Great Ships Initiative

A Ballast Discharge Monitoring System for Great Lakes Relevant Ships:

A Guidebook for Researchers, Ship Owners, and Agency Officials

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CHAPTER 1: INTRODUCTION

GUIDEBOOK PURPOSE

The purpose of this Guidebook is to share with regulatory authorities, ship owners and researchers basic guidelines developed by the Great Ships Initiative (GSI) for collecting and analyzing representative samples of living organisms in ballast discharge from Great Lakes-relevant ships. Specifically, this Guidebook details methods for retrieving quantitative samples from ships to determine live organism densities in three size classes of organisms (equal to or greater than 50 micrometers in minimum dimension, less than 50 micrometers and equal to or greater than 10 micrometers in minimum dimension, and less than 10 micrometers in minimum dimension), water quality parameters, and whole effluent toxicity tests. Methods associated with sample analysis are not currently part of this Guidebook, but GSI Standard Operating Procedures for analysis are the same as for land-based tests of ballast water treatment systems (BWTSs), and can be downloaded from GSI's website (www.greatshipsinitiative.org). It is important to note that the methods described here are preliminary and subject to revision over time. GSI will periodically update this Guidebook and repost new versions on its website over time.

GSI designed these ship discharge monitoring methods for *planned* ship discharge monitoring exercises (these methods would not be suitable to surprise spot checks). As such, the methods in this Guidebook are highly applicable to a wide range of quantitative ballast treatment performance research and validation, including type approval testing and planned treatment performance monitoring events post approval. Any application of these methods to regulatory purposes, however, would require close review and revisions of method specifics per specific regulatory guidelines.

Chapter 1 presents an overview of the GSI ship discharge sampling approach. Chapter 2 describes details of the sample and return port installations necessary for this sampling approach to be used on Great Lakes-relevant ships. Chapter 3 details the set-up and break-down processes for implementing this approach for a sampling event. Chapter 4 provides a discussion of the feasibility of the methods, including their strengths and weaknesses based on GSI trials in the field.

BACKGROUND ON THE GREAT SHIPS INITIATIVE (GSI)

GSI is a collaborative project led by the Northeast-Midwest Institute (NEMWI) devoted to ending the problem of ship-mediated invasive species in the Great Lakes-St. Lawrence Seaway System and globally. NEMWI is a Washington, D.C-based non-profit and non-partisan research organization dedicated to the economic vitality, environmental quality, and regional equity of Northeast and Midwest states. In support of that goal, NEMWI has established through GSI a superlative freshwater ballast treatment evaluation capabilities at three scales—bench, land-based, and on board ship. GSI research is carried out collaboratively with contracting entities including the University of Wisconsin-Superior (UW-S), AMI Consulting Engineers, Broadreach Services, and the University of Minnesota-Duluth (UM-D).

GSI testing takes place at the scale appropriate to the treatment's state of development. The goal is to help meritorious BWTSs progress as rapidly as possible to an approval-ready and market-ready condition through supplying rigorous status testing or certification testing of biological efficacy. To assure relevancy of test output, GSI test protocols, generally, are as consistent with the International Maritime Organization (IMO) Convention for the Control and Management of Ships' Ballast Water and Sediments Convention (IMO, 2004) and federal and state requirements as practicable. For example, United States Environmental Protection Agency (USEPA), Environmental Technology Verification (ETV) Program testing is performed consistent with ETV protocols (e.g., NSF International, 2010).

A GSI Advisory Committee comprises top-level officials of key stakeholder groups and provides direct input on GSI award decisions, program direction, finances and fund-raising. The GSI Advisory Committee, which meets three times a year, includes elected leadership, environmental organizations, port directors and federal officials from the United States and Canada, and industry representatives.

GSI's Quality Management Plan (GSI, 2011) outlines the activities that GSI uses to ensure that personnel have the necessary education, qualifications, and experience needed to effectively carry out their specific roles and responsibilities within the project.

BACKGROUND ON GSI SHIP DISCHARGE MONITORING PROJECT

GSI received funding from the Legislative Citizen's Commission on Minnesota Resources (LCCMR), the Maritime Administration and the Great Lakes Protection Fund to design, install and test a ship-based ballast discharge sampling approach on the range of commercial cargo ships which ply the Great Lakes. The primary goal of this GSI project was to inform ship owners, researchers and regulators of effective and efficient methods for carrying out ballast discharge monitoring on Great Lakes ships. A secondary goal was to initiate the installation of effective sampling ports on Great Lakes-relevant ships for BWTS testing and monitoring.

GSI developed a proposed sampling approach, which included permanent sample port flange installation guidelines consistent with those of the IMO (IMO, 2004) and the USEPA ETV Program (NSF International, 2010); portable sampling system equipment and methods for shipboard use; and portable sample analysis equipment and methods for port-side use.

GSI personnel visited a range of ships to identify best locations for sample port flanges given a set of the project criteria (see Chapter 2). Sample locations that had potential to meet most or all of these criteria were identified and photographed during the ship visit, and later modeled using computational fluid dynamics (CFD) to determine which location would deliver the most representative sample.

GSI in consultation with the ship owner then selected the best location based on the inspection information, and the ships were then outfitted with sample flanges. GSI then visited the ships to trial and review the GSI sampling approach in real-world applications. This Guidebook provides the method and lessons learned from this project activity. The sample ports will stay in place for possible future use in research and compliance monitoring. Data gathered on living organisms in ballast discharge sampled through this project will be provided to the State of Minnesota and published on GSI's website.

SAMPLING APPROACH OVERVIEW

It is important to note that hardware and personnel alone will not deliver useful sampling exercises. The sampling team must also have a robust and valid test plan and standard operating procedures to accompany any ship sampling exercise. The test plan will describe the objectives of the test, the hypotheses, the experimental design, the analytical methods, and quality control and quality assurance plan for the work. The standard operating procedures will detail specific methods. The GSI website (www.greatshipsinitiative.org) includes test reports on ship-based ballast treatment research providing examples of these documents.

GSI designed the sampling approach described here to be applicable to a range of test plans. It employs simultaneous, in-line and continuous collection of large and small quantities of sample water from subject ballast water discharge to estimate live organism densities and types in and water quality characteristics of that discharge. The method is adaptable to a wide range of sampling intensities and ships with diverse ballast line diameters, and ballast system types.

Details of the sampling approach are provided in subsequent chapters. Fundamentally, the process involves:

- Prior installation of two permanent 4 inch diameter blind flanges in a strategically selected segment of the ship's ballast line (detailed below), and insertion of a temporary sampling pitot in one such flange;
- Space and services on the ship to support sample collection (detailed below);
- A port-based set-up, sampling and ballast team of four people, and nearby analytical space and equipment (detailed below); and
- A time window affording 45 minutes to one hour for sampling system set-up and 45 minutes to one hour for its break-down in addition to the selected sampling period duration.

Figure 1 illustrates the GSI sampling system lay out. In summary, the installation of the blind flanges—a relatively minor permanent change to the ship costing less than $5,000--is completed according to strict location guidelines well before sampling is to occur. At the time of, or just prior to, the sampling event, an elbow shaped sampling pitot is installed in the upstream flange to deliver flow to the sampling system. For zooplankton sampling (i.e., organisms equal to or greater than 50 micrometers in minimum dimension), sample flow from the discharge line is pumped from the sampling pitot at a known flow rate through a plastic line equipped with a flow meter into a 35 micron plankton net that is suspended in a 50 gallon tub with a level transmitter and a bottom discharge flange. The fraction of the ballast line flow pumped through the sample port should remain constant throughout the sampling process. This ratio is monitored using an in-line magnetic flux flow meter on the sample line, and a portable ultrasonic flow meter mounted to the ships ballast piping. A second pump draws spent sample water from the 50 gallon tub through plastic line to the return flange in the ballast line for discharge overboard with other ballast water. The water level in the tub is maintained at near full as the net filters the plankton into a bottom cod-end. A small side stream of the sample water flow (pre-plankton net) is directed into a carboy for whole water samples which can be used to assess water quality, protists (i.e., organisms less than 50 micrometers and equal to or greater than 10 micrometers in minimum dimension), bacteria (i.e., organisms less than 10 micrometers in minimum dimension), and effluent toxicity. Grab samples can be extracted from the line (i.e., hose) feeding into the nets, or through a dedicated side port off the main sample line which can be opened and closed. Sample analysis can take place on-ship, but is easiest to arrange off-ship.

