



# Solution for the **HIGH SEAS**

**C**ompared to other primary energy sources such as petroleum, coal or nuclear power, natural gas is readily available and relatively clean. Demand for it has, therefore, increased significantly in the past few decades. While petroleum demand has increased by only 66% since 1970, the figure for natural gas exceeds 216%. In many markets, gas is still undervalued compared to oil, despite the fact that this fuel has great potential in the transport sector, e.g. to power ships or transport goods by road. Experts thus expect further substantial growth in gas demand. The role played by LNG is an increasingly important one: 30% of global gas imports already make use of this product form. Growth in this sector increased by 46% in the decade from 2001 to 2010, and for the current decade predictions even reach 56% by 2020. This development is particularly pronounced in the Middle East, driven by Qatar and Yemen.

Beginning in 2014/2015, LNG projects are expected to start production in Australia. In the future, Russia, the US (with its shale gas deposits), West Africa and East Africa could also contribute to supplies. There is still enormous

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potential in the field of unconventional gas resources, for which marketing in the form of LNG is also possible. According to an overview by Kawata & Fujita<sup>1</sup>, these unconventional sources constitute 90% of the existing reserves in many areas of the world, including Asia, Australasia, Latin America, North America and Western Europe.

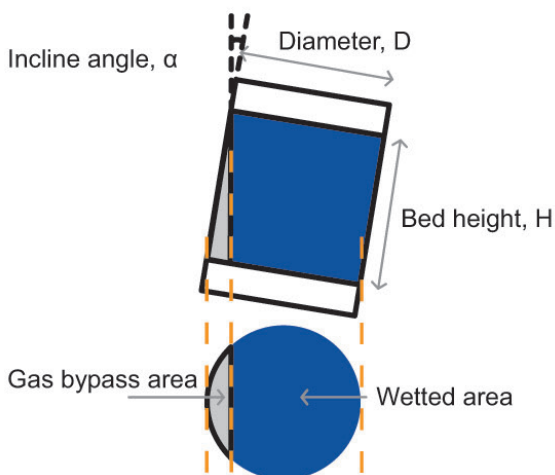
## Growing importance of floating production systems

Many new gas reserves have been discovered offshore in recent years, which explains the growing importance of floating production systems. There are a number of good reasons for this development. Compared to onshore plants, these systems are cost-effective, have short delivery times, are readily constructed and can be used as seasonal or temporary solutions. Since the gas fields often lie far from coastal regions, laying pipelines to onshore stations is, at the very least, a demanding task with a price tag to match, and may even prove technically unfeasible. For remote sites in particular, production platforms on ships that can handle both preconditioning and liquefaction of the gas would seem to be a ready-made

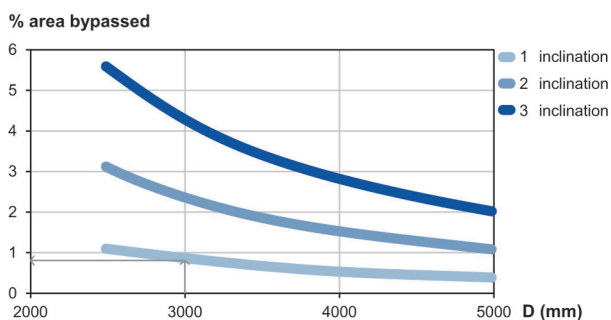
solution. Combined production and liquefaction may even have cost advantages over comparable onshore plants. According to current perceptions, key regions for such 'combination ships', which are even larger than aircraft carriers (the ones in the US Navy, for example, are 'only' 317 m long), would be mainly Australia and Papua New Guinea, and to a lesser extent Southeast Asia, Brazil, Canada and West Africa. The first commercial project off Australia's north coast is Shell's Prelude project, with a ship 488 m long.

