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COMBINED TEST WITH THE IMPROVED PERFORMANCE TWISTER™ SUPERSONIC SEPARATOR AND THE GASUNIE CYCLONE SEPARATOR

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ABSTRACT

The Twister™ is a novel gas dew pointing device in which natural gas flows through a separation section at supersonic velocity. Due to the low static pressure and the resulting low temperature at these supersonic conditions, liquid formation occurs inside the Twister. Liquid droplets in the submicron range are separated from the gas stream in the Twister tube due to extremely high rotational forces (> 500,000 times gravitational acceleration).

An improved version of the Twister concept was tested in the Research Laboratory of Gasunie Engineering and Technology during October and November 2005 in a closed loop test facility using a multiphase pump. Advanced CFD models were used to improve the internal design of the Twister separator, leading to a new design with a reduced overall pressure drop. The most important aim of the experimental work was to verify CFD model calculations of pressure drop and liquid separation performance.

For this purpose a complete gas treatment facility was designed and built, consisting of a liquid injection and atomising section and a separator section, complete with quality measurement upstream and down stream of the Twister tube. A variable speed controlled multiphase pump with an after cooler was used to compensate for the pressure drop in the closed loop system. A compact Gasunie cyclone separator was used to handle the secondary gas stream of the Twister Tube. The test installation proved to work well during the experiments. In this paper the main test results with the improved performance Twister are presented and compared with design calculations. The separation performance of hydrocarbon components are described, showing the separation performance for the tested combination of the Gasunie cyclone separator and the Twister supersonic gas/liquid separator. From the measurement and model calculations, it will be concluded that the hydrocarbon recovery can meet the required C5+ recovery of 50%.

TABLE OF CONTENTS

Abstract

1. Introduction and problem description

2. Test objectives

3. Supersonic gas/liquid separator

4. Characteristic features

5. Comparison of separator types

6. Gasunie Closed Test Loop Facility

7. Improvement of the internal design

8. Hydrocarbon separation
   8.1. Performance of the Gasunie cyclone separator
   8.2. Hydrocarbon condensate recovery in the supersonic flow tube

9. Conclusions

References

List of Figures

1. Features and parts of the supersonic gas/liquid separator.
2. Droplet growth curve for n-nonane / methane mixtures in the laboratory of EUT.
3. Simplified Process Flow Diagram of the Multi Phase Closed Test Loop at Gasunie.
4. Calculated and measured pressure profile across the Twister flow tube.
5. Liquid catching performance of the standard Gasunie cyclone separator.
6. Hydrocarbon recovery measured and calculated in the supersonic separator.

1. Introduction and problem description

Twister B.V. has developed an improved performance supersonic separator for low pressure drop applications. To demonstrate the technical viability of this improved design concept, an experimental validation of the concept was performed in the Gasunie research laboratory in Groningen. At the start of testing in April 2005, the laboratory had an open test loop available for tests. In this configuration, natural gas from the high pressure grid flowed to the gas grid of the city Groningen. The maximum achievable capacity was depending on the gas demand of Groningen, which varied over the day and over the year. Earlier experiments in April and May 2005 demonstrated that the operational testing was limited as a result of the gas demand fluctuations.

In order to continue with the test programme, the test facility at Gasunie needed to be modified to find a solution for these operational limitations. The intention was to modify the facility in such a way that experiments were possible with maximum flexibility in operational conditions without being limited due to restrictions in the gas demand or gas quality. A closed multiphase test loop was proposed and has been developed. The results of a validation of the improved version of the supersonic flow tube in the multi phase test loop are presented in this article .

2. Test objectives

The test at Gasunie Engineering & Technology laboratory was part of the improved performance Twister development plan. The objective of the validation experiments were to determine answers to the following questions :

1. Is the measured temperature and pressure profile across the supersonic flow tube in accordance with the model calculations ?
2. Is the measured separation efficiency for hydrocarbons at 25 % pressure drop correctly predicted by the models ?

In gas conditioning processes, separation equipment is designed to remove produced liquids and to prevent carry over of liquids and solids into the system downstream. In many applications a combination of different separation techniques are used. During the testing in the Gasunie Engineering and Technology high pressure laboratory, the Twister supersonic separator was operated in combination with the Gasunie cyclone technology. The overall separation performance was therefore also dependent on the liquid catching performance of the Gasunie cyclone separator. In this paper attention is also paid to the measured and calculated separation performance of the Gasunie cyclone separator.