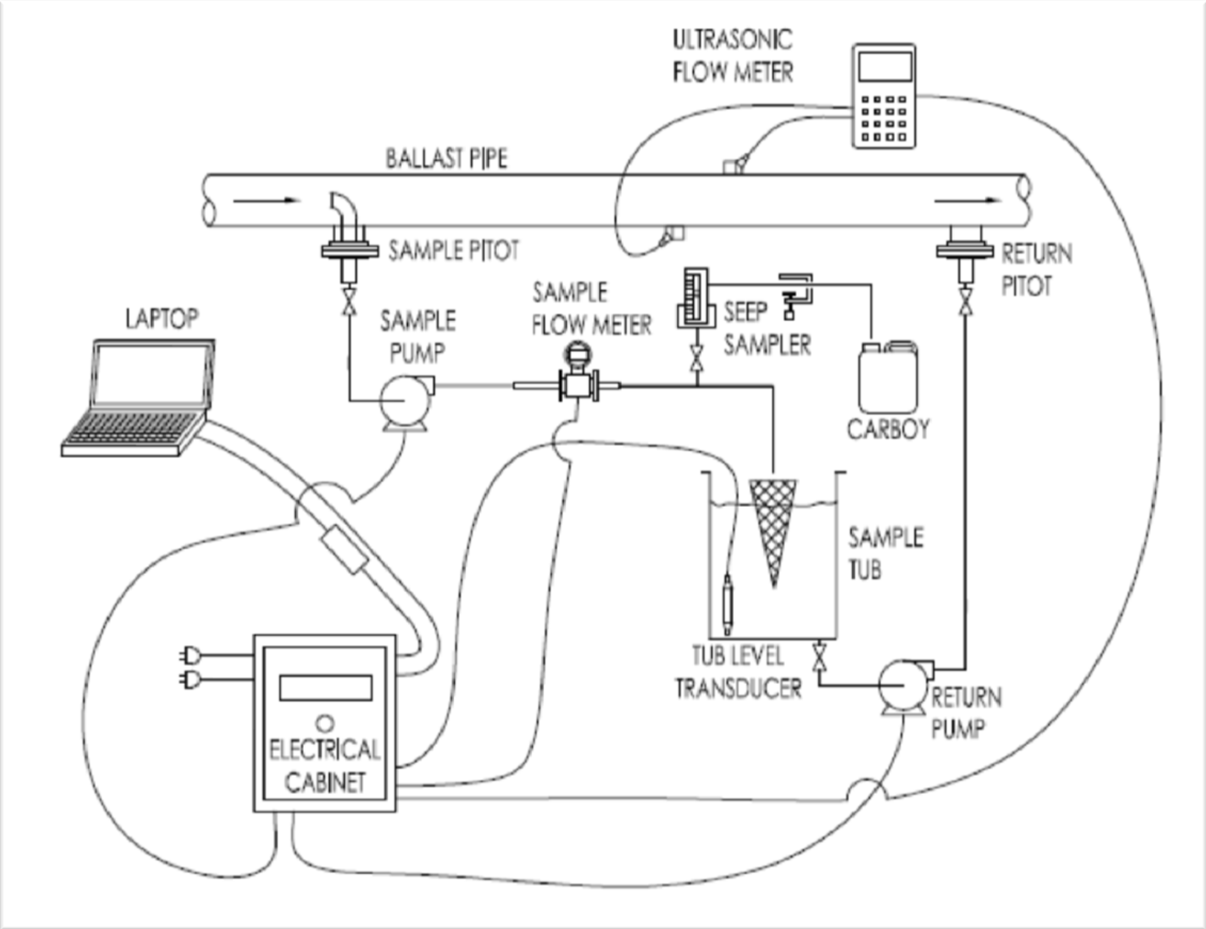


Figure 1. Schematic of the GSI Ship Discharge Sampling System and Component Parts.

CHAPTER 2: SAMPLE PORT/RETURN PORTS

GSI sample ports and return ports are installed as 4 " 150 # ANSI flanges with blinds. GSI employs stainless steel bent elbow style pitots (Figure 2) installed so that the opening faces into the flow at the center of the pipe. GSI first determines the target sample volume per unit ballast discharge based on experimental design criteria. Then it assures the internal diameter of the pitot opening is large enough to assure that sample water pumped through the pitot will provide that volume, but at a subisokinetic flow velocity that ranges between 44%-25% of the discharge flow velocity of the ship. An isokinetic flow rate occurs within a pitot when the sample water flow velocity is the same as discharge line flow velocity. A subisokinetic velocity means there is a slower flow velocity in the pitot than in the line being sampled. Consistent with recommendations by the United States Coast Guard to maintain a pitot inlet of 1.5-2.0 times the isokinetic diameter(USCG, 2008), GSI assumes that subisokinetic flow helps prevent organism damage by edge interactions with pitot inlet and walls. Assuming most ballast systems are designed for a flow rate of around 10 feet/second, the pitot sizes required to collect a range of volume of sample water per hour is shown in Table 1.

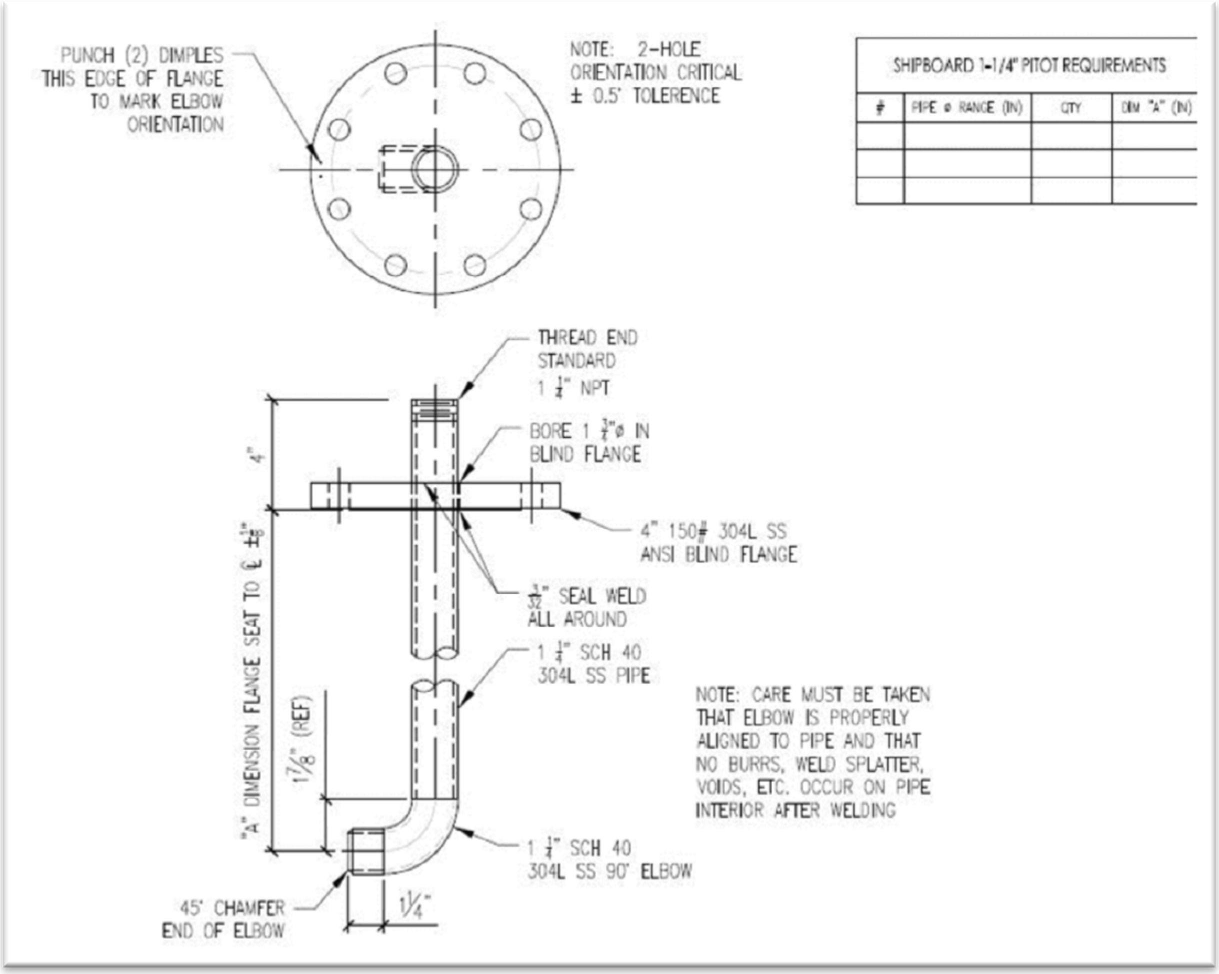


Figure 2. Diagram of Elbow Pitot for Ballast Discharge Sampling.

