# Green Technology Impact Reduction through use of Energy Efficiency Technology


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**ABSTRACT**

Due to legislation and statute, ship owners and operators are increasingly required to fit "Green Technology" equipment to their ships that, whilst important with respect to benefitting the environment, do not provide any obvious economic benefit (other than, for example, not limiting the potential areas of operation due to non-compliance with the requirements to enter various Emission Control Areas (ECAs), etc.). Examples of such equipment include: ballast water treatment plant, sulphur oxide scrubbers and nitrogen oxide selective catalytic reduction plant.

This paper looks at areas of opportunity where energy efficiency technologies, such as various waste heat recovery devices, frequency drives, etc., can be employed to minimise the engineering impact of "Green Technology" equipment integration and to provide ship owners and operators the potential of reduced through life costs to outweigh the costs associated with such retrofits. This will have the benefit of incentivising the owners to fit the "Green Technology" equipment and systems and even adopt it early in order to maximise through life benefits whilst badging their companies with a "green operator" status with the associated good publicity.



*Key Words: Retrofit, ensuring compliance, green technology, Energy efficiency technologies, ballast water management (BWM), ballast water treatment (BWT), SOX scrubbers, NOX Selective Catalytic Reduction Plant (SCRs), energy recovery, waste heat recovery*.


## 1. INTRODUCTION & BACKGROUND

Reducing the impact of shipping on the environment directly through environmental protection or, more, indirectly by reducing the energy consumption (largely fossil fuel derivatives) is, rightly so, driving technical developments in the shipping industry. Unfortunately, environmental protection and the energy efficiency of a vessel do not always go hand in hand.

Environmental protection legislation invariably results in the fitting of equipment either on board a ship or in a land based facility to treat the waste products of processes on board ships, and more recently to inhibit the movement of viable organisms which could damage other ecosystems. Put simply, the addition of equipment requires space and power for it to be operated, and also adds to the overall weight, which will likely reduce the overall efficiency of a vessel.

The addition of Chapter IV to IMO MARPOL Annex VI has introduced the need to manage ships' energy efficiency through the design & construction phase, and through life. The requirements are embodied in two forms:

- The Energy Efficiency Design Index (EEDI), captured in Ref. 3 (IMO, 2011), which is concerned with benchmarking the efficiency of the Ship design against other similar vessels;
- The Ship Energy Efficiency Management Plan (SEEMP), captured in Ref. 4 (IMO, 2012), which is concerned with managing energy efficiency of the Ship through life.

The SEEMP can be seen as a tool to aid operators in the efficient operation and management of the Ship. The SEEMP shall support the energy efficiency goal setting in order to meet overarching energy efficiency targets and/or the reduction in annual fuel consumption.

The SEEMP needs to be present on board of all ships (from Jan 2013), and the content should be written in accordance with IMO Guidelines (it is worth noting that it is not currently a requirement to demonstrate incorporation of IMO Guidelines in the SEEMP).

The IMO has also provided guidance to ship operators to support the reduction of Greenhouse Gas (GHG) emissions in the form of the Ship Energy Efficiency Operational Indicator (EEOI), as captured in Ref. 5 (IMO, 2009).

Compliance with environmental legislation impacts a number of ship egress points. However, the main areas where new statute is impacting concern the reduction in air pollution and the control of harmful aquatic organisms in ballast water. Equipment which has to be retrofitted to gain compliance with such legislation places significant burden on the ship and this paper demonstrates how the impacts to vessel energy efficiency by installing air pollution reduction and ballast water treatment equipment may be alleviated by retrofitting additional and complimentary energy efficiency equipment and systems, and not to look at the issues concerning environmental protection and energy efficiency in isolation.

This paper introduces the retrofitting of simple solutions and concepts which have been proven to reduce fuel consumption, either directly or through the reduction in power consumption, to ease the impact of Green Technology operation.

## 2. ENVIRONMENTAL PROTECTION AND ENERGY EFFICIENCY REQUIREMENTS

This paper discusses the impacts that recent changes in environmental protection legislation have had for efficient operation in shipping, however this is not the first case in which efforts to improve efficient operation have been retarded by legislation.

The introduction of the compound Tributyltin (TBT) in anti-fouling products provided more cost effective means for utilising anti-fouling systems at the time, and therefore helped more efficient shipping operations. Use of anti-fouling paints containing TBT has since been prohibited by the IMO due to detrimental impacts observed and linked to the use of TBTs. Alternative anti-fouling systems and operations are available, but it is understood these alternatives deliver performance at a higher cost to the operator, and therefore the end consumer of the product.

### 2.1 STATUTE AND LEGISLATION

IMO MARPOL Annex VI and related MEPC resolutions regulate airborne pollution (notably Sulphur Oxides (SOx), Nitrogen Oxides (NOx) and particulate matter) in Emission Control Areas (ECAs) which are associated with specific protected sea areas. The regulations control the content of emissions but also the fuel oil products used on board.

The simplest way to reduce the emissions of a vessel is to reduce the mass of fuel consumed. The EEDI benchmarks vessel types to force new build vessels to integrate energy efficient equipment and systems to achieve a specified energy efficiency level. The flexibility in how the energy efficiency level is met is down to the ship designer and owner and also what industry can offer. An intelligent ship designer should also take cognisance of the likely future trends in energy efficiency and what aspirations the ship owner may have and will include in their SEEMP to best support future vessel improvements whilst providing cost effective vessel acquisition. It should be noted that Ref. 3 states that Regulations concerning EEDI (Regulation 20 & 21) “shall not apply to ships which have diesel-electric propulsion, turbine propulsion or hybrid propulsion systems.”

Ref. 2 (IMO, 2017) confirmed agreement on the implementation dates of, and therefore compliance to the International Convention for the Control and Management of Ships' Ballast Water and Sediments, more commonly known, and herein referred to as the BWM Convention (BWMC) (See Ref. 8 (IMO, 2004)). The whole ship impact of the BWMC and its relevance to vessels has been widely discussed (See Ref. 7 (Fearnley, 2017)) but, put simply, for all vessels which BWMC is applicable; a Ballast Water Treatment System shall be installed and operated in accordance with an approved Ballast Water Management Plan from circa 2024.

### 2.2 UNITED STATES SPECIFIC

The United States adopted IMO MARPOL Annex VI through the Act to Prevent Pollution from Ships (APPS), and the collaborative working between the Environmental Protection Agency (EPA) and United States Coast Guard (USCG) enforce the requirements of MARPOL in the North American and United States Caribbean Sea ECAs. In addition to vessels operating in US waters, engines on US vessels are also be subject to additional environmental protection requirements through the Clean Air Act.

The United States requirements for control of invasive organisms in Ballast Water largely align with the IMO BWMC; however two significant differences are discussed here:

1. The USCG issued rules for the management of Ballast Water which are in force now for all new builds and existing ships who want to discharge ballast water into US Water;

2. The USCG rules require USCG approval for BWT systems, which need to demonstrate that all but a very small number of organisms which are discharged into US waters are dead, as opposed to IMO BWMC which requires all but a very small number of organisms are not viable (capable of surviving or reproducing).

As a result of point 2 above, at present, only a small number of IMO approved systems are also approved by the USCG. It requires considerably more energy for a BWT System to render organisms dead in the BWT testing process; therefore, BWT systems which have been designed to ensure organisms are not viable (in accordance with IMO testing), and optimised against ballast capacity, now may need to be redesigned to deliver more “destructive” power to the potentially invasive organisms.

## 3. EQUIPMENT FOR ENVIRONMENTAL PROTECTION COMPLIANCE

### 3.1 CUSTOMER CONSIDERATIONS

Compliance with environmental protection statutory requirements should be reviewed at a fleet level to ensure that any changes made are necessary and the most cost effective for achieving environmental protection compliance, but also delivering energy efficiency and therefore economic performance for the fleet.

The factors below are some example considerations that should be made across the fleet:

**Table 1: Fleet Considerations for Environmental Protection and Energy Efficiency Compliance**

| Factor | Question |
|---|---|
| Operating Profile | Can a reduction in average vessel speed and therefore fuel consumption and the resultant reduction in emissions be traded for voyage time?<br>Can an increase in average vessel speed be traded for reduction in ballasting rates to reduce the size of BWT system? |
| Operational Areas | What proportion of fleet vessels operate between different international and territorial waters?<br>Can voyages to the US be consolidated to a smaller number of vessels to limit the extent of USCG approved equipment and systems required?<br>What levels of UV transmittance (and therefore BWT performance) are expected?<br>Will the vessel operate for elongated periods in Fresh Water? |
| Fuel Type | Is it more cost effective to operate using low sulphur[1] fuel or provide exhaust gas cleaning systems to achieve emission regulations for SOx? |
| Vessel Longevity | Is it more cost effective to retrofit vessels to comply with applicable legislation or does it better suit the company’s business plan to invest in new vessels? |
| Port Infrastructure | Do ports have the necessary infrastructure to support the ship whilst moored (i.e. cold ironed), and can BWT be managed through off board systems? |

### 3.2 SHIP IMPACTS OF BWT RETROFIT

Considering a Ship with single ballast system, provided with two ballast pumps with combined capacity 600m$^3$/hr, the following space, weight and power demands for the integration of a UV type Ballast Water Treatment plant could be expected (figures based on review of broad range of IMO approved systems):

1. The sulphur limit for fuel oil consumed will be reduced from 3.5% to 0.50%. This limit will come into force from 1 January 2020, as discussed in Ref. 1 (IMO, 2016).

**Table 2: Space Weight and Power Impacts of a nominal 600m³/hr Ballast Water Treatment Plant**

| Space ($m^3$) | Weight (kg) | Power (kWe)[2] |
|---|---|---|
| 21.5[3]:<br>4100mm(L) x 2500mm(H) x 2100mm(D) | 2250 | 50 (Normal)<br>60 (Backflush) |

More often than not, an existing ballast pump specification will be closely matched to its system operating point to run efficiently. It will therefore have little scope in its capability to deliver the increased head (at the rated flow) for integrating BWT. In addition, backflushing operations require significant differential pressure across the filter which in many cases would drive the specification of a ballast pump's discharge head above that of normal BWT operations. In most cases, one of the options below would provide the most economical solution:

- Replace existing ballast pumps which have ability for both normal and backflushing operations;
- Provide the differential pressure across the BWT filter with a dedicated backflush pump.

For the example considered above, the BWT plant is provided with a dedicated backflush pump. In this particular example the backflushing process will increase the peak BWT plant electrical power by 10kWe, which is approximately 20% of the total power consumed during a backflush operation.

In addition to providing the power to integrate BWT Plant (and integrated backflush pump), to overcome the additional system pressure losses from the integrated BWT Plant and deliver the same flow rate, Ballast pumps would be expected to deliver an additional 10m discharge head, notwithstanding any additional frictional pressure losses associated with the integration of the Ballast Water Treatment plant, which could be in the order of another 10m additional discharge head.

A Ballast pump rated at 300$m^3$/hr with original discharge head of 15m would almost certainly need to be replaced to deliver 300$m^3$/hr and a new discharge head of 35m. If the retrofit engineer is fortunate, the change to the pump to deliver the increased performance may not necessitate a change in pump casing, however a larger motor and starter will be required. For such an increase in performance an indicative power demand increase for the ballast pump set will be in the order of 64kW[4].

For the BWT Plant integration retrofit, the Space Weight and Power (considering backwash operations) impacts for the major items, for the example discussed above, would be as follows:

| Space ($m^3$) | Weight (kg) | Power (kWe) |
|---|---|---|
| 21.5 | 2330 = 2250 + 80 | 114 = 50 + 64 |

For this nominally sized ballast system, which would be considered small compared to the capacities required of large commercial vessels; these are sizeable integration impacts, especially the challenge to provide sufficient power to the potential connected load. Further detail of the complexities and impacts in retrofitting BWT can be found in Ref. 7 (Fearnley, 2017).

To put the Ship Impacts into better context, an assumed reference vessel and operating profile will be used. Here we will consider a ship with the below principal particulars:

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2. Power consumption considered is worst case, which are ballast operations in water with low UV Transmittance.

3. BWT Plant considered to have an installed envelope of 4100mm(L) x 2500mm(H) x 2100mm(D).

4. Pump and motor power calculations based on a pump efficiency of 65% and a motor efficiency of 80%.

**Table 3: Assumed Reference Vessel Principal Particulars**

| | Value |
|---|---|
| Type | Container Carrier (~14000 TEU including 800 which can be reefer) |
| Maximum Speed | 24knots (100% MCR) |
| Economical Speed | 14-15 knots |
| Main Engine | 1 x 80080 kW Two-Stroke engine; with Fixed Pitch Propeller |
| Power Generation | 4 x 3.8MWe Diesel Generators |

The above reference vessel will perform the below assumed voyage, considering a return trip from North Europe to Asia:

**Table 4: Assumed Nominal Ship Voyage**

| | Value |
|---|---|
| Duration | 75 days |
| Number of Ports | 14 |
| Average Port Stay | 20 hours |
| Total time in Suez Canal | 30 hours (2 passes) |
| Journey Distance | 22500 miles |

Based on the above voyage and considering all Reefer electrical connections are operational, and assuming an even allocation of frozen and chilled containers which consume on average 8kW per container, the following Main Engine and Diesel Generator (DG) loadings are assumed:

**Table 5: Assumed Main Engine and Diesel Generator Loadings**

| | In Port (alongside)[5] | Suez Canal | In Transit |
|---|---|---|---|
| Main Engine Average Loading | 0% | Considered same as ECO transit | 50% (approx. 40% for ECO transit) |
| Diesel Generator Average Loading | 82% (3 DGs) | 82% (3 DGs) | 82% (3 DGs) |

Table 5 includes the ME operating mode referred to as ECO Transit. The reference vessel has a defined reduced engine speed to provide economical ship speeds and improved fuel efficiency.

It has been considered that the Diesel Generators are more likely to be more highly loaded on the return journey due to the change in the type of containers, however for the purposes of this analysis this difference is considered negligible for the comparisons that are drawn. In addition, it is assumed that the portion of fuel consumed by the ME in harbour, for slow turning operations, can be considered negligible.

5. No shore power supply available

For the retrofit of a BWT system into the reference vessel, and replacement of ballast pumps in the ballast system which is assumed to be in the order of 1500m$^3$/hr as it is used predominantly for vessel control, the change in peak power demand alone will be or the order of 285kW, or a change in DG loading whilst in port of approximately 3%.

Assuming the Ballast system has an average utilisation factor of 50% whilst in port, per voyage, this would equate to an additional ~2100 USD in fuel cost for operating a BWT plant, assuming Rotterdam bunker price (Ref 17).

## 4. OFFSETTING THE IMPACTS OF FITTING GREEN TECHNOLOGIES

In this section we discuss some options that are available in retrofitting complimentary equipment and systems to recover and potentially increase the overall ship efficiency following Green Technology installations.

### 4.1 ENERGY RECOVERY FROM COMBUSTION PROCESS

One of the most abundant sources of heat energy on a Ship is the main engine exhaust, and can provide some of the greatest gains in energy recovery on board. For this reason many ships are fitted from build with exhaust gas economisers / boilers to generate steam to drive a steam turbine generator, supplementing the power generation plant of the vessel, which helps improve the energy efficiency and therefore, lowers the operating costs of the platform.

Engine manufacturers can offer waste heat recovery systems to provide significant energy savings. For example, Wärtsilä offer a waste heat recovery plant which can recover energy from the exhaust gas stream without impact on the engine power. A concept based on the Wärtsilä Waste Heat Recovery plant is shown below:

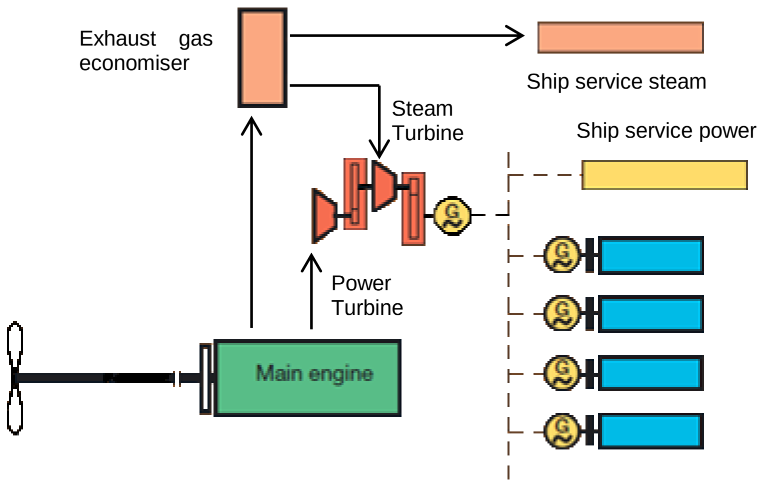



Figure 1: Example Waste Heat Recovery Plant Arrangement

(Based on arrangement in Ref. 9 (Wartsila, 2007)

Wärtsilä claim that the Waste Heat Recovery plant can provide electrical power regeneration of up to 9.8MWe at 100% MCR (considering the same engine as the reference vessel). For the reference vessel, this could mean that when in transit at high main engine loads, maximum waste heat based electrical regeneration can be achieved such that the ship service DGs may not be required.

A waste heat recovery plant which can provide such magnitudes of power generation comes with some drawbacks, not least its size and weight, making retrofit integration of such plants challenging. Nonetheless, exhaust gas heat recovery systems on a smaller scale could still provide a cause worthy benefit to reduction in fuel consumption.

Ref. 6 (Fearnley, 2014) discusses the integration aspects of exhaust gas heat recovery in greater detail, albeit with greater emphasis on new build Naval platforms, but the platform and support impacts are fundamentally the same.

There is currently no requirement to retrofit SCRs on existing ships, with the statute only being applicable to new tonnage. It is likely that if an economiser could have been installed at build along with an SCR as required for entering Emission Control Areas (ECAs) it would have been; and therefore it is unlikely to be worthwhile investigating whether such technology can be retrofitted if it is not there. However, should statutory requirements change in the future necessitating SCRs to be retrofitted to existing ships fitted with an economiser, it is likely that there will be little scope to install the SCR upstream of the economiser where it will need to be installed (as high inlet temperatures to the SCR reactor are essential). Therefore, the issue in this case will be whether the energy efficiency system (the economiser) can be retained when designing for the integration of the SCR. This may also have an impact on the baselined EEDI of the ship if she was built after that regulation came into force.

## 4.2 EFFICIENT ENERGY CONSUMPTION IN CENTRAL COOLING PROCESSES

Cooling systems on board ships are often sized against the most onerous design condition, such as maximum external ambient and sea water (SW) temperatures combined with maximum engine loads. In reality, many platforms do not operate for extended periods in such operational conditions. Cooling systems which operate on a constant flow, with single speed pumps, are considerably cheaper to purchase than multi or variable speeds systems due to a greater level of technology complexity and control system integration, and as such historically have been chosen for many cooling duties.

With greater focus on the energy efficiency of the platform, and the requirement for Ship Owners to integrate Environmental Protection technologies which increase fuel consumption, it is time to look more closely at variable flow cooling systems to provide better through life energy consumption. In this section the paper will focus on how retrofitting variable speed pumps for sea water cooling duties can help recover some of the energy consumed by Environmental Protection technologies.

For the reference vessel main engine provided with fresh water cooling circuits, the central cooler will require a sea water flow of approximately 2590m$^3$/hr with inlet and outlet temperatures 32°C and 50°C respectively. Assuming that such a pump has 2.5 bar total head, this equates to constant power consumption in the order of 345kW.

Considering the assumed operating profile, regardless of the time of year sea water temperatures will not be as high as 32°C for the entire voyage. Therefore, without regard for engine loading, there is conceivable benefit for employing variable speed cooling pumps to maintain the heat removal via the central cooler from the fresh water cooling circuits. The graph below demonstrates how the sea water cooling flow could be varied according to the external sea water temperature to maintain constant heat transfer, noting there may be changes in the heat transfer efficiency of the central cooler as the sea water flow reduces:

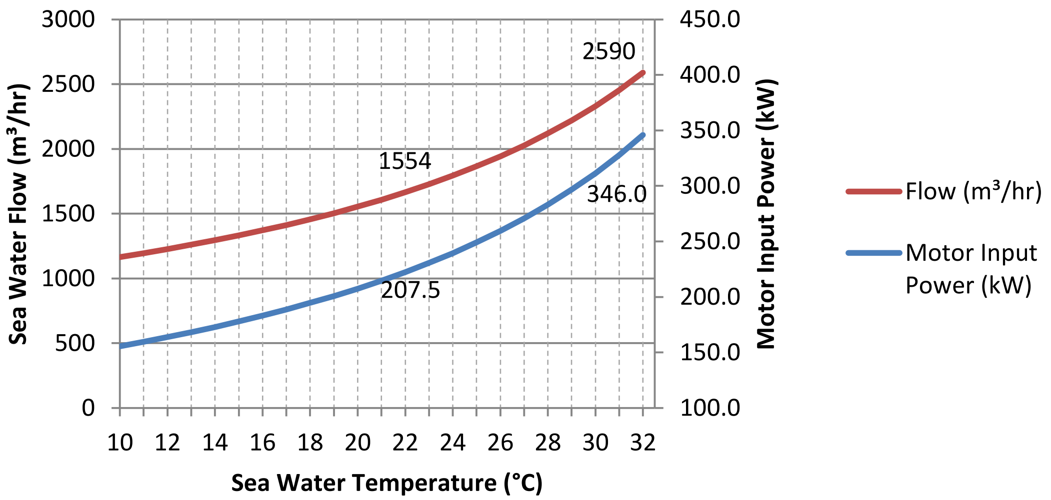



Figure 2: Demonstration of Opportunity for Variable Sea Water Flow against Sea Water Temperature

Assuming an average sea water temperature of 20°C[6] for the voyage, having the ability to vary the flow of the sea water central cooling pumps could save on average up to 135kW. For the transit duration of the nominal voyage considered for this reference vessel, this could equate to a saving in fuel cost over 10k USD (calculated in accordance with Ref. 17).

A similar analysis for variable flow cooling applied to the DG SW Cooling systems, using an average sea water temperature of 20°C for the voyage, would yield similar savings, in the order of 175kW. The resultant fuel consumption reduction could lead to a monetary saving in the order of 17k USD (calculated in accordance with Ref. 17).

Variable speed drives could also be utilised to vary flow rate according to main engine loading and therefore the heat rejected to the fresh water cooling circuits. Assuming a linear change in heat rejected to the fresh water cooling circuits, the required sea water cooling flow for the main engine loading for the ECO / Suez Transit operating mode would be approximately 1050m$^3$/hr, and the sea water central cooling pumps would be drawing up to 200kW less than when the main engine is operating at full load. For the operating profile considered, this could provide savings of around 1.3k USD for the Suez Transit alone.

Savings associated with the power consumed for the sea water central cooling system would be significant for transit at a lower 'ECO' MCR loading, however this would need to be analysed at a whole ship level to understand ship wide fuel savings associated with lower equipment loading and a greater number of operating hours per voyage for the same route.

Pump manufacturers are pursuing the supply of intelligent cooling systems to provide better overall system efficiency by delivering a cooling flow rate based on actual real-time heat rejected from prime movers. One example of such a product offering is OptiSave™ from DESMI, whose main components are as follows:

- Sea Water Cooling pump and motors;
- Frequency converters;
- Fresh Water and Sea Water Temperature Indication;
- Sea Water Pump Pressure Indication.

Retrofitting variable speed cooling and control is relatively un-intrusive for existing systems. The major change items are the pump motors, the associated frequency drives and their control system. It may be possible to re-use existing pumps so long as the pumps' operating curves are suitable for the estimated cooling demand profile. It is also likely today, with the trend towards reduced manning, that remote indication and monitoring for many key system parameters such as temperature of the fresh and sea water cooling systems will already exist within the system.

The integration of such a variable speed drive control and monitoring system can also interface with platform control systems which could enable real time reporting of system performance and energy consumption in the Engine Control Room and even the Owner's shore side offices.

A case study for the retrofit of the DESMI OptiSave™ system onto the LPG Tanker "Victoria Kosan" (based on discussion with DESMI, Ref. 10), which has 39kW sea water cooling pumps and operates with an average sea water temperature of 23.5°C, documents the OptiSave™ system providing accumulated savings of 66% in a 3 month period, with an estimated payback period of just one year.

### 4.3 EFFICIENT ENERGY CONSUMPTION IN CHILLED WATER PLANT OPERATIONS AND COOLING WATER SUPPLIES

The philosophy for variable speed cooling can equally be applied to other sea water cooling systems. Savings can be realised by retrofitting a Chilled Water Plant cooling system with a variable sea water flow arrangement.

A typical simple cooling control installation will include a single speed sea water pump with thermostatic control of the sea water outlet temperature. More efficient control of the refrigeration system would involve head pressure control, which can also be performed using a single speed pump

6. An assumption for a voyage between Northern Europe and the Far East. Average figure aligns with that observed by DESMI customers making the voyage described for the reference vessel above.

but the degree of cooling water diverted overboard is controlled to maintain a refrigerant head pressure set point at the condenser. In both arrangements there will be many instances where the load on the chilled water plant will vary significantly and savings should also be made in the supporting cooling system.

Considering a nominal Chilled Water Plant with 750kW capacity and maximum condenser sea water flow of 175$m^3$/hr (based on maximum sea water temperature of 32°C), the profile of required condenser sea water flow against sea water temperature will similar to Figure 3.

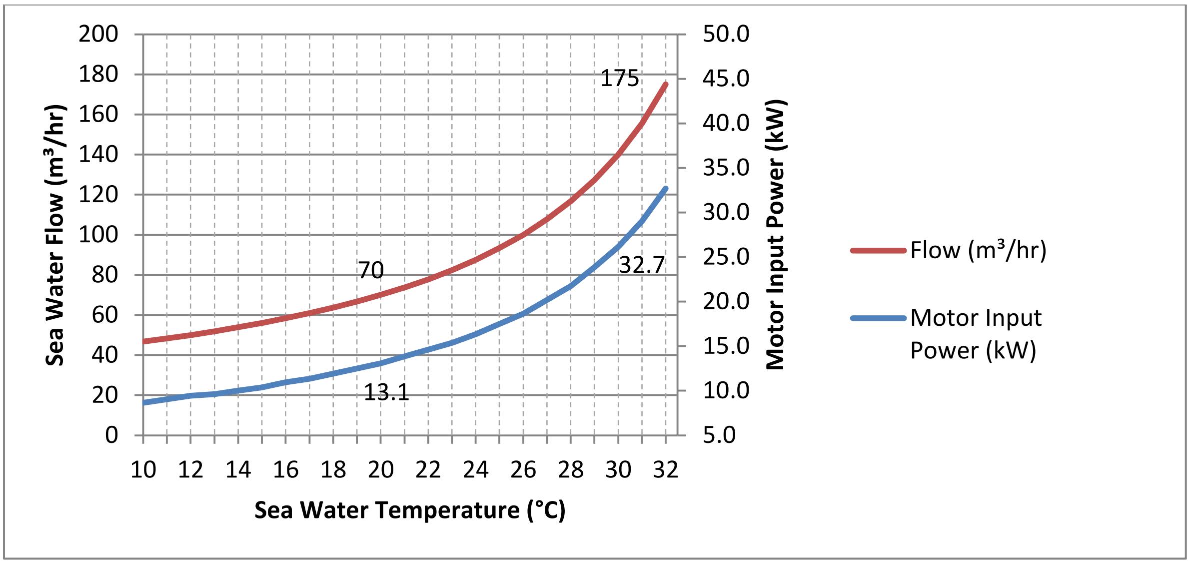



Figure 3: Variable Sea Water Flow against Sea Water Temperature for Nominal Chilled Water Plant load of 750kW

As with the main engine sea water cooling analysis, assuming an average sea water temperature of 20°C for the voyage, having the ability to vary the flow of the chilled water plant sea water cooling pumps could save on average up to 20kW, which could be up to 1.9k USD savings associated with fuel consumption. In reality, the savings in sea water power consumption could be greater than this: if on average the sea water temperature is circa 12°C lower than the design condition, the chilled water plant load would be lower due to an average atmospheric temperature, requiring even less condenser cooling than considered in this simple analysis.

## 4.4 HEAT ENERGY RECOVERY IN SEPARATION PROCESSES

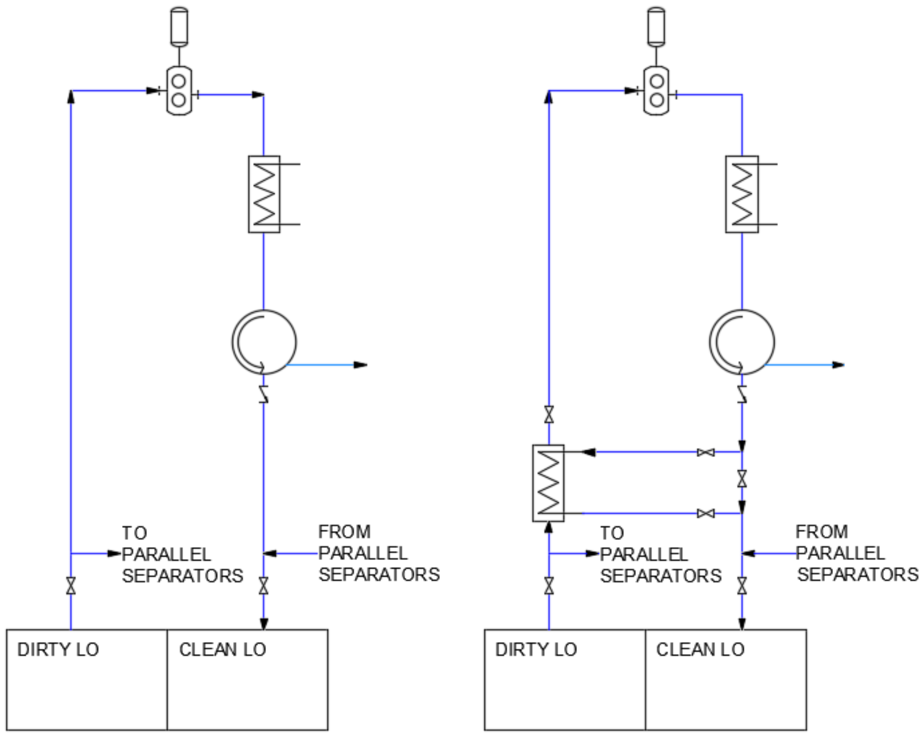
Effective separation of fluid mixtures, including unprocessed bilge water, Lubricating Oil (LO) and Fuel Oil (FO) bunkers, most commonly involves the heating of the unprocessed liquid to aid the separation of the different elements present. In many cases, the heat energy in the liquids which are discharged from the separator is pumped overboard or dissipated when the liquid returns to a tank.

For bilge water treatment processes, the integration of a heat exchanger to recover the heat energy in the discharged bilge water to pre-heat the flow of unprocessed bilge water is relatively simple, so long as the system still provides sufficient Net Positive Suction Head Available (NPSH(A))[7] for the bilge water pump. Some manufacturers, such as Alfa Laval, can offer heat recovery systems (utilising a plate heat exchanger) with the supply of a bilge water treatment system, and claim reductions in heating energy of over 40%. The power consumed by a bilge water treatment plant is not significant, but this is proof that the integration of simple heat recovery devices can provide energy savings.

Scaling this concept for energy recovery up, there is the potential for more significant energy recovery when considering the heat input to Lubricating Oil and Fuel Oil separation processes. Suppliers should be able to provide options such as heat recovery in the separator package, showing it is possible to integrate a simple heat exchanger into existing purification systems.

7. Net Positive Suction Head available is a measure of the pressure available at the pump inlet, and must be greater than Net Positive Suction Head required by the pump to avoid cavitation.

A typical single separator purification system is shown in the figure below, detailing how simple it can be to integrate a heat exchanger to transfer heat recovered from the processed (clean) to the unprocessed fluid (dirty), to minimise the amount of energy wastage through dissipation in the ships tanks.




a. Before waste heat recovery retrofit  b. After waste heat recovery retrofit

Figure 4: Heat Exchanger Retrofit into Purification System

For the main engine support systems of the reference vessel above, the LO and FO purification systems will need to be sized for approximately 11215 litres / hour for LO and approximately 16435 litres per hour for FO to meet manufacturer's specifications.

With regards to heat recovery from the FO purification system, any heat energy removed from the processed FO to pre-heat the unprocessed FO will lead to a reduction in the power consumption of the FO separators for heating, however this is likely to result in an increase in heating demand within the FO service tanks, as the FO is to be maintained at around 60 degrees centigrade. There may be benefit in using heat recovery in the FO purification system, however the payback period will be significantly larger than that for the LO purification system, therefore for the purpose of the analysis in this paper it is discounted.

Based on engine manufacturer specification separator heaters in the purification systems will be utilised to raise the LO temperatures from approximately 45 to 90 degrees centigrade, which at rated capacity will require approximately 265kW. Heat recovery from the processed fluid could be up to 90% (taking into account fouling losses); however such heat exchangers are likely to be significant in size and weight making their physical integration for retrofit difficult. Heat recovery of 40% processed fluid energy (as with the bilge water treatment plant) is considered to provide an optimised heat exchanger size, in terms of spatial integration, cost and heat recovery, and would reduce the separator heater power consumption by over 100kW. For reference vessel and the considered voyage, assuming separation is performed using electric heating, this could be a fuel cost saving in the order of 9.5k USD.

To process the significant purification flow for the main engine of the reference vessel, it is assumed that 4 separators would be provided. For the purpose of effective separator heater control, it is expected that a heat recovery heat exchanger would be provided for each separator within the pipe leading to and from each specific separator.

## 4.5 ENERGY RECOVERY THROUGH REUSE OF WATER

The advancement in sewage treatment processes has enabled ships to discharge processed wastes closer to shore, as a result of the discharged products being much 'cleaner'. Some sewage treatment plant manufacturers even state it is possible for the effluent water to be re-used within the ship as technical water. If the effluent quality is suitable for being recycled into technical water from the fitted sewage treatment plant, it is conceivable for some small system modifications (to pump the effluent water to a technical water storage tank) there would be fuel consumption reduction in reducing the operating hours from the desalination plants as there is a lower overall water production requirement, assuming the ship has separate domestic and technical water production plants.

## 4.6 ENERGY USAGE REDUCTION THROUGH IMPROVEMENT IN POWER QUALITY

Retrofit of variable speed drives and other non-linear loads (such as LEDs) to reduce the aggregate power consumption of ship systems will induce harmonics to the power distribution system. Before this is performed, the current power quality of the electrical distribution network should be known, including the nature of the present connected drives to understand the compatibility with any new potential variable speed drives, as the presence of harmonics may impact the performance or even damage other equipment.

Regardless of whether variable speed drives already exist or are to be retrofitted, improvement in power quality can yield improvement in operating costs through the reduction in equipment degradation and/or malfunction. Active management of power quality has been proven (base on two different projects discussed with Withington S (DESMI), ref. 10) to translate improved Total Harmonic Distortion (THD) (THD current (I) has greatest opportunity for yield as it is not regulated by class, unlike voltage THD) of the electrical distribution system into reduction improvement in equipment efficiencies and ultimately generator load.

## 4.7 ENERGY USAGE REDUCTION THROUGH EDUCATION AND INTELLIGENT SUPPORT

The SEEMP guidelines advocate raising awareness and providing necessary training for personnel both on-shore and on-board. The ship can be provided with energy efficient technologies, but if the crew do not understand how the equipment is operated, or are not provided with the right training to correctly operate and maintain the equipment, the ship's energy efficiency calculated on paper cannot be realised, or maintained. From the results of Ref. 16 (Banks et al ,2014), it is apparent that within the industry, the rate of effective training provided to ships' crew is not necessarily keeping up with the evolution of energy efficient equipment and their safe and effective operation and maintenance.

To compliment the training provided to the crew, and the investment in energy efficient technologies to improve platform fuel consumption, it should be possible to monitor the use and performance of systems to track real energy consumption. System performance indicators should be monitored and the data analysed and tracked to understand any trends in energy consumption against operating profiles. This data can be used to inform the way in which a system is operated to reduce energy consumption but potentially reduce wear on equipment and extend maintenance periods – reducing company operating costs. Further, Ref. 15 (Pehliven, 2000) suggests that if energy conservation techniques are applied over a long period and across a number of different platforms, incentives given to the ships' crew to operate the platform in a more energy conscious way can lead to a change in operator behaviour, and ultimately lead to fuel consumption reductions in the order of 10 to 15% for diesel and gas-turbine ships.

Monitoring the trends of equipment performance and associated power consumption can also help inform the assessment of equipment condition and fleet time maintenance requirements. The ship owner can use this data to understand whether a replacement piece of equipment which would operate more efficiently and therefore be more cost effective than the equipment it is replacing.

BMT SMART offer the SMART$^{VESSEL}$ and SMART$^{FLEET}$ system solutions which capture system data and provide analysis in real time or against historical data (Ref. 14), as well as validating and benchmarking the results. The acquired system data is combined with external environmental data (such as wind, waves) and automatically processed for a number of different performance parameters, as defined by the ship owner. The programmes provide visualisations of key indicators and trends on board and to the ship owner's shore side offices as required.

## 5 CONCLUSIONS AND RECOMMENDATIONS / FURTHER WORK

Ships owners need to accept that, in order to meet the statutory obligations, Green Technologies will need to be retrofitted and operated. Ship owners will also, naturally, be looking at opportunities to reduce operating costs to improve the fleet performance and sustainability of the business. Unfortunately the two do not always go hand in hand. However, with intelligent investment the ship owner can maximise their opportunities to mitigate the impact of installing the necessary Green Technologies.

With respect to the case study detailed in the main body of this paper, the table below shows that, when considered across the entire reference voyage duration, the additional fuel consumption associated with the operation of the BWT plant can be outweighed with a number of the technologies discussed in this paper. In addition, the opportunities provided through the selection and retrofit of a combination of energy recovery and energy efficiency systems can overcome potential issues of generator overload associated with power hungry Green Technologies.

**Table 6: Green Technology versus Energy Recovery Enhancement Retrofits**

| | Green Technology Impact | | Energy Efficiency Improvement | |
|---|---|---|---|---|
| | **Power Consumption (kW)** | **Voyage Cost (k USD)** | **Power Consumption (kW)** | **Voyage Cost (k USD)** |
| Ballast Water Treatment | +285 | +2.1 | | |
| Separation Heat Recovery | | | -100 | -9.5 |
| ME Central Cooling SW Pump Variable Speed Drives – Water Temperature | | | -135 (average) | -10 |
| DG Central Cooling SW Pump Variable Speed Drives – Water Temperature | | | -175 (average) | -17 |
| - Engine Loading in Suez Transit | | | -200 | -1.3 |
| Chilled Water Plant SW Pump Variable Speed Drives – Water Temperature | | | -20 (average) | -1.9 |
| Sum - Harbour | 285 | | -295 | |
| Sum - Voyage | | +2.1 | | -39.7 |

Of course there will be additional costs associated with the purchase, installation and through life support of equipment retrofitted to increase the energy efficiency of the platform, but most of the changes considered here use simple and proven technologies, and therefore should already be familiar to the crew. As such, there should be minimal additional outlay to train staff and develop maintenance plans for the retrofitted energy efficient equipment.

Intelligent operators may already provide a good deal of training and incentive to their employees, and significant cost savings may already be achieved through the company's management plans. Regardless of its current effectiveness, it is suggested the ship owner should ensure that education and incentives for ship's staff is addressed through the SEEMP, and continually reviewed to maximise its benefit. It can be seen however, that even if we assume that the crew are well trained and incentivised; the impact of installing the BWT is readily offset by installing various energy efficiency technology.

Hardware retrofitting has also been shown to provide significant benefits, as shown on the table above. Analysis in this paper has discussed the use of variable speed drives to account for varying environmental sea water temperature and cooling load, and with some relatively un-intrusive system modifications, the average connected load can be significantly reduced, and deliver substantial fuel savings.

In addition to the advantages and relatively short payback periods that retrofitting of variable speed drives for cooling pump duties can provide, there is a secondary benefit which is provided through the introduction of the conversion machinery. In accordance with Ref. 13 (Wymann & Pieder, 2014), variable speed drives can provide short term ride through capability for short voltage dips (down to about 70-80% nominal voltage), due to the energy that is stored in the drive and conversion machinery.

In this paper we have looked at the application of variable speed drives for SW cooling duties. This concept is applicable for other duties whereby the system loads can change based on operating profile and environmental condition, and could be utilised in FW cooling and ventilation systems. More in depth analysis should be performed to understand the tangible benefits of power quality improvement, and the associated pay back periods. It would also be worthwhile investigating other systems where tuning the flow rate or duration of use could be assessed. An example would be to batch purify fuel in line with consumption rather than running the FO purifiers continuously with any excess clean fuel being carried over to the settling tanks.

It has been shown that heat recovery in various systems can bring tangible benefits (e.g. in bilge water treatment and LO purification systems). Further work should be performed in assessing such benefits in other systems including, but not limited to, the FO purification system and in BWT systems where a level of pre-heat is required (common in electro-chlorination type BWT systems).

## ACKNOWLEDGEMENTS

The authors wish to thank BMT for their permission to undertake this study. Support from Alfa Laval and DESMI in providing equipment information to inform this study is appreciated. The findings and conclusions are those of the authors alone.

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