In the first part of the paper a general description is provided of the Twister separator. A comparison of the separation performance of a supersonic Twister separator and existing gas/liquid separators is made based on the critical liquid droplet size. The closed test loop facility that is used for the experimental validation of the supersonic and the cyclone gas/liquid separators is described. In the final section, test results are presented in relation to the objectives formulated in this paragraph.

3. Supersonic gas/liquid separator

The Twister tube is a new type of gas/liquid separator which operates at supersonic flow conditions. The separator entails a converging-diverging flow tube with a centre body creating an annular flow passage. Due to its shape the flow is expanded through a constriction to supersonic velocity. Via a flow splitter, the liquids are separated from the dried gas stream.

In figure 1 the parts of the Twister tube are shown: (1) the expansion section, (2) the separator section and (3) the pressure recovery in the outlet.

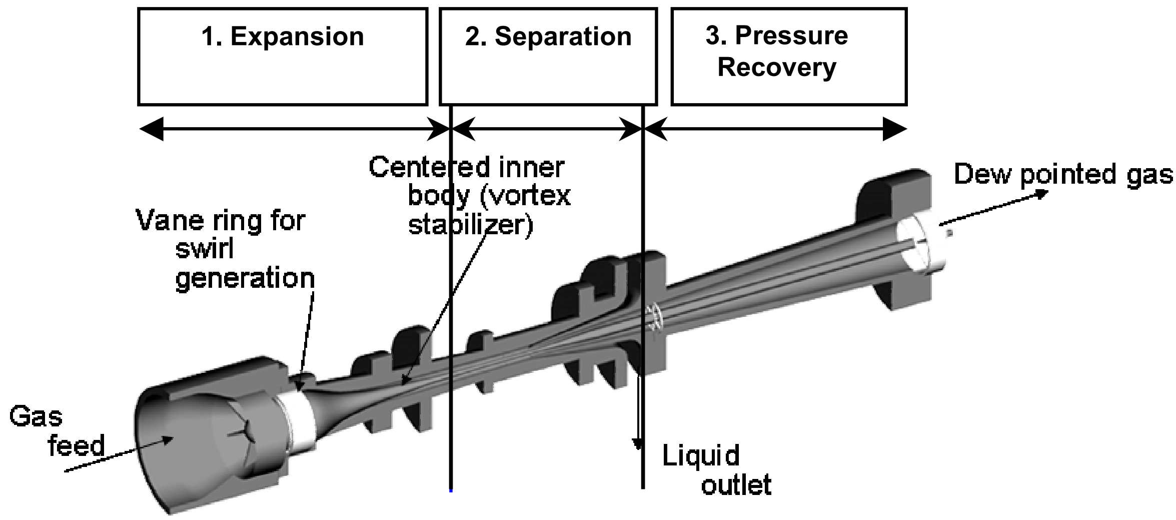

Figure 1: Features and parts of the supersonic gas/liquid separator.

In the expansion section of the Twister tube a pressure and temperature reduction is achieved by transforming potential energy (total pressure) into kinetic energy. Due to the geometry of the expansion section (Laval nozzle) the saturated natural gas is accelerated to supersonic flow conditions. Mist of condensate and water droplets will be formed. A vane ring at the entrance of the Twister tube will generate a swirl in the gas stream with high rotational forces, centrifuging the liquid droplets to the wall of the separation part. At the end of the separation part a vortex finder flow splitter is installed to separate the liquids from the dried gas stream. In the diffuser part of the tube the gas velocity is partly converted into static pressure.

4. Characteristic features

A supercritical expansion occurs in the Twister tube which leads to characteristics features:

1. High gas velocity in the inner body with Mach number Ma > 1.
2. Low temperatures resulting in condensation of C2+ vapours.
3. High rotational forces in the separation part with a typical acceleration in the range up to 500.000 g.
4. Separation of liquid droplets in the submicron range.

