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SMART, SUSTAINABLE: A LIFE CYCLE APPROACH TO FUEL ECONOMY AS APPLIED TO DREDGING VESSELS

ABSTRACT

In times when energy is scarce, fuel prices are rocketing and global warming awareness is high, finding efficiencies in fuel consumption are in everyone's interest. The International Maritime Organization (IMO) states that although international shipping is the most energy efficient mode of mass transport and only a modest contributor to overall carbon dioxide (CO_2) emissions, a global approach to further improve its energy efficiency and effective emission control is needed as sea transport will continue growing apace with world trade.

This article offers a comprehensive overview of how one of the major dredging contractors applied methods of sustainable fuel efficiency to their trailing suction hopper dredgers (TSHDs), while taking a life cycle view. After indicating the specific limiting conditions for dredging vessels as compared to other types of shipping, the challenges and opportunities are discussed in each phase of a dredging vessel's life cycle: from its design, during its operational life, until decommissioning. This is illustrated with results from pilot projects and studies.

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INTRODUCTION

"It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century". This infamous quote from the latest IPCC report on Climate Change (IPCC, 2013) summarises and confirms speculations that have dominated the debate on climate change for decades.

Because of the very nature of waterborne transport, the dredging industry is already contributing to more sustainable transport solutions, particularly when compared to road transport (which is usually the only other suitable alternative). Fuel usage per tonne transported over road is a multiple of the equivalent over water. CO_2 contributions from road transport have risen sharply over the last 80 years (see Figure 1). Where possible, a shift from road transport to marine transport is the way forward in controlling CO_2 emissions.

With more than 1,100 dredging vessels worldwide, of which about half are trailing suction hopper dredgers, DEME believes that dredging companies can contribute to the call of the International Maritime Organization (IMO) for improvements in energy efficiency.

The industry should not wait for policies and regulations to rethink the fuel efficiency performance of their dredging vessels, but should achieve sustainable growth by improving energy efficiency with regard to carbon emissions.

Energy objectives at DEME are quantified through an increase in efficiency of 7% by 2022 compared to 2011. To achieve its emission objectives, the company implemented a group-wide Greenhouse Gas and Energy Management system, conform the ISO 14064 (Greenhouse Gases standard) and based on the ISO 50001 (Energy Management Systems standard). The measures set forth include efficiency actions at office, vessel and project level.

Above: The operational differences between dredging vessels and freight ships are substantial. Freight shipping moves cargo from one port to another, sailing at a constant speed, whereas dredging vessels are work-boats that are sometimes in transit. As a result, general fuel economy principles for freight shipping should not be applied to dredging vessels.

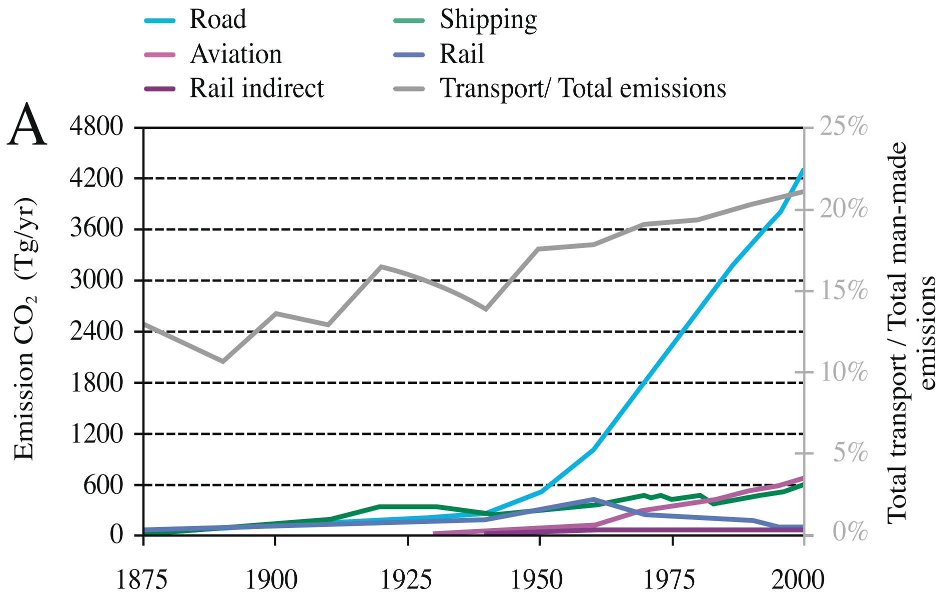

Figure 1. Historical development in CO_2 emission from the transport sector (left axis) and development in CO_2 emissions from the various transport subsectors as a fraction (right axis) of total human-made CO_2 emissions (excluding land use changes) (PIANC, 2008).

Life Cycle Analysis

In a Life Cycle Analysis (LCA), the environmental impact of a product is measured throughout all phases of its life cycle, namely construction, operation and disposal. When applied to trailing suction hopper dredgers (TSHDs), the LCA of a middle-sized TSHD stresses the clearly dominant contribution of the operational phase (Figure 2).

Furthermore, the use of fossil fuels and the environmental burden related to its emissions are dominant in all life cycle phases (CEDA, 2011). This demonstrates the required focus on fuel efficiency when searching for improvements to lower the environmental impact of a TSHD.

Apart from the obvious environmental benefits of fuel efficiency, the economic benefits are as important, particularly in today's competitive globalised economy. Fuel prices have risen over the last decade, at a far greater pace than general inflation. Since 2004, the fuel index as assessed by BCIS (Building Cost Information Service, UK) has increased 4 times faster than the labour and supervision price index (Figure 3).

Because the operational fuel costs for TSHD dredging can be as high as 20% of the total project cost, any savings on fuel consumption has an immediate positive effect on the competitiveness of dredging rates.

Regulatory context

The regulatory context is changing as well. IMO's MARPOL Annex VI Regulations for the Prevention of Air Pollution from Ships, in force globally since July 2010, established general fuel oil sulphur limits as well as more stringent restrictions on sulphur emissions in certain protected areas: the SO_X Emission Control Areas (SECAs). The progressive reductions are soon reaching their final stage inside the SECAs, where the limit of sulphur content in bunker fuels will be set at 0.10%.

To date, the most realistic (technical and economic) solution for the dredgers operating in a SECA with regard to primary methods of SO_X compliance (0.10%), would be to run on Marine Diesel Oil (MDO) (EuDA, 2013). Considering that MDO is about 40% more expensive than LS380 (1% sulphur) or even 50% more expensive than regular IFO380 grade fuels, the financial impact of such restrictions is very considerable, incentivising the search for fuel economy even more.

DREDGING FLEET SPECIFICS

Although the size of the dredging fleet is marginal as compared to the global shipping numbers, the differences in the types of operations are substantial. Therefore, general fuel economy principles for freight shipping should not be applied to dredging vessels. Freight shipping generally moves cargo from one port to another and has a well-defined

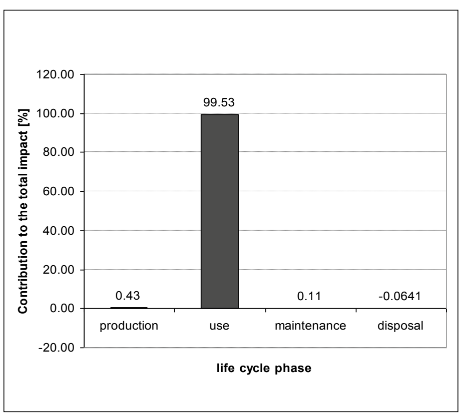

Figure 2. Environmental impact of the life cycle of a TSHD (CEDA, 2011).

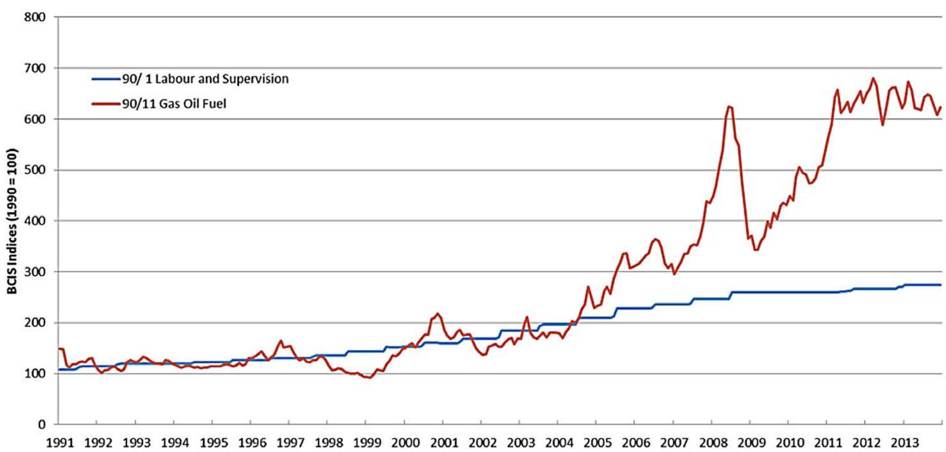

Figure 3. Evolution of BCIS fuel and labour indices 1990-2013.

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plan of operations. During most of their design life, these vessels will be sailing at constant speed while transitting.

A TSHD is a work-boat and not merely a transport vessel. Its purpose is to perform works in a unique project environment, working under a regime characterised by variation on an hourly basis. This can be variation in sailing speed (full speed, trailing speed, positioning), cargo (empty, full), draught, type of activity (trailing, pumping ashore, bottom-door disposal) and so on. Furthermore, the area of operation is not pre-defined and can range from Arctic seas to Caribbean waters. A dredging vessel can be operational in a small area (e.g., North Sea) for years, but could easily be sailing all oceans when repetitively mobilising from one project to the other.

Flexibility is a key word: Globally operating dredging companies look for dredging vessels that can be deployed for many types of activities, in many types of conditions, in order to increase their annual usage percentage. This flexibility and versatility of operations are the major challenges in defining fuel economy programmes for dredging vessels.

INTRODUCTION TO LIFE CYCLE

The concept of Life Cycle Analysis (as introduced above) is used as a roadmap to discuss opportunities for fuel economy for TSHDs. The following 3 stages in the life cycle of a TSHD play a vital role in fuel economy:

1. Conceptual Design
2. Operational Life
3. Decommissioning

STAGE 1: DESIGN

Concept of a dredging vessel

A fuel-efficient TSHD requires a clever design that makes the adequate considerations on fuel economy during the conceptual stage. The requirement for versatility is the biggest challenge for TSHD designers to make an optimal selection of engine setup.

Firstly, there is the question of total engine power. The main engines distribute their energy over various processes, which do not necessarily run simultaneously. Driving pumps and driving propulsion are the main processes. When trailering, the engine power is distributed over both propulsion and pumping. When sailing full, all power is available for propulsion. When pumping ashore, little to no propulsion power is required and all power is available for driving the inboard pumps. In all these phases, the engines ideally run at their optimum power output. In any case, the designer should avoid installing latent engine power, which would only be used in rare occasions.

This is inefficient both in investment costs as well as in operational fuel consumption. Good planning and discussions need to be held between the design team and the operational team to understand what types of operations are targeted and need to be designed for. Questions that need to be considered are:

- What kinds of soil will be dredged?
- How far would these soils need to be hydraulically pumped?
- What would be the typical sailing distance between the dredge area and the disposal area?
- Will the vessel be regularly mobilised over great distances (trans-ocean)?

The operational team would want full flexibility, while the designer would ideally want a small, pre-defined power demand range. Clearly concessions will need to be made. To illustrate the difficulty in optimising engine selection during the design stage, take the example "mega-trailers".

Mega-trailers are the largest types of TSHDs, typically with a hopper capacity beyond 30,000 m³. Such mega-trailers are typically deployed where economy of scale is to their advantage. Project conditions would then be characterised by large sailing distances between dredging site and disposal or pumping site. In such conditions, engine design would focus on sailing (high sailing speed). On the other hand, these mega-trailers are regularly deployed for dredging down to the deepest seabed relying on their long suction pipe (in combination with an underwater pump). Such operations are usually characterised by precision dredging with manoeuvring and positioning being the governing activity (e.g., the dredging of trenches for the oil & gas industry). These two types of operations demand very different loads of the main engines.

The multi-disciplinary deployment of the global dredging fleet today amplifies this difficulty. Vessels are now used in the renewables sector, working under very different conditions compared to what was anticipated at the time of their design and construction.

Secondly, there is the optimal working range of the main engines, where fuel consumption per unit of energy is the lowest (most efficient combustion). Vessel speed sailing, vessel speed dredging, suction power and pumping power: All of these power demands need to be aligned as engines will run most efficiently at their optimum load (Figure 4).

In order to measure the energy performance of a new vessel and facilitate decision making, the IMO have launched the concept of an Energy Efficiency Design Index (EEDI) (MEPC, 2011). The EEDI for new ships is an important technical measure and it aims at promoting the use of more energy-efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g., tonne mile) for different ship types and size segments. However, given the complexity of the engine setup and energy demands for dredging vessels, as described above, the dredging industry has for the time being been exempted from these requirements.

Fuel-efficient engine design

As identified by the European Dredging Association (EuDA), fuel efficiency would be an appropriate starting point in the reduction of emissions of pollutants. Over the last decades, intrinsic improvements in the design of TSHDs have already led to a 7.5% reduction in CO_2 emission per m³ loaded.

Apart from the technological progress in the design of fuel-efficient engines, the scale increase of TSHDs also contributes to better fuel economy. Namely, with the increase of hopper capacity and engine size comes more efficient energy use because of the economy of scale when sailing over longer distances and the more efficient transport energy demand. The latter is demonstrated in Figure 5: for the largest TSHDs, one volume unit can be transported at a certain speed with the lowest energy demand. One needs to be careful when such mega-trailers are deployed in other types of dredging cycles (e.g., short sailing distances). Fuel efficiencies can be lost rapidly when conditions are unfavorable.