An essential intermediate step in gas treatment, between extraction from the wellhead and liquefaction of the gas, is acid gas removal. This is required as natural gas is always contaminated with acid gases, in particular carbon dioxide (CO<sub>2</sub>) and hydrogen sulfide (H<sub>2</sub>S). Whereas pipeline gas may still contain molar traces of CO<sub>2</sub>, LNG must be practically free of CO<sub>2</sub> so as not to interfere with the cryogenic liquefaction process. CO<sub>2</sub> is critical because it freezes out and clogs the liquefaction units, ultimately leading to system failure. The threshold concentration for CO<sub>2</sub> prior to liquefaction must therefore be below 50 ppm. BASF has gained considerable experience with its acid gas removal process based on the OASE absorption solvent. Treatment plants using the OASE technology have now been realised in approximately 400 projects worldwide.

Generally speaking, however, no offshore extraction and liquefaction systems that include acid gas removal have actually been implemented on floating vessels to date. The initial idea was to accommodate such facilities on small ships. Studies have demonstrated, however, that the influence of the water's motions on the apparatus is not predictable or controllable. Experts are therefore currently considering ships in the medium-to-large range, as seen in Shell's Prelude project. Solutions realised on the high seas also have a reduced environmental impact, since the entire onshore civil engineering aspect, requiring considerable tracts of land, does not apply there. This is also an important argument in favour of floating LNG (FLNG). In addition, the level of inherent security is higher offshore. Shipyard conversion of production and liquefaction ships for new projects has also been considered as a possibility once a given gas field is exhausted.



**Figure 1.** Influence of column inclination on wetting of internals.



**Figure 2.** The gas bypass area is dependent on the column diameter and the inclination angle.

## Acid gas removal under offshore conditions

BASF recognised the central importance of the effect of the motions of the sea, and hence of the ship's motion, for instance on the acid gas removal unit (AGRU). For this purpose, absorption columns are used, through which the gas to be scrubbed flows from bottom to top and is brought into contact with the acid gas removal solution, or 'scrubbing liquid', in countercurrent flow. Several types of internals for enhancing the mass transfer are conceivable. These include a variety of column trays and packed beds with random packing or structured packings. An initial result of BASF's research was the insight that the structured packings produced the best results, because they not only facilitate intensive mass transfer between gas and scrubbing liquid, but in particular increase the level of operational reliability. This result is in accordance with

literature.<sup>2,3</sup> Five years ago, BASF began process impact investigations of the inclination of the column due to the motions of the sea. Ultimately, this approach addresses the key issue in the performance of the acid gas removal process under specific offshore conditions.

BASF has demonstrated undesirable effects as a function of the parameters column height, column diameter and motion data such as column inclination, whereby areas at the edges of the column are no longer wetted with scrubbing liquid and are left dry (see Figure 1). No mass transfer takes place here, with consequences for the CO<sub>2</sub> content of the gas. A simple example illustrates this behaviour. Consider a gas with a CO<sub>2</sub> content of 5%. Assuming a bed height of 5 m, a bed diameter of 3 m and a column tilt of only 1° produces the following result: even if more than 99% of the available space is thoroughly wetted, ideally resulting in a CO<sub>2</sub> content of zero on the wetted part, a 'dry' surface area of only 0.83% is sufficient to produce 415 ppm CO<sub>2</sub> in the treated gas, well above the 50 ppm threshold (see Figure 2).

Once the CO<sub>2</sub> concentration is above 100 ppm, the CO<sub>2</sub> sublimates to the cryogenic heat exchangers and brings the liquefaction to a halt. Operation on this basis is therefore not tolerable, because the dry ice that forms significantly impairs the capacity of the cooling systems, resulting in major problems. Greater column height and additional inclination increase the described effects, leading to further deterioration of the CO<sub>2</sub> washout. In each case, the calculations show that even minor maldistributions of the liquid impact the result significantly. BASF has also detected this using a computational fluid dynamics (CFD) model.

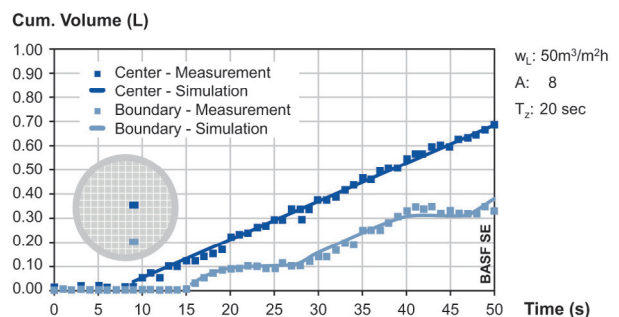
## Simulating offshore conditions via CFD model

The CFD model was created to describe the effect of static tilt and dynamic motion of the FLNG vessel on the flow of liquid in the column. Sufficient contact between gas and liquid is essential to the design of absorption columns as described above. The inertial effects of the liquid were included in the model. They can only be neglected to the extent the force of gravity predominates, which is normally the case at average acceleration levels. However, the inertial effect increases with higher acceleration due to the more pronounced movement of the column or its increase in height. Under typical operating conditions, the liquid flow is controlled primarily by gravity, whereas the gas flow depends on the pressure difference. Therefore, the primary effect of column inclination is on the liquid flow.

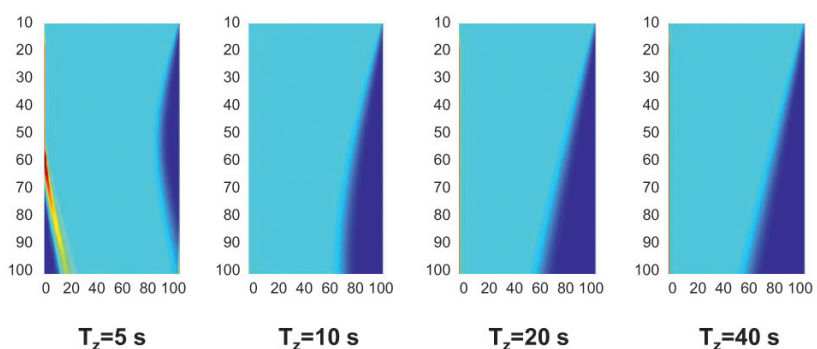
The CFD model has been validated experimentally. In cooperation with a partner, hydraulic tests were carried out on a real column, whereby the settings could be varied between static and dynamic inclination. The test rig consisted of a column with a diameter of 1 m and a bed height of up to 4.4 m. The column was either continuously or

periodically inclined at an angle of up to 10°. A measuring device was installed at the bottom of the column, capable of detecting the distribution of liquid flow depending on the experimental conditions. For this purpose, a large number of small measuring cells were placed under the column to detect the liquid-gas distribution at different loads. This facilitated confirmation of segments with scrubbing intensity greater than 100%, as well as segments with a significantly below-average transfer between gas and scrubbing liquid.

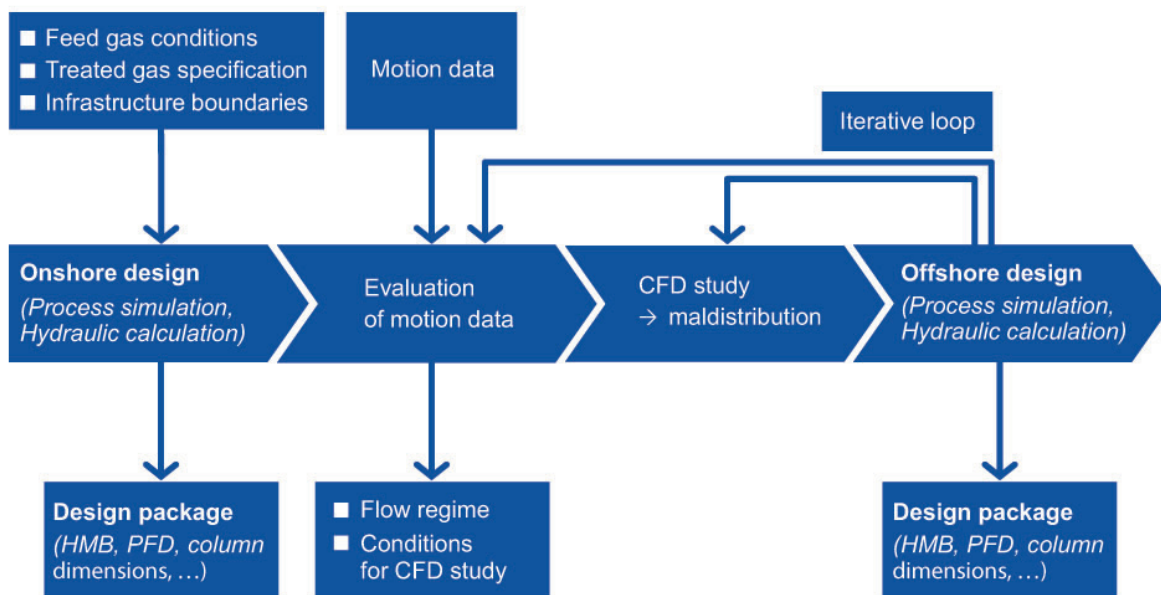
The experiments were carried out for a wide range of motion parameters. The period time, the inclination angle and the hydraulic load were varied, with data records selected to represent the most common sea swell conditions. The CFD model was set independently of the experiments, that is to say the results of the experiments were only used to validate the model. The experimental and simulated data for local distribution of liquid flow on the bottom of the column were compared for an extreme inclination of ± 10° and a period time (T<sub>z</sub>) of 20 sec. (see Figure 3). The experiments are indicated by dots, the simulated results by solid lines. The comparison reveals a close correlation between experiment and simulation. Similar levels of correlation were determined for other motion conditions, as long as the assumptions made for the CFD model were not violated.



**Figure 3.** Comparison of experimental and simulated data for local distribution of liquid flow on the bottom of the column.



**Figure 4.** Influence of the period time on the liquid maldistribution (column height = 2.2 m, column diameter = 1 m, oscillation = +/- 8°).



**Figure 5.** Marination procedure from onshore to offshore design.

## Robust design for marine conditions

BASF researchers have also studied the influence of the bed height of the internals in the column. It is apparently beneficial to install a larger number of beds, since multiple beds compensate the motions of the ship more harmoniously. To minimise maldistribution of the scrubbing liquid (e.g. due to trickling or the wall effect, and especially due to motion), it is important to install a liquid collector and redistributor once a certain bed height is reached. This restores even distribution of liquid over the underlying bed. This redistribution principle is even more important in the FLNG process than in fixed columns, due to the larger maldistribution factor. This is why the standard distributor needs to be replaced by a special redistributor for the floating application.

Maldistribution also depends on the oscillation period, increasing as the periods grow longer, e.g. with an increase of 5/10 sec. to 20 sec. Therefore, the period time was varied in the CFD tests, while all other parameters were kept constant. With short periodicity, the liquid distribution is observed to be highly dynamic. However, with longer periods, the liquid in the column oscillates as a solid block, similar to a pendulum. This results in an increasing bypass for the gas, through which it can travel without contacting the scrubbing liquid (see Figure 4).

Thanks to experience with gas scrubbing and extensive studies of the behaviour of the AGRU with FLNG, BASF can offer a robust design for such cases. However, optimal design in any given case depends on many factors, which all influence the heat and mass transfer: sea motion conditions, the position of the AGRU on the moving vessel, the geometry of the column (height and diameter of beds), the number of beds, and the feed gas conditions. Of particular importance is the redistribution of the scrubbing liquid, which interrupts the bed-to-bed maldistribution. Investigations by BASF have

shown that acid gas removal is also feasible under marine conditions, if careful attention is paid to the determining factors. The path to optimal design begins with development of the corresponding onshore plant, including process simulation and hydraulic calculation. The subsequent marination procedure covers the evaluation of the relevant motions and CFD studies for calculation of maldistribution of the scrubbing liquid under the prevailing conditions. The offshore plant, and the design of its components, can then be derived from this approach (see Figure 5).

## Conclusion

Currently, three projects are vying for the privilege of putting the first FLNG plant into operation. In addition to the aforementioned Shell project in Australia's Browse Basin, there is the Exmar and Pacific Rubiales Energy project in the Caribbean, as well as the Petronas project in the Kanowit gas field, Malaysia. Development of FLNG has doubtless gained momentum, and BASF is well equipped to master the resulting tasks in the field of acid gas removal. **LNG**

## References

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