6th IMarEST Ballast Water Technology Conference, 12-13 January 2017, London, UK
https://doi.org/10.24868/bwtc6.2017.009

Examining Flow Dynamics in Ballast Water Management Systems

Mark Riggio[a]
[a]Hyde Marine Gold, 2000 McClaren Woods Dr, Coraopolis, PA 15108, US

ABSTRACT

With the recent ratification of the 2004 International Convention for the Control of Ships' Ballast Water and Sediments (BWMC) (herewith "the Convention"), the need to install Ballast Water Management Systems (BWMS) onboard existing vessels is expected to grow to an $18 - $25B USD market in the coming few years. As BWMS are added to vessels, these systems will invariably affect the ballasting of ships systems and without a careful study of the dynamics of introducing both a fine mesh mechanical filter and a disinfection stage, the performance of a BWMS onboard a vessel may be compromised significantly. This paper will examine the hydrodynamic impacts of installing a ballast water management system both in the engine room and on deck, the flow dynamics required for proper operation of fine mesh, self-cleaning ballast water treatment filters, and the relative impacts to ballast flow and how these impacts may affect proper sizing of the ballast water management system. The paper will be based both on theoretical design and calculation as well as real-world experience stemming from nearly 400 installed Ultraviolet (UV)-based Ballast Water Treatment Systems (BWTS). The paper should have value for ship owners, designers, installers, and BWTS manufacturers, each of whom may have experienced variable system performance.

Keywords: Ballast water, hydrodynamics, flow dynamics, UV-BWTS

1. Introduction

The spread of invasive species through ships' ballast water has been documented as a significant vector in the decrease of biodiversity and significant economic impacts to coastal communities around the world. Because of this threat, the International Maritime Organization (IMO) introduced the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWMC). The Convention was introduced in 2004 with the goal of requiring installation of ballast water management systems (BWMS) on all ships to stem species transfer on an implementation schedule stretching from 2009 through 2019.

One of the primary factors in the extended implementation schedule proposed by the regulation was the relatively significant impact, both from a cost and from an operational standpoint that BWMS installations would have on vessels. Although much research and effort has been put into examining the cost impacts of BWMS installation, much less has been put into the real impacts that installation of a BWMS may have on vessel operations. Further exacerbating the lack of fundamental knowledge about how ships will be impacted by these systems has been both the relative lack of vessels having installed systems and the low proportion of those ships with installed systems installed routinely using those systems.

Our experience with the design, installation, and integration of ballast water treatment systems has revealed three primary issues that need to be addressed during the initial

Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

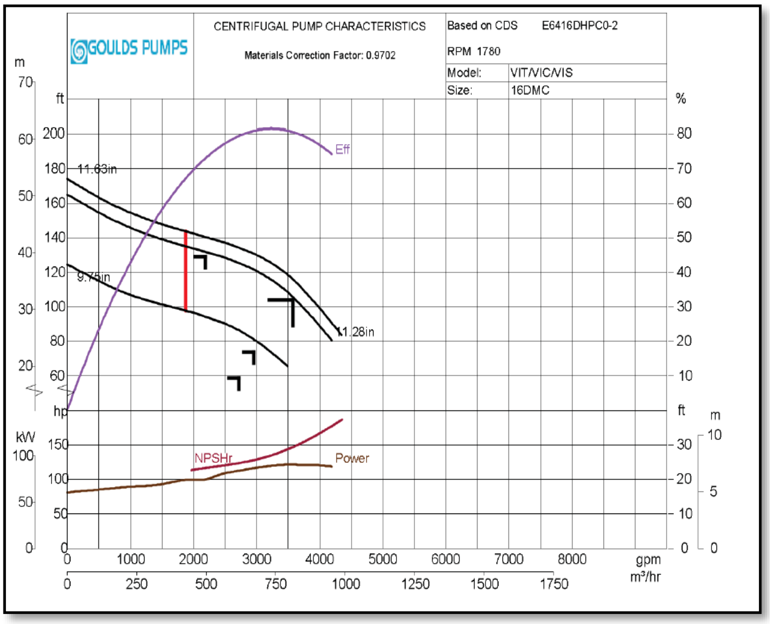
design phase to ensure that systems are successfully installed. Each of these areas, if not addressed at the design stage, can cause larger problems in the future and operational disruptions for the ship's crew throughout the operational life of the BWMS.

2. Operational Concern 1: Ballast pump performance

The first concern is the impact that the system will have on the performance of the ship's installed ballast pump. Ships are primarily designed at new construction with ballast pumps capable of matching the loading capacity of the ship. Ballast pumps are then installed with a discharge pressure designed to fill the vessel's ballast tanks but also designed not to over-pressurise the ballast tanks if the tanks are inadvertently overfilled.

This balance can easily be upset if a BWTS is installed on the vessel since the BWMS will invariably introduce some change to the design head loss of the overall ballast system. If we examine a sample pump curve (Figure 1), we can see that this deck-mounted, centrifugal deepwell pump is designed to draw the water from the seachest up to the main deck, at a discharge head pressure of 105 ft. At this pressure, the pump will output approximately 3600 gpm (817 m^3/hr). A typical BWMS will impart a minimum of 23 ft (0.7 bar) of additional head on the ballast system which backs up the ballast pump curve from 105 ft of head (design) to 128 ft of head (observed), reducing flow from 3600 gpm to 2250 gpm (511 m^3/hr).

Figure 1. Ballast Pump Curve for a Goulds Pumps Centrifugal Deepwell Pump (Courtesy of Goulds Pumps via W&O Supply)



This simple addition of a small amount of additional pressure may increase ballasting time for a vessel from a design of 8 hours to potentially nearly 13 hours due solely to the decreased flow at the new position on the pump curve. This also leads to the question as to what is the suitable size for the BWMS in the scenario. Traditionally, the Treatment Rated Capacity (TRC) of the BWMS was matched to the output capacity of the ballast pump. In this

Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

example, sizing the BWMS for the design capacity (3600 gpm) would be oversized for the theoretical maximum throughput of the pump (2250 gpm).

Interestingly, many pumps are offered with multiple impeller options. For instance, the pump in Figure 1 is offered with three different impellor sizes (11.63 inches, 11.28 inches and 9.75 inches). Again, looking that pump curve we can identify that if the designer identifies this and includes an impellor replacement as part of the overall scope of the BWMS installation, they can shift to the 11.63 inch impeller and then the new pump/discharge head combination gives 3100 gpm flow (704 m^3/hr) and would only increase ballasting time by just over one hour (9.28 h versus 8 h).

This highlights one of the critical differences between systems that are installed on a ship and systems that are properly integrated into the ship. Proper initial design of the system can help identify both the increased head placed on the ballast pump and system selection can be made based on the lowest impact to ballast pump performance as well as provide opportunities for the vessel to overcome these requirements. Often after the installation is complete and the system is not functioning the ship owner is left to deal with these types of issues or thinks that the BWMS has cause the issue.

3. Operational Concern 2: Automatic backwashing filter clogging

The single most common initial problem following the installation of a BWMS is the unacceptable performance of automatic backwashing filters. These filters form an integral part of the overall treatment system and are the primary barrier for large organisms, shells, fish, and other treatment-resistant life stages of organisms entering the ballast water tanks. Unlike the main sea chest strainers, BWMS filters are often fitted with very fine mesh filters and are capable of automatic cleaning while in operation. This allows for the vessel to continue ballasting during challenging water conditions. There are three primary principles of automatic backflushing: jetting, suction indexing, and flow reversal.

The though the most reliable form of automatic backflushing is jetting, this filter is largely impractical for BWMS use. In this type of filter flow is then stopped from the filter and the clean side of the filter is pressurised with a backwash pump. This pump increases pressure on the clean side of the filter and the filter opens a drain line from the dirty side to an overboard drain so that the pressure of the clean side of the filter is forced back across the filter for forced cleaning. This type of cleaning is very effective, but due to the interruption of ballast water flow needed to develop pressure on the clean side of the filter, it is not efficient for ballast water operation.

The second, and most common type of BWMS filter, is a suction indexing filter. These types of filters use a suction nozzle which placed directly adjacent to the filter screen on the dirty side of the filter and is opened to a drain line during operation. Some filters use multiple nozzles for each filter and others use a single long rectangular nozzle to clean the filtration element. The resultant differential pressure between the clean side of the filter and the open drain line creates flow across the filter element from the clean to the dirty side directly through the suction nozzle and overboard via the drain line.

Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

The third type of BWMS filter is a flow reversal design. In these types of filters, the filtration elements are commonly arranged in multiple, smaller candle designs and an indexing arm moves from element to element and opening the element to the drain line. Flow on these types of filters is typically from the interior to the exterior of the element and as the indexing arm opens the filter up to the drain line it blocks flow from the filter inlet creating a similar pressure differential from the clean side of the filter to the drain line as the suction indexing filter but across the whole filter element.

Both the suction indexing and flow reversal filters have the distinct advantage of not restricting ballast flow during operations. Unfortunately, this creates concerns for cleaning efficiency because the filters are reliant on developed differential pressure between the clean side of the filter and the drain line. Clean side pressure is heavily dependent on a number of critical factors, including screen cleanliness, system pump pressure, back pressure on the piping system, and head losses inherent to the drain line connection. Drain line pressure is reliant on position, draft, and piping design. Each of these are factors that change both from vessel to vessel and dynamically during the ballasting operation.

For example, as the filter begins to load, fouling creates differential pressure (Δp) across the filter and decreases pressure on the clean side. A typical suction indexing filter will generates 0.3 bar Δp across a clean filter. For a typical 3 bar ballast pump, that leaves 2.7 bar of pressure available for cleaning. However, as the filter clogs, that pressure differential may increase to 0.7 or 1 bar across the filter, reducing the pressure available for cleaning to 2.3 or 2 bar. When coupled with backflush drain line backpressure of 0.7 – 1.0 bar, maintaining a suitable differential pressure between the clean side can be challenging. It is typical for well designed installations to have 1.0 – 1.5 bar Δp available for backflushing when the filter starts to clean. As pressure increases in the filter element due to clogging, this differential only lowers and can prevent proper cleaning.

Another consideration when using clean side pressure for cleaning is the variability of backpressure available on the downstream side of the BWMS. In order to develop backpressure on the clean side of the filter, it is necessary for the system to be pumping against a sufficient resistance. If the system is pumping directly to double bottom ballast tanks, or to empty wing tanks in the aft end of the ship, the vessel's piping systems may not offer sufficient resistance to generate the 1 bar minimum pressure on the downstream side of the filter to generate flow in backflush. Some filters utilize pressure control valves on their outlet to help add resistance to the clean side of the filter, but without some mechanical means to do so, this pressure is heavily reliant on factors outside of the control of the system designer. To prevent the eventual erosion of this differential pressure there are two different engineering solutions: use dirty side pressure for establishing backflush flow and use of a suction pump drain line.

The use of inlet (dirty side) pressure is a good engineering solution to overcome the pressure loss due to clogging (See Figure 2). As the filter continues to load, unlike the clean side pressure, the dirty side pressure increases by the differential across the filter giving more differential to overcome drain line pressure. During the initial stages of backflush, inlet side water flows through the element to establish flow to the drain. Once flow is established, the

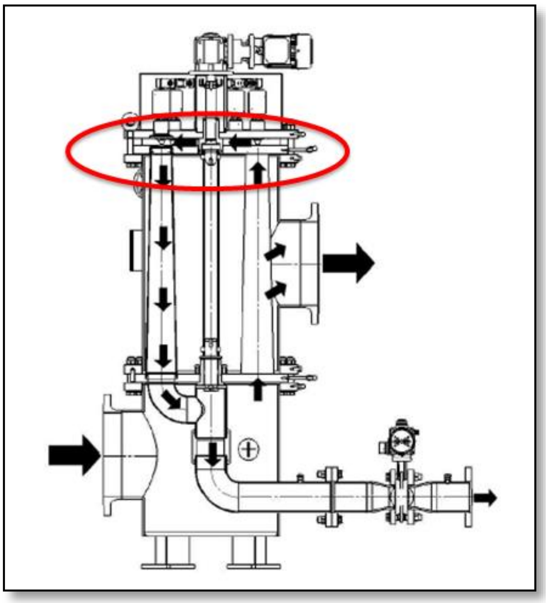
Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

filter closes off the inlet flow and draws from the clean side like more conventional filters. This allows cleaning at much greater filter element fouling than standard indexing filters.

Using a filter backflush pump is another solution to ensure generation of negative pressure at the indexing point. This solution allows for both a guarantee of flow from the clean side of the filter to the drain line by inducing suction and ensures that the drain line pressure can be overcome by designing the pump to overcome any pressure that the installation creates due to design. Despite the extra costs and integration requirements needed to install a backflush drain pump, it is recommended that pumps be installed on the drain line of any filter not utilising inlet pressure to begin backflushing.

Figure 2. Filter using inlet pressure to generate flow during initial stage of backflushing. Red circled area shows path for inlet side water to establish flow to drain line. Arrows are direction of flow of ballast water in the filter (Image courtesy of Hydac International)



4. Operational concern 3: Piping losses

The third operational concern about installing a BWMS is not accounting for the head loss in the ballast system due simply to piping design. Although related to the first concern about not addressing the increased pressure head added by the BWMS, it is critical to consider the additional piping as well when considering the impact to the performance of the ballast pump. This concern is principally related to the need to modify existing piping systems to retrofit a BWMS into an existing vessel. Ships not designed from new construction with BWMS need to find space to install the system and often this space is less than ideal for the piping configuration. This piping will often be done during a shipyard period or underway and may require field welding or pipe fabrication that prevents proper internal protection for the pipe materials. Additionally, existing piping may have existing rust or other imperfections that are not accounted for in calculations assuming new piping.

Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

For piping head loss calculations, the head loss due to friction (h_f) is calculated based on the equation 1:

$$h(f) = f(\frac{L}{D})(\frac{V^2}{2g})$$

Equation 1

where λ = pipe friction factor, L is the length of pipe, D is the diameter of pipe, V = fluid velocity of the fluid, and g is the acceleration due to gravity. The pipe friction factor, then, can be seen has a direct impact on the head loss. This pipe friction factor is calculated by the equation:

$$\frac{1}{\sqrt{f}} = -4.0log10\left\{\frac{\frac{\epsilon}{d}}{3.7} - \left(\frac{5.02}{Re}\right) log10(\left(\frac{\frac{\epsilon}{D}}{3.7}\right) + 13/Re)\right\}$$

Equation 2

Where ε = Roughness factor, D= Diameter of the pipe and Re = the Reynolds number of the fluid in the pipe. This Roughness Factor should be determined by the manufacturer of the pipe, however for typical commercial grade steel pipe, a roughness factor of 0.0045 mm is standard but this can quickly increase up to a factor of 1 – 3 mm for corroded piping. By increasing the roughness factor by a factor of 100x or more, the friction factor and head loss in piping systems can quickly increase beyond the capacity of the ballast pump.

Finally, although the head loss through fittings, open valves, and check valves are considered to be minor losses, simply looking at a typical installation and accounting for the number of added fittings, piping, valves, and other equipment can quickly add a significant additional impact to the overall head loss in the ballast system following the installation of a BWMS.

5. Conclusion

When written in 2004, the IMO BWMC was a well-designed instrument. By starting the implementation phase in 2009 (five years after the convention was written) it was believed there would be time for the Convention to be ratified and manufacturers to get systems through the approval process. Then by requiring the initial implementation to be done on newbuild vessels, the inevitable problems of integrating systems with existing vessels would largely be addressed during the initial five year cycle. Starting in 2014, the remaining existing vessels could begin to install systems that were well known on ships that were ready for them.

Unfortunately, as the Convention languished in the ratification phase for over ten years and many ships either did not install systems at new construction or never used the installed systems, this learning period will largely take place during the upcoming retrofit phase. It is critical that vessel owners look to the experience of their peers who have already installed systems as well as to the number of companies who have successfully taken part in retrofit projects to learn what they need to account for to successfully navigate this integration period.

Contact: telephone +1 (724) 218-7304

https://doi.org/10.24868/bwtc6.2017.009

By accounting for the effect that BWMS installations will have on a ship's ballast pump, how the backflush arrangements can significantly influence performance of a system, and how accounting for pipe fittings, arrangements and long-term pipe conditions, ship owners can have the best chance to successful install BWMS onboard their vessels. Failure to follow these basic engineering principles and placing too much reliance on the manufacturers and installers to simply "make the system work" on a ship may result in systems that are not able to meet the ship's expectation without any fault of the BWMS or the installation company.

Figure 3. Typical BWMS Installation. Photo by Hyde Marine

References

Marine Engineering, 3rd Edition. 1980. Society of Naval Architects and Marine Engineers.
Native Dynamics, Absolute Roughness of Piping Material. 2017. https://neutrium.net/fluid_flow/absolute-roughness/ , accessed January 8, 2017
R. Shankar Subramanian. 2014. Pipe Flow Calculations. http://web2.clarkson.edu/projects/subramanian/ch330/notes/Pipe%20Flow%20Calculations.pdf, accessed January 6, 2017

Contact: telephone +1 (724) 218-7304