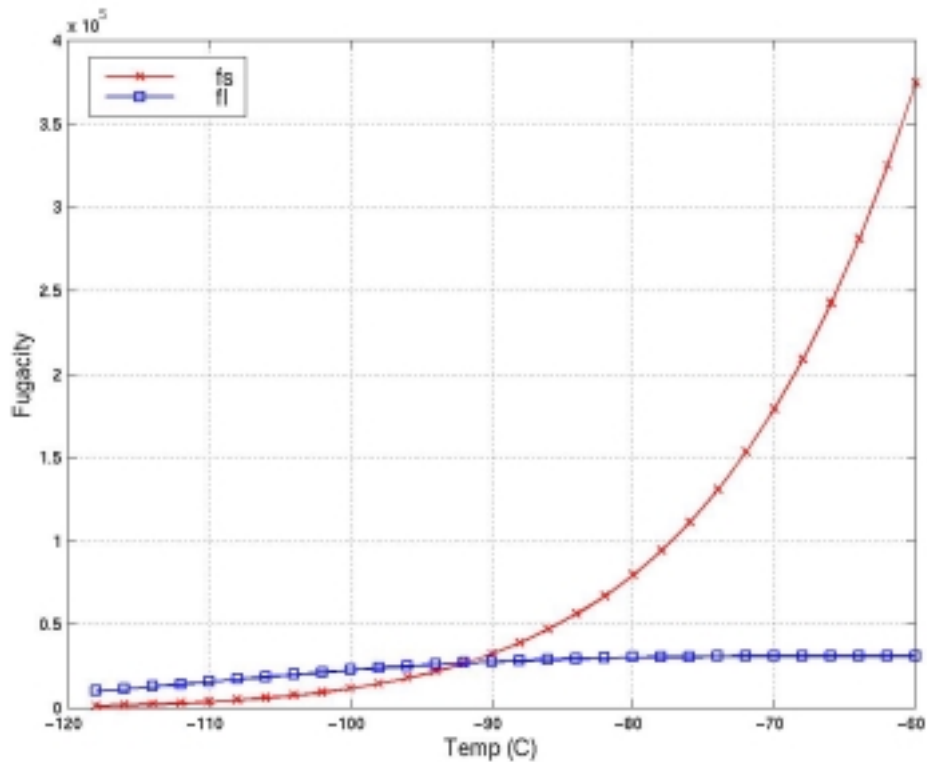
Solid phase fugacity (indicated by the red line) and liquid phase fugacity (indicated by the blue line) for CO₂ as functions of temperature. The temperature in the crossover point is the CO₂ freezing point