Table 1. Relationship of Sample Pitot Diameter to Sample Water Flow Rate

	Sample Pitot, Flow Rate at 10 ft/sec Ranging From 1.5 - 2.0 Times The Isokinetic Diameter								
Diameter (in)	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4
Flow (Gal/Hr)	359.4 - 202.2	597.8 – 36.3	1066.1 - 599.7	1468.7 - 826.1	2454.2 - 1380.5	3522.5 - 1981.4	5489.7 - 3087.9	7386.9 - 4155.1	9555.2 - 5374.8
Flow (M3/Hr)	1.4 - 0.8	2.3 - 1.3	4 - 2.3	5.6 - 3.1	9.3 - 5.2	13.3 - 7.5	20.8 - 11.7	28 - 15.7	36.2 - 20.3

Step by Step Approach to Pitot Diameter Selection

1. Determine Test Plan Sample Volume/Rate requirements (e.g., the test plan requires 6.0 m^3 in 2 hours or 3.0 m^3/hr).
2. Assure the pump is capable of that flow rate.
3. Consult with the ship engineer to determine ship ballast discharge flow rate (usually around 10 ft./sec., but not always).
4. Select a pitot diameter that assures the flow velocity is in the subisokinetic range of 44 % - 25 % ballast discharge flow rate. If they ballast at 10 ft./sec, table 1 can be used (e.g., For a desired flow rate of 3.0 m^3/hr, per table 1, a 1.25" pitot can be used since its valid range of 4.0-2.3 m^3/hr).

Criteria for Sample Port Location

The location of the sample port is critical to its ability to deliver representative samples of live organisms in ballast discharge. Both fluid dynamic properties of a location, physical access and safety considerations come into play. A suitable location for a return flow port is somewhat simpler as the flow mechanics of the return location are unimportant, but locating it a minimum of two pipe diameters down downstream of the sample port assures that it in no way interferes with the sample port fluid dynamics. GSI uses the criteria detailed in Table 2 to guide GSI selection of sample port location.

Table 2. GSI Criteria for Sample Port Location in a Ship Ballast System.

Criteria	Reason
Single location services all tanks equally.	A single sample point means fewer flanges are needed, and less sampling effort is required.
Long length of straight pipe preceding the sample port.	Long lengths of straight pipe create a “fully developed” flow characteristic, assuring water is well-mixed at the point of sampling, and samples are representative of the discharge.
Locations as close to overboard as possible.	Samples collected closer to discharge will more closely represent the quality of water entering the receiving system.
A suitable adjacent area for sample processing, suitable for technician occupancy, and with accessible light and power supply.	A sample port alone won’t deliver a good sample. Technicians must be able to work in proximity to it to collect and process samples.
Necessary clearances to install the sample pitot.	The sample team or ship personnel must be able to install and remove the pitot without damaging other equipment.
Piping that can be isolated.	Piping around the sample location must be isolated so that the sample equipment can be safely installed or removed.
No explosion or other hazards.	Explosive environments require special equipment to assure safety of the ship, crew and sampling team.

SAMPLE PITOT LOCATIONS IN BALLAST SYSTEMS FOUND ON GREAT LAKES-RELEVANT SHIPS TYPES

A ballast system comprises the pump, sea chests and piping associated with moving ballast water on and off the ship. Most ships have two ballast systems mirrored along the centerline of the ship: one system services the port side tanks and the other the starboard tanks. Thus, most ships require a minimum of two sample points for monitoring ballast discharge. Ballast systems associated with ships in service on the Great Lakes can be quite different from each other, as will the best location for a sample point given the criteria noted in Table 2. During GSI ship inspections, three fundamentally different types of ballast systems were identified:

- Distributed Manifold Ballast System (Figure 3): In a distributed manifold system a single pump or pair of pumps is installed in the engine room with ballast main(s) traveling the length of the ship. Branches off the main service each tank. Flow in or out of the tank is controlled by manual or actuated valves at the ballast tank. This ballast system design typically had straight lengths of pipe suitable for sampling locations in the ship tunnel.

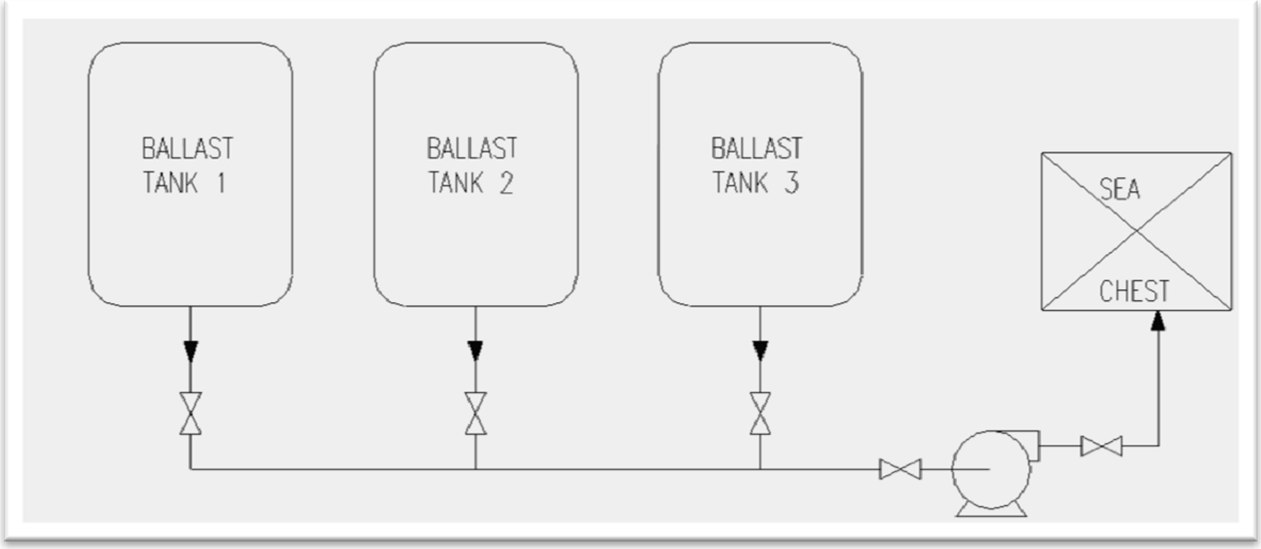


Figure 3. Schematic of Distributed Manifold Ballast System Design.

- Centralized Manifold Ballast System (Figure 4): This ballast system style is similar to a distributed manifold except each ballast tank has an individual line leading back to the engine room; the lines combine prior to the pump. All the ballast system valves are located together in the engine room.

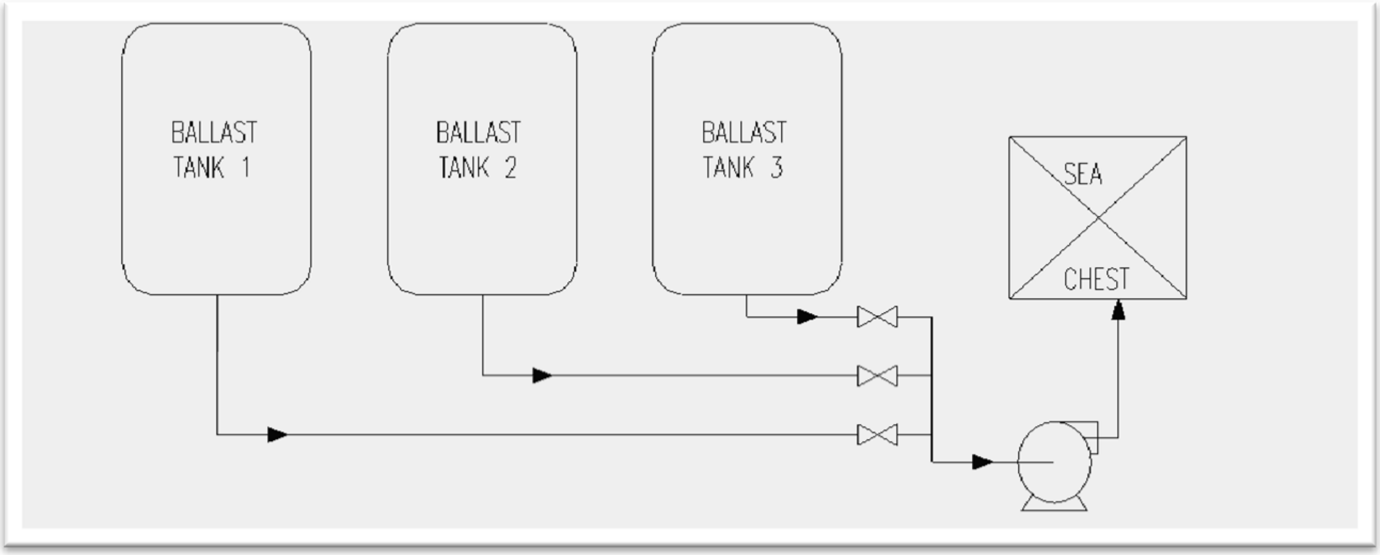


Figure 4. Schematic of Centralized Manifold Ballast System Design.

