BERNARDETE GONÇALVES CASTRO, SERGIO OOIJENS AND LEO W. VAN INGEN

Above: A self-propelled sea-going dredger at work. Finding technological solutions to comply with new emissions regulations calls for action, not only from dredge operators, but as well from manufacturers of dredging equipment, since the dredging equipment is the source of the emissions.

APPROACHING EMISSIONS IN DREDGING

ABSTRACT

The international emission legislation for the shipping industry has become increasingly stringent in recent years and will become even more stringent in the coming years. Growing environmental awareness and social challenges like air quality, climate change and energy scarcity have resulted in the latest emission legislation as set forth in the IMO (International Maritime Organization) and EPA (US Environmental Protection Agency) regulations. This emission legislation also challenges the dredging industry.

It calls for action from both the dredge operators as well as manufacturers of dredging equipment, since dredging equipment is the source of the emissions. Currently two paths can be recognised in the industry: creating balanced emission legislation on one side and continuing to develop new clean technologies on the other side.

Ideally these paths cannot be seen separately. Adjusting technology to new legislation does not by definition always result in a lower energy consumption and environmental impact. A large contribution can be achieved by better focussing, not only on the emissions per installed kW, but on the total energy consumption per dredging project or per cubic metre (m^3) or cubic yard (yd^3) of dredged material. This contribution is often not regulated despite its significant influence on the actual impact.

These efficiencies in the dredging project can be reached technically by optimising a dredger as well as by proper operation and project management. This article describes the continuous developments being carried out at IHC Merwede and their potential for addressing the challenges of a clean and lean dredging process in the future. The article first appeared in the Proceedings of the PIANC World Congress in June 2014 and is published here in an adapted version with permission.

INTRODUCTION

The international emission legislation for the shipping industry has become increasingly stringent in recent years and will become even more stringent in the coming years. Growing environmental awareness and social challenges like air quality, climate change and energy scarcity have resulted in the latest emission legislation as set forth in the IMO (International Maritime Organization) and EPA (US Environmental Protection Agency) regulations. This emissions legislation also challenges the dredging industry.

It calls for action from both the dredge operators as well as manufacturers of dredging equipment, since the dredging equipment is the source of the emissions. Currently two paths can be recognised in the industry: creating balanced emissions legislation on one side and continuing to develop new clean technologies on the other side.

1. *Creating new legislation*: In response to the emissions legislation trends, a number of activities have been initiated, specifically the active involvement in the development of an alternative IMO EEDI (Energy Efficiency Design Index) calculation method for dredging vessels (CO_2 index for vessels). This alternative CO_2 index will better translate the function-related CO_2 emissions of dredging equipment.
2. *Finding technological solutions to comply with new regulations*: From the innovation perspective, research on emissions

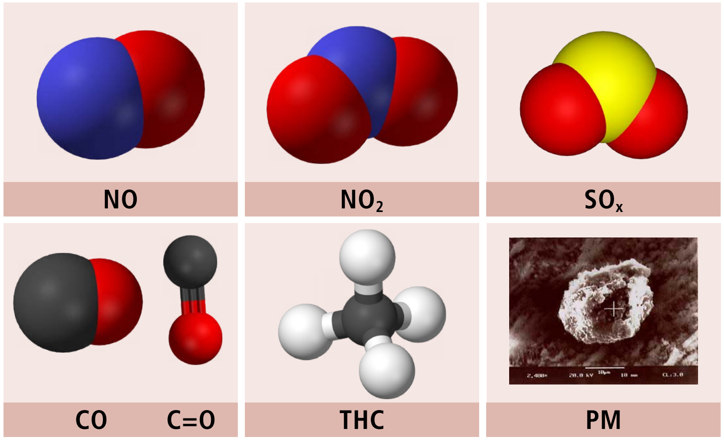

Figure 1. Images of the regulated emissions.

reduction technologies and innovative drive technology is being conducted. This includes research on the applicability of after-treatment technologies as required onboard dredging vessels for emissions compliance with, e.g., IMO Tier III in ECAs (Emission Control Areas) and EPA Tier 4 emission limits for marine engines, starting in 2016.

On the other hand alternative energy sources or energy management systems should be investigated to see if they can create a solution. Research on gas power technology is being carried out at various levels, from the fundamental level of engine modelling to the integration of gas-powered ship designs.