### 2.3.2 Process evaluation for NMVOC condensation

As base case, cooling to –43 ^{0}C and compression of VOC/inert gas to 7.5 bar is used.
A one-stage plant and a two-stage plant using propylene as refrigerant have been simulated. The compressor shaft power requirement is significantly reduced by using a two-stage plant. The effect on using an economizer in the one-stage plant gives a moderate reduction in power requirement. Using the cold in the condensate to reduce the refrigeration duty gives a significant reduction in power requirement for the refrigeration compressors.
For Statfjord VOC composition a simple one-stage plant recovers 75 wt.% NMVOC and a simple two-stage plant recovers 85 % at the same power requirement (cooling to –43 ^{0}C, VOC compression to 7.5 bar). Using R410A as refrigerant gives a reduction of 5-10 % in power requirement for the refrigeration plant.
By expanding the uncondensed gas to a temperature of –80 ^{0}C and using the cold in the gas and the condensate a recovery rate of 90 wt.% NMVOC may be obtained.
A two-stage plant using the cold in the condensate is recommended at this stage.
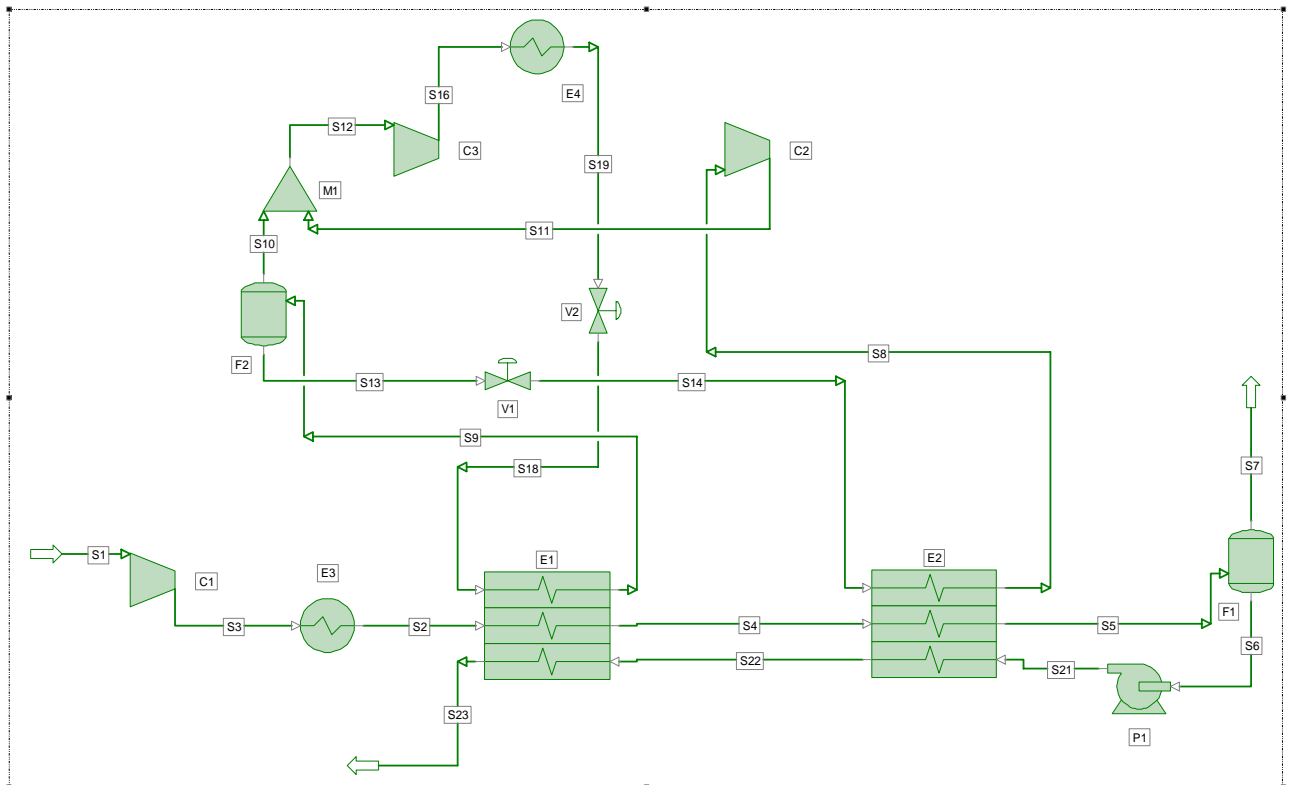
Two-stage refrigeration plant with use of cold in the condensate

2.4 Memo *NMVOC Recondensation – Case Study*

A study on the calculation and selection of a recondensation plant for the recovery of lost NMVOC vapour, based on simulation of crude oil loading operations using the software HCGAS, has been performed. The HCGAS calculations are performed by SINTEF Civil and Environmental Engineering and MARINTEK.
The process simulator PRO/II with Provision from SimSci has been used for the process calculations.
The requirement for the recovery plant is 75 wt. % of NMVOC recovery related to the emissions without the introduction of VOC control options.

For all calculations the VOC/inert gas mixture is assumed to be dry. In the cases were drying is necessary it might be of interest to remove water by compression, cooling and condensation. In such a case it will be natural to also remove some condensate at an intermediate temperature. This will give a few percent points lower recovery rate and a refrigeration duty somewhat lower than stated in this work.

Three cases with the combination of VOC control options, STTA loading, vapour return and recondensation have been addressed.