- Multiple Independent Ballast Systems (Figure 5): Ships with multiple independent ballast systems have no common piping between ballast tanks. Every ballast tank on the ship has a separate sea chest, ballast pump and piping. This style of ballast system is rare within and outside the Great Lakes.

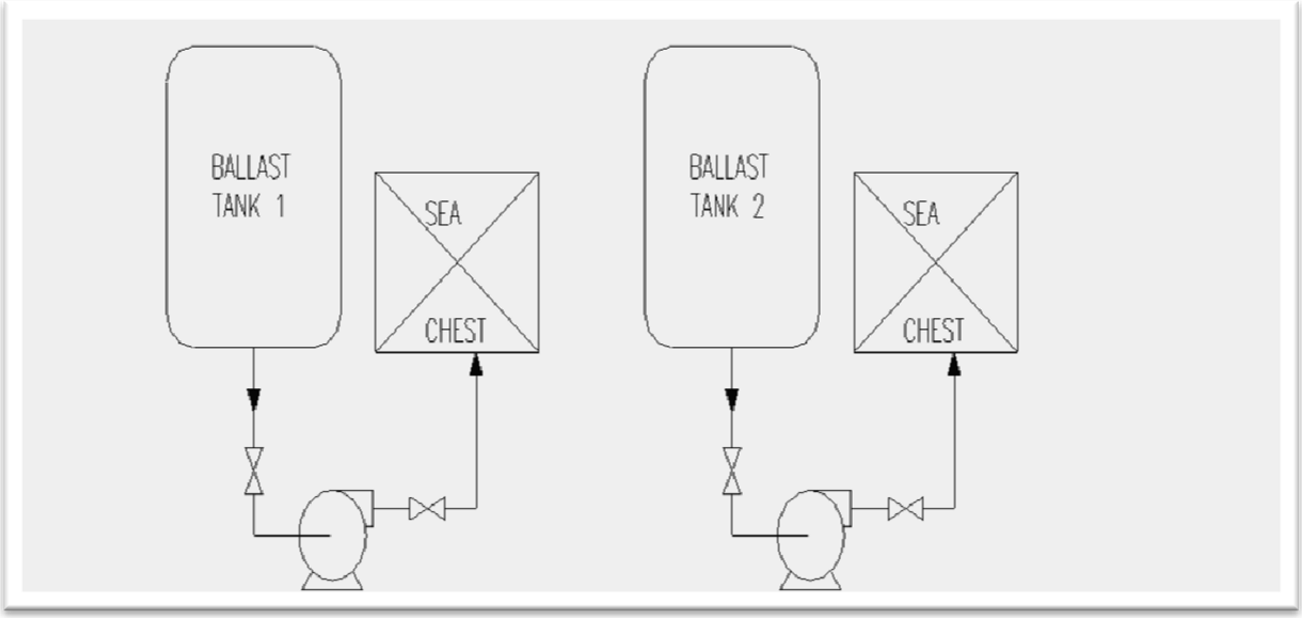


Figure 5. Schematic of Multiple Independent Ballast System Design.

POWER REQUIREMENTS

Power requirements for sample collection systems should be kept to a minimum. The GSI sampling system runs off of two 13 amp 120 volt circuits at 60 hertz. Although it has been easy to find this supply on U.S. and Canadian ships it becomes more difficult with foreign vessels that operate with different electrical standards

PITOT CUSTODY

The GSI team prefers to provide the pitot to the ship master for installation into the flange sometime within a week or two prior to the ship's arrival at the port at which sampling is scheduled. After the sample visit the ship crew returns the pitot to the GSI sample team. GSI does not install sample pitots permanently in the ships in order to assure that bio-fouling inside of the pitot does not bias sampling outcomes, and to assure that structural defects of the pitot will not endanger ship operations. If necessary, GSI can install the pitot on the day of sampling, but this approach expends limited time available for set-up, and sample collection, processing and analysis.

GSI recommends that pitots be owned by the testing agency and loaned to the ship being evaluated. Upon pitot return after a sampling event the GSI team inspects the pitot for any damage. Having the pitot belong to the sample team also puts the responsibility of maintaining a specialized piece of equipment in the hands of those that will need to operate it. The research team can then size the pitot aperture to deliver the desired flow to discharge ratio (i.e., volume of sample water per unit volume of ballast discharge).

STEP-BY-STEP PROCESS FOR SAMPLE PORT COMMISSIONING

In summary, steps employed by GSI to identify and install sample ports on ships are as follows:

1. **Pre-Installation Ship Inspection.** A ship inspection is conducted to identify and document features of sample locations with potential to meet most or all of these criteria. Also possible locations for a return flow port downstream of the sample port, and sample processing, are assessed and identified at this time.
2. **CFD Models.** A qualified engineering firm models potentially suitable locations using computational fluid dynamics (CFD) to determine which locations in fact provide well-mixed samples of ballast discharge (i.e., have fully developed flow or are closest to fully developed flow).
3. **Installation Design to Ship Owner.** Once a location is determined by the sample inspection team the location is submitted to the ship owner for approval, class society review and installation.
4. **Flange Installation.** Once the ship owner and agrees to the design, the ports can be installed with blind flanges.
5. **Pitot Installation.** Prior to a sampling event the blind flange will be removed and replaced with a sample pitot of an appropriate size.

CHAPTER 3: EQUIPMENT, SET UP AND TEAR-DOWN

GSI selected sampling equipment for its reliability and portability. All of the equipment and components of the process described here are no greater than 45 lbs in weight. GSI includes spare parts for critical components in case of component failure during sampling. Set up and tear-down of the sampling system consumes approximately one and one half hours each by two technicians.

SAMPLING SYSTEM COMPONENTS

The following components comprised GSI's sampling system:

Sample Pitot and Sample and Return Port Flange
Manufacturer: Custom designed and manufactured
Model: NA
Description: The flanges are custom made from 4" 304L stainless steel blind flanges. The sample pitot is made from 1-1/4" sch. 40 304L stainless steel pipe. There is a 1-1/4" full port ball valve with plug installed on the outlet of both to prevent leaking. The pitot is a 90 degree elbow section of pipe sized to allow water to be collected from the center of the ballast line. The elbow is mounted in the 4" sample port blind flange. The pitot aperture is sized to deliver 1.5-2 times isokinetic flow from the line being sampled. The return flange is a board flange with threaded nipple welded to match the size of the pitot. Prior to testing the pitot is installed inside the 4" sample port and the return flange is installed on the return port. See Figure 6 for installation example.

Figure 6. Sample Pitot and Sample and Return Port Flange.

Electrical Cabinet
Manufacturer: Various Components assembled by Rockwell Automation
Model: N/A
Description: Contains the PLC, Motor Drives, and other necessary components to monitor and control the system logic. See Figure 7 for installation example.

Figure 7. Electrical Cabinet.

Ultrasonic Flow Meter
Manufacturer: Fuji Electronics
Model: FSC w/FSD410B1 transmitters
Description: Sensors use ultrasonic waves to measure the flow velocity in a pipe and calculate the flow rate. This is used to monitor the ballast discharge rate without needing to install anything inside of the ships pipes. Figures 8 and 9 depict example ultrasonic flow meters and flow meter transducers, respectively.

Figure 8. Ultrasonic Flow Meter.

