HIGH LEVEL ANALYSIS OF CO_2 CAPTURE ON LNG FUELLED SHIPS

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Abstract

Recently, there has been an increased level of interest from the maritime sector towards ship based carbon capture (SBCC) as a way to achieve at least 50% emission reduction by 2050. The SBCC technology works especially well when integrated on LNG fuelled ships, which drastically reduces the variable OPEX of the system. This study considers the integration of a CO_2 capture, liquefaction and temporary on-board storage plant on a hypothetical LNG fuelled ship. It is found that by heat integration of the exhaust gas with the capture plant, and the LNG vaporization with CO_2 liquefaction, a capture percentage of ca. 80% can be achieved, using the available utilities. Additionally, a techno-economic analysis has been conducted which has shown that for the hypothetical vessel discussed in this work, the cost of CO_2 capture is 168 €/ton CO_2. For the future perspective, considering higher average loads of the engine/ship, and standardization of the technology, the cost of CO_2 capture could theoretically drop to 45 €/ton CO_2.

Keywords: *CO_2 capture, LNG, SBCC, process modelling, TEA*

1. Introduction to carbon capture and storage in the maritime sector

The maritime sector has set the goal to reduce their carbon emissions by at least 50% by 2050 [1]. To this extend, a lot of research is conducted towards the deployment of zero emission fuels (ZEF's). However, these fuels are still at a relatively low TRL, and are expected to remain expensive in the coming decades [2]. Ship-based carbon capture (SBCC) on existing or new-built vessels could play a large role in decarbonizing the maritime sector before 2050. At the moment of writing, there are several number of papers available that discuss the conceptual designs of SBCC technology on board of LNG and diesel fuelled vessels [3]–[6], but no piloting or demonstration campaigns have been reported so far. The SBCC technology consists of a CO_2 capture, liquefaction and temporary on-board storage plant. In this study, a techno-economic analysis for the SBCC technology, using the first generation 30wt% MEA capture solvent, is performed for a hypothetical LNG fuelled ship, and recommendations for successful large-scale implementation of the technology are given.

2. Reference vessel and CO_2 capture plant description

The case study discusses a hypothetical vessel with an LNG fuelled electric propulsion (single) engine with a maximum continuous rating (MCR) of 9.2 MW [7]. The hypothetical sailing profile of the considered ship is shown in Figure 1, assuming that 20% of the total time the ship is in harbor with the main engine off. The total single voyage time (for which the CO_2 storage tanks are designed), is assumed at 14 days.

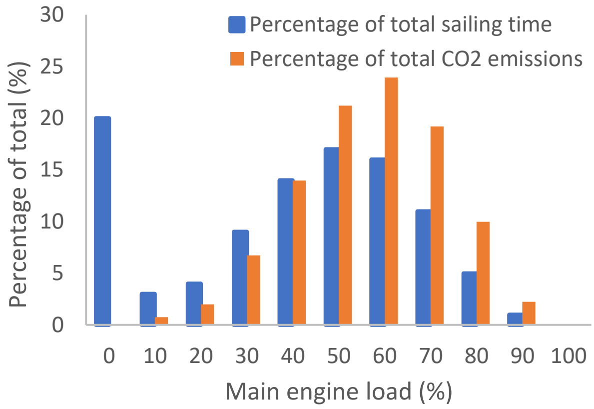

Figure 1, sailing profile and percentage of CO_2 emissions for the reference vessel.

The synergy of implementing CO_2 capture on an LNG fuelled ship comes mainly from the heat integration between the exhaust gas and the CO_2 capture plant, and the heat integration between the LNG evaporation and CO_2 liquefaction, as shown in Figure 2. This drastically reduces the variable OPEX, and only electricity is needed as utility (cooling water is relatively inexpensive at sea), and the total cost will be CAPEX dominated.

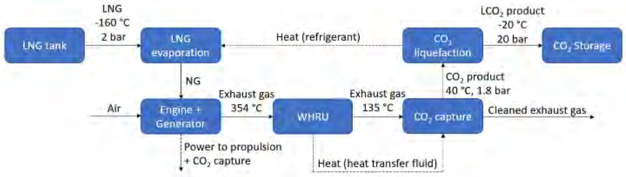

Figure 2, simplified schematic overview of the LNG fuelled vessel integrated with a CO_2 capture plant.

The CO_2 capture plant is designed at 75% engine load of the main engine. The main results from the reference vessel (which serve as input for the SBCC design) can be found in Table 1. The electricity demand of the CO_2

capture plant is estimated (before modelling) at 2.5% of the power generation of the vessel, and this is added to the propulsion system power demand.

Table 1, main results from the reference vessel.

Parameter	Units	Value
Propulsion power demand	kW	6900
SBCC power demand (estimation)	kW	175
Total main engine power demand	kW	7075
WHRU heat recovery	kW_{th}	3163
Cooling capacity of LNG	kW_{th}	232.1
Flue gas flow rate	kg/hr	47592
CO_2 concentration in flue gas	Vol% (wet)	4.17

A schematic representation of the CO_2 capture and liquefaction plant can be found in Figure 3. The main restriction for the capture plant design is the maximum height of equipment on the ship, assumed to be 15 meters in this study. This leads to an maximum packing height of approximately seven meters for each column. The water wash is designed as a separate column, as opposed to being placed on top of the absorber. For the heat transfer fluid (HTF) between the flue gas and the capture plant, oil is assumed, while for the refrigerant, to transfer the heat from the CO_2 to the LNG, ammonia is assumed. The CO_2 capture plant is modelled with ProTreat, while the CO_2 liquefaction plant is modelled with Aspen.

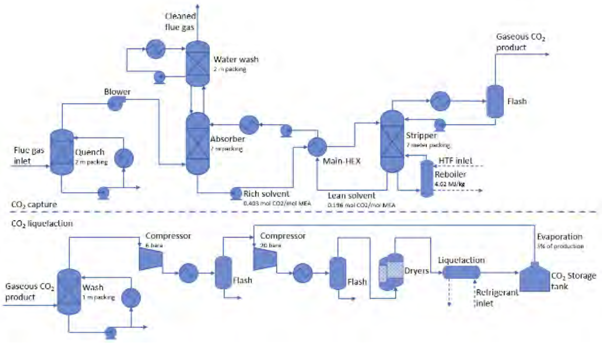

Figure 3, CO_2 capture, liquefaction and storage plant for the SBCC case study.

The main results from the capture, liquefaction and storage plant can be found in Table 2. The CO_2 capture rate can be limited either by the heat availability in the flue gas, or the cooling capacity of the LNG for the CO_2 liquefaction. In this specific case, both limitations give a similar capture rate, which is 80.2%. For simplification of the analysis in this study, it is assumed that all parameters are constant at different engine loads, and 80.2% of the CO_2 in the exhaust gas at a specific engine load can be liquefied. For engine loads higher than 75%, is it assumed that part of the exhaust gas is vented, so that no flooding occurs in the quench and absorber columns.

Table 2, main results of the CO_2 capture and liquefaction plant

Parameter	Units	75% engine load (design)
CO_2 capture percentage	%	80.2
CO_2 capture flow rate	kg/hr	2467
Solvent flow rate	kg/hr	55000
Hot-oil flow rate	kg/hr	230000
Ammonia flow rate	kg/hr	4000
Reboiler duty	kWth	3163
Total electricity demand of plant	kWe	201.6
Total cooling duty of plant	kWth	4939
CO_2 liquefaction duty	kWth	232.1

3. Techno-economic analysis

The techno-economic analysis is performed using the Aspen Capital Cost Estimator V10 (ACCE). The main assumptions for this study can be found in Table 3 and Table 4.

Table 3, main cost assumptions for the TEA. TPC = total process costs.

Parameter	Units	Value
Cost year (Europe)	-	2019
Discount factor	%	8
Depreciation of plant	Years	15
Maintenance costs	% of TPC	2.5
Operators costs	k€/year	0
Technologist costs	k€/year	100
Insurance costs	% of TPC	2
Administrative and overhead labour costs	% of O&M labour	30
LNG costs	€/ton	400
Solvent costs	€/ton	1500

Table 4, specific assumptions per case study. Case 1 is the base case; Case 2 discusses constant high engine load of the engine; Case 3 discusses standardization of the SBCC concept, and Case 4 is a combination of Case 2 and 3.