Case no.	Plant location	VOC application	Pump rate	Crude type
1	Shuttle	fuel	high	Statfjord C
2	FPSO	fuel	low/high	Statfjord C
3	FPSO	fuel	low/high	Gullfaks A

For Case 1, with Statfjord C crude type, STTA loading and no vapour return to the production unit requires cooling to about -20 ^{0}C at a pressure of about 7.0 bar to obtain a recovery of 75 wt. % NMVOC, related to the NMVOC emissions without any control options.

For Case 2, with Statfjord C crude type, STTA loading at shuttle tanker and vapour return to the FPSO, only cooling with sea water will be sufficient if the pressure of the vapour to the recovery unit is about 20 bar and the requirement for recovery is 75 wt.% NMVOC for the total system. In this case, drying of the gas may be avoided.

For Case 3, with Gullfaks A crude type, STTA loading at shuttle tanker and vapour return to the FPSO cooling to about –40 ^{0}C at 10 bar will be required to obtain a recovery of about 75 wt.% NMVOC.

For Case 2 and 3 the time for loading the FPSO will be dominant compared to the time for loading the shuttle tanker. During the period of loading the FPSO, loading rate and also the vented amount of VOC is lower. The conditions during the loading of the FPSO will be dimensioning for the recovery unit.
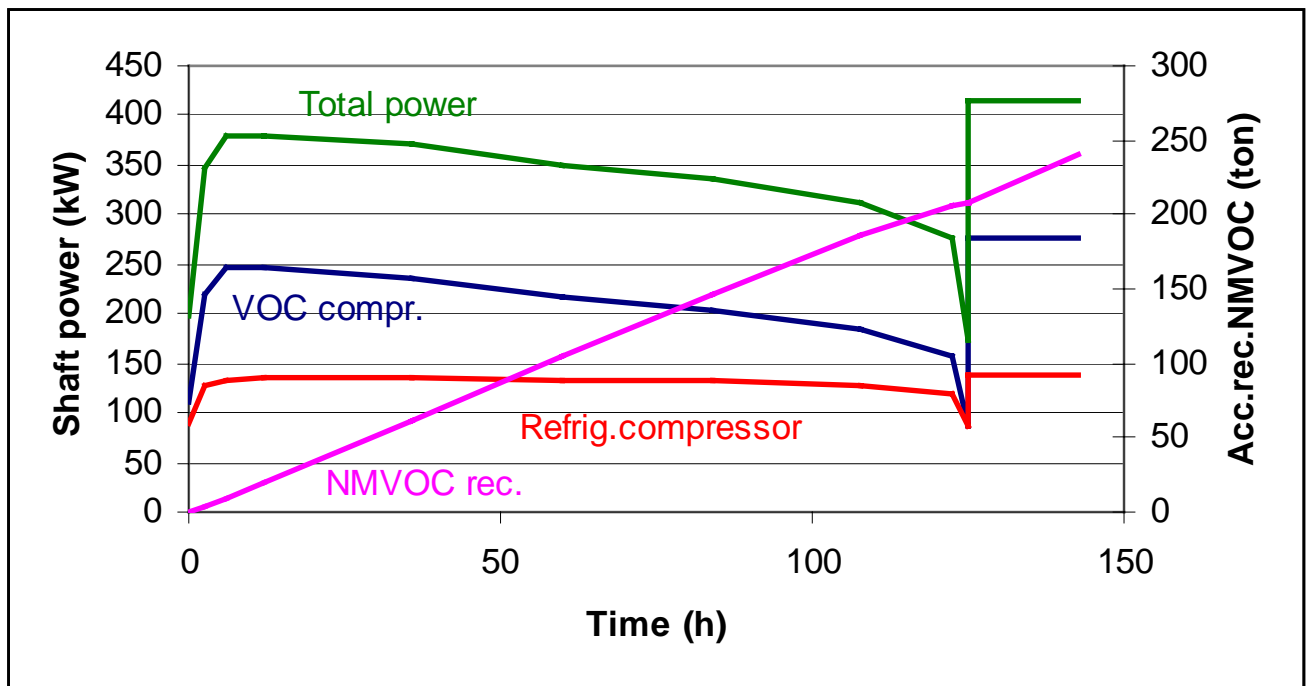
Power requirement and accumulated recovered NMVOC for case 3.

2.5   Report *Effects and measures related to water content in VOC/inert gas mixtures*

It is shown in the present report that the influence of ice- and hydrate formation on heat exchanger performance is considerably large. Thus operation of the recondensation plant without water treatment is not appropriate.

Different approaches for water treatment have been considered:

1. Separation of the water from the inert gas downstream the deck water seal in the inert gas production plant.

2. Partial water removal from the VOC/inert gas mixture by cooling to 5°C.

3. Dehydration using adsorption or absorption.

4. Methanol inhibition for ice/hydrate control.

Conclusions are made for the different approaches listed above:

- **Approach 1**.This is the preferred method for water removal, but it requires that the amount of water in the loaded oil is relatively small (For Statfjord oil the water content is approximately 0.07 wt.%) and that the entrainment of water in the VOC/inert gas mixture is not significant.

- **Approach 2**. This might be adequate in case of shell-and-tube heat exchangers and shell-side condensation, however, in case of plate-and-frame heat exchangers this kind of pre-treatment will be insufficient due to possible ice- and hydrate inlet blockage of the heat exchangers.

- **Approach 3.** These methods are common in case of gas drying. It is concluded that a system based on adsorption and regeneration by means of pressure difference (PSA) is recommended due to reasons as low dew-point temperature requirement, relatively small throughput and the fact that a glycol plant (absorption) might be difficult to control for highly varying compositions.

- **Approach 4.** This approach should be avoided due to too large amounts of inhibitor and unwanted consequences for the environment.

If water entrainment in the released VOC/inert gas mixture during loading is negligible, the best choice is separation of the water from the inert gas before entering the tanks. If the water entrainment is significant (dependent on the water content in the specific oil and liquid water presented in the storage tanks before loading), it is recommended to use an adsorber unit for drying of the released VOC/inert gas mixture.

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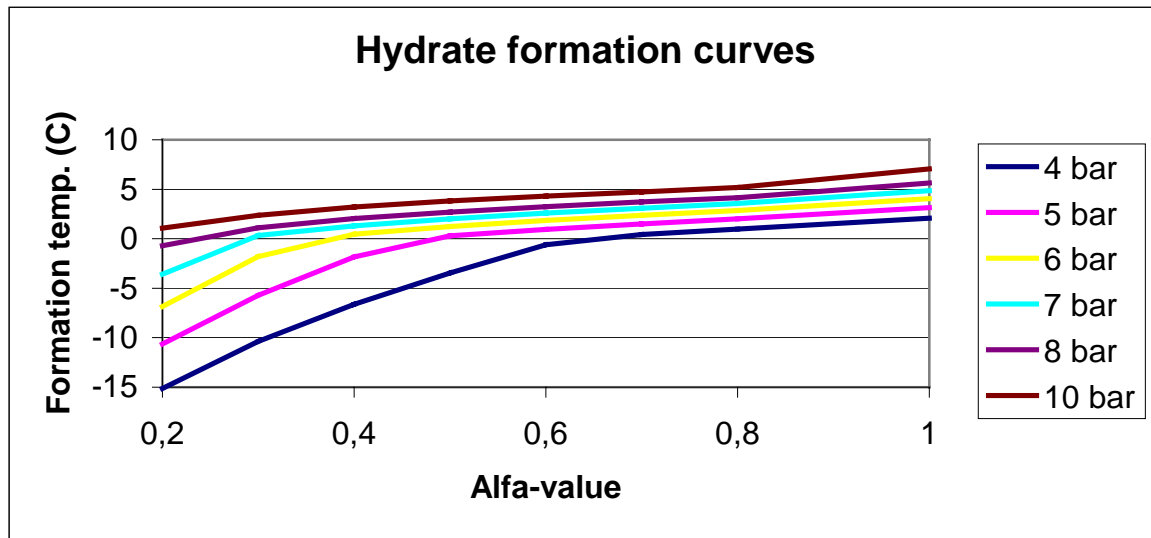
Hydrate formation temperature at different pressure levels as functions of α-values