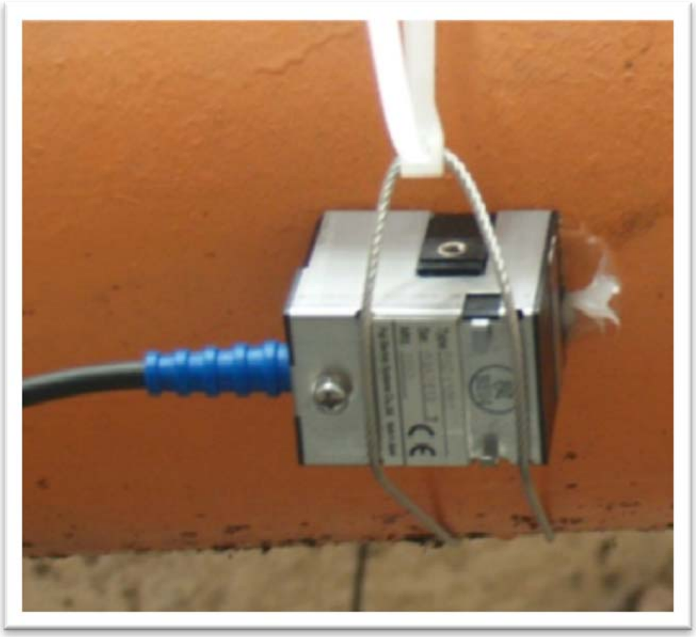


Figure 9. Flow Meter Transducer.

Tub Level Transducer
Manufacturer: Ametek DrexelBrook
Model: 750 Series Well Watcher Submersible Level Transmitter
Description: A transducer (see Figure 10 for an example) is lowered to the bottom of the sample tub where it monitors the level of the water in the tub.

Figure 10. Tub Level Transducer.

Sample Flow Meter
Manufacturer: Yamatake
Model: MTG18A
Description: A two-wire electromagnetic flow meter monitors the flow rate of water being sampled by the sampling system. See Figure 11 for an installation example.

Figure 11. Sample Flow Meter.

Sample Pump and Return Pump
Motor: Dayton 1TRZ6
Pump: Jabsco 777-9001
Coupling: Lovejoy AL095 & 68514471706
Frame: Custom built aluminum
Description: Both sample and return pumps are identical flexible impeller pumps. The sample pump draws the water to from the ships ballast lines and pumps it to the sample tub. The return pump removes the water from the sample tub and pumps it back into the ships ballast lines. See Figure 12 for installation example.

Figure 12. Sample Pump.

Sample Tub
Manufacturer: RubberMaid
Model: 32 Gallon Heavy Duty trash can
Description: The trash can has been modified to include a bulkhead fitting with a valve on the bottom to use as a water outlet, and an adjustable riser to hold the sample nets. See Figure 13 for an installation example.

Figure 13. Sample Tub.

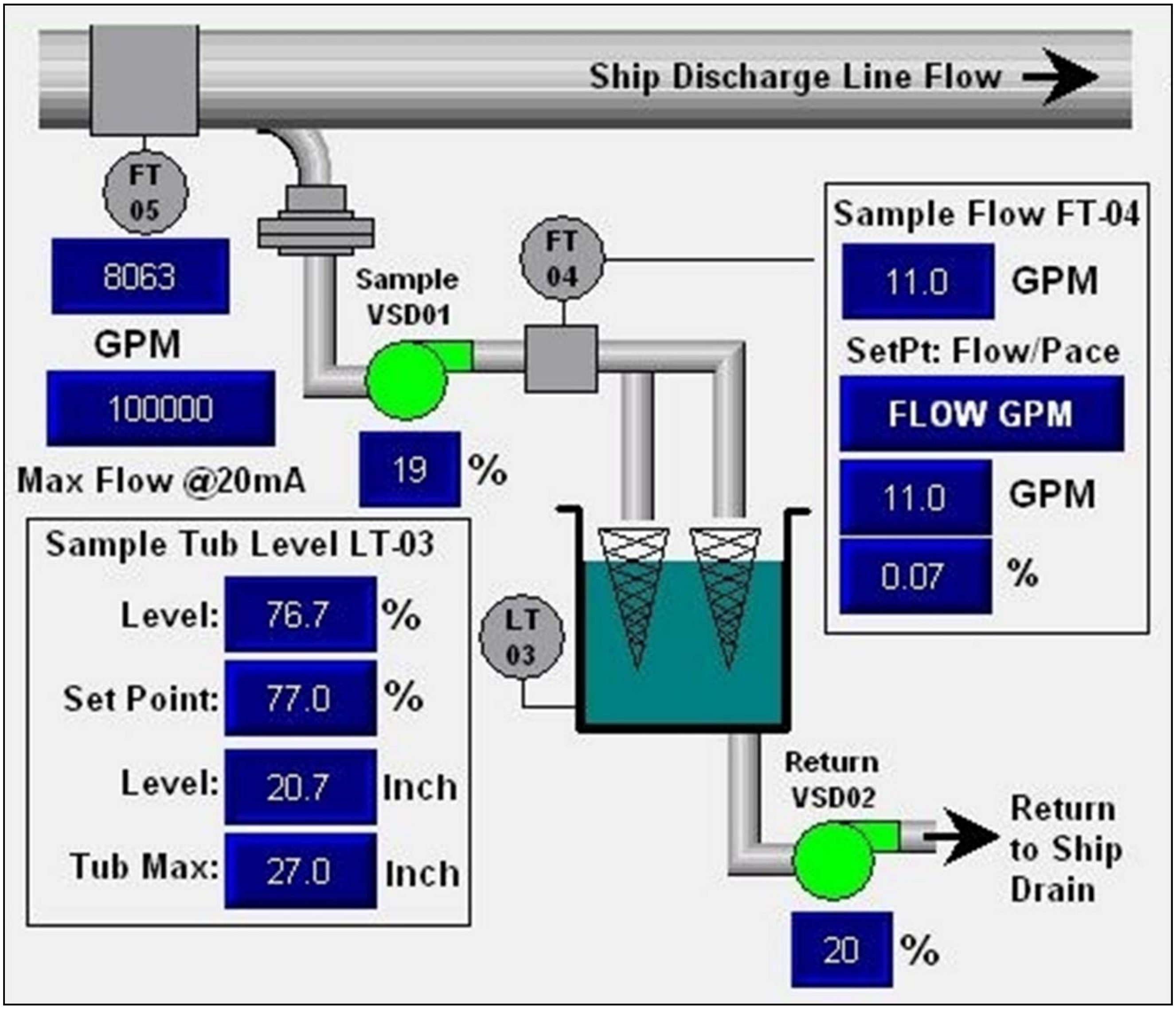
Laptop
Manufacturer: Panasonic Semi-rugged Toughbook
Model: CF-52
Description: The laptop provides the interface for running the Ballast Sampling Program and data logging. The Toughbook provides some splash resistance and fall protection as well as dust protection that is above what a typical laptop would provide. A secondary function of the laptop is to provide access to equipment manual, troubleshooting guides and other useful information while in the field. See Figure 14 for example.

Figure 14. Lap Top.

Human Machine Interface (HMI) Software

The GSI shipboard sample equipment is controlled using FactoryTalk Historian ME. FactoryTalk is a brand of HMI software that includes graphical representation (see Figure 15). Any HMI software used to control sampling equipment should include the following abilities:

1. Control of pump actives through PLC loops,
2. Ability to set sample pump as a percent of ballast line flow,
3. Data Logging and live data display, and
4. Fault and warning notifications.



8063 GPM

100000 Max Flow @20mA

19 %

Sample Tub Level LT-03

Level: 76.7 %

Set Point: 77.0 %

Level: 20.7 Inch

Tub Max: 27.0 Inch

Sample Flow FT-04

11.0 GPM

SetPt: Flow/Pace

FLOW GPM

11.0 GPM

0.07 %

20 %

Figure 15. Sample Screen Image from GSI HMI Software.

SAMPLE GEAR

Sample gear included the following items:

Plankton Net and Cod-End
Manufacturer: Sea-Gear Corporation
Model: 9000 (30cm, 3:1, 35 micrometer mesh)
Description: Zooplankton samples are collected by concentrating the sample volume through a 35 micrometer mesh plankton net (i.e., 50 micrometers on the diagonal) into a 1 Liter cod-end for analysis. A minimum of one plankton net is required per sample. The plankton nets used by GSI during shipboard sampling were purchased from Sea-Gear Corporation of Melbourne, Florida (Figure 16).