With a focus on development of electric drives, IHC Merwede as a leading shipbuilder has been conducting research on innovative and advanced drive systems. In particular, permanent magnet technology and technical components such as frequency drives, variable speed generators and energy management systems. This will contribute to more efficient drive systems, also when they utilise the design of shore-powered electrical driven dredges. These innovative drives are highly integrated and have extended workability coupled with high efficiency and low emissions.

LEGISLATION FOR SUSTAINABLE SHIPPING

Growing environmental awareness and social challenges like air quality, climate change, and energy scarcity have resulted in the latest emissions legislation as set forth in the International IMO and US EPA regulations.

Recent legislation covers the emission of NOx (Nitrogen Oxides), SOx (Sulfur Oxides), THC (Total Hydrocarbons) and PM (Particulate Matter) (Figure 1).

EU, CCNR and EPA Legislation

Globally the current emissions legislation is not uniform, but it is converging towards commonly established emission levels. Next to the IMO for sea-going vessels, three different sets of legislation exist that apply to dredging vessels, the European Union (EU), CCNR (Central Commission for Navigation on the Rhine) and US EPA legislation. The three regulations are still being discussed for harmonisation. The limits stipulated by these three are expected to become identical soon. Figures 2 and 3 show a few legislation limits, illustrating the developments in legislation towards lower emissions.

IMO Energy Efficiency Design Index (EEDI)

Furthermore, IMO also launched legislation aiming at improving the energy efficiency of marine vessels by addressing the CO_2 emissions, called IMO EEDI. The basic formula dictates that the CO_2 emission (as a function of fuel consumption) is divided by the vessel tonnage and the sailing speed. This legislation covers a number of vessel types and requires newly built vessels to decrease their CO_2 emissions in subsequent steps of 10%, 20% and 30% respectively.

The EEDI will cover all vessel types in the near

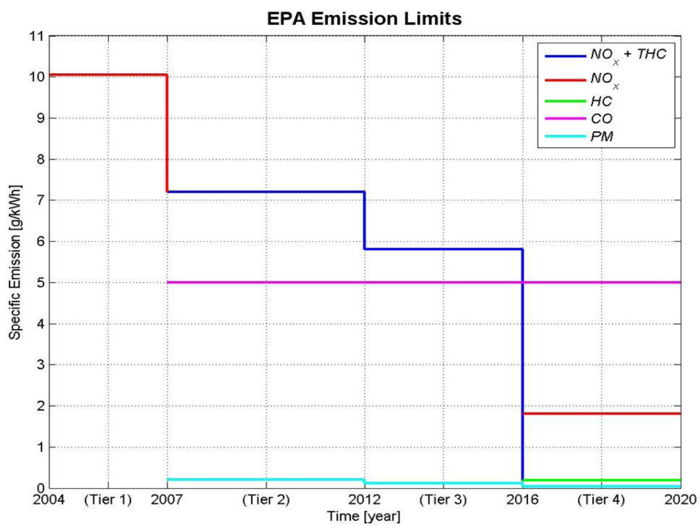

Figure 2. EPA emission limits of several exhaust gas components in time.

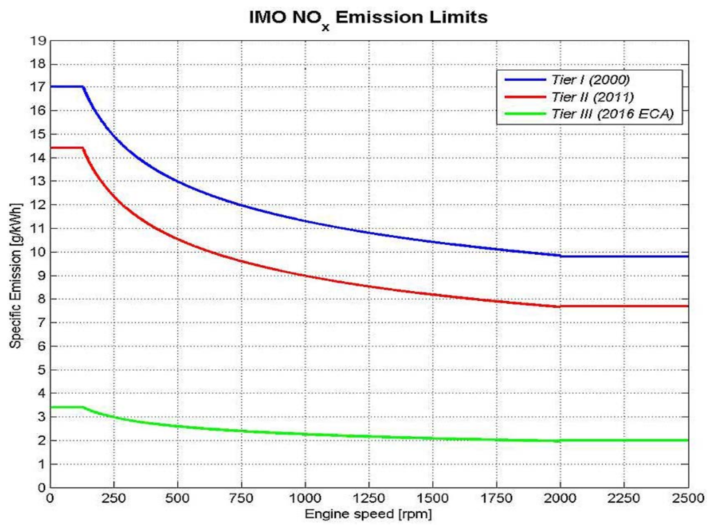

Figure 3. IMO NO_x emission limits (Tier III currently under discussion).