Parameter	Units	Case 1	Case 2	Case 3	Case 4
Average engine load	%	40	75	40	75
CO_2 Capture rate	ton/yr	11675	22387	11675	22387
EPC costs	-	Aspen	Aspen	10% of Aspen	10% of Aspen
Process contingency	%	30	30	10	10
Maintenance costs	% of TPC	2.5	2.5	1	1
Installation factor	-	Aspen	Aspen	50% of material	50% of material

The main results for the base case (case 1) can be found in Figure 4. The calculated total cost of CO_2 capture is estimated at 168 €/ton CO_2 and is fully CAPEX dominated (as fixed OPEX is mostly a function of CAPEX). The CAPEX division shows that the capture plant accounts for 40%, the liquefaction plant for 20%, the storage tanks for 10% and the engineering, procurement and construction (EPC) for 30% of the total capture costs. Note that in this study, for the EPC costs, the results from the ACCE software are used, which will not take all relevant costs associated to ship based installation into account (e.g. costs associated to docking and downtime of ship).

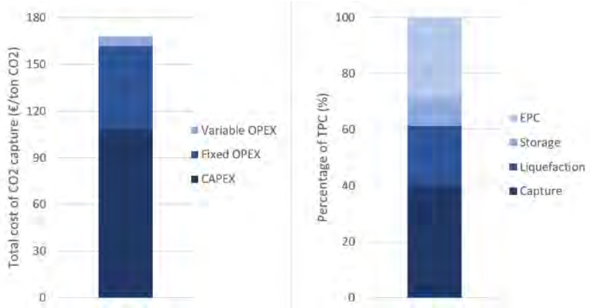

Figure 4, (left) division of CAPEX into capture, liquefaction, storage and EPC costs, (right) division of CAPEX, fixed OPEX and variable OPEX of the total CO_2 capture costs.

Lowering the specific CAPEX (€/ton CO_2) of the SBCC technology could lead to drastic reduction of the total CO_2 capture costs. This can be achieved by increasing the CO_2 capture flowrate for a given plant size and/or lowering the plant costs. Increasing the total CO_2 capture flowrate without changing the equipment design can be achieved by avoiding to run the engine at low engine loads (see Table 2). To illustrate this, case 2 is defined in which the engine operates constantly at 75% engine load, opposed to the average engine load based on the sailing profile shown in Figure 1, which approximately doubles the CO_2 capture rate with the same installation. Standardization of CO_2 capture plants for SBCC is proposed as a strategy to lower the plant costs, assuming a drastic reduction of equipment and EPC costs (case 3). Case 4 is the combination of both strategies: running the engine at high engine loads and standardizing the CO_2 capture plant. The assumptions per case are given in Table 4, and the resulting CO_2 capture costs are found in Figure 5.

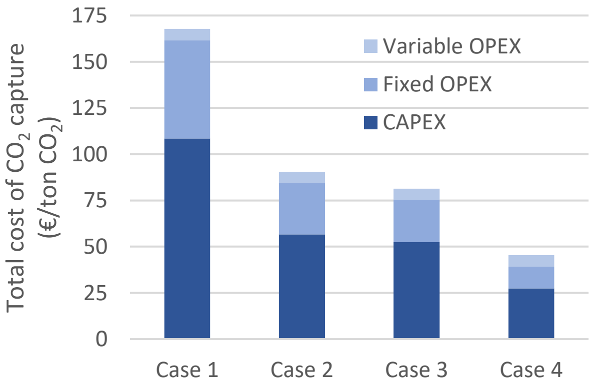

Figure 5, results of the four case studies considered in this study.

Figure 5 suggests that the total capture costs of SBCC can be drastically reduced, with the strategies for lowering the specific CAPEX. The total capture costs could drop anywhere between the 45 and 80 €/ton CO_2. Moreover, sailing more often at higher engine loads will have additional economic and environmental benefits (e.g. competitive advantage; lowering CH_4 slip).

4. Conclusions

In this study, the SBCC technology on LNG fuelled vessels is evaluated. Because of the high synergy between the LNG fuelled vessel and the CO_2 capture plant, variable OPEX is reduced drastically as compared to CO_2 capture in power and industry. This means that for SBCC on LNG fuelled vessels, the CO_2 capture costs are dominated by the CAPEX. In the design proposed in the current study, a height restriction was imposed to the capture equipment, leading to a specific reboiler duty (SDR) of 4.62 MJ/kgCO_2, which is considerably above the optimal range obtained using 30wt% MEA in gas-fired power plants, with similar CO_2 content in the flue gas. This illustrates clearly that the optimization for the SBCC technology should not be centred on the SRD, and attention should be given to mass transfer rates.

For the base SBCC case investigated in this study, the capture costs are estimated at 168 €/ton CO_2. To lower these costs, sailing at more constant high engine loads, and standardization of the capture equipment should be considered, which could drop the total cost of CO_2 capture anywhere between 45 and 80 €/ton CO_2.

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