Figure 16. Plankton Net (35 micrometers with Attached 1 Liter Cod-End.

Sample Collection Containers: Carboy, 20 Liter
Manufacturer: ULine
Model: S12768
Description: high-density polyethylene (HDPE) containers for time-integrated sample collection, the type and quantity of which are dependent on the test plan. For example, the time-integrated “seep” sample is collected using a 19 liter HDPE carboy (one per replicate; Figure 17). For collection of whole effluent two time-integrated “seep” samples are collected; one for whole water samples and one for whole effluent toxicity testing. From one time-integrate sample, total suspended solids and percent transmittance subsamples, as well as, whole water

for analysis of protists are collected using HDPE sample bottles (Figure 17). Organic carbon samples (i.e., non-purgeable organic carbon and dissolved organic carbon) are collected using 125 mL glass sample bottles prepared by soaking in Micro-90® Concentrated Cleaning Solution (Figure 17). Microbial samples (a minimum of three subsamples per carboy) are collected using sterile 1 liter polypropylene bottles (not pictured). Extra sample containers should be carried aboard.

Figure 17. Sample Collection Containers used for Shipboard Sampling Events.

Transport Coolers and Ice Packs

Description: To ensure sample integrity, proper sample holding and transport is of the upmost importance. Following sample collection, sample bottles are immediately placed into small sample transport coolers (Figure 18) and are kept cold until they are delivered to the sample analysis personnel by using a minimum of two ice packs per cooler (Figure 18).

Figure 18. Small Sample Transport Cooler with Samples and Ice Packs.

YSI Multiparameter Water Quality Sonde with Data Display and Logging System
Manufacturer: YSI Incorporated (Yellow Springs, Ohio)
Model: YSI 6-Series Model 6600 V2-4 Sonde and YSI 650MDS Data Logging System
Description: Water quality parameters are measured from the time-integrated sample using a YSI Multiparameter Water Quality Sonde (Figure 19). It is recommended that two Sondes be brought onboard in case one of the Sondes is not functioning correctly. The 6600 V2-4 Sonde (Figure 19) was used by GSI and included sensors to measure the following parameters: specific conductivity, salinity, pH, temperature, dissolved oxgen (concentration and percent saturation), turbidity, and total chlorophyll. The measured values are displayed using the YSI 650 MDS data logger (Figure 20).

Figure 19. YSI 6-Series Multiparameter Water Quality Sonde (YSI 6600 V2-4).

Figure 20. YSI 650 MDS Data Logging System.

Standard Operating Procedures, Test Plan, Datasheets and Laboratory Notebooks

Description: A copy of the Test Plan, as well as, the sample collection standard operating procedures must be brought on board during the sampling event and must be readily accessible to the sample collection team. The appropriate datasheets will be identified in the Test Plan and extra datasheets should be brought onboard, along with extra pens (indelible ink only). Data may also be recorded in laboratory notebooks, although pre-printed datasheets are preferred due to the increased efficiency of data recording.

PERSONAL PROTECTIVE GEAR AND DRESS

The equipment listed below is the recommendation and in most cases the required protective gear for personnel involved with the shipboard ballast sampling and operation of the equipment. The requirements of the vessels or the facilities through which the vessels are accessed may vary and the sample team is expected to follow safety procedures required of the dock or ship, including Occupational Safety and Health Administration (OSHA) requirements.

- Hardhat
- Steel toe boots
- Safety Glasses
- Hearing Protection (ear plugs or muffs, or in some cases both may be advisable)

- Flashlight or headlamp
- Work Gloves
- Work Clothing – work clothing should cover arms and legs, and fit in a manner as to not create a safety hazard. Jewelry (including rings) is not recommended and on many facilities not allowed.
- Transportation Worker Identification Card (TWIC) – Some facilities require for access.

EQUIPMENT SET UP AND TEAR-DOWN

Equipment loading and unloading to and from the ship should be as swift as possible to minimize disruption to ship operations, and to avoid the possibility of needing to re-route entry during the loading. Two to four people can effectively accomplish set up and tear down within 45 minutes to one hour for each operation. It is advisable to have one member of the set-up team assigned to sonic flow meter set-up while the others bring the rest of the gear to the sampling location since flow meter wet up can be time consuming. Make sure that hose unions have the rubber grommet installed and that all connections are proper and snug. Equipment should be laid out with consideration to:

- Keeping walkways clear of wires and other equipment,
- Keeping wires and hoses neat, using wire ties to secure hoses and wiring out of the way, and
- Planning for good work flow.

Once all of the hoses are installed, the valves may be opened on the sample and return ports and at the pumps and sample tub. With the software program in manual mode, verify pump rotation by powering the pump motor for a few seconds while someone checks for rotation. If the pump does not turn, the motor should be disconnected from the electrical cabinet and the guard removed to allow the pump to be manually turned over several times. This usually should require a “Lockout/Tagout” procedure. The guard should then be reinstalled and the pump rechecked.

During equipment tear-down, first close the sample port and return port valves and secure the plugs. GSI’s Ballast Sampling System is designed to automatically empty the sample tub at the conclusion of a test. Depending on the amount of water left in the sample tub, it may be best to place the control program into manual mode and completely drain the sample tub of water, tilting the sample tub to get the water into the drain. The sample lines must be manually emptied into the sample tub. Other tasks are:

- Packing the pump for removal,
- Removing the hoses from the sample pitots via unions,
- Shutting the valve on the return port to prevent any flow that may otherwise push back through the return pump,

- Backing up the data log file separately from the laptop,
- Packing and removing from the vessel the remainder of the hose, wiring, and equipment,
- Conducting a final visual check to assure that all equipment and personal items have been removed, and
- Ensuring that both the Sample and Return port valves are fully closed and the plugs firmly installed.

CHAPTER 4: OUTCOMES AND RECOMMENDATIONS

Overall the sampling method and supporting equipment performed well during GSI's ship visits. GSI successfully loaded, set up and operated the sampling process described here within a feasible time window, and "left no trace" upon departing the ship, except for the pitot flange, which was removed later by the ship crew.

COSTS

The costs of carrying out a sampling event using this method (excluding scientific supplies associated with sample analysis) are detailed in Table 3.

Table 3. GSI Costs Per Sampling Event.

	Cost Factor	**Time/Cost**
One-Time Costs	Ship Inspection	$1,500
	Installation of flanges in a ship	$2,000-$5,000
	Reuseable Operational Equipment	$45,000
	Biological Sampling Equipment	$500-$2000, depending on Test Plan
	Set up and Tear Down of Sampling Equipment	1.5 – 2 hrs (total) assuming 2-3 staff
Per Sampling Event Costs	Sample Collection Staff Time	TBD, depending on Test Plan
	Staff Travel	TBD, depending on Test Plan

EQUIPMENT PERFORMANCE

Sampling operational equipment performed as expected with the following exceptions:

The Ultra-Sonic Flow Meter on the ships' ballast discharge line performed inconsistently and unreliably, jeopardizing the extent to which representativeness of the sample can be proven. It is important to sample a constant fraction of the ballast line flow through using an in-line magnetic flux flow meter on the sample line, and a portable ultrasonic flow meter mounted to the ships ballast piping. If one of these monitors is inconsistent, there is no direct means to assure that the sample volume and the flow volumes are proportional throughout the sampling process. Without this information, it becomes difficult to translate organisms per unit volume in the sample to organisms per unit volume in the ballast discharge:

$$\frac{Sample\ Flow\ Rate\ (inline\ magnetic\ flux\ flow\ meter)}{Ballast\ Line\ Flow\ Rate\ (portable\ ultrasonic\ flow\ meter)} = Constant$$

The ultrasonic flow meter was also difficult to mount properly. It is highly recommended that ship owners and authorities encourage treatment system developers to include flow meters in their systems that have a proven in situ performance to within 3 %. It is also recommended to have a standardized output connection so that the sample team can make use of that flow meter to facilitate the constant percent sampling necessary for a representative sample.

It was necessary to tune up the PLC Control Loop. Because the sampling equipment is used on a number of different ships each having different arrangements, flow rates and pressures, sometimes it is necessary to fine -tune the automation of the sample system to prevent unstable rates or oscillating rates of the sample flow. It is recommended that the PLC control loop parameters be available, i.e. the Gain, Reset and Rate.