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future. At IMO current discussions are about the formulas and corrections to be used to vessel type and specific situations (e.g., an ice-class vessel should not be disadvantaged and requires special correction factors). The dredging industry is actively taking part in these discussions on future emissions legislation in order to define an alternative CO_2 index for dredging equipment, which will be further discussed below.

However, even were there an alternative CO_2 index for dredging vessels, it is questionable if this would ultimately bring the best solution in reducing CO_2 emissions for these types of vessels. Although a dredger is considered a ship, the purpose of a dredger is not only the transport of material but also its excavation – and a significant part of the vessel's energy consumption is related to this separate and specialised excavation process. The efficiency of an excavation installation is a very complex process dependent on the efficiency of the excavation process itself, the hydraulic transport efficiency, the sedimentation efficiency and so on. On top of this comes the integrated interaction between these processes.

Finally, the efficiency of dredging equipment is still enormously influenced by local circumstances as well as the users (both operators and managers) and legislators. These parameters are difficult to be expressed in rules or targets.

Although the essential role of emissions legislation in the development of cleaner technologies is recognised, this legislation must be defined on a sound basis that can truly lead to more sustainable maritime operations in general and dredging in particular. This is not always the case and the main reasons can be summarised as:
- the isolated and local emissions reduction approach and
- the lack of systems-perspective to tackle this complex issue so far.

Systems thinking originated in the 1980s as the development of science and technology and led to the awareness of the need to approach complex systems in a different manner, including the interconnections existing in them (Checkland, 1981). This article describes this in more detail and suggestions are made for a possible pathway to more sustainable equipment, dredging processes and emissions legislation.

LIMITATIONS OF CURRENT LEGISLATION

From an innovation perspective, research on emissions reduction technologies and innovative drive technology is being conducted. This includes research on the applicability of after-treatment technologies as required onboard dredging vessels for emission compliance with e.g., NO_x IMO Tier III in ECAs (Emission Control Areas) and EPA Tier 4 emission limits for marine engines starting in 2016. On the other hand the question can be investigated whether alternative energy sources or alternative

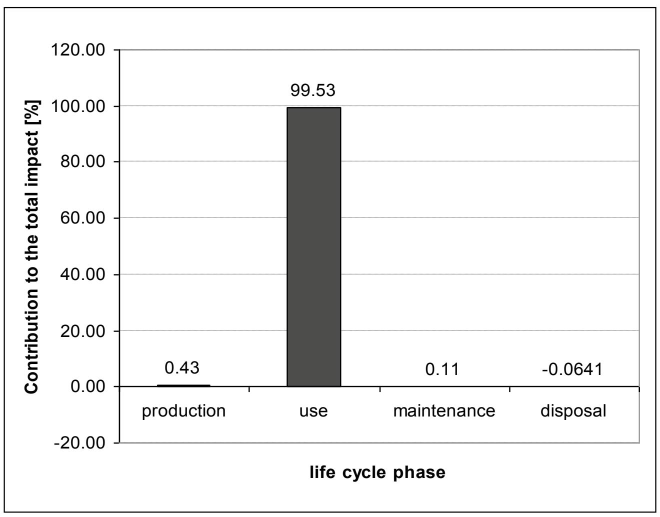

Figure 4. Environmental impact of a dredging vessel during its whole life (source CEDA, 2011).

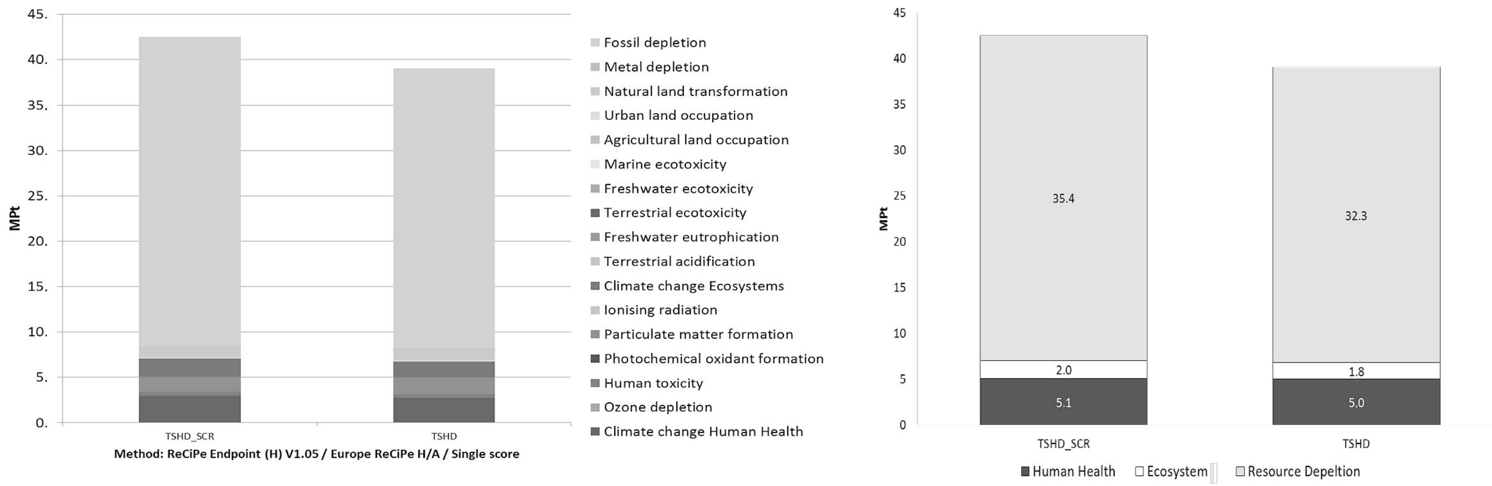

Figure 5. Life Cycle Analysis of an IMO NOx Tier I versus a Tier III power supply. Results: a) left, all categories adding up; b) right, impact grouped into the three main impact areas: Human Health, Ecosystem Quality and Resource Depletion (source Castro et al., 2013).

energy management systems create a solution. Research on gas power technology is also being carried out at various levels, from the fundamental level of engine modelling to the integration of gas-powered ship designs.

Emissions legislation tends towards future harmonisation. A few examples are: the CCNR emissions legislation, the strictest of all legislation that applies to *new-built inland* vessels. It is even more stringent than the IMO legislation, already demanding fuels now with very low sulphur content (0.1% S in European Sea Ports and 0.001% in inland shipping areas).

The NO_x + THC (Total Hydrocarbon Content) emission limits for inland waterways are currently ±7.2 g/kWh (*EU Stage IIIA* and *CCNR Stage II*). The NO_x+THC emission limit in the USA is ±5.8 g/kWh (*EPA Tier 3*). In 2016 the NOx emission limits will drop to 1.8 g/kWh in the inland waterways of the United States (EPA) and the European Union (EU) and to 0.4 g/kWh on the River Rhine (CCNR).

These current legislation developments call for action from both the dredge operators and manufacturers of dredging equipment, since the dredging equipment is the source of the emissions. Figure 4 shows that the operational phase is responsible for the large majority of the environmental impact as a result of fuel use and emissions.

Manufacturers, such as IHC Merwede, strive continuously to offer their customers advanced and cost effective dredge drive systems and equipment for a more sustainable and clean dredging future. Therefore much effort has been put into developing vessels with minimum fuel consumption and thus, minimum emissions. This is one of the key pillars for sustainable equipment design.

As Figure 4 shows, the effort to minimise fuel consumption appears to be the right focus for dredging situations. To mention a few examples, this focus has resulted in the development of a lower resistance hull design for dredging vessels (resulting in a 20% fuel saving), high efficiency dredge pumps (5% fuel saving) and optimal jet systems (10% higher production). Unfortunately these developments in fuel efficiency are doomed to be slowed down by upcoming legislation, namely, the NOx emission legislation and the IMO EEDI.

Limitations of the NO_x legislation

The NO_x emission legislation dictates a low emission from the exhaust pipe of vessels. This emission reduction can only be solved partly by internal engine modifications. As a result of the lower combustion temperatures imposed, the required reductions of emissions to comply with Tier II were attained to the detriment of lower engine efficiency (about 5%). Further reduction as required to comply with Tier III legislation (which is 80% lower than Tier I), requires a post-combustion treatment system. The SCR technology (Selective Catalytic Reduction) seems to be the best established technology by now. However such a system does not run for free onboard vessels. Internal feasibility studies indicate that the lower combustion temperature, additional equipment and increased exhaust back-pressure add up to 10% higher fuel consumption compared to Tier I.

A system-perspective based analysis, a so-called "Life Cycle Impact Assessment" (for more information see Goedkoop et al., 2009), shows that this figuratively and literally end-of-pipe solution has no benefit when the

Table I. Inventory of emission values of the emissions of Nitrogen compounds to air and water, per liter of fuel used (heavy fuel emission data).

Substance	Compartment	Unit	Heavy Fuel Combustion	Heavy Fuel Combustion + SCR (80% Lower NO_x)
Nitrogen	Water	mg	3.86	3.86
Nitrogen oxides	Air	g	1.68	0.34
Nitrogen, organic bound	Water	mg	13.81	13.81

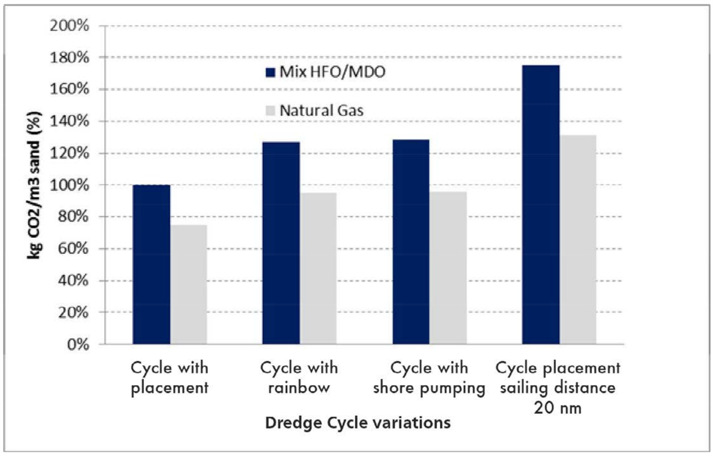

Figure 6. CO_2 per yd^3 or m^3 dredged sand for a TSHD, variation compared to minimum requirements (dredge cycle with sand placing), sailing distance (from 10 nm to 20 nm) and fuel type.

whole system is taken into account. Figure 5 shows the total NO_x emission of a Tier I and a Tier III vessel respectively over its entire lifetime (Castro et al., 2011). Surprisingly, the total amount of NO_x emission is similar and the fuel consumption is 10% higher.

The NO_x reduction at the local vessel exhaust is indeed decreased by 80%. However, as Table I shows, the additional 10% fuel consumption leads to extra emissions in the upper chain as a result of amongst other things, additional oil production, fuel refining and transportation. The emission of NO_x is apparently lowered at the vessel location, which is the original aim of this legislation. Nevertheless, in a broader perspective, the NO_x emission is higher. As a result, the effect of exhaust gas emissions reduction by using after-treatment technology is the same total exhaust emission plus an additional 10% fossil fuel depletion. Besides, the post-combustion treatment system implies significant investment and operational costs.

The NO_x legislation only applies to newly built vessels. When owners have a choice it is expected that areas with additional NO_x limits will be served with older and less environmentally friendly dredge units.

A similar situation arises for the SO_x reduction by use of scrubbers in the exhaust system. It is clear that this legislation will not lead to a more sustainable situation, neither at local nor on a global level. Furthermore, it will increase the CO_2 emissions, which goes against the IMO EEDI legislation.

Limitations of the IMO CO_2 index

The recent IMO EEDI legislation has been defined and entered into force for some vessel types and the fuel consumption and benefits to the environment are weighted in the form of a CO_2 index. However, the formulas used are too general and only reasonably apply to large ocean-crossing freight vessels. The dredging industry is actively taking part in the discussions about future emissions legislation and defining an alternative CO_2 index for dredging equipment. In this index the specific type and operational characteristics of dredging vessels and projects are included. In short, the index is defined in terms of CO_2 emissions per m^3 or yd^3 dredged soil, depth, sailing distance and soil type.

Figure 6 shows some examples to illustrate how deeply dredging conditions influence the final value of this "index". For example, the required sailing distance for dredging-discharge locations has a very large impact on the total CO_2 emissions per m^3 or yd^3 dredged material. Figure 6 also shows that the use of natural gas has clear benefits, as this fuel has a lower CO_2 emission per Joule, compared to usual fuels (MDO and HFO).

These discussions are still taking place and will hopefully lead to a more appropriate formulation of the emissions legislation for dredging vessels. Legislation for sustainable shipping must consider the whole (eco-) system where humans operate in order to push innovations forward in a beneficial pathway. Therefore, a "systems perspective" (Checkland, 1981) is the right focus – or one will definitely miss important interconnections and only reach local benefits at global higher costs. Natural and also industrial systems are complex and phenomena such as emissions cannot be isolated without leaving out important aspects. By adopting a systems perspective for environmental legislation issues, a sustainable balance among People, Planet and Profit can be better pursued.

Furthermore, emissions to water are also important in dredging. Underwater sound legislation is in development now. Companies like IHC Merwede also contribute actively within the CEDA work group, which published a position paper on underwater sound (CEDA 2011). In addition, research has been carried out on turbidity where IHC Merwede participated in the 'Building with Nature' programme and is now developing

Figure 7. A view of the innovative bulbous bow design, which reduces wave-making resistance.


Figure 8. Left, the traditional hull shape; right, the improved bulbous hull which resulted in 20% lower fuel consumption.

internal knowledge and special equipment to reduce or eliminate undesired turbidity and underwater sound.

TECHNOLOGICAL SOLUTIONS

Proper legislation is one way to push innovation towards sustainability. On the other hand, the industry itself develops and applies clean technology solutions. These developments are not always rewarded in terms of legislation and more in general by the efficiency of the operation of the vessel itself. However, they do contribute significantly to the reduction of emissions per yd^3 or m^3 dredged. A few examples of recent developments show how innovations can boost the overall efficiency as well as reduce emissions.

Hull design

The shape of the hull influences the wave pattern of the ship which finally influences the energy consumption of a vessel at a given sailing speed. This new bulbous bow design, which reduces wave-making resistance, can be seen in Figure 7. In Figure 8 two sister ships are shown. The only difference between both ships is the shape of the hull. As can be seen in the pictures, the ship on the left has a significant higher bow crest. In practice this resulted in a difference of 20% more fuel consumption during sailing than in the ship with the improved hull shape.

Pump design

Over the past years pump designs have evolved significantly. In the late 1990s a first step was made to increase efficiencies from 80% up to 93%. In practice this leads to an enormous reduction in emissions per m^3 or yd^3 of dredged material. With modern tools such as CFD, pumps can be optimised to have a good balance between efficiency, sphere passage, but also suction properties (making higher densities possible). An example is the cutter special pump shown in Figure 9, combining these properties.

Efficient excavation tools

In recent years new excavation tools for both hopper dredgers (such as the wild dragon head, Figure 10) as well as the cutter dredgers (Lancelot cutter and dredging wheel, see Figure 11) has increased production rates in designated soil types. This resulted in a lower use of energy in m^3 or yd^3 dredged material. This cannot be found back in legislation.

Efficient drive trains

Besides the efficiency of the dredge pump, research has also been conducted on innovative and advanced drive systems, considering frequency drives, variable speed generators and energy management systems. These drive systems have each their own energy losses, but together they also create the opportunity to optimise the working points of the total system. This contributes to more efficient drive systems. Even more when it is utilised in the design of shore-powered electrical driven dredges. These innovative drives are highly integrated and have extended workability coupled with high efficiency and low emissions.


Figure 9. The cutter special pump provides a good balance between efficiency, sphere passage, but also suction properties.

Automation

With the introduction of modern drive trains, also a wide range of automation and control systems have been introduced over the past years. Control systems have made it possible to perform relatively complex dredge projects. Interesting examples are the Dynamic Positioning and Dynamic Tracking systems which made highly accurate dredging with hopper dredgers possible. These automation systems also introduced possibilities to reduce fuel consumption as such as production optimisation with Automatic Pump Controllers and Automatic Cutter Controllers.

Figure 10. The wild dragon draghead enables higher mixtures, thus improving productivity.

Alternative fuel sources

Alternative fuels and energy sources also contribute to create solutions. Natural Gas is considered to be a short-term viable alternative to oil-based fuels for the shipping industry. It is plentiful and a relatively cleaner fuel. Research on gas power technology is also being carried out, from the fundamental level of engine modelling to the integration of gas-powered designs for dredging. Longer-term alternatives include hydrogen (Figure 12) and bio-based fuels.

Waste heat recovery and energy management

The possibilities of Waste Heat Recovery (WHR) technologies from the exhaust gasses has also been investigated. About 50% of the energy contained in fuels is lost in the exhaust. WHR systems that have been developed can be integrated in the existing drive trains and contribute to a fuel consumption reduction of 5% to 10%.

Together with Energy Management systems, all the above-mentioned technologies such as advanced drivelines, electric drives, cleaner fuels and waste heat recovery, can add up to significant efficiency improvements and more sustainable dredging operations. This research on the integration of post-combustion exhaust gas treatment systems, such as SCRs and Scrubbers, offers clients alternative power management systems.

Emissions to water

Emissions to water have also been addressed over the past years. Equipment suppliers have participated in discussions and measurement campaigns and recently published a joint position paper on underwater sound (CEDA, 2011), low spill equipment such as environmental cutter heads, low turbidity equipment, IHC's environmental valve and alternative overflow system and advanced design of overflow positioning to optimise settling in the hopper and minimise turbidity emissions through the overflow. Also a selection of alternative hydraulic oils and lubricants that are more environmental friendly was published.

Recently the so-called Waterhammer® has also been developed in which the hydraulic fluid is replaced by seawater. It is also

Figure 11. Lancelot cutter increases production, and thus lowers energy use per cubic metre dredged material.

Figure 12. Testing Hydrogen as auxiliary fuel supply during the trial of the IHC Beaver 40.

equipped with a Noise Mitigation that considerably reduces noises and eliminates the risk of oil spills and minimises noise disturbance during foundation laying at sea.

The above-mentioned developments are a selection of new technologies that contribute to cleaner and more sustainable dredging and offshore operations. Although these often require additional financial investments, the return-on-investment is relatively shortened as a result of lower fuel costs and emission fees.

Dredging takes place in a global market and it is important that the legislation supports the development of clean technologies in a level-playing global field. Technology suppliers must contribute their part in technology development and innovation and must actively participate in the development of standards and legislation.

OPERATION AND PROJECT MANAGEMENT

A dredge vessel is a typical work-boat in which performance is not only defined by the sailing properties, but also by the use of the dredge equipment and systems as installed onboard. This introduces an additional human influence on the performance of the machine itself. This means emissions in practice cannot be defined by a nominal calculated output but, moreover by the use of dredgers in practice. A competent crew will strive to operate efficiently focussing on both production (and uptime) and cost.

Training

One way to enable the crew to get the most out of the dredging vessel is by continuous education. In the field production improvements can be reached by proper training of crew and project management. During simulator trainings on a cutter simulator by the Training Institute for Dredging, operators were shown the impact of their behaviour on both production and fuel consumption simultaneously. This awareness leads not only to the optimisation of the control parameters (such as pump speed, step size, and so on), but also to a more fluent and efficient operation.

As a small example: if a dredge operator can improve the stepping forward handlings with a cutter dredger, this in principle does not influence the nominal production settings such as flow, cutting speed and so forth. But when the operator is able to perform the procedure as fluently as possible and thus reduces this "stepping time", the overall efficiency can be improved significantly.
This awareness is important for operators, but also for the shore-based project management that in the end decides where and how a dredge unit is going to be used. This applies not only to the production rates but also to wear and tear and fuel consumption.

Legislation

Finally, the emissions of a dredger are not only defined by the dredging installation, local circumstances and the crew, but also by the legislation itself. Legislation to restrict environmental impacts, such as turbidity and noise, is likely to influence efficiency and emissions.

CONCLUSIONS

Legislation is a necessity and is essential to push forward further clean technologies. However, adjusting technology to new legislation does not by definition result in a lower energy consumption and environmental impact. When designing legislation, a system-based perspective approach, where the interconnections of all elements in the industrial and natural systems are taken into account, is the right focus. For dredging, a large contribution can be achieved by focussing not only on the emissions per kW, but on the total energy consumption per dredging project or per m^3 or yd^3 of dredged material. This contribution is often not regulated but has an enormous influence on the actual sustainability of the dredging process.

A higher sustainability in the dredging project can be reached technically by optimising the dredger as well as by proper operation and project management. Shipbuilders such as IHC Merwede are continuously developing cleaner alternatives and more efficient dredging, mining and offshore applications for addressing the challenges of a clean and lean dredging process in the future. They also actively participate in the development of legislation and standards in order to contribute to a global level-playing balance between technology and sustainability that truly benefits nature and humans.

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