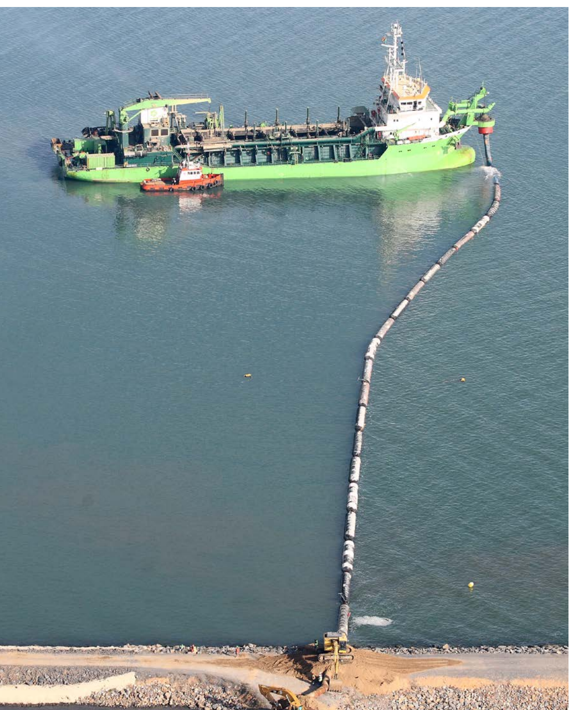

Figure 4. Multi-disciplinary deployment of the global dredging fleet amplifies the differences of their fuel efficiency during different operations.

Methods during design

Important gains in fuel efficiency have over the recent years been achieved in the design stage by improvements, developments and considerations on the following aspects:

- 3D design technology has simplified studying the effect of streamlining and curving a vessel's hull in the right places while trying to maximise its carrying capacity. Such studies define, amongst other things, the optimum *block coefficient*.
- Use of different materials, optimise space for accommodation units and stores, management of spares, use of high tensile steels and reduced steel usage through the creation of 3D complex forms all aim at reducing *lightweight ship*.
- Developments in the *type of drive system*: electric versus diesel direct. While electric has clear advantages in terms of flexibility, one should be aware of every conversion of energy from diesel engine to generator and generator to electric motor. Each conversion causes a loss of energy efficiency of up to a few percentages. For direct drive systems with gearbox this conversion loss only needs to be accounted for once. Furthermore, one should allow for the energy efficiency of a generator and electric motor.
- Thorough understanding in every aspect of the *energy household*. The size of the engine (installed power) is governed by the most demanding cycle status (trailing, sailing, pumping). The vessel's power is balanced out in any phase of operation minimising any latent engine power.

STAGE 2: OPERATIONAL LIFE

While the design phase of a vessel is very short in comparison to its operational life, unmistakably, a fundamental misconception in the design phase will drastically impact the total fuel cost (and thus operational cost). Nevertheless, once the TSHD has been built, there are several opportunities to improve fuel efficiency during the operational life.

Methods

Fuel economy initiatives during the operational life either focus on 1) reducing the energy demand (preventive) or 2) increasing the fuel combustion efficiency (reactive). The preventive approach is clearly the more sustainable one. For every method,

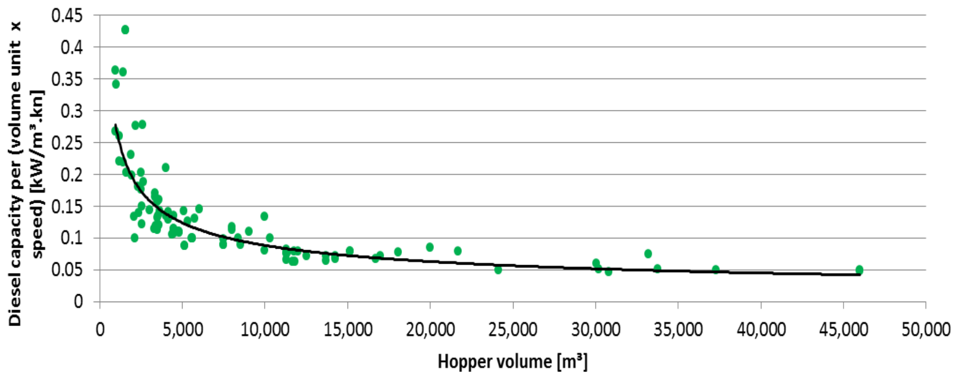

Figure 5. Economy of scale: Diesel capacity efficiency of IADC member vessels only (International Association of Dredging Companies).

the cost versus the benefit should be investigated when making a decision to proceed.

Creating awareness

Bringing awareness (to the operators, engineers, technical superintendents, planners, and others) means improving the understanding of the operational processes consuming fuel. Creating awareness goes hand in hand with fuel consumption measurement and reporting.

These two aspects are fundamental to increasing understanding of fuel consumption on a TSHD and support fuel efficiency decisions. Fuel consumption measurement requires fuel counters, which are generally implemented as flow meters installed at the heart of the engine room, between the fuel tanks and the engines. Such new fuel measurement techniques are gaining in importance over the more traditional measurement techniques such as manual sounding or the use of pingers. These traditional measurement techniques deliver less accurate data, which are prone to errors owing to non-standardisation (different persons performing sounding at different times of the day or week). Reporting of manual soundings is useful for understanding average trends, but cannot provide for real-time data.

To understand the impact of certain actions on fuel consumption, fuel counters should have digital output which can be added to the dredging console display on the vessel's bridge (Figure 6), integrated in the SCADA system (supervisory control and data acquisition). An example of such digital visualisation is shown in Figure 7.

Controlling the energy demand

From an operational point of view, fuel efficiency can be achieved by maximising payload while minimising fuel consumption. Firstly, focussing on payload, the principle is straightforward: Don't move around non-paid load at the expense of burning precious fuel. Some typical actions that can be taken are:

- Avoid water trapped on top of dredged materials in the hopper
- Spares: leave parts on the shore when not needed
- Optimise bunker volumes (don't take full bunkers if not required).

In addition to this, the vessel's Lightweight Tonnage (LWT) needs to be monitored frequently and considerable differences with the design LWT need to be investigated. Usually such differences arise from ad hoc adaptations and maintenance over the years.

Secondly, savings in fuel demand have an immediate contribution to fuel efficiency. Such savings can be achieved on multiple fronts. Some typical processes where fuel demand can be controlled are listed here:

- Rely on shore power when the TSHD is alongside a quay. Whether this is during a planned event (maintenance, bunkering, working schedule, and so on) or unplanned (weather downtime), the use of (green) shore power can be a sustainable alternative to burning carbon fuels. This requires suitable connections on the quayside.
- Idle ship power management: monitor what engines and power users need to remain switched on and which ones can be switched off when the ship is idle.
- Lower sailing speed when downtime is anticipated (tides, locks, bad weather and

Figure 6. The dredging console display on a vessel's bridge.

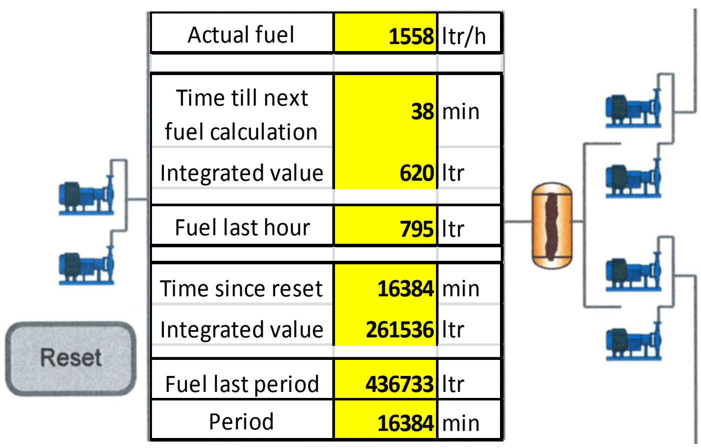

Figure 7. SCADA (supervisory control and data acquisition) visualisation of real-time fuel consumption.

Figure 8. Fuel efficiency test programme on TSHDs working under the same environmental conditions are being conducted

such), both during voyage (Panama Canal, Suez) as well as during project execution.
- Reduce resistance in the water: perform regular hull maintenance by removing fouling and applying coatings.
- Polish propellers to increase propulsion efficiency.
- Reduce draghead resistance without giving in on dredging production.

The observation made so far by DEME is that operational fuel economy opportunities are present in a multiple of smaller aspects, owing to the complexity and diversity of operational activities of dredging vessels. There is no golden egg and efforts need to be made in all of these smaller initiatives to achieve an overall distinctive saving.

Fuel combustion efficiency

A popular fuel saving option is the use of fuel additives, which is becoming a market on its own. Several dredging companies are testing different kinds of products. The effectiveness of such products is under review.

Testing

The effectiveness of many of these initiatives is difficult to predict or calculate and can usually only be assessed empirically. When performing such tests, the challenge is to create exact conditions to distillate the effect of a certain factor. As an illustration, DEME is running a test programme where the effectiveness of an anti-fouling system is investigated by the comparison of two sister vessels, operated on the same site: one vessel with the system, the other one without (Figure 8). Such test setups enable correct assumptions about the overall benefit of a fuel economy option.

Standardised approach

The initiatives presented above are at company level, and can therefore be managed centrally. For initiatives at individual project level, a standardised approach is recommended.

Operational fuel improvement exercises consist of five short stages:

1. Identification of opportunities (from the early stage: kick-off meetings)
2. Preparation of operational key performance indicators (KPIs)
3. Launch and mobilisation of involved parties through a detailed action plan
4. Progress follow-up and evaluation
5. Close-out stage

This follows the DMAIC project methodology: **D**efine, **M**easure, **A**nalyze, **I**mprove and **C**ontrol.

CASE STUDY: LINCSHORE BEACH RENOURISHMENT PROJECT 2010-2015

The Lincshore Beach Renourishment 2010-2015 scheme provides for the protection of about 11,000 homes against the flood risk on the English East Coast. Its annual scope of works includes the renourishment of beaches with about 500,000 m³ of sand. These sands are dredged from offshore licensed borrow areas and are pumped hydraulically onto the beaches (Figure 9).

Because of the shallow nature of the Lincshore coast, the dredging vessel can only approach the coast and discharge its load at high water. The dredging vessel's cycle is therefore determined by the tidal cycle, which is one high tide every 12 hours. Since the sand borrow areas are close by, the vessel can sail at less than full speed to and from the dredging location, as the ship would need to go on standby anyhow while waiting for the tide to rise.

Before the start of the 2013 campaign, specific preparations were taken to evaluate optimal fuel usage under these circumstances. A simple and effective Key Performance Indicator (KPI) was set, namely, fuel usage per m³ of loaded sand in the hopper.

Measurement

A flow meter, part of the booster unit of the fuel oil system, was used as a fuel counter and was linked to the PLC (programmable logic controller). The flow meter is located between the daily service tanks (both marine gasoil and heavy fuel oil) and the mixing tank. This indicates that the flow to the engines and their corresponding fuel consumption was not measured directly.

Furthermore, allowance had to be made for return fuel from the engines, which is not consumed. This was achieved by continuous gauging of the mixing tank level and by maintaining a constant level with the feeder pumps, considering the amount of fuel requested by the engines via the circulation pumps. With this setup, it could be assumed that the measured fuel flow was equal to the fuel consumption by the engines.

These measurements were compared and benchmarked with the daily soundings of the bunker tanks, which is regular practice on board of dredging vessels. Applying the correct temperature coefficient to allow for the density variation of up to 7% owing to the temperate difference of about 50°C to 60°C between bunker tanks and flow meter was important.

Method

Figure 10 shows the fuel consumption at various loads of the main engines. Several trials were done with changing loads of the main engine during sailing, and overall fuel consumption per cycle was evaluated. These were compared to identify an optimal working method.

Trials

To properly evaluate the effectiveness of a certain fuel economy setup, trials had to be executed over several days up to a week. This allowed for balancing out the changing environmental conditions such as sea-state, different borrow areas, different sand characteristics and different pumping distances. This variability of the background conditions is a general concern for fuel consumption evaluation during dredging operations as compared to more "industrial" activities such as freight shipping (sailing at constant load).

Figure 9. Lincshore Beach Renourishment project, eastern coast of the UK.

Pitch reduction during sailing empty or loaded

First trials were done with reduced pitch of both propellers, done in incremental steps of 5%. Engine load and sailing speed dropped accordingly, resulting in lower fuel consumption. However, to ensure the vessel remains steerable and its sailing direction is in line with its heading, a minimum speed is required. When sailing at death slow speed, the impact of wind and current on the sailing direction requires a compensating large steering angle of the rudders. The vessel will continue its desired sailing direction, but with its heading under a different angle.
This causes unnecessarily high resistance and should be avoided. As a result of these first trials, it was assessed that a 55% pitch was optimal (see Figure 11, "Stage 1 Improvements").

However, two aspects had a negative effect on fuel consumption at reduced pitch: Engine load dropped below the optimum (see Figure 10) and less time was spent at the anchorage where the vessel waits on the high tide and where fuel consumption is minimal. Furthermore, low engine loads result in faster contamination (decreasing fuel efficiency), requiring a frequent turbo-wash (which is also energy consuming).

Therefore, during a second trial phase (see Figure 11, "Stage 2 Improvements"), the assessments done with regard to optimal pitch were further refined, considering engine load versus fuel consumption characteristics. Engine loads between 75% and 85% were targeted. This resulted in a higher sailing speed, offering greater steering control. Owing to the larger sailing speed (and higher fuel consumption), more hours were spent at the anchorage, where fuel consumption on standby is an absolute minimum. Fuel saved during standby time should compensate for the extra fuel burnt to deliver more power and higher sailing speed.

This can be evaluated by the following equation:

Fuel consumption [g] =
specific fuel consumption [g/kWh]
x time [h] x power [kW]

Weather permitting, these set-ups can be applied while one main engine is shut down, further reducing the overall fuel consumption.

In addition to trials during sailing empty and loaded, fuel economy initiatives were also done during pumping and dredging. Automated control of the pumping and

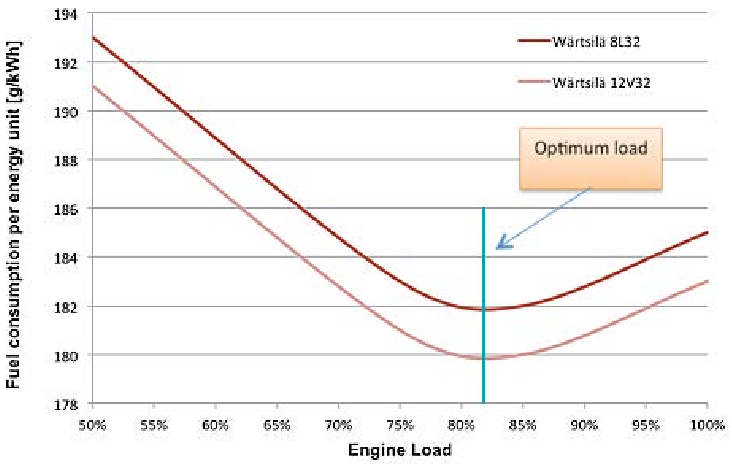

Figure 10. Optimum engine load for fuel consumption (Wärtsilä, 2013).

dredging process keeps the load on the dredging engine lower than when done manually. During the 2013 campaign, a reduction of over 100 tonnes of fuel (equivalent to over 300 tonnes of CO_2) was achieved. Figure 11 shows the realised improvements, referenced to standard fuel consumption of the TSHD.

STAGE 3: DECOMMISSIONING

Technical innovation is key in the newest generation of dredging vessels. This is embedded in the design process. TSHDs have moved from mechanical devices towards hi-tech working tools, where information technology and automated processes form a central nervous system. As a result of technological progress, with time, a vessel's design basis has a higher risk of being labelled old-fashioned and will be outperformed by newer, more efficient vessels. Nonetheless, savings that can be achieved by implementing newer technology need to be weighed against the required investments, following the BATNEEC principle (Best Available Technology not Entailing Excessive Costs) (CEC, 1984). This analysis is done by the vessel's designers when they make a projection of the anticipated decommissioning date, while accounting for re-fit options during its lifetime (Figure 12).

This internal strategic decision process for assessing the decommissioning date is troubled by challenges caused by external factors. An important example is the regulations requiring reduced sulphur emission in certain regions (see above "Context"). In normal cases, regulatory changes would not apply to a vessel if introduced after its keel-laying. With this particular regulation, it will need to be complied with on all operational technology and thus has retroactive effects on older dredgers.

Ship owners operating in these SOx emission control areas (SECAs) have only a few options. First of all, operators could shift to SECA-compliant fuel on their vessels, which however would ask for a retro-fit of the engines that are designed to run on heavy fuel oil, mainly because of the differences in caloric values. Furthermore, the price per tonne and the availability of such fuels are issues. The other option lies in the removal of pollutants from the exhaust gases. This requires retro-fitting the vessels with scrubber installations. For existing dredging vessels, this latter option is not straightforward because of lack of space and issues with payload and stability.

On the background of this uncertainty caused by regulatory changes, the decommissioning aspect of a TSHD comes in the spotlight. The main question is: When is the right time to decommission an old TSHD and have it replaced with an efficient new TSHD? It is no exception that the actual lifetime of a dredging vessel is well above 30 years, with several operators extending the life of their vessels by performing a thorough retro-fit. Obviously, no 30-year-old design has allowed for the current dredging market reality and regulatory framework and, back then, nobody

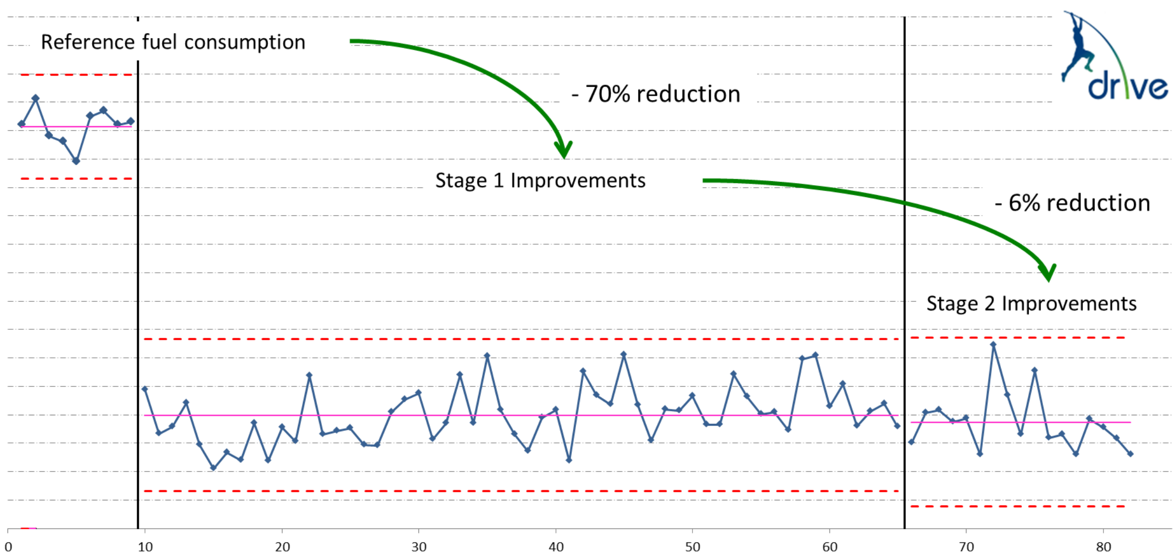

Figure 11. Fuel consumption improvements at Lincshore beach renourishment.

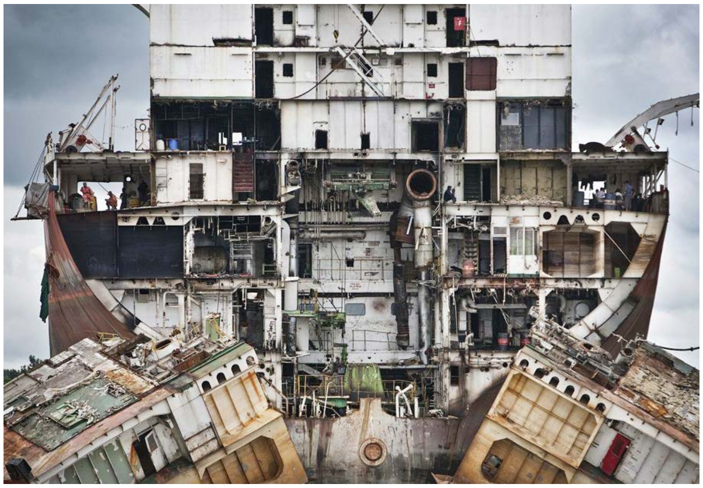

Figure 12. Decommissioning is sometimes a necessity. The fuel efficiency of an older rusty boat cannot compare to a newly designed vessel.

had access to the technology that exists now. With that in mind, why not shorten the design life of a TSHD?

A long design life translates into tough (read: heavy) vessels that last longer. With a shortened design life, vessels would progress towards light-weight, economic TSHDs, standardised and suited for its limited purposes. Instead of continuing to use vessels into ages where younger vessels easily outperform their older sisters (on all aspects, but particularly on fuel efficiency), why not incorporate a shorter life cycle into the original design conception and save on material usage? The technical inferiority of older vessels will be less, fuel efficiencies will be better and expensive retro-fitting programmes can be avoided.

In view of the Life Cycle Analysis, one could object to such an approach, as the environmental burden of the construction and disposal phases will considerably gain in relevance. Indeed, the relative contributions will have to be rebalanced, but given the current marginal contribution of construction and disposal (see Figure 2) it is projected that the gain during operational life will easily outweigh such negative effects.

CONCLUSIONS

This article provides a new perspective on fuel efficiency improvements in the dredging industry. The main drivers encouraging application of fuel economy principles are the environmental effects, the economic effect and the regulatory framework. The analysis here has been drafted as guidance to dredging industry members for setting up and implementing fuel efficiency programmes within their organisations. DEME has started working on a series of initiatives, which are described in the document, but this work will have to be continued for a considerable time as there is a long way ahead.

Several recommendations (such as the use of fuel additives, coatings and fuel measurement) are still in the testing phase and their effectiveness needs confirmation. Participation in joint initiatives and partnerships with stakeholders will hopefully take place, with plans to report back on some of its findings within the next months and years.

As a final note, the reality is that dredging companies will always have to allow for economic viability when implementing the best technologies available to protect their clients and their own competitiveness.

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