The 32 Gallon heavy duty tub (sample collection barrel) though strong and light was awkward to bring aboard. Attaching backpack straps in the future may remedy this. Delivery of the 19 liter carboys for effluent toxicity testing was improved by placing each carboy inside a frame backpack for navigation from the sampling location to the dock.

RECOMMENDATIONS

Key lessons learned in terms of sample event planning and staffing were:

Scheduling of the sampling event is subject to changes in weather, ship equipment, and port schedules. Even when the ship has docked, the schedule is still subject to change. Depending on each ship and each cargo load, the ballasting and deballasting operation varies and may start and stop at various times, i.e., 6 hours of sampling may actually take 12 hours. Fresh sampling and analysis personnel are essential to quality data. It is recommended that sampling and analysis crew shifts of 24 hours be in place to address schedule contingencies.

Equipment set-up and break-down is easier when shared among several team members. Initially, the engineers were more familiar with the equipment set-up. As more sampling events took place, personnel became familiarized with the set-up and break-down and could therefore provide more support and assistance in those areas.

The ship pumping schedule is subject to variation making “beginning, middle and end” grab samples difficult to plan. The ballast pump (or pumps) move water at a rate that may be faster than the loading of cargo, resulting in starting and stopping of the pump (and therefore sampling). As a result, determining three sets of discrete grab samples spaced approximately near the beginning, middle and end proves difficult. One hour samples seemed to work for all parties (i.e., each sample was one hour of collection). The test plan should require that a certain volume, duration, or number of tanks of ballast water discharge be sampled instead.

Have a dedicated handling and sample transport person. This additional person allows maximum support aboard the ship and efficient delivery of the samples. This person could also return the previous samples’ cooler and ice packs to ship personnel, eliminating the need to carry multiple transport equipment aboard the ship.

CONCLUSIONS

The operational method for sampling ship discharge described in this Guidebook is a feasible and cost-effective approach which can yield representative samples for a range of experimental objectives. It appears to be applicable to most ships which ply the Great Lakes. The costs of the exercise are dominated by one-time investment in operational equipment. Installation of sample ports on ships is a relatively minor one-time expense. Costs of deployment of the sampling team and sample analysis are largely dictated by the test plan under consideration, and the number of schedule changes associated with the ship visit.

REFERENCES

GSI (2011). Great Ships Initiative (GSI) Quality Management Plan. Northeast-Midwest Institute, Washington, DC.

IMO (2004). International Convention for the Control and Management of Ships Ballast Water and Sediments. As adopted by consensus at a Diplomatic Conference at IMO, London, England, February 13 2004.

NSF International (September, 2010). Generic Protocol for the Verification of Ballast Water Treatment Technology. Version 5.1. EPA/600/R-10/146. Produced for the USEPA, Environmental Technology Verification Program in Conjunction with U.S. Coast Guard, Environmental Standards Division and U.S. Naval Research Laboratory, Center for Corrosion Science and Engineering. NSF International, Ann Arbor, Michigan.

United States Coast Guard (2008). Analysis of Ballast Water Sampling Port Designs Using Computational Fluid Dynamics. United States Coast Guard, Research and Development Center, Report No. CG-D-01-08. February 2008.

APPENDIX 1 - MV INDIANA HARBOR SAMPLE LOCATION INSPECTION REPORT

Great Ships Initiative

MV Indiana Harbor Sample Location Inspection

MV Indiana Harbor Sample Location Inspection

Great Ships Initiative
March 14, 2011

Contents

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Purpose of Inspection

In 2010, the Great Ships Initiative (GSI) received funding from the Legislative Citizen's Commission on Minnesota Resources, the Maritime Administration and the Great Lakes Protection Fund to assist in the design, inspection, installation and testing of ballast discharge sampling apparati and processes on 10 commercial cargo ships operating in the Great Lakes. The goal of this GSI project is to develop, test and evaluate best ballast discharge sampling approaches relevant to Great Lakes shipping. As such, the project will install and trial ballast water discharge sampling systems using guidelines and methods developed to be as consistent as possible with those proposed by the International Maritime Organization (IMO), as well as the United States Environmental Protection Agency's Environmental Technology Verification Program. Upon identification of the best possible locations for installation of the proposed ballast discharge sampling approach, GSI in coordination with the ship owners will outfit the vessels with 4" sample ports. After installation, the ships will be visited by GSI research personnel to trial and review the sampling system, and collect biological samples using the sampling system. The sample ports will stay in place for possible future use in research, type approval testing and/or compliance monitoring.

This report summarizes GSI's recommendations for installing a ballast discharge sampling system onboard the MV Indiana Harbor -- a Great Lakes self-unloading bulk freighter operated by American Steamship Company of Williamsville, New York.

Criteria to Guide Selection of Sample Port Location

Among other engineering requirements, sample port locations onboard the target vessels will ideally be at points in the ballast discharge line with fully developed turbulent flow. Most ships will not have a location that meets all criteria, so engineering judgment will guide determinations of the best sample locations available. GSI criteria for sample location include locations that:

- Service all tanks equally by a single sample location is best if available.
- Are preceded by long lengths of straight pipe (USCG, 2008).
- Are close to overboard providing representative discharge samples in terms of proximity to the point of entry into the receiving system.
- Are nearby to a suitable area for sample processing, including adequate space for one 50 gallon open top barrel, sample bottle coolers and a technician.
- Have adequate lighting, power, and potable rinse water.

GSI team members will document through photographs and measurements all sample locations with potential to meet most or all of these criteria during a vessel visit. Each possible location will then be modeled using computational fluid dynamics (CFD) to determine whether there is fully developed flow at that location (that is, water passing that location is in a well mixed state). Also possible locations for a return flow port downstream of the sample port will be assessed; a suitable location for a return flow port is anywhere downstream of the sample port as long as the location does not interfere with the fully developed flow at the sample port.

Ship Description

The MV Indiana Harbor is a Great Lakes self-unloading bulk freighter operated by American Steamship Company of Williamsville, New York. Built in 1979, the vessel has an overall length of 1,000 ft., a beam of 105 ft., and a depth of 56 ft. She is powered by four 3500 HP General Motors Electro Motive Division (EMD) diesel engines and has a deadweight capacity at MS Draft of 80,900 Gross Tons. The vessel is primarily used for long-haul transport of iron ore pellets and western coal on the upper four Great Lakes.

In terms of her ballast system, the MV Indiana Harbor has 18 ballast tanks including forepeak and afterpeak, four ballast pumps at 13,000 gpm each (52,000 gpm total), and a total ballast capacity of 16,424,360 US gallons (62,166 m3)..

MV Indiana Harbor Inspection

GSI personnel from AMI Engineers' Joe Radniecki P.E. and Tyler Schwerdt boarded the MV Indiana Harbor on January 8th, 2011. The vessel was loading iron ore at the CN docks of Two Harbors, MN at the time of the inspection. The engineers received a guided tour of the ship from Chief Engineer Ralph Biggs. Throughout the tour, the AMI representatives completed the attached survey form (Appendix A) in consultation with the ship crew. Important features of the ship's ballast system lay-out also were recorded photographically.

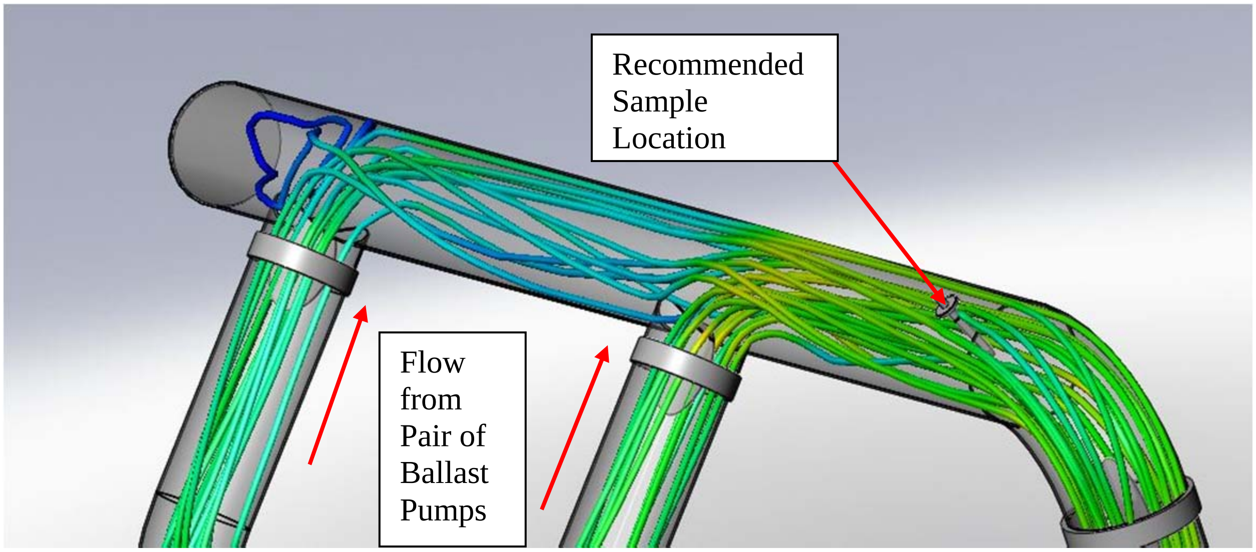
MV Indiana Harbor Ballasting System Description