Comparison to conventional gas conditioning technologies
In conventional gas treatment processes a Joule – Thomson valve is used to achieve an isenthalpic pressure and temperature reduction. When the Joule – Thomson valve is replaced by a supersonic nozzle as used in the Twister tube, a near isentropic expansion is established, resulting in 10 – 20 % less compressor power compared to plants using a Joule-Thomson valve. The supersonic gas/liquid separator in these processes can be installed as in line separator with a compact design. The inlet gas stream is split into a dry primary gas stream leaving the outlet of the Twister tube and a liquid enriched

secondary stream. The mass flow rate of secondary gas stream is about 30 % of the inlet gas flow rate. Due to this limited flow rate the size of the secondary cyclone separator can be reduced.

5. Comparison of separator types

A comparison of separation properties of different separator types are presented in the overview below. The critical droplet size of existing and new types of separators are mentioned, showing the improvement of the separation performance for small liquid droplets in the submicron range for the supersonic gas/liquid separator.

Comparison of critical droplet size of different type of separators:

- Liquid catcher : 30 – 50 micron.
- Siphon : 30 – 50 micron.
- Cyclone separator : 4 – 20 micron.
- Supersonic gas/liquid separator : 0,5 – 1 micron.

Kinetic studies of nucleation and liquid droplet growth in Natural gases at high pressure have been executed in Eindhoven University of Technology (EUT) laboratories. In cooperation with Gasunie Engineering and Technology, drop wise condensation out of a supersaturated vapour was initially studied for binary hydrocarbon mixtures [2]. Experimental, homogeneous nucleation and droplet growth were investigated using a pulse-expansion wave tube, a facility which was developed for in situ measurements of vapour fractions. A typical example of the droplet growth curve for a binary mixture of n-nonane / methane is presented in figure 2.

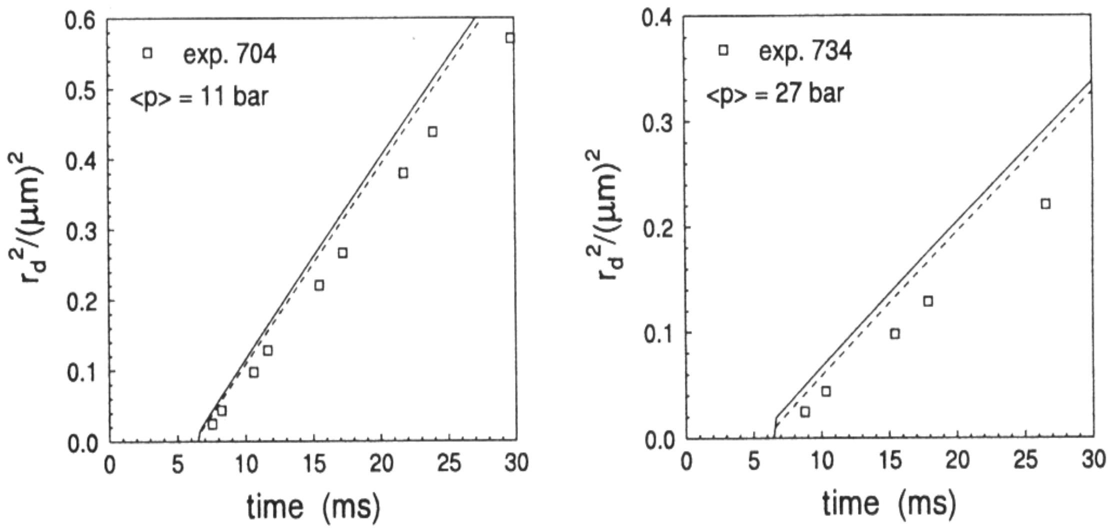

Figure 2 : Droplet growth curve for n-nonane / methane mixture measured in the laboratory of EUT [2].

The saturation vapour density and the surface tension are essential parameters in any nucleation model. It can be concluded from the EUT measurements and model calculations that:

- The initial droplet size due to nucleation is very small, and the droplet size is in the submicron range 0.1 – 0.5 micron. Measured values of the liquid droplet radius r_d are presented in figure 2.
- Nucleation and droplet growth is a fast process with a typical time schedule of milliseconds. For conventional separation technologies the calculated and measured droplet size is too small for a good separation.

Droplets in the submicron range can be separated in the Twister tube due to the high acceleration rates that are achieved in the separation section. The separated liquids will be transported to the wall of the flow tube due to these rotational forces and the secondary stream (enriched with liquids) is separated from the primary gas stream in the central part of the flow tube. An essential part of the gas treatment process is the secondary cyclone separator in which the enriched gas/liquid stream of the supersonic flow tube is split up. The secondary gas stream is transferred downstream and is mixed with the primary gas of the supersonic flow tube.

An experimental set up in the Gasunie Engineering and Technology laboratory was operated to determine the separation efficiency of Twister on dispersed liquids resulting from condensation out of high pressure Natural gas. The set up of these experiments are described in the next paragraph.

6. Gasunie Closed Test Loop Facility

To demonstrate the technical viability of the supersonic separator concept, tests were executed at Gasunie Engineering and Technology laboratory in Groningen. The tests were carried out in a closed test loop facility using a twin screw multi-phase pump to recompress the gas stream. Objective of the research activities is to verify model calculations of pressure drop and separation efficiency via experimentations. For this purpose a complete gas treatment facility was designed and built in the laboratory, consisting of a liquid injection section and a separator section with quality monitoring.

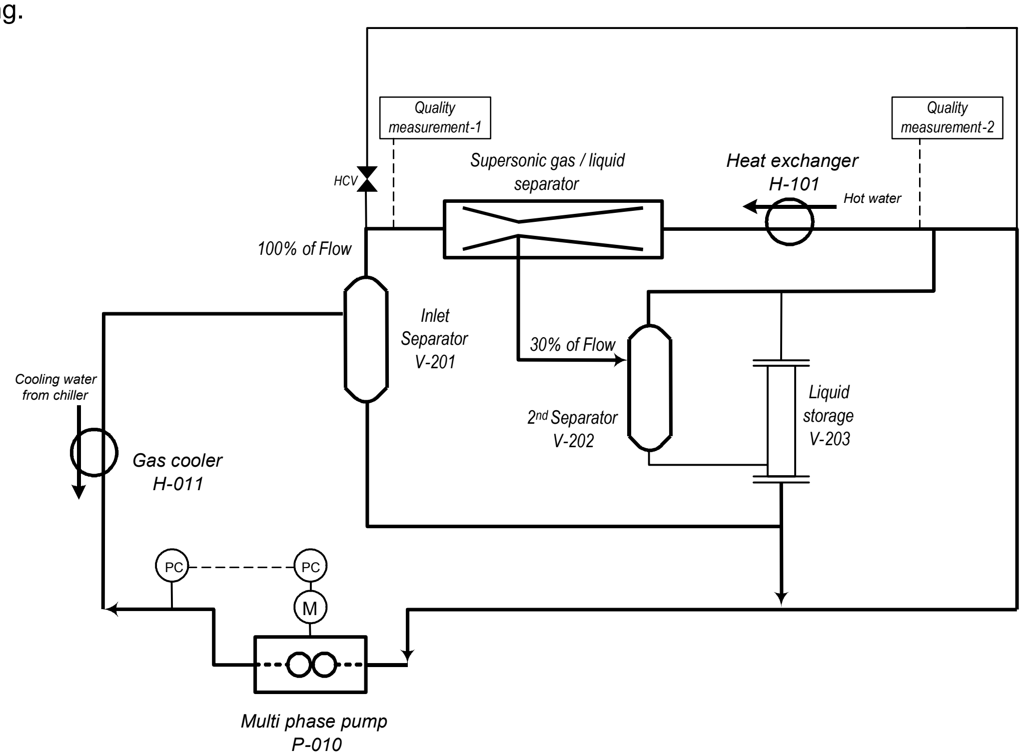

Figure 3: Simplified Process Flow Diagram showing the Multi Phase Closed Test Loop at Gasunie.

A variable speed controlled multiphase pump with after cooler were used to compensate for the pressure drop in the closed loop system. A compact Gasunie cyclone separator was used to handle the secondary gas stream of the Twister Tube.

As commonly encountered in treatment processes, an inlet separator was installed upstream to separate the bulk of liquids and to avoid damage of the rotational part of the flow tube. During the experiments in the laboratory two different Gasunie cyclone separators were installed:

1. An inlet separator upstream of the Twister Tube designed for 100% of the gas flow rate (V-201).
2. A secondary cyclone separator with a limited size to separate liquids from the enriched secondary stream designed for 30% of the gas flow rate (V-202).

Experimental conditions during the experiments are summarized below :

Gas flow rate in the range	: 10.000 – 15.000 m^3(n)/h.
Outlet Gas pressure of the multi phase pomp	: 26 – 36 bar(a).
Inlet pressure of the multi phase pump	: 19 – 25 bar(a)
Gas temperature after gas cooler	: 17 – 30 °C.

Additionally high pressure liquid injection facilities for water, condensate and/or n-pentane were installed to increase the feed concentration of higher hydrocarbon vapours and of water vapour in the inlet gas stream of the Twister separator. The minimum outlet temperature of the gas cooler was set at 17 °C. During the design of the test facility much attention was paid to safety aspects such as the pressure and temperature protection of the system. During the safety study (HAZOP and R&EI analyses) attention was given to noise measurements, the vibration and pulsation risk, including validation measurements. The test installation was shown to work well during the commissioning/start up and during the experiments.

7. Improvement of the internal design

In this paragraph the results are presented to compare calculated and measured pressure and temperature profiles along the Twister Tube. Calculations of the pressure profile across the Twister flow tube were executed using Computational Fluid Dynamics calculations (CFD). Based on CFD-calculations the internal design of the supersonic separator was improved as follows:

1. The geometrical design of the inner body was optimised.
2. The location of the rotational element was transferred downstream.

The calculated pressure profile of the improved performance Twister design is presented in figure 4 below and compared with the measured pressures.

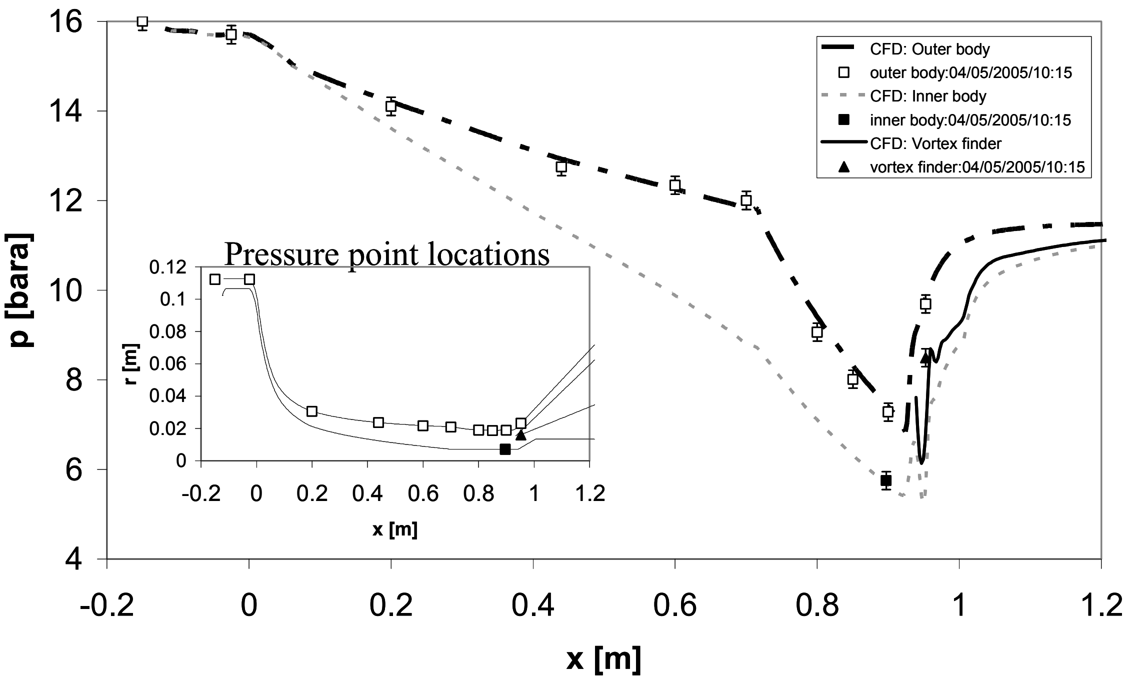

Figure 4: Calculated and measured pressure profile across the Twister flow tube.

Conclusions drawn on the basis of pressure measurements at Gasunie Engineering & Technology :

- The overall pressure loss across the Twister is reduced to 25 – 27% of the feed pressure. The overall pressure loss is therefore significantly reduced compared to the previous Twister concept (33% of feed pressure).
- Model calculations and measurements of the pressure profile along the Twister tube are in good correspondence with each other if the accuracy of the measurement is considered.
- The expansion ratio and therefore condensed liquid mass fractions are predicted sufficiently accurate using advanced CFD model simulations.

8. Hydrocarbon separation

The pressurized gas stream including the non evaporated liquids leaving the gas cooler H-011 are fed into an inlet cyclone separator with internal diameter of 375 mm. In the multiphase pump hydrocarbons and water will evaporate at normal operating conditions. The liquids that will condense in the gas cooler are separated from the gas stream in the inlet separator. Measured and calculated separation performance data of the cyclone separators used in the multiphase test loop are described in the next paragraph.

8.1 Performance of the Gasunie cyclone separator

The method to determine the liquid catching efficiency (i.e. liquid separation efficiency) of the Gasunie cyclone inlet separator, independently from the Twister supersonic separator, is described in detail in reference [3]. Results of the liquid catching efficiency are presented in figures 4 were the catching efficiency is plotted against the superficial velocity in the separator vessel. Information of the inlet separator is :

- Internal vessel diameter of the Gasunie cyclone separator : 375 mm
- Sizing of inlet and outlet piping : 6 Inch
- Internal type : GU mono cyclone (internal type-2)
- Operating pressure : 26 – 36 bar(a)
- Operating temperature : 17 °C
- Type of liquid used during performance measurements : Tri Ethylene Glycol
- Liquid droplet size during performance measurements : 30 and 50 micron

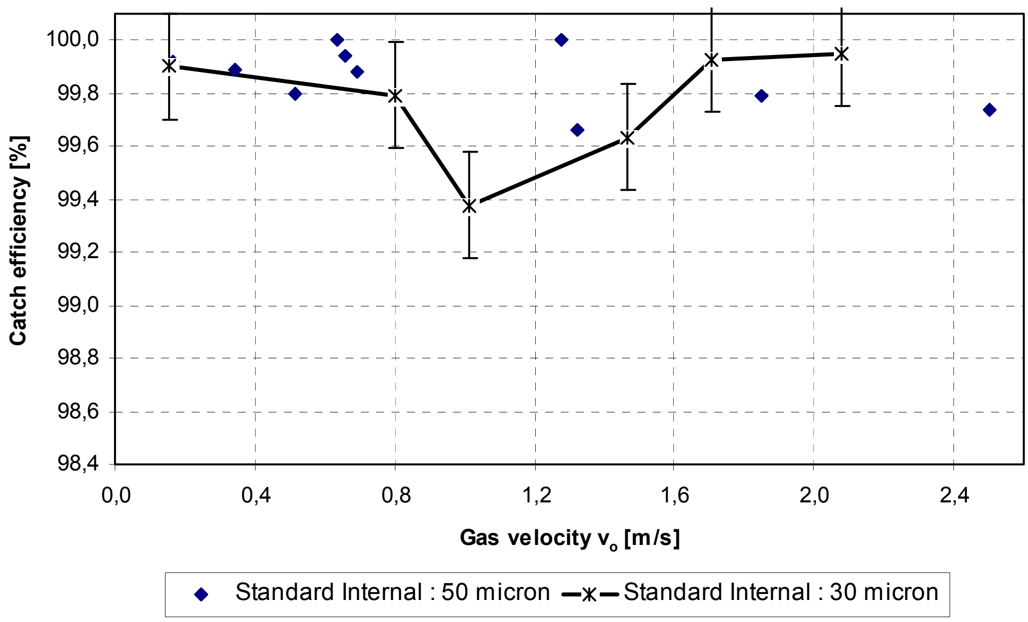

Figure 5 : Liquid catching performance of the standard Gasunie cyclone separator [2].

Uncertainty of the liquid catching efficiency

The used definition of liquid catching efficiency is:

$\eta_{sep,liquid} = \dfrac{L_2}{L_2 + L_3}$ where L_2 is the separated liquid by the cyclone and L_3 is the total mass flow rate of liquid carry over that is separated downstreams .The uncertainty of the liquid catching efficiency is mainly determined by the uncertainty in the carry over L_3 resulting in an uncertainty in the liquid catch efficiency of ± 0.3% for the 30 μm droplets and ± 0.2% for the 50 μm droplets.

For all the experiments the mass imbalances between liquid input and output were carefully checked. To improve the readability of figure 5 the uncertainty bars are not shown for each curve but for the 30 micron curve only.

To determine a reliable carry over, it is of major importance that a minimum amount of liquid will leave the system by evaporation. For this reason tri-ethylene glycol is chosen as a liquid to perform these measurements. From process calculations with PRO-II it is concluded that the liquid loss due to evaporation of tri-ethylene glycol is negligible. A conclusion drawn from figure 5 is that there is no significantly difference in catching efficiency between the measurements at 50 micron and 30 micron droplet size within the measurement inaccuracy.

The liquids mainly produced in the supersonic flow tube are fed together with 35 % slip gas to a secondary separator (V-202). The separated liquids of the separator V-202 are dumped into a liquid storage vessel with an increased liquid storage capacity (V-203). The treated gas of the separator V-202 is mixed with the dry gas produced by the supersonic tube. Most important characteristics of the secondary separator V-202 :

- Internal vessel diameter of the Gasunie cyclone separator : 200 mm
- Sizing of inlet and outlet piping : 2 Inch
- Internal type : GU mono cyclone (internal type-2)

Based on the performance measurement mentioned in figure 5, a calculation model for the critical liquid droplet size of the Gasunie cyclone separator is validated. With this validated model calculations are made to determine the performance of the secondary cyclone separator V-202 using the process conditions as encountered during the experiments. The results of these calculations are presented in the overview below.

Critical droplet size for hydrocarbons and water calculated for the Gasunie cyclone separator 2”/200 mm at 24 bar(a) and a gas temperature of 25 °C :
- Gas flow rate 5400 m^3(n)/hr : d_{98}-value 5 – 7 micron.
- Gas flow rate 10800 m^3(n)/h : d_{98}-value 4 – 5 micron.

The calculated parameter indicated as d_{98} value is the critical liquid droplet size separated in the cyclone with an efficiency of 98%.

8.2 Hydrocarbon condensate recovery in the supersonic flow tube

After separation of the liquids in the inlet separator (i.e Gasunie cyclone separator), the saturated gas stream enters the improved performance Twister supersonic separator. This supersonic operated device is capable to suppress the hydrocarbon dew point of the gas. The hydrocarbon dew point is largely effected by the concentration of the heavy hydrocarbon components in the gas stream. Two gas chromatographs (GC) are installed to determine the hydrocarbon condensate recovery of the Twister tube. These GC’s were installed:

1. At the inlet of the supersonic flow tube downstream of the inlet cyclone separator.
2. In the primary gas outlet stream on the outlet of the supersonic separator downstreams of a heat exchanger H-101. If there is liquid carry over from the supersonic flow tube, the liquid is evaporated in this heat exchanger.

Because the inlet stream and primary outlet stream are in the gaseous phase, the hydrocarbon condensate recovery is a better performance measure than the traditional liquid separation/catching efficiency. The hydrocarbon condensate recovery (η_{rec}) of a specific component (i) is defined as:

$$\eta_{rec,i} = \left[1 - \frac{y_{i,out}}{y_{i,in}}\right] \cong \frac{x_{i,mid}}{y_{i,in}} . \eta_{sep,liquid}$$

In this definition y_i is the vapour fraction of component (i) and x_i the liquid fraction of component (i), whereby the subscripts (in), (out) and (mid) denote respectively: inlet, primary outlet and mid Twister tube conditions. The traditional liquid separation efficiency ($\eta_{sep.liquid}$) was already defined in paragraph 9.1 (page 10)

Both gas chromatographs determine the hydrocarbon concentration in the gas phase for the components C_1 to C_9. Based on the GC measurements the recovery of the hydrocarbon components in the supersonic flow tube is determined using the following parameters :

- Recovery of the concentration of C_5 and higher components (C_5+).
- Recovery of the concentration of C_6 and higher hydrocarbon components (C_6+).

The hydrocarbon recovery of the components C_1 to C_6 measured during the experiments with the multiphase test loop and the calculated values using HYSIS simulations are presented in figure 6. From the data the recovery factor for C_5 + and of C_6+ is calculated.

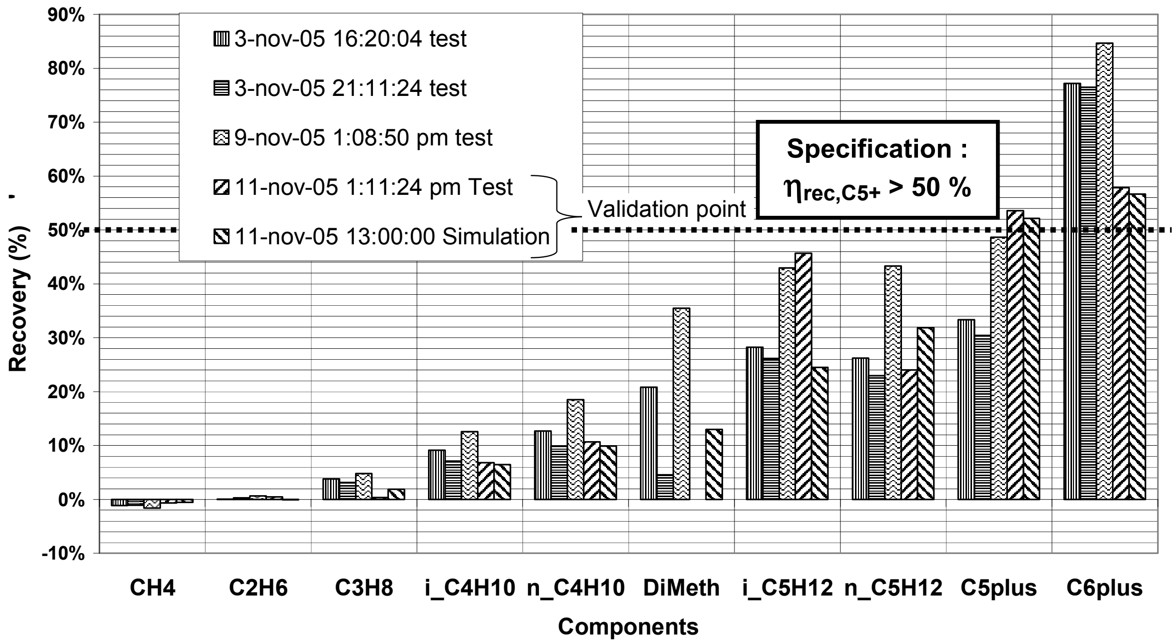

Figure 6 : Hydrocarbon recovery measured and calculated in the supersonic separator.

As expected, the results presented in figure 6 show an increase of the hydrocarbon recovery with carbon number. For the C_5 plus fraction and for the C_6 plus fraction the measured recovery exceeds 50%, which is the required specification for the current project. The measured values for the hydrocarbon concentration of the C_5 and C_6 components were in good agreement with the design calculations performed with the process simulation software HYSYS in combinations with CFD models.

9. Conclusions

Two major improvements in the Twister™ technology have resulted in a reduction of the pressure loss of the improved performance Twister, compared to the previous Twister concept, whilst maintaining a high efficiency on hydrocarbon recovery. These two being:

- Use of advanced multiphase flow models (CFD) for determining the flow path design of the Twister tube.
- The conceptual change to induce the swirling motion at the entrance of the Twister tube using a vane ring.

These experimental results were obtained by extensive use of a specially designed closed test loop facility at the laboratory facilities of Gasunie Engineering & Technology. This facility allowed for endured testing at different feed temperatures, pressures and compositions.

A hydrocarbon vapour recovery for C5+ of at least 50% is achievable with the improved performance Twister Supersonic Separator in combination with a Gasunie cyclone separator. This is a significant improvement over a conventional Joule-Thompson process operating in the same envelope. Therefore the combination of an improved Twister supersonic separator and Gasunie cyclone separator meets the targeted specification for the hydrocarbon separation efficiency.

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