The starboard and port sides of the MV Indiana Harbor each operate an independent ballast system with the exception of a crossover that can be used to connect the two systems offering redundancy in the case of mechanical failure. The ballast systems are symmetrical around the centerline of the ship. The ballast system for each side of the ship uses the same two pumps run simultaneously for both ballasting and deballasting depending on the valve arrangement. Except for the engine room most of the ships ballast piping is inside of the ballast tanks. Branches from the main line leading to individual tanks loop outside of the ballast tank wall into the ship tunnel for valve access. See the picture to the right. On the interior of the tank the pipe turns 90 degrees downward and terminates in a bellmouth close to the tank floor. The portion of piping inside the tank was not inspected as it was not accessible during the visit.

Findings

The best location for installation of a ballast discharge sampling system onboard the MV Indiana Harbor, i.e. which fits the GSI location criteria, including fluid dynamic recommendations and processing requirements, is in the vessel's engine room at a point in the piping after flows from both pumps have combined. This location can serve one half of the ship's ballast tanks under typical circumstances, and both sides under exceptional circumstances. A photo of the location is shown below looking down the length of the header towards discharge on the starboard side. The photo was taken standing in a suitable sample processing area that is immediately adjacent to the sample collection location.

The area pictured above was analyzed with computational fluid mechanics to insure its acceptability for sampling. Although the flow at this point is not fully developed it is the closest to fully developed available on the existing piping.



Recommendations:

GSI recommends placing the sampling port in the MV Indiana Harbor’s engine room downstream of where the two pump flows merge together before discharge on the port side for the following reasons:

Positives
Post-pump location gives a better picture of ballast system induced mortality.
Sample location can service half of the ships ballast tanks from a single location.
Available lighting, power and wash water.
Pipe length and arrangement delivers the closest to fully developed flow available.
Location can be isolated.
Existing sample ports nearby can be used for return flow.
Nearby processing and analysis areas.
Due to installation being on straight length standard sampling port and pitot can be used.
Negatives
Not fully developed flow, but it is the closest to fully developed available.

For the purpose of this project a sampling location servicing the port side of the MV Indiana Harbor from the engine room is sufficient. The sample location on the port side is recommended based on the ships current arrangement. Modifications caused by the addition of a ballast water treatment system may require the sample location(s) to be moved or modified.

Note relevant to upcoming NaOH ballast treatment trials on this ship: If sampling needs to target a subset of ballast tanks such as that planned for summer 2011 to test the NaOH/CO_2 ballast treatment system, it is still recommended to sample at the above location (in the engine room) as opposed to the tunnel proximate to the treated tanks discharge to the ballast system. Installing a sample port closer to a specific set of tanks would require a sample port for each of the targeted tanks. The majority of the ballast piping upstream of the engine room is on the interior of the tanks and inaccessible. The only accessible piping is an elbow such that the standard sample port and pitot design would have to be custom designed and modified.

References

U.S. Coast Guard Research and Development Center / CG-D01-08 (2008), *Analysis of Ballast Water Sampling Port Designs Using Computational Fluid Dynamics.*

Appendix A – MV Indiana Harbor Inspection Survey Form

GSI Ship Monitoring Sample Access Evaluation Sheet

Ship: Indiana Harbor

Ship Type: Bulk Carrier

Evaluation Date: 1/7/2011

Evaluation Location: Two Harbors CN Dock

Contact Person: Ralph Biggs 312-499-7998

Existing Fluid Analysis of Location: Yes / [✓ No] / Available

Existing Treatment System : Yes / [✓ No Describe]

NaOH System available
sometime

Ballast Tank Capacities:

Access Procedures

Required PPE / Certifications / Training:

Comments:

Sample Location: engine room   Comments

permitted confined space: Yes [✓ No]
Isolated: [✓ Yes] / No 4 valve
Above Water Line In All Draft Conditions: Yes [✓ No]
Most Narrow Location:
Ship ladder Only Access: [✓ Yes] /No

Waste Water Repository: Ballast Line / Bilge / Other: old sample port
Pump Needed: [✓ Yes] /No 1.5"
110v Power available: Yes /No Other:
Adequate Lighting: [✓ Yes] / No

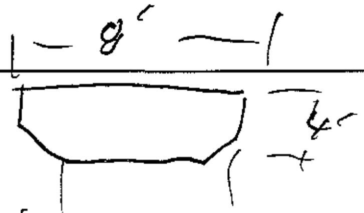
Suitable For 4" Flange: [✓ Yes] / No
2'4" Clear From Pipe Face: [✓ Yes] / No
Entering And Tightening Concerns: Yes / [✓ No]

Material: [✓ Steel] / Other:
Line Size:
Straight Length:
Upstream Obstruction: T 151" From COT T To weld on L
Downstream Obstruction: L
Location: Prepump / [✓ Postpump]

Pressure Range :
Flow Rate Range:
Typical Ballasting Duration:

Sample Location: engine room Comments

Processing Area



Processing Area Dimensions (sketch if irregular):

Space for 2 sample tubs 1.6m H x 1m D and coolers: Yes /No

Max Temp of 85 Deg (30Deg C): [✓ Yes /No], If No Max of ____

Distance From Sample Location: 4'

Flat Floor: [✓ Yes] /No

110v Power available: [✓ Yes]/No /Other:

Adequate Lighting: [✓ Yes] / No

Wash Down Water Available [✓ Yes] No

Analysis Area

Adjacent to Processing Area: [✓ Yes]/No

Within 10 Minutes Travel to Processing Area: [✓ Yes]/No

Area (suggested min 5m x 0.5m sketch if irregular):

Flat Floor: [✓ Yes]/No

110v Power available: [✓ Yes]/No /Other:

Adequate Lighting: [✓ Yes]/No

Wash Down Water Available

Sample Location: Tunnel Comments

Processing Area

Processing Area Dimensions (sketch if irregular): 4' x 15'

Space for 2 sample tubs 1 6m H x 1m D and coolers: [✓ Yes] /No

Max Temp of 85 Deg (30Deg C): Yes /No , If No Max of _____not concern

Distance From Sample Location: 0

Flat Floor: [✓ Yes] /No

110v Power available: Yes /No /Other: Limited Lighting

Adequate Lighting: [✓ Yes] / No

Wash Down Water Available Yes /[✓ No]

Analysis Area

Adjacent to Processing Area: Yes/[✓ No]

Within 10 Minutes Travel to Processing Area: [✓ Yes] /No Same as Belt

Area (suggested min 5m x 0.5m sketch if irregular):

Flat Floor: [✓ Yes] /No

110v Power available: Yes /No /Other:

Adequate Lighting: [✓ Yes] /No

Wash Down Water Available No

Sample Location: Tunnel Comments

permitted confined space: Yes [✓ No]

Isolated: Yes /No

Above Water Line In All Draft Conditions: Yes /No

Most Narrow Location:

Ship ladder Only Access: Yes /No

Waste Water Repository: [✓ Ballast Line] / Bilge / [✓ Other:] downstream

Pump Needed: Yes /No

110v Power available: [✓ Yes] /No Other: Linten off light

Adequate Lighting: [✓ Yes] / No

Suitable For 4" Flange: [✓ Yes] / No

2'4" Clear From Pipe Face: [✓ Yes] / No

Entering And Tightening Concerns: Yes [✓ No]

Material: Steel Steel / Other:

Line Size: 14"

Straight Length: none

Upstream Obstruction: elbow

Downstream Obstruction: elbow

Location: [✓ Prepump] / Postpump

Pressure Range :

Flow Rate Range:

Typical Ballasting Duration: