DEMONSTRATION ON A SHIP

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The demonstrator

The MV Kruibeke

KRUIBEKE (IMO: 9719288) is a LPG Tanker that was built in 2017 and is sailing under the flag of Belgium.Her carrying capacity is 38000 cubic meters Liquid Gas and her current draught is reported to be 9.7 meters. Her length overall (LOA) is 180 meters and her width is 30 meters. The ship is owned and operated byEXMAR (https://www.exmar.com/en/all-exmar-fleets/kruibeke).

Why this location? Current knowledge of gas tanker corrosion problems

The current state of knowledge about the corrosion problems on board gas tankers is rather limited. Research thus far has focused on problems in the ballast tanks and the hull.

After all. as part of the normal operation of a ship, ballast tanks are often loaded and unloaded with ballast water. When the ballast tank is filled, the seawater is in direct contact with the steel tank wall. When the ballast tank is emptied, a small amount of ballast water always remains in the tank. This means that the atmosphere is always very humid, with a high concentration of chloride in the air. This leads to high corrosion rates. This is compounded by the fact that periodic inspection and maintenance is impractical and expensive. This is due to the difficulty of accessing the tanks, the potential lack of oxygen, the potential presence of toxic gases and the lack of natural lighting. The combination of these factors means that corrosion rates in ballast tanks can reach high levels (De Baere et al., 2013).

Since the introduction of double hull tankers in 1993, all cargo tank support structures have been relocated to the ballast tanks. This exposes these vital parts of the ship to an atmosphere where the rate of corrosion can be much higher than in most cargo atmospheres. The significance of this risk is evident when considering the fact that the remaining economic life of the ship is directly influenced by the condition of these parts. For this reason, many experts have recognized the seriousness of the corrosion problem in ballast tanks (De Baere et al., 2013).

Another part of the ship that is commonly known to be highly susceptible to corrosion is the hull. Since the hull is in constant contact with seawater and an unlimited amount of oxygen is present, a high rate of corrosion can be achieved. As a result of the constant flow, any corrosion products that could reduce the rate of corrosion are removed by the abrasive particles in the water. The part of the hull exposed to wave action is subject to an even higher rate of corrosion. Contact with tugs and fenders in ports can damage the coating, creating areas of the hull where the steel is less protected from corrosion (Zayed, Garbatov, & Guedes Soares, 2018a). To protect the hull from corrosion, MV Kruibeke is equipped with an Impressed Current Cathodic Protection (ICCP) system. This is a corrosion protection technique that uses an impressed electric current to reduce and control corrosion in metal structures.

However, this is as far as extensive research has gone. In reality, corrosion is often a serious problem in many other parts of the ship's systems. For example, the seawater discharge line and scrubber discharge line are often damaged by corrosion, resulting in high repair costs. To get a more accurate view on the state of the problem, a series of interviews were conducted with members of the Exmar ship management team, to determine other locations on board where corrosion has a high impact upon the The locations that emerged from these interviews are:

- Sea chest strainer
- Ballast water treatment system strainer
- Scrubber discharge line
- Fire pump manifold
- Seawater discharge line
- Spray line
- Seawater cooling system
- Cargo cooling system
- Steam lines
- Scuppers drain lines
- Ballast tanks
- Cooling system of the cargo compressors
- Fire lines
- Manifold reducers
- Bottom of anchor chain locker

- *Ballast water treatment system strainer*

In the interviews with Exmar, it was noted that corrosion was often found in the strainer of the ballast water treatment system. This is to be expected as the strainer is made of steel and is in constant contact with seawater. When the treatment system is active, high flow rates are present in the filter. When the treatment system is inactive, there is still a small amount of seawater in the strainer, creating a very humid atmosphere that facilitates the continuation of the corrosion process.

In addition, it was reported that many other parts of the ballast water system are often damaged by corrosion. The components of the ballast system are used intensively and wear is inevitable.

- *Scrubber discharge line*

The amount of sulfur oxides a ship can emit is regulated in certain areas. Ship operators have a number of options to comply with these regulations.

The ship can switch to low-sulfur fuel, which is more expensive than regular fuel oil. If it is more cost effective, a scrubber can be installed. The scrubber reduces the amount of sulfur in the emissions to bring the ship into compliance. This is done by spraying seawater on the emissions. A number of vessels in the Exmar fleet are equipped with a scrubber.

The interviews revealed that corrosion is often found in the scrubber discharge line. This is the line through which seawater is discharged after being sprayed on the exhaust gases. This water has been treated to neutralize the sulfuric acid. However, a small amount of sulfuric acid remains in the seawater. Despite the fact that special coatings have been applied to the line, corrosion rates are still high.

- *Fire pump manifold*

The post fire pump manifold distributes the pumped seawater to the various systems served by the fire pumps. This manifold is constructed of STPG 370E galvanized steel.It is often subject to corrosion damage, which may be due to the inferior quality of the coating on the steel. However, cavitation and high flow rates inevitably lead to increased corrosion rates.

- *Seawater discharge line*

Seawater used in the ship's systems is discharged through the seawater discharge line. This line is constructed of STPG 370E steel and coated with polyethene.

Corrosion is a common problem in this line. According to Exmar personnel, at least one Exmar tanker per year has a leak in this line. The cost to repair this leak is high. The vessel has to be taken out of hire and, if drydocking is not an option, divers have to come in and repair the leak. In some cases, the out-of-hire period can be several weeks and the cost of the leak can amount to 10% to 20% of the vessel's maintenance budget.

- *Spray line*

The spray line is used to spray seawater onto the deck and accommodation for firefighting purposes, to protect the deck from brittle fracture in the event of a cargo spill, or simply to rinse the deck. According to Exmar personnel, this line is often subject to corrosion damage. As this line is not used all the time, a certain amount of seawater remains in the line when it is not in use. Initially, the corrosion rate is high due to the high amount of oxygen in the line and the high salt content of the seawater. After a while, the oxygen in the pipe will be consumed by the corrosion process and the corrosion rate will decrease. However, it is more likely that the pipe will be used again before the oxygen depletion is complete. As a result in a new supply of oxygen and seawater is introduced into the line, and the corrosion rate may again be high.

- *Seawater cooling system*

Seawater is used as the coolant for the cooling systems of the engine and other essential machinery. The heat exchangers for the lubrication oil and freshwater cooling systems use seawater to facilitate cooling. According to Exmar personnel, the seawater part of these systems often corrodes.

- *Cargo cooling system*

To control the pressure and temperature in the cargo tanks and pipes, LPG cargoes are intensively monitored and conditioned. This can be done by using a series of cargo reliquefaction units or by using a vaporizer.

A key component of a reliquefaction unit is the condenser. The condenser liquefies the cargo, which has been vaporized and heated in the multi-stage compressors it passes through before reaching the condenser. The condenser is actually a heat exchanger that uses seawater to cool the cargo vapors. The vaporizer, which is actually a heat exchanger using seawater, is used to heat the cargo liquid to evaporate it. According to Exmar, the seawater piping in these two systems is often prone to corrosion.

- *Steam lines*

The steam pipes aboard a ship are used for a variety of purposes. On most of Exmar's gas tankers, they are made of galvanized steel with a heat-resistant coating. Each pipe is surrounded by a layer of insulation. The steam pipes are often found to be corroded. This is probably due to the amount of condensation that remains in these pipes when they are not in use..

- *Scuppers drain lines*

The scuppers are used to drain water collected on deck. Corrosion is often found in the scupper discharge lines. This is attributed to the infinite amount of oxygen, water and salt in the water.

- *Cooling system of the cargo compressors*

Cargo compressors are cooled by circulating a mixture of glycol and fresh water. Corrosion is often found in the piping of this cooling system. As this is unlikely to be a completely closed system, there is sufficient oxygen for corrosion to occur.

- *Fire lines*

The fire line is used to supply seawater to the fire hydrants, spray lines and other systems on board. It is often found to be corroded. The same situation as described in section will occur in the fire main, causing corrosion.

- *Manifold reducers*

The LPG cargo supply lines from a port facility do not always have the same dimensions as the cargo liquid lines from the ship's manifold. To solve this problem, the vessel has a number of manifold reducers that act as spools. These reducers are stored on deck.

According to Exmar personnel, these reducers are made of different steel alloys of different qualities, resulting in accelerated corrosion rates. As the reducers are stored on deck, they are often splashed with seawater, leaving a small layer of salt on the steel when the seawater evaporates. Consequently, the next time water (seawater, rain, condensation...) is present on the reducer, the salt content will be higher, resulting in higher corrosion rates.

- *Bottom of anchor chain locker*

The anchor chain locker is a compartment in the foredeck for storing the anchor chain. The chain is sprayed with seawater to wash off any mud when the anchor is retrieved. Since this is not always effective, mud will build up on the bottom of the locker. This mud is not removed by the eductor in the chain locker. Since there is also seawater and oxygen in the locker, any steel components in the locker that come into contact with water will begin to corrode. Since most of the seawater is at the bottom of the locker, this is where the highest corrosion rates will occur.

Baseline: most suitable locations for sensor systems

After consulting and discussing the various possibilities with members of the Exmar Shipmanagement Team, it was determined that the following locations were the most interesting and practical:

- Strainer of the lower sea chest
- Ballast water discharge line
- Scrubber overboard pipe

Location 1: Strainer of the lower sea chest

- *Advantages*

There are many aspects that make the sea chest strainer an interesting place to measure corrosion rates and environmental parameters. Since the low sea chest is practically always in use when the ship is not in coastal waters, the water in the strainer is almost constantly changing. The composition of seawater varies greatly depending on the geographical location of the vessel. This results in a wide range of environmental conditions and associated corrosion rates, adding unique data to the data set.

Another advantage of the strainer as a location for a sensor system is that it is easily accessible. The strainers are cleaned and inspected on a monthly basis, so they are placed in easily accessible locations. This makes installation easier. It also allows the sensor system to be checked at these predetermined times.

The design of the sea chest strainer allows ample space for the installation of the sensor system. It is located inside the filter, which means that if any part of the sensor system comes loose, it will be caught by the filter. It will not be able to damage any part of the system.

- *Disadvantages*

Due to the high flow rates in the strainer, a strong sensor mounting frame is essential. All parts of the sensor system must also be able to withstand these flow rates. Another disadvantage is the need for a cable throughput. This adds to the complexity of the sensor system design. It is also less convenient to work on the sensor system compared to a sensor system based on a branch, as the process to reach the sensor system is more labor intensive.

Location 2: Ballast water discharge line

During the interviews, it was noted that the strainer in the ballast water treatment system is often corroded. However, since it was not practically feasible to install a corrosion system in the ballast water treatment system strainer, and since sufficient knowledge of the environmental conditions and corrosion rate in the ballast tanks is already available, it was decided to install the sensor system on the ballast water discharge line.

- *Advantages*

The amount of ballast water on board varies depending on the ship's operating conditions, i.e. whether the ship is loaded or empty. When the ship is fully loaded, there is usually a minimum amount of ballast water on board. On the other hand, when the cargo tanks are empty and the ship is sailing in ballast, the ballast tanks are almost full. This means that the ballast water on board is frequently changed, with ballasting and de-ballasting taking place several times a month. As a result, parts of the ballast water system are in almost constant contact with seawater. This makes the ballast water system an ideal location for a sensor system.

The Marine Growth Prevention System (MGPS) is an important system that protects the MV Kruibeke's systems from corrosion. The sensor system in the sea chest strainer measures the corrosion rate of the water just treated by the MGPS. The corrosion rate is measured again after the water has passed through the entire ballast system. This is done by the sensor system in the ballast water discharge line. As a result, it is possible to evaluate the effectiveness of this system.

The sampling point provides a convenient connection point for branching off the discharge line. It is located in the engine room with sufficient space for the sensor system and several options for the discharge of the branch were possible. Another advantage is that the sampling point is easily accessible, making installation and maintenance of the sensor system easier.

- *Disadvantages*

Because the discharge line is lined with polyethylene, it was not possible to install the sensor system inside the pipe. The risk of damaging the lining by mounting the sensor system inside the pipe was too great. Therefore, it was decided that the most practical solution would be to branch off the discharge line. A disadvantage of a branch is that the true conditions in the pipe are only partially measured by the sensor system. For example, the flow rate in the discharge line is not the same as in the branch.

However, the environmental parameters will be mostly the same as in the discharge line as long as the branch line is not obstructed. If this line is blocked, the water supplied to the sensor system will be affected by the conditions in the engine room. It may become warmer due to the high air temperature in the engine room. Also, the water in the sensor system will not be renewed with water from the discharge line, as only a small flow would be possible.

Location 3: Scrubber overboard pipe

- *Advantages*

The scrubber overboard pipe is a suitable location for the sensor system as the pipe is constantly filled with wash water. When the scrubber is active, the wash water absorbs various substances present in the exhaust gases. This creates interesting environmental parameters and greatly affects the corrosion rate. As Exmar reported that this pipe is often very corroded, the measurement results could help Exmar find a more suitable method to reduce the corrosion rate.

- *Disadvantages*

A disadvantage of this measurement location is that placing the sensor system directly in the pipe is relatively complex and costly. Maintenance of the sensors would also be impractical. An alternative may be to make a branch on the pipe and route the wash water through a freestanding sensor setup. This method ensures a smooth installation and makes maintenance easier. However, the disadvantage is that the flow rate will not be the same as in the pipe.

However, the MV Kruibeke does not have a scrubber. It was therefore decided that only two demonstrators would be installed in this study.

Construction of the demonstrator: The sensor system

A sensor system was designed for each measurement location. Each sensor system consists of an environmental parameter sensor, a corrosion rate sensor, and corrosion test coupons. The environmental parameters measured are acidity (pH), temperature, salinity, oxygen content, conductivity, redox potential, chlorophyll content, and chloride concentration. The corrosion sensor calculates the corrosion rate using the linear polarization resistance method. The corrosion test coupons are used as a second means of measuring the corrosion rate in the system. These test coupons are pieces of steel made from alloys S235, 316L, and S355.

These sensors and coupons were installed in a shipboard system. Since a vessel is a highly valuable asset and any damage can lead to severe consequences, any risk of damage or dangerous situations must be avoided. This significantly increased the complexity of the sensor setup design. While in most demonstrators the sensors can simply be mounted on a sturdy rack without having to deal with high water pressure and the risk of causing a potentially dangerous leak, the situation aboard a ship is very different.

Scuba probe

The Scuba90 sensor is a water quality probe manufactured by Royal Eijkelkamp Soil & Water B.V.. It has a diameter of 90 mm and a length of 450 mm. It has an operating temperature range of -50 °C to +50 °C. The maximum depth for the Scuba is 200 m, the maximum depth for the ISE sensor (chloride ion concentration) is 15m. It is equipped with a data memory for 1 million readings. It operates on a 12V power supply (Royal Eijkelkamp Soil & Water B.V., 2022).The Scuba sensor is equipped with a number of sensors that measure environmental parameters. The probe is typically used to characterize groundwater wells, rivers or lakes. The Scuba probes ordered for the SOCORRO project are only equipped with sensors that measure environmental markers that influence the corrosion rate. These measurements are carried out every half hour and take 5 minutes to complete.

The Scuba probes are equipped with different sensors:

Temperature is measured by an electrical resistor (thermistor), the resistance of which changes in a predictable way with temperature (Figure 1, 1).

Dissolved oxygen is measured using an optical sensor (Figure 1, 2). This sensor consists of a blue light source, a sensing surface and a red light receiver. When the sensing surface is exposed to water, an amount of oxygen equivalent to the amount of oxygen in the water diffuses into the sensing surface. The sensor works on the principle of fluorescence. Fluorescence occurs when a molecule absorbs light at one wavelength and then emits that energy at a different wavelength. The oxygen-active compound in the sensing surface absorbs energy as blue light and then emits the energy as red light. The blue light is turned on and off during each measurement cycle. The red light receiver measures the time it takes for the fluorescence to extinguish after the blue light is turned off. This time is proportional to the amount of oxygen dissolved in the water. The output of the sensor is corrected for the temperature and salinity of the water.

The **conductivity** of water is measured using the four-electrode method. The sensor (Figure 1, 3) is equipped with two pairs of graphite electrodes arranged in a stable geometry. A constant voltage is applied to one of each pair of electrodes and the current required to maintain the voltage level is measured. As the conductivity of the water increases, so does the current. Total dissolved solids (TDS) and salinity are calculated from the conductivity.

The acidity (**pH**; Figure 1, 4) is measured using a glass pH electrode in combination with a reference electrode. The voltage drop across the glass membrane of the pH electrode is measured. From this, the pH value is calculated.

The **oxidation-reduction potential (ORP)** is measured using a voltage measurement circuit consisting of an ORP electrode and a reference electrode (Figure 1, 5 and 7). The ORP is measured as the voltage drop across the platinum membrane of the ORP electrode. Platinum does not react with the ions in the water and will not exchange electrons unless the ions are very strong. The potential created by this refusal to exchange electrons is what is measured as ORP.

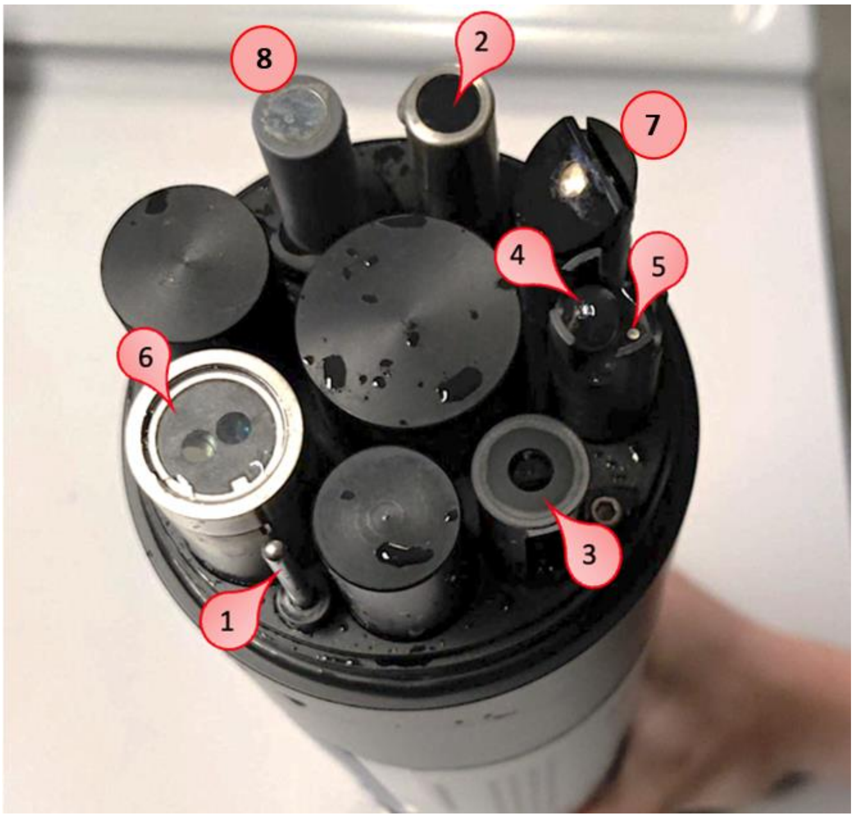

Figure 1. Different sensors of the Scuba Probe.
1: temperature sensor, 2: optical sensor (dissolved oxygen), 3: conductivity sensor, 4: pH glass, 5: ORP sensor, 6: fluorometer for chlorophyll determination; 7. reference electrode; 8. chloride sensor.

Chlorophyll concentration is measured by means of a fluorometric sensor (Figure 1, 6). These sensors operate on the principle of fluorescence. The fluorometric sensors emit light at a specific wavelength and measure the different wavelength received in return. The more chlorophyll molecules there are in the water, the more light of the wavelength they absorb and the more they fluoresce at a specific, different wavelength. The amount of chlorophyll in the water is related to the amount of reflected light.

The **chloride ion concentration** in water is measured using an ion-selective electrode (ISE) in combination with a reference electrode (Figure 1, 7-8). This sensor operates in the same way as an acidity sensor except that the glass pH electrode is replaced by a chloride-selective membrane. The electrode filling solution contains a chloride salt and the difference between the concentration of this salt and the chloride concentration in the water causes a charge separation. This is measured relative to the reference electrode as a voltage. This voltage changes predictably with changes in the chloride concentration in the water.

- *The different end caps*

The Scuba sensor is constructed out of a plastic cylinder, housing the sensors on one end and a cable connection point on the other end. Different caps can be screwed on the end of the sensors. For transportation and storage, a closed and watertight capsule (Figure 2) is provided. Since the sensors are preferably kept in a humid atmosphere, a small amount of water is to be hold in the capsule.

Figure 2: Storage cap on the Scuba probe.

Another cap that is available is one with openings on the side (Figure 3). These are most suitable in the case that the Scuba sensor is submerged in water. The cap is designed for efficient flowthrough of water along the sensors as well as to provide protection against big articles in the water. This cap was fitted on the Scuba probe that was installed in the sea chest strainer. Before installation, it was fitted with a copper mesh in order to prevent marine growth on the sensors.

For the sensor system for the ballast system a specially designed flow cell (Figure 4) was produced. On this flow cell custom holes were made, to attach the press tubes for the inlet and outlet. As in the sea chest strainer setup, a copper mesh was fitted in the flow cell to prevent fouling (Figure 5).

Figure 3: End cap with openings on the side.

Figure 4: Specially designed flow cell (end cap).

Figure 5: Copper mesh in the flow cell.

Sensor maintenance

There are two types of maintenance for the Scuba probe: cleaning and calibration.

The manufacturer recommends that the probe is cleaned at regular intervals. For the sensors on board MV Kruibeke it was decided that this was to be carried out every 2 months. This is done using a toothbrush, dishwasher soap and fresh water. A detailed description of this operation is included in the manuals provided to the ship's crew.

Calibration should only be performed if the data shows abnormal readings. It was decided that before requesting a calibration from the ship's crew, the readings from the Scuba sensors in the ballast setup and the sea chest strainer setup should first be compared. This can be achieved by pumping the water from the sea chest strainer directly to the ballast water discharge line and comparing the readings of the environmental sensors in both installations.The calibration method for each sensor is described in the manufacturer's manual and summarised in Table 1. Acidity and ORP probes are expected to suffer most from fouling and poor water quality, as they rely on glass membranes.

Table 1. Calibration of the different sensors on the Scuba 90

Sensor	Calibration method	Calibration points
Temperature	No calibration needed	Not applicable
pH	Two-/three-points	pH 4, pH 7, pH 10
ORP	1 point	ORP standard 200 mV
Conductivity	1 point	CD standard, 0.5 M, 58670 µS (brackish – salt water) CD standard, 0.1 M, 12856 µS (brackish water) CD standard, 0.01 Molar, 1412 µS (freshwater) CD standard, 0.001 Molar, 147 µS (fresh/glacial water)
Dissolved oxygen	1 point	100% saturated distilled water (shaken heavily to saturate water with O_2)

The LP corrosion probe

The linear polarisation sensor (CCube, The Netherlands; Figure 6) is a corrosion measurement system developed specifically for the SOCORRO project. It provides a means to monitor the corrosion rate in real-time. The sensors use a micro-electrochemical cell to measure the corrosion rate of a metal surface by detecting changes in electrical resistance. It measures the corrosion rates of the alloys S235, 316L and S355 every 4 hours. Each measurement cycle takes approximately 10 minutes to complete.

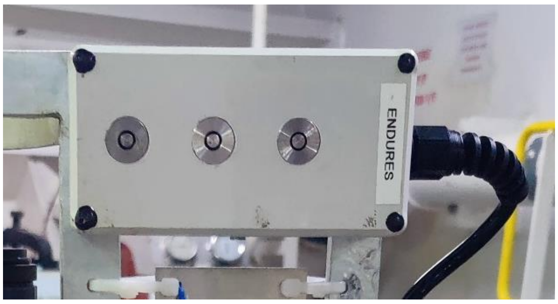

Figure 6: C-Cube sensors, mounted on the sensor rack of the sea chest strainer setup.

The working and reference electrodes of the C-Cube sensor are housed in a plastic box, designed for installation underwater. The plastic box is filled with epoxy resin. It has a height of 150 mm, a length of 60 mm and a width of 50 mm.The sensor box is connected to a logger box, which houses the potentiostat and data logger. The logger box is placed outside of the measured solution. The logger box is fitted with a cellular antenna, to allow the measured data to be sent over cellular network to C-Cube. C-Cube then transforms the rough data to interpreted data and sends it to the researchers of the SOCORRO project.

The C-Cube sensors operate on the basis of linear polarization (LP) technology. The exact design and method of operation of the C-Cube is a trade secret of the company. Linear polarization is an electrochemical technique for the instantaneous measurement of average corrosion rates of metal surfaces. As the C-Cube sensor contains electrodes for three different alloys, it creates an electrochemical cell for each of them. By applying a small polarization potential (voltage) to an electrode in a solution (seawater), the current required to maintain a given voltage shift is measured (Speight, 2015). The ratio of the applied potential and the resulting current response is the polarization resistance. This resistance is in inverse proportion to the uniform corrosion rate (Campos-Silva & Rodríguez-Castro, 2015). The LPR technique is based on a set-up consisting of a working electrode, a counter electrode and a reference electrode. The working electrode is made of the alloy to be monitored.

One of the disadvantages of this method is that it can only be carried out successfully in a relatively clean, aqueous electrolytic environment. The LPR method is not suitable for gases or water/oil emulsions where electrode fouling may prevent the collection of reliable data (Speight, 2015).

Corrosion coupons

The corrosion coupons (Figure 7) are used as a reference measurement for the LPR measurements taken by the C-Cube sensors. This is achieved by performing mass loss measurements. The coupons are steel samples of the same alloys as those used in the C-Cube sensors, i.e.: S235, 316L and S355. These coupons are in contact with the seawater in the setups.

Prior to installation, each coupon is fitted with a plastic tag. An organic solvent or hot alkaline cleaner is used to degrease the coupon. Once this is completed, the coupon are not to be touched with bare hands. Before installation, the coupons are measured and weighed. These measurements are recorded for each coupon.

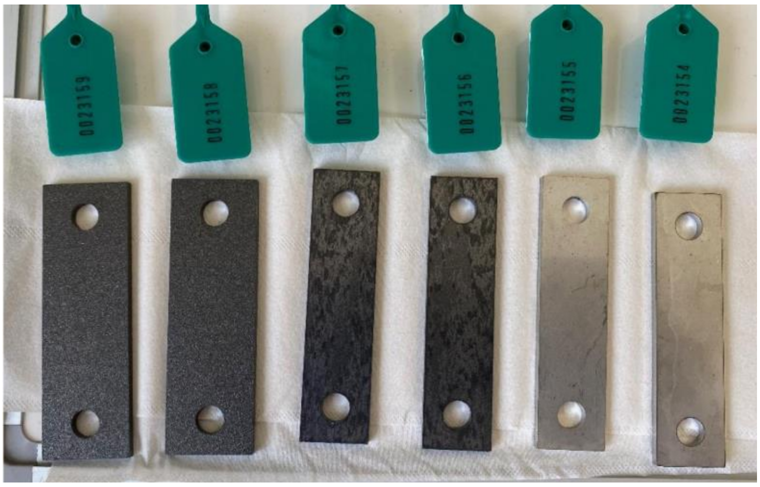

Figure 7: Corrosion coupons.

Electrical cabinet

A sealed electrical distribution box was designed and built within the SOCORRO partnership to power the sensors and support the Scuba while uploading data. To this end, the distribution box is equipped with an internal heating element (Figure 8, 2) to maintain a constant temperature of approximately 15-20 degrees Celsius.

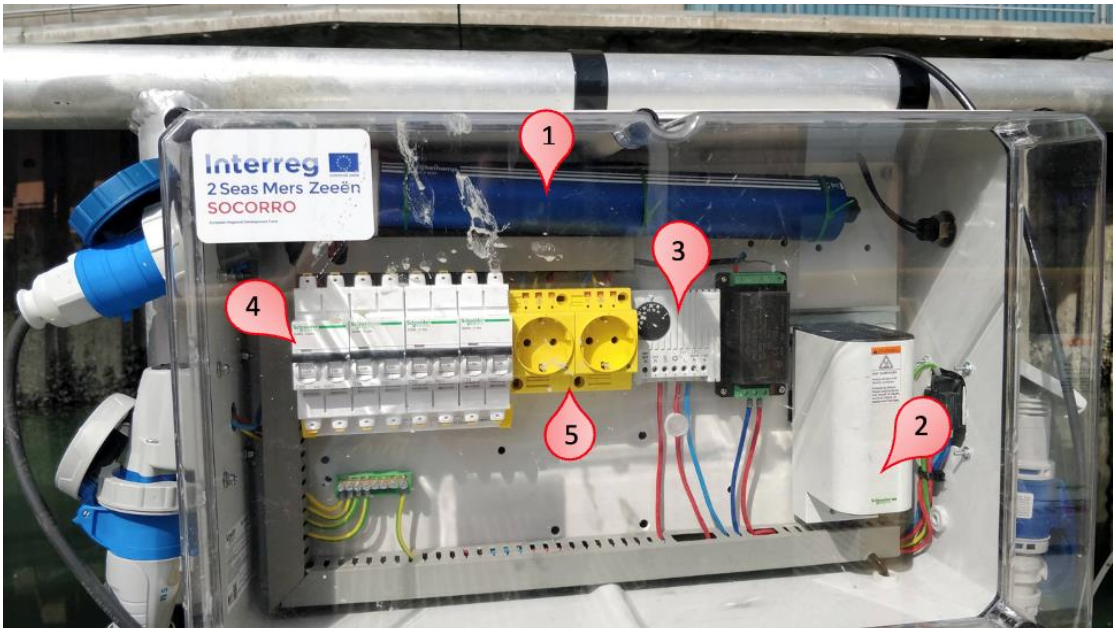

Figure 8. Electrical distribution box for sensors.
1: 4G modem, 2: internal heating, 3: thermostat, 4: circuit breakers, 5: sockets

This heating element is connected to a thermostat (Figure 8, 3) that controls the activation of the element when the temperature falls below the desired value and switches it off when the maximum temperature is reached. To prevent short circuits and electrical damage to the equipment, the entire distribution box is fitted with fuses (Figure 8, 4). In addition, two CEE 16A plugs (Figure 8, 5) are provided to connect a laptop or other electronic devices on site if necessary.

The system is powered (220V) from the ship's electrical system via a CEE connector. The system then provides connections for the sensors and the heater which is built into the cabinet. The C-Cube Logger Box is powered via a CEE plug on the outside of the cabinet. The Scuba sensor is powered by a USB charger plugged into a 220V socket. There is an additional socket on the outside of the cabinet that can be used for the laptop charger. The heater is connected with a thermostat. As a safety measure, several circuit breakers are installed. These are: the main circuit breaker, the C-cube connector, the heater and the sockets.

All connections and circuit breakers are labeled. A copy of the one-line diagram is placed in the electrical cabinet.

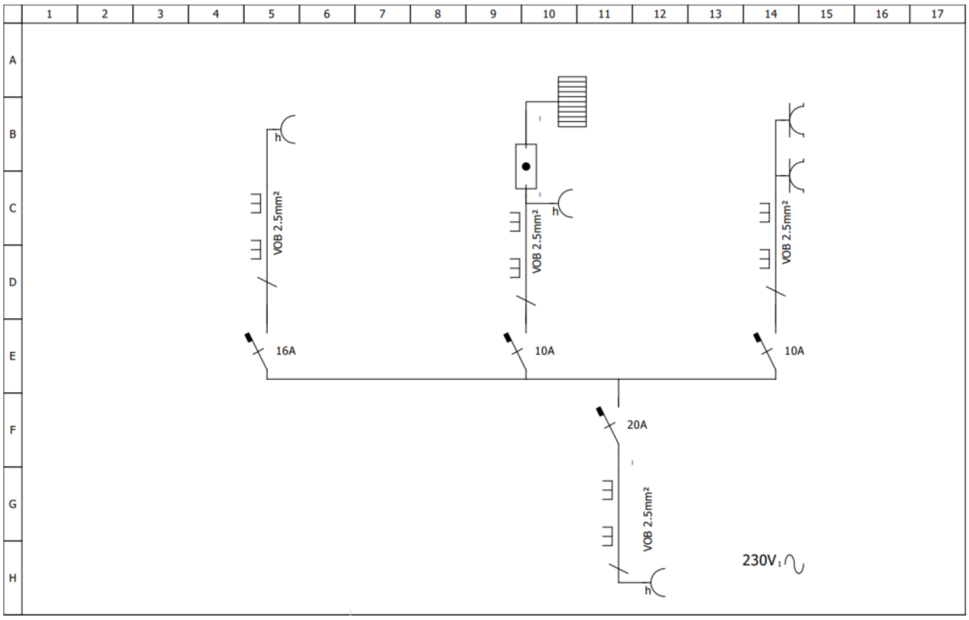

Figure 9: One-line diagram of the electrical cabinet.

Cable glands

The C-Cube and Scuba sensors are fitted with a data cable to facilitate data exchange and power supply. Special cable glands (Thermal Detection Ltd.) have been ordered to feed the data cable through the steel components. The Teflon seal in the cable glands is custom made to fit the exact diameter of the cable. The cable glands are designed to withstand pressures of up to 100 bar.

To install the cable gland, a hole is drilled in the position where the cable gland is to be fitted. The cable gland is then welded to the steelwork on both sides of the hole. The cable can then be fed through the gland and the gland tightened. The glands are manufactured from 316LSST steel. The steel into which the glands are fitted is S235 steel. The glands are designed not to be re-closed after the tightened gland has been opened as this could result in reduced watertightness.

Construction of the demonstrator: The lower sea chest strainer setup

The sea chest is a recess in the hull of a vessel below the waterline. It is used to supply the vessel with seawater for e.g. engine cooling, ballast and firefighting purposes. The sea chest is protected by a ‘sea chest grating’ to prevent the passage of large objects like garbage, fish and nets. A typical vessel has two sea chest, one placed higher than the other. It depends on the situation which sea chest is being used: in areas where the under-keel clearance of the vessel is smaller, it might be preferable to use the high sea chest, as the low sea chest might suck too much mud.

Every sea chest is connected to a strainer (Figure 10), which is used to prevent the passage of particles larger than 5 mm. The strainer is constructed out of a large diameter pipe, with an in- and outlet for the seawater. Inside this pipe a filter is placed, which can be taken out to be cleaned. The filter has a circular opening on the side of the inlet to allow the particles to be trapped inside the filter. This design makes it easier to remove the particles out of the system. A steel cover closes off the strainer. The cover is fixed to the pipe using bolts and nuts. Inside the filter, a lot of free space is available where a sensor system can be placed.

The strainer is made of structural carbon steel. It is coated with 2 coats of 320 µDFT modified epoxy. The filter is constructed of stainless steel. The perforations of the filter are 5 mm in diameter.

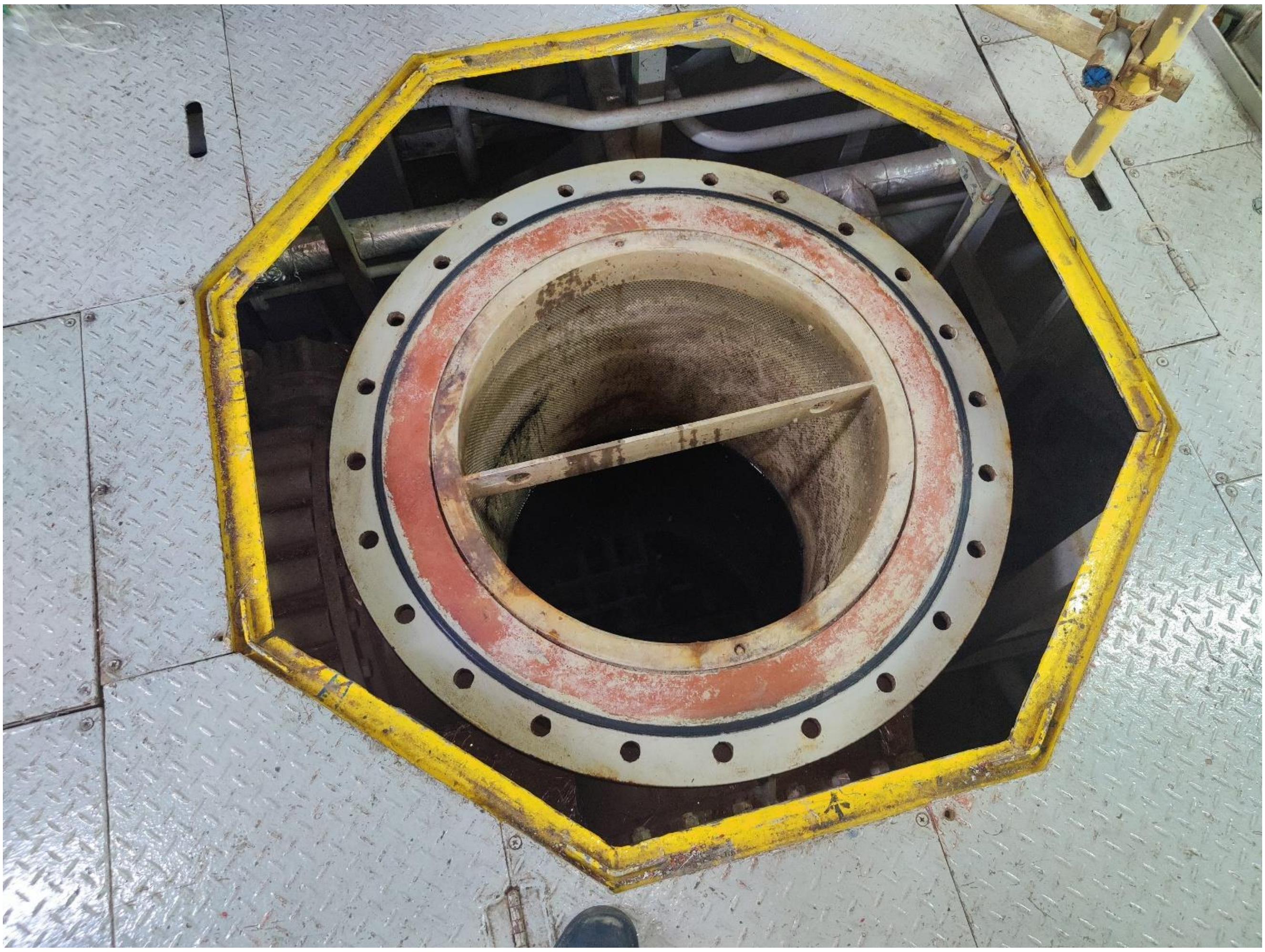

Figure 10: The sea chest strainer without cover.

On the top of this cover a smaller vent pipe with a valve is fitted. When the strainer is emptied or filled, this valve is opened and air is supplied or evacuated through the pipe. The seawater that escapes through the pipe is collected by a steel water collector right below the end of the pipe (Figure 11). This vent pipe has been modified to accommodate the data and electricity cables for the sensor system inside the strainer (see below).

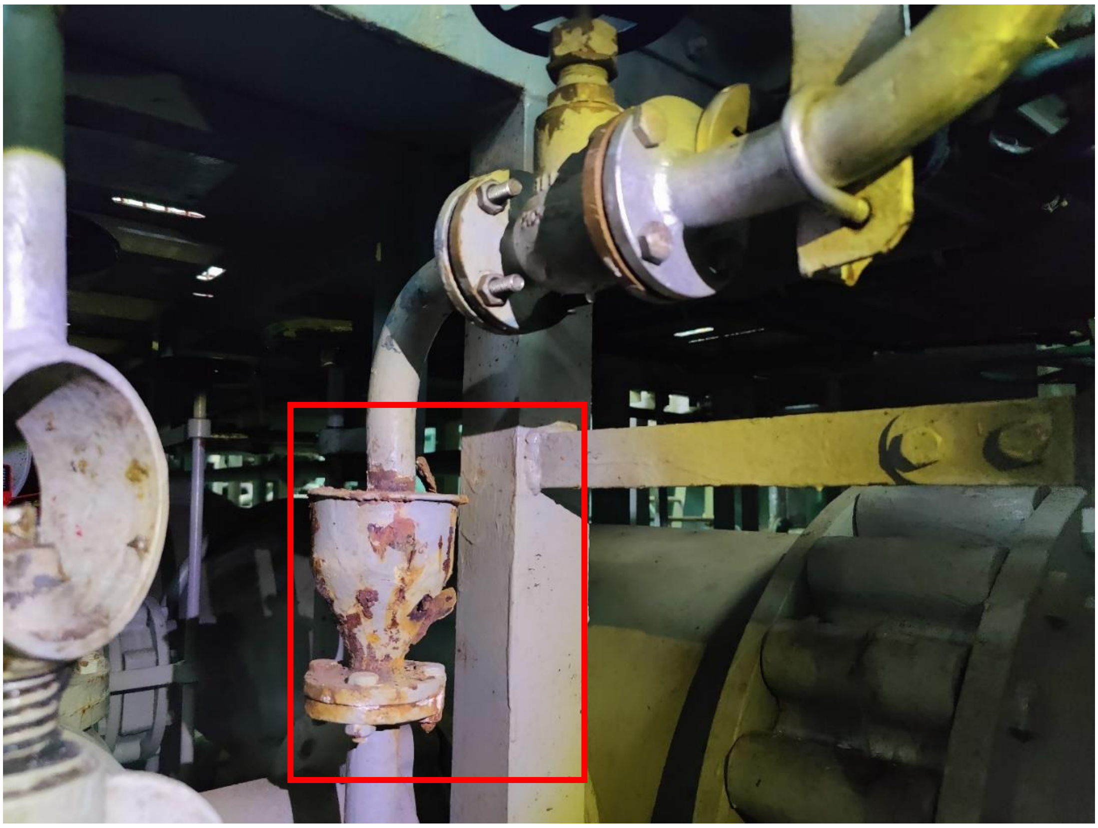

Figure 11: Collector for the seawater when the valve is open.

The Marine Growth Prevention System (MGPS) (Figure 12) is mainly designed to prevent the accumulation of marine growth in the ship's systems. Additionally, it reduces the risk of corrosion. The MGPS is based on the electrolytic principle and consists of copper and aluminium anodes which are supplied with a fixed impressed current from a control panel. The anodes generate ions when the current is applied. These ions are injected into the seawater through a nozzle in the sea chest. These ions are then transported by the seawater and carried into the pipe system. Consequently, the MGPS protects all the systems that are supplied with seawater from the sea chest against corrosion and marine growth, including the sea chest strainer and the ballast water system.

The copper anodes produce copper ions which prevent marine growth. The ions are released during electrolysis in the following reactions.

Anodic reaction	$Cu \rightarrow Cu^{2+} + 2e$
Cathodic reaction	$2H_2O + 2e \rightarrow H_2 + 2OH^-$

The aluminium anodes produce aluminium ions. These form an anti-corrosive layer on the inner surface of the seawater pipes. The ions are released during electrolysis in the following reactions.

Anodic reaction	$Al \rightarrow Al^{3+} + 3e$
Cathodic reaction	$3H_2O + 3e \rightarrow 3/2H_2 + 3OH^-$
Product of Al(OH)$_3$	$Al^{3+} + 3OH^- \rightarrow Al(OH)_3$

The MGPS is made up of an anode treatment tank containing 2 copper anodes, 2 aluminium anodes and 1 stainless steel (SUS) cathode. Power is supplied from a control panel. A number of flow meters are fitted to check that the system is operating correctly. The treated water is supplied to the sea chests by means of injection nozzles (Figure 13).

Figure 12: Antifouling (MGPS) anode treatment tank

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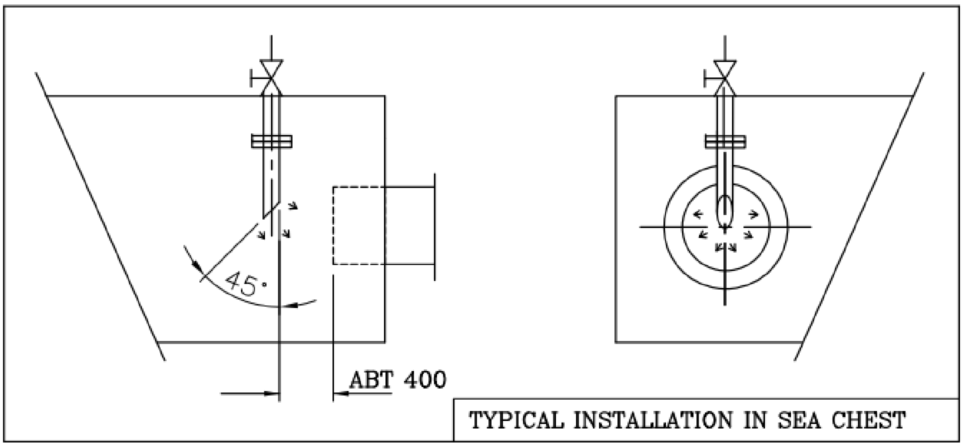


Figure 13: Injection nozzles in the sea chests (MGPS)
Source: *(Hanjin Heavy Industries & Construction Co. LTD., 2017)*

Design of the sea chest strainer setup

As the high flow rates in the sea chest strainer create a harsh and demanding environment for the sensor setup, it was decided that it would be best to use a steel rack for the suspension of the sensor system components. This rack was welded onto the strainer cover. To facilitate the throughput of the data cables, the vent pipe was modified. The electrical cabinet and the C-Cube logger box were mounted near the measurement setup.

The sensor rack (Figure 14, Figure 15) is designed to hold the Scuba sensor, C-Cube sensor and 15 corrosion coupons. Because of the steel bar fitted in the middle of the filter, there was not a lot of space left to fit the sensor rack. Because of this, the rack had to be fitted perpendicular to the direction of the incoming flow of seawater. Naturally, this creates a strong force on the rack, requiring it to be designed as strongly as possible. The rack does not touch the strainer.

Figure 14: Sensor rack with Scuba sensor, C-Cube sensor and corrosion coupons, lifted out of the strainer.

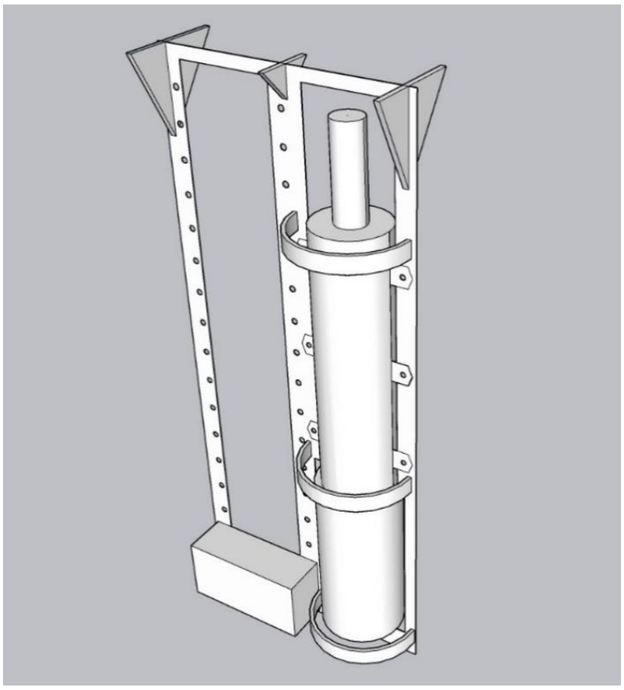


Figure 15: 3D view of the rack with the sensors mounted.

The rack is constructed out of hot-dipped galvanized carbon steel. It has a height of 715 mm, a width of 305 mm and a thickness of 5 mm.

On the rack, space is provided to fit the Scuba sensor. This sensor is mounted onto the rack using aluminium clamps, which are electrically isolated from the rack by using plastic washers. 3 steel guards were fitted onto the rack to prevent the sensor from being hit by the side of the strainer when lifted. On the bottom of the Scuba sensor, the end cap with openings on the side as described in section 0 was fitted. The C-Cube sensor was mounted to the rack using bolts and nuts. The data/power cables of the Scuba sensor and the C-Cube sensor are routed through the modified vent pipe (Figure 16, Figure 17,

Figure 18).

The 15 corrosion coupons which comprises 5 S235 alloys, 5 316L alloys and 5 S355 alloys were attached to the rack using plastic zip ties.

Figure 16. The various parts of the modified vent pipe.

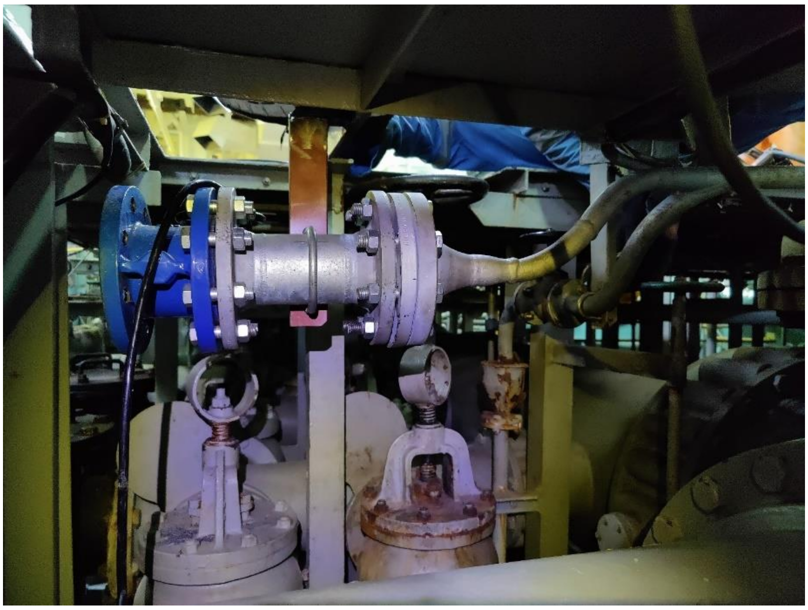


Figure 17: The modified vent pipe.

This was achieved by dismantling the vent pipe and replacing an elbow piece with a T-piece. By doing this, the strainer could still be vented while suitable arrangements could be arranged for the cable throughputs.

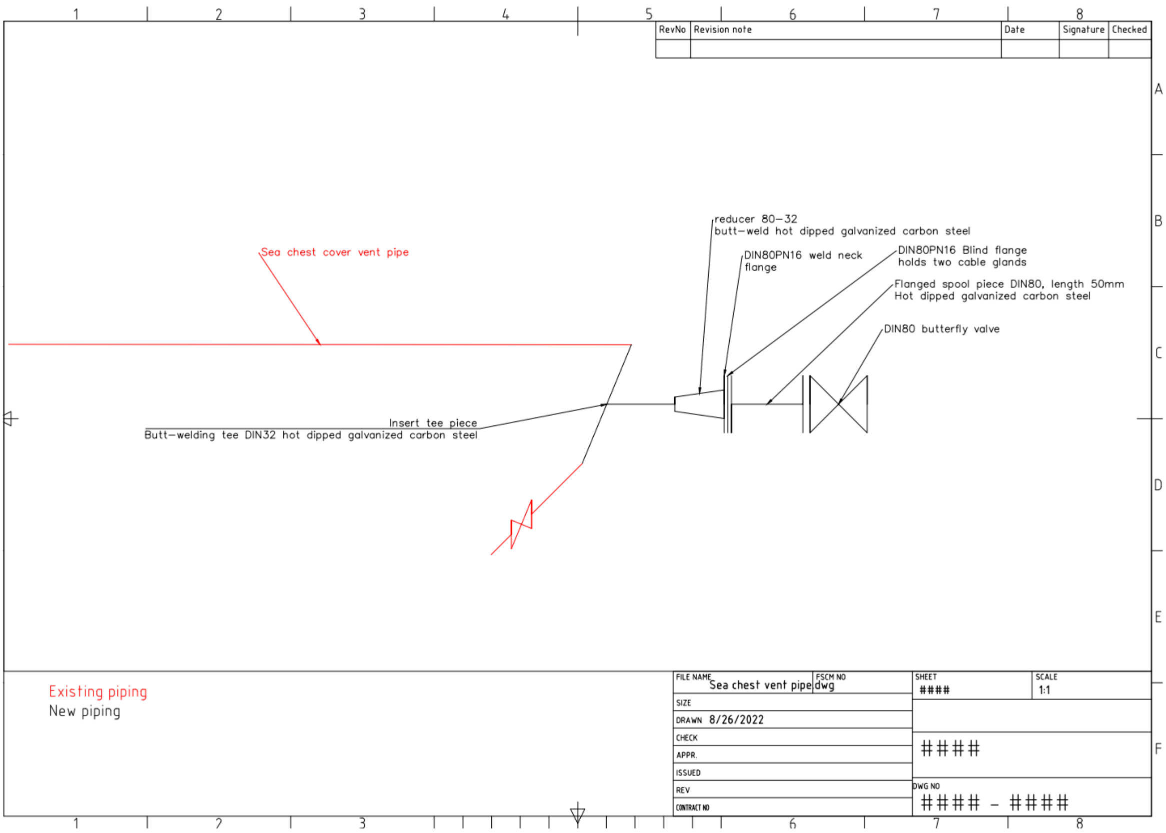


Figure 18: Schematic overview of the modified vent pipe.

On the other side of the T-piece, a reducer was fitted, providing a transition from DIN32 piping to DIN80 piping. On this reducer a weld neck flange was mounted. On this weld neck flange a blind flange was mounted. This blind flange was fitted with 2 welded cable glands to provide for the watertight throughput of the cables. On the other side of the blind flange a flanged spool piece was mounted. This spool piece was attached to a butterfly valve.

All the piping is hot-dipped galvanized. After installation of the modified vent pipe all parts were coated with 2-component grey paint. The different parts and their sizes and materials are described in Table 2.

Table 2: Overview of the parts of the modified vent pipe. Listed from strainer to electrical cabinet.

Item	Size & material
Vent pipe	DIN32 carbon steel
T-piece	DIN32 carbon steel
Reducer	DIN32-80 carbon steel
Weld neck flange	DIN80 PN16 carbon steel
Blind flange with 2 welded cable glands	DIN80 PN16 carbon steel
Flanged spool piece	DIN80 carbon steel
Butterfly valve	DIN80 cast iron

The butterfly valve was fitted as an extra safety measure. In case of leakage of the cable glands and the strainer cannot be quickly isolated, the cables can be cut and the butterfly valve can be closed.

Figure 19: Mounting of the electrical cabinet and C-Cube logger box.

To mount the electrical cabinet and C-Cube logger box, steel bars were welded onto an I-beam forward of the strainer (Figure 19). The cabinet and logger box were fixed to the steel bars with bolts and nuts. The steel bars were coated with two-component white paint.In order to be able to remove the strainer cover, enough spare length of the Scuba sensor cable was left to move with the cover. The C-Cube cable can be disconnected from the logger box.

A detailed manual specifically compiled for the sea chest strainer setup was provided to the crew. In this manual the SOCORRO project, the working principles and design of the setup are described. Furthermore, detailed step-by-step procedures are outlined for setup maintenance (strainer opening, sensor cleaning and strainer closing) and data retrieval. A list of spare parts and a troubleshooting section are included.

The list of spare parts refers to the parts that are stored in a steel box in the storage room in the engine room workshop. All the parts are numbered for easy retrieval.

Data collection method

The ship's crew is asked to send the data files of the Scuba sensor and C-Cube sensor every 2 months (Table 3). The data retrieval in case of the Scuba sensor is done by downloading the data directly from the sensor to the provided laptop over USB. A laptop is included in the spare parts left on board specifically for the data retrieval of the Scuba sensors. Instructions on this are provided in the operating manual and in a video clip saved on the desktop of the laptop.

The data of the C-Cube sensor is sent over cellular network. As there is no cellular connection in the engine room, the logger boxes have to be disconnected and brought to the bridge when the vessel is close to the shore. Here the boxes have to be powered on and the data is then sent automatically.

The corrosion coupons are to be collected in two phases. The instructions on how to properly dismount and store the coupons are provided in the operating manual.

Table 3: Planned periods for data retrievals.

Data batch	Month	Data Scuba	Data C-Cube	Corrosion coupons
1	November 2022	X	X	
2	January 2023	X	X	
3	March/April 2023	X	X	X
4	May/June 2023	X	X	
5	July/August 2023	X	X	X

Construction of the demonstrator: The ballast water discharge line setup

Description of the ballast water system

The MV Kruibeke is equipped with 10 separate water ballast tanks with a total capacity of 12,885.17 m^3. This ballast water is pumped on board or discharged using 2 ballast pumps with a capacity of 500 m^3/h each. The ballast water is treated with an Alfa Laval Pure-Ballast treatment system, which is equipped with a filter and AOT reactor (Hanjin Heavy industries & Construction co. ltd., 2017).

The ballast water is essential for the safe operation of the vessel. Ballast operations are carried out to accommodate changes in the distribution of cargo and consumables, as well as in response to other operational requirements. It is used to control the ship's trim, list, draught, stability and stresses. For the regular operation of the vessel, this means that various ballast operations are carried out multiple times a week.

Ballast water can contain aquatic organisms or pathogens that can be harmful to the environment if discharged into the sea. For this reason, the International Convention for the Control and Management of Ships' Ballast Water and Sediments was drawn up in 2004. This Convention contains requirements and guidelines for a safe ballast water management plan and system. To meet these requirements, the MV Kruibeke is equipped with an Alfa Laval Pure-Ballast treatment system, which includes a filter and an AOT reactor (Hanjin Heavy industries & Construction co. ltd., 2017). The ballast water management plan describes the standard operational guidelines for planning and managing ballast water and describes the safe procedures to be followed.

Description of the ballast water discharge line

The ballast water discharge line (Figure 20) is the outlet of the ballast water system (Figure 22). After the ballast water has been treated in the ballast water treatment plan in accordance with the International Convention for the Control and Management of Ships' Ballast Water and Sediments, it is pumped overboard through this pipe.

Figure 20: Ballast water discharge line

This discharge line is used frequently, as ballasting and de-ballasting operations are sometimes carried out several times a week as part of the ship’s regular operations.

The pipe is made of carbon steel pipe (STPY400) with a diameter of 350 mm (schedule 60 pipe 14 inch). It has a polyethylene lining on the inside to protect the pipe from corrosion and is painted with standard paint on the outside (Figure 21). The pipe can be closed off by means of a hydraulically operated butterfly valve.

Figure 21: Polyethylene lining in a piece of pipe

In front of this valve there is a sampling point is placed which is closed by a globe valve. Another sampling point is located upstream of the ballast water treatment system. These two sampling points allow samples of raw and treated water to be taken. Sampling of ballast water is usually carried out by authorized inspectors during port state control.

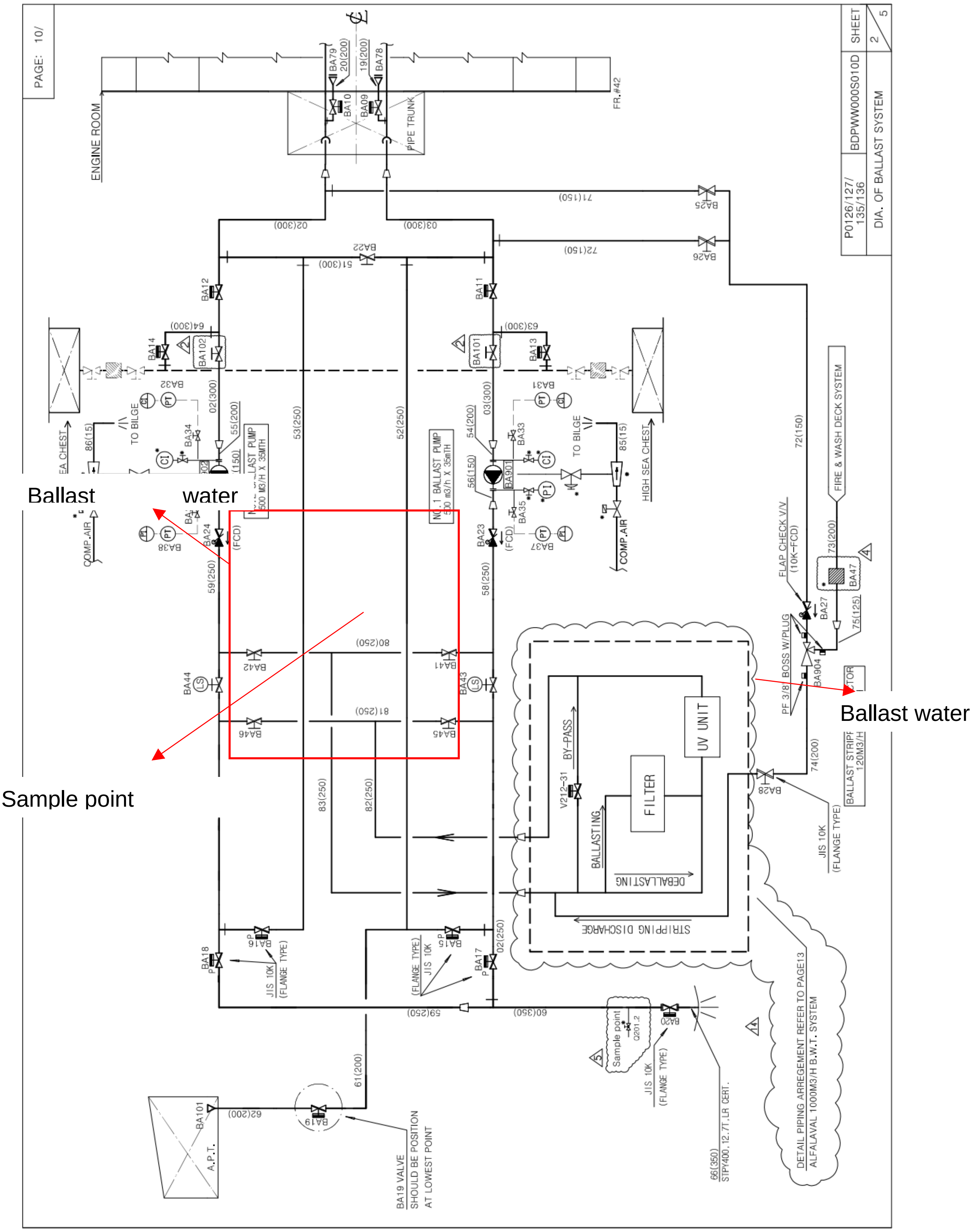


Figure 22: Ballast piping diagram
Source: Modified from (Hanjin Heavy industries & Construction co. ltd., 2017)

Corrosion prevention in the ballast system

Corrosion in the various parts of the ballast system is a well-known problem in the maritime industry. Therefore, several measures have been developed to reduce the risk of corrosion in different parts of the ballast system. The ballast pipes in the engine room and the ballast water treatment plan are made of STPG 370E standard steel. They are polyethylene-lined on the inside for corrosion protection and painted on the outside with standard paint. Other pipes in the ballast system are made of glass fiber reinforced epoxy or copper-nickel 90/10 alloy. The bell mouth is made of galvanized mild steel. These materials have a very good resistance to corrosion (Hanjin Heavy industries & Construction co. ltd., 2017).

The ballast tanks are made of steel and painted with BANNOH 2000 brown. The aft and forward peak tanks are painted with BANNOH 2000 grey (Hanjin Heavy Industries & Construction Co. LTD., 2015a). BANNOH 2000 paint is a multi-purpose epoxy primer designed to resist corrosion (Chugoku Samhwa Paints Ltd., 2021).Using the MGPS, copper and aluminium ions are injected into the water supplied by the sea chests. This is to protect the systems it supplies, including the ballast system, from corrosion and marine growth.

Ballast water treatment system

The ballast water treatment system is used to remove or destroy harmless biological organisms from ballast water. When invasive, these organisms pose a significant threat to marine ecosystems. As shipping has been identified as a major pathway for the introduction of species into new environments, the IMO developed the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004. This Convention establishes a set of standards that outline the requirements to be met by ships.

In the Regulation D-2 Ballast Water Performance Standard it is stated that:

> “Ships conducting ballast water management shall discharge less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers in minimum dimension and less than 10 viable organisms per milliliter less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations.” (International Maritime Organization, 2004)

In order to meet or exceed the requirements of this standard, it is essential to have a ballast water treatment system. The ballast water treatment system on board the MV Kruibeke is an Alfa Laval Pure Ballast treatment system, consisting of a filter and an AOT reactor (Figure 23).

- Each time ballast water is loaded, it passes through the filter and the AOT reactor before entering the ballast tank. During ballast water discharge, the water passes through the AOT reactor again before being discharged overboard. During the ballast tank stripping process, the ballast water is passed through the filter and AOT reactor. As a result, the system is used intensively and in normal operation all ballast water is treated through this system.

- The filter is used to remove the larger particles from the water, after which the main treatment process takes place in the AOT reactor. This reactor uses UV light and advanced oxidation technology to eliminate all biological organisms in the water.
- The UV light inactivates the DNA of the cells. This prevents the organisms from growing again. In addition, UV light produces free radicals. These radicals react instantly with micro-organisms and other organic contaminants, causing their cell membranes to be destroyed. The radicals are extremely short-lived, existing for only a few milliseconds. As no chemicals are added to the process, there are no toxic residues. This means that there is no impact on the environment.

According to the manufacturer (Alfa-Laval), the process does not affect corrosion in any way (Hanjin Heavy industries & Construction co. ltd., 2017).

Example of layout with 1 AOT reactor.

1. *Filter inlet valve*
2. *Filter (only one is illustrated)*
3. *Filter bypass valve*
4. *Lamp drive cabinet (LDC)*
5. *Control cabinet with main control panel*
6. *AOT reactor*
7. *Control valve*
8. *CIP (cleaning-in-place) module*
9. *Flow meter*
10. *Filter outlet valve*
11. *Backflush valve*

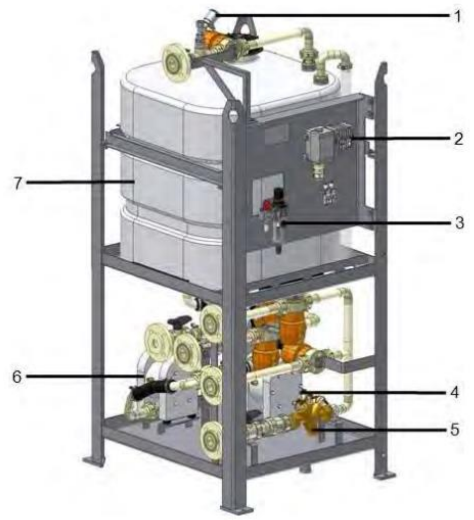
Figure 23: Example of the layout of a Alfa Laval Pure-Ballast treatment system.
Source: (Hanjin Heavy industries & Construction co. ltd., 2017)

- *CIP system*

To make sure the ballast water treatment system remains fully operational, the cleaning-in-place (CIP) system (Figure 24) performs an automatic cleaning cycle after each ballast or deballast operation. By doing this, the UV lamps and sensor in the treatment system remain as clean as possible, in order to maximize their effect.

After the ballast operation has completed, the CIP module first rinses the AOT reactor with fresh water. Afterwards, a CIP fluid cleaning agent (Alpacon Descalant Offshore, consisting of citric acid monohydrate) is circulated. This liquid has a low pH and removes scaling, calcium chlorides, metal ion build-up and chemical fouling. After the cleaning cycle has been completed, the CIP liquid is returned to the CIP module tank. The liquid is not dangerous to the environment or polluting. It is designed to be used a large number of times.

As a consequence, the overboard pipe for the CIP liquid is only used sporadically and is not likely to be used during the time the sensor system is installed in the ballast system. However, as a precautionary measure, a check valve was installed on the discharge line of the sensor system (Hanjin Heavy industries & Construction co. ltd., 2017).



CIP module

1. *Deaeration valve*
2. *Valve block*
3. *Regulator*
4. *Pump (CIP liquid)*
5. *Backflow preventer*
6. *Pump (reactor drain)*
7. *Tank for CIP liquid*

Figure 24: Layout of the CIP module.
Source: (Hanjin Heavy industries & Construction co. ltd., 2017)

Design of the ballast water discharge line setup

By consulting with the vessel's crew and technical personnel at the Exmar office it was decided that it would be most convenient create a branch off of the main ballast water discharge line. This is economically and safety wise the more interesting option, as it would be cheaper and safer than fitting a new spool piece into the discharge line. It is also easier to re-use this system on any other pipeline.

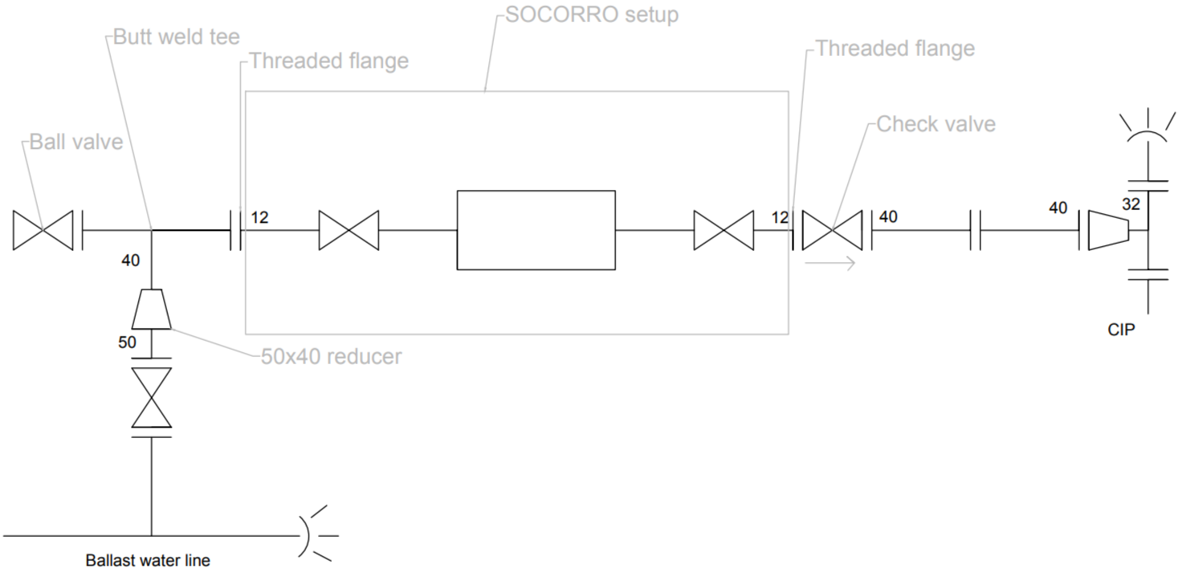


Figure 25: Schematic overview of the piping arrangement for the ballast water setup.

For the branch off (Figure 25), a sample point was identified as close as possible to the ballast water discharge point. A T-piece of pipe with flanges on each end was attached to this sample point. In this way, a flow of ballast water to the sensor system as well as the possibility to take samples was possible. The water then passes through two flow cells along the different parts of the sensor system. Based on the pitot principle, water will only pass through the sensor system when there is a flow in the ballast water discharge line. For the discharge of the water that had passed through the sensor system, a piece of piping was attached to the portside CIP discharge line.

- *Water supply for the sensor system*

To provide a supply of water to the sensor system, the sample point on the ballast water discharge line (Figure 26) was modified. Originally, it was only an elbow piece of pipe with a valve attached to it.

Figure 26: The original sample point on ballast water overboard line

Because the short piece of pipe behind the valve was attached by flanges, exchanging this piece for the T-piece of pipe was convenient (Figure 27). By doing this, a valve could be placed on one end providing a sampling point for the crew, while the other end could be used to supply the sensor system.

To connect one end of the T-piece to the supply pipe for the sensor system, a reducer was fitted to the supply pipe (Figure 28). From this reducer, stainless steel press tubes were used. This press tube was connected to a ball valve and to the flow cell. The ball valve before the flow cell makes it possible to close off the supply of water in an convenient manner, in order to allow for maintenance or reparations works.

All the piping, except for the stainless-steel press tubes, were coated using a two-component white paint.

Figure 27: The T-piece attached to the original valve (top) and the new sampling point (right).

Figure 28: Reducer in the supply line for the flow cell.

- *Flow cell for C-Cube sensor and corrosion coupons*

For the C-Cube sensor and the corrosion coupons, a tubular flow cell (Figure 29) was designed and constructed in which the C-Cube sensor could be placed and 12 corrosion coupons could be suspended. One end of the flow cell the blind flange can be dismounted from the cell. This flange is fitted with a hole for a smaller pipe through which water can be supplied to the flow cell. On the inside of the flange two pieces of steel bars are welded. In these bars the appropriate amount of holes are drilled to suspend the corrosion coupons in between the bars. The corrosion coupons were mounted using zip ties, to prevent conduction between the coupons and the steel bars. To accommodate a throughput for the cable of the C-Cube sensor, a cable gland was installed on the blind flange.

On the other side of the flow cell, the blind flange is welded to the pipe. A hole is provided to be used the connection point for the discharge pipe. This point was placed higher in order to prevent sediment from entering and clogging the discharge pipe.

Figure 29: Flow cell for the C-Cube sensor and corrosion coupons.

To install the flow cell, two U-clamps were used (Figure 30). Using these clamps, the flow cell is mounted on the back side of a spare parts rack close to the ballast water discharge line. A steel structure was constructed to place the flow cell on. Finally, the structure was coated using two-component white paint.

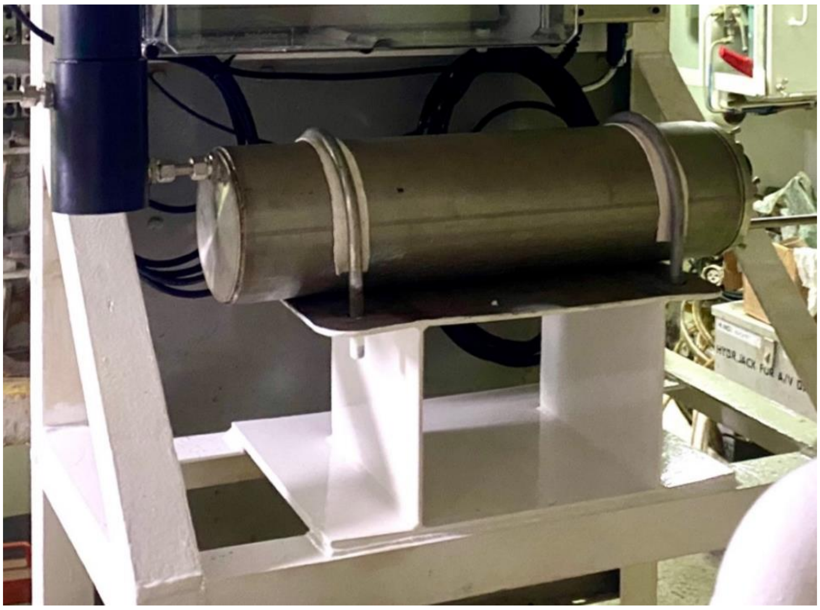


Figure 30: Mounting of the flow cell.

- *Discharge for the branch off*

The water flows from the sensor system to the CIP discharge line, due to the nature of this system, the pipe is only used once sporadically. On the CIP discharge line are no sample points. After discussing the possibilities with the engineers and technical superintendents on board, it was decided that it would be best to modify a spool piece of the CIP discharge line. A piece of piping was welded perpendicularly onto the line and at the end of this attachment a weld neck flange was installed. By modifying the CIP discharge pipe like this, the discharge line of the sensor system could be connected to the flange.

At the end of the experiment, the lines of the sensor system can be removed and a blind flange can be placed on the flange. By constructing the system in this way, there is no need to replace the spool piece of the CIP discharge line with a new spool piece.

The outlet of the large flow cell is connected to the flow cell of the Scuba sensor using a press tube (Figure 31). This flow cell is designed and produced by the researchers of the SOCORRO project. Inside the flow cell a copper mesh is fitted to prevent fouling of the sensors. The outlet of the flow cell of the Scuba sensor is connected to a ball valve.

After this, the water flows through a reducer and a check valve. This check valve is necessary to prevent water flowing from the CIP discharge line into the sensor system. Because the CIP discharge water contains chemicals that could potentially damage the Scuba sensor or C-Cube sensor, it was necessary to install a check valve on the discharge line of the sensor system. The chemicals in the CIP system are not dangerous for the marine environment and are not polluting.

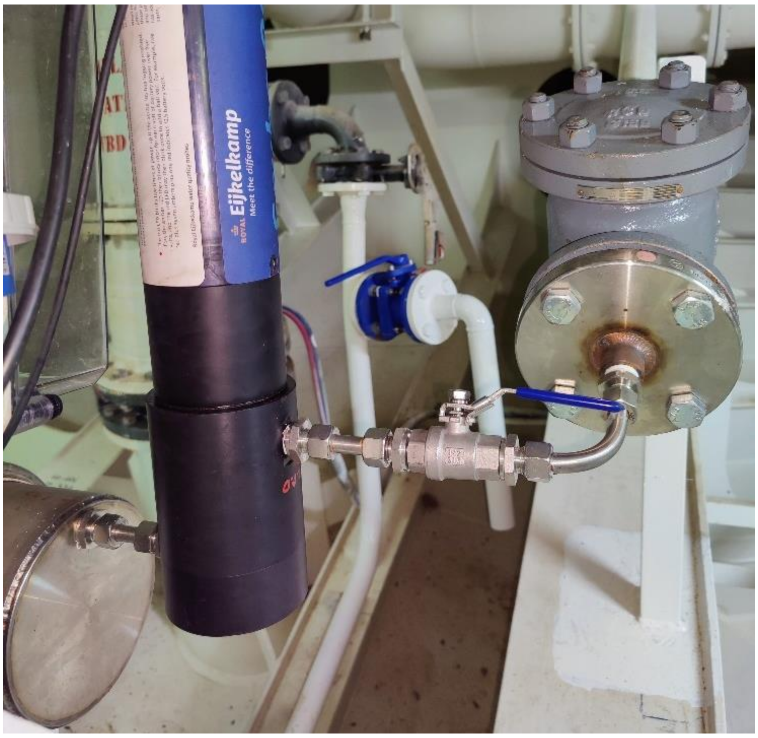


Figure 31: Flow cell of the Scuba sensor (left), reducer and check valve (right).

All the piping, except for the stainless steel press tubes, were coated using a 2-component white paint.

- *Electrical cabinet and C-Cube logger box mounting*

The electrical cabinet for the water ballast sensor system (Figure 32) was mounted on the backside of the same rack as the flow cell. This was done by welding 2 steel bars to the back of the rack. These bars were coated using 2-component white paint.

Holes were drilled in these bars so the electrical cabinet could be mounted on it. Next to the electrical cabinet space was provided to mount the C-Cube controller box. Both cabinets were secured using bolts and nuts.

Figure 32: Electrical cabinet ballast water sensor system and C-Cube controller.

- *Scuba sensor mounting*

The Scuba sensor in the ballast water sensor system is mostly supported by the inlet and outlet of its flow cell (Figure 33). To reduce the vibrations of the sensor while the engine is running, a steel bar was welded onto the side of the spare parts rack. By doing this, the steel bar was positioned next to the Scuba sensor. The sensor was then secured to the bar by using a hose clamp.

- *Operating manual and spare parts*

As for the sea chest strainer setup, a detailed manual was created for the ballast water discharge line setup. This manual, that is provided to the ship's crew, describes the design of the setup, the working principles of the sensors. It also provides step-by-step instructions for setup maintenance and data retrieval. A list of spare parts and a troubleshooting section are included as well.

The list of spare parts refers to the parts stored in a steel box in the storage room in the engine room workshop. All parts are numbered for easy identification.

- *Data collection method*

The methods for the data retrieval are the same as described for the sea chest strainer setup.

Figure 33: Scuba sensor mounting method.

Results: sea chest strainer

The position data shows that after departing from the port of Dubai (UAE), the vessel sailed to the port of Sharjah (UAE). It then sailed to the port of Ras Tanura (Saudi Arabia) to load cargo. The measurements start when the vessel left the anchorage off Sharjah (UAE) and departed towards Ras Tanura (Saudi Arabia). The vessel then sailed several times between the ports of Ras Tanura (Saudi Arabia) and Kandla (India). Each time, the vessel spent between 1-4 days at anchor before entering the port of Ras Tanura (Saudi Arabia). Before entering the port of Kandla, the waiting period was significantly longer, as the vessel spent between 5-10 days at anchor. During the measurement period, the vessel sailed as shown in Table 4.

Table 4: Positions of the vessel during measurement period of sea chest Scuba.
Source: Modified from data provided by Exmar (2023)

Action	Location	Date	Duration
Departed from	Port of Dubai (UAE)	4/09/2022	
			8 hours
Arrived at	Anchorage near Sharjah (UAE)	4/09/2022	
			8 hours
Arrived at	Port of Sharjah (UAE)	5/09/2022	
			2 days
Arrived at	Anchorage near Sharjah (UAE)	6/09/2022	
			2 days
	Beginning of measurements.	**8/09/2022**	
			2 days
Departed from	Anchorage near Sharjah (UAE)	10/09/2022	
			1 day
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	11/09/2022	
			1 day
Arrived at	Port of Ras Tanura (Saudi Arabia)	11/09/2022	
			1 day
Departed from	Port of Ras Tanura (Saudi Arabia)	12/09/2022	
			4 days
Arrived at	Anchorage near Kandla (India)	16/09/2022	
			10 days
Arrived at	Port of Kandla (India)	26/09/2022	
			2 days
Departed from	Port of Kandla (India)	28/09/2022	
			5 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	2/10/2022	
			2 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	4/10/2022	
			1 day

Departed from	Port of Ras Tanura (Saudi Arabia)	5/10/2022	
			1 day
Arrived at	Anchorage near Fujairah (UAE) for bunkering	6/10/2022	
			1 day
Departed from	Anchorage near Fujairah (UAE)	7/10/2022	
			2 days
Arrived at	Anchorage near Kandla (India)	9/10/2022	
			10 days
Arrived at	Port of Kandla (India)	19/10/2022	
			2 days
Departed from	Port of Kandla (India)	21/10/2022	
			3 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	24/10/2022	
			1 day
Departed from	Port of Ras Tanura (Saudi Arabia)	25/10/2022	
			4 days
Arrived at	Anchorage near Kandla (India)	29/10/2022	
			9 days
Arrived at	Port of Kandla (India)	7/11/2022	
			2 days
Departed from	Port of Kandla (India)	9/11/2022	
			4 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	13/11/2022	
			1 day
Arrived at	Port of Ras Tanura (Saudi Arabia)	14/11/2022	
			1 day
Departed from	Port of Ras Tanura (Saudi Arabia)	15/11/2022	
			2 days
Arrived at	Anchorage near Fujairah (UAE) for bunkering	17/11/2022	
			12 hours
Departed from	Anchorage near Fujairah (UAE)	17/11/2022	
			2 days
Arrived at	Anchorage near Kandla (India)	19/11/2022	
			5 days
	Last data retrieval performed.	**24/11/2022**	
			5 hours
Arrived at	Port of Kandla (India)	24/11/2022	

- *Temperature*

As can be seen from the time plot of the temperature (Figure 34), the vessel returned to the port of Ras Tanura three times. This can be determined by the number of temperature peaks. If the temperature data is compared with the position of the vessel at the time of the measurements, it is clear that the temperature depends entirely on the geographical position of the vessel.

Comparing the temperature history with the position data, the following can be concluded. The temperature measured near the United Arab Emirates and Saudi Arabia is significantly higher than the temperatures measured in the Arabian Sea and Indian waters. As the vessel moves from the Persian Gulf through the Arabian Sea towards India, the temperature decreases. The temperature is lowest as the vessel passes through the Arabian Sea.

The temperature reaches a minimum when the vessel arrives at the anchorage near Kandla. This may be due to the increased flow through the sea chest when the anchor is dropped as the fire pumps are activated for this operation. While the vessel is at anchor, the temperature remains at a higher constant temperature. From the moment the vessel enters Kandla port, the measured temperatures are lower than during the anchorage but higher than during the passage through the Arabian Sea. This is to be expected as the port terminal is located on a river.

When the vessel sails from India to Saudi Arabia, the temperature increases. The temperatures reach similar highs when the vessel is anchored at the anchorage near Ras Tanura (Saudi Arabia) and when it is at the terminal.

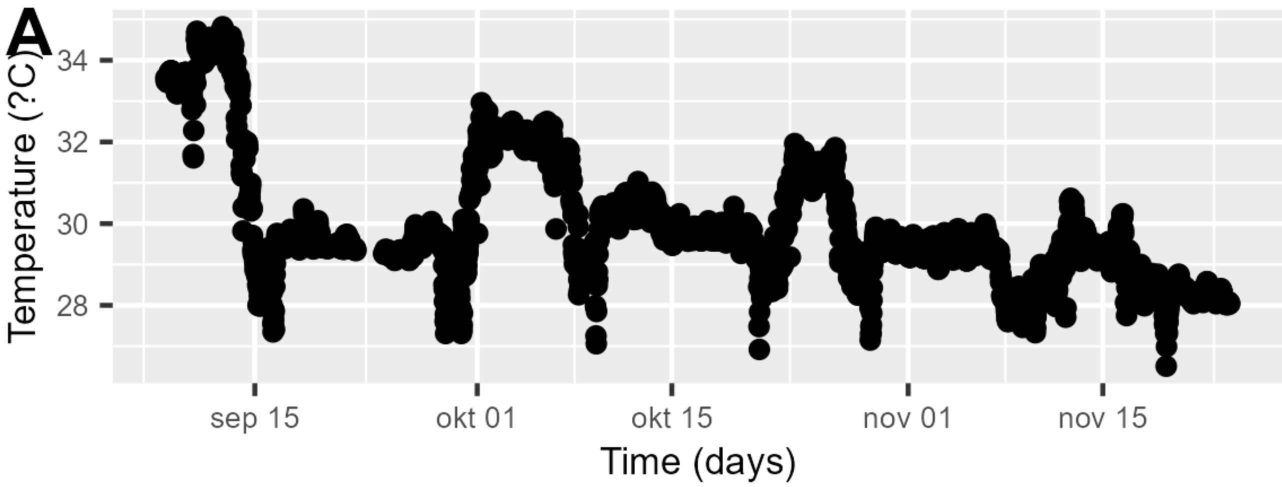


Figure 34: Timeplot temperature Scuba data sea chest strainer.

- *Dissolved oxygen*

Dissolved oxygen levels (Figure 35) follow a rather volatile pattern. At certain times there is no dissolved oxygen in the water. These drops occur very suddenly, after which they rise again rather quickly.

At the time of the first low reading, the vessel was anchored near Sharjah and on its way to Ras Tanura. The moment the vessel reaches the anchorage at Ras Tanura, the dissolved oxygen suddenly reaches higher levels. The next low values (October 25, 2022) were measured while the vessel was in the port of Ras Tanura. At the same time, lower pH and ORP values were measured.

Low dissolved oxygen was then measured again from October 29, 2022 to October 31, 2022. At this time, the ship had just arrived at the Kandla anchorage. However, the low level only lasted for 2 days and then gradually increased. The ship stayed at the anchorage for 9 days, during which the measured content was significantly higher.

From November 13, 2022, to November 14, 2022 the measured dissolved oxygen was low again. At that time, the ship was anchored near Ras Tanura and at the terminal. At the moment the ship started the voyage, the measured values were higher again. At the same time, lower pH values and oxidation reduction potentials were measured.

Low values were measured from November 19 to November 20, 2022. At this time the ship had just arrived at the anchorage of Kandla. Again, low values were measured for only 2 days, while the ship remained at the anchorage for 5 days. This time no real decrease in pH and ORP was recorded.

It is possible that there was only a small amount of dissolved oxygen in the sea chest strainer at these times because the high sea chest was in use instead of the low sea chest. However, this would not explain the lower temperatures measured when the ship arrived at Kandla anchorage.

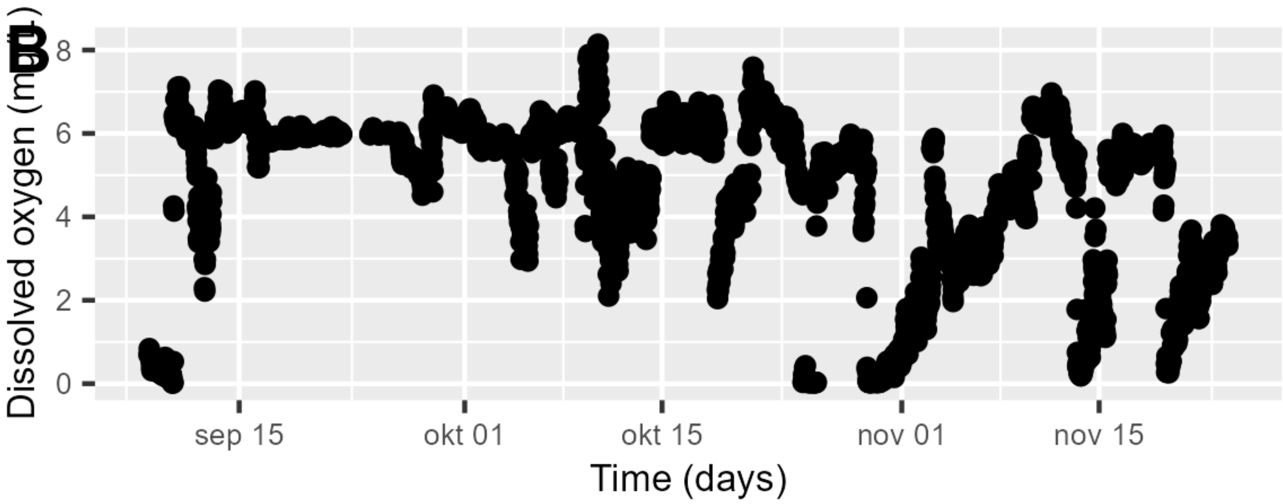


Figure 35: Timeplot dissolved oxygen Scuba data sea chest strainer.

- *Conductivity*

In a number of instances, conductivity (Figure 36) reaches minimum levels:

The first time conductivity reaches low levels is when the vessel is in the port of Kandla (October 26-28, 2022). This is probably due to the lower salinity levels in the Kandla port, as it is located in a river. The measurements show that the vessel returned to the port of Kandla from October 19 to 21 and from November 7 to 9.

Each time the vessel was near Ras Tanura, some rather low measurements were taken. At that time, the vessel was sailing from the anchorage off Ras Tanura to the terminal or had just left the terminal on its way to Kandla. Only a small number of low readings were taken each time.

On October 10, low conductivity levels were recorded for a period of 12 hours. At that time, the ship had been at the Kandla anchorage for 12 hours. After these very low readings, the conductivity level suddenly increased and remained fairly constant for the remaining 9 days the ship was at anchor.

It is very obvious that when the ship sailed from the Persian Gulf to India, the conductivity decreased. We can conclude that the conductivity of the seawater in the Persian Gulf is higher than that of the seawater in the Arabian Sea and near the port of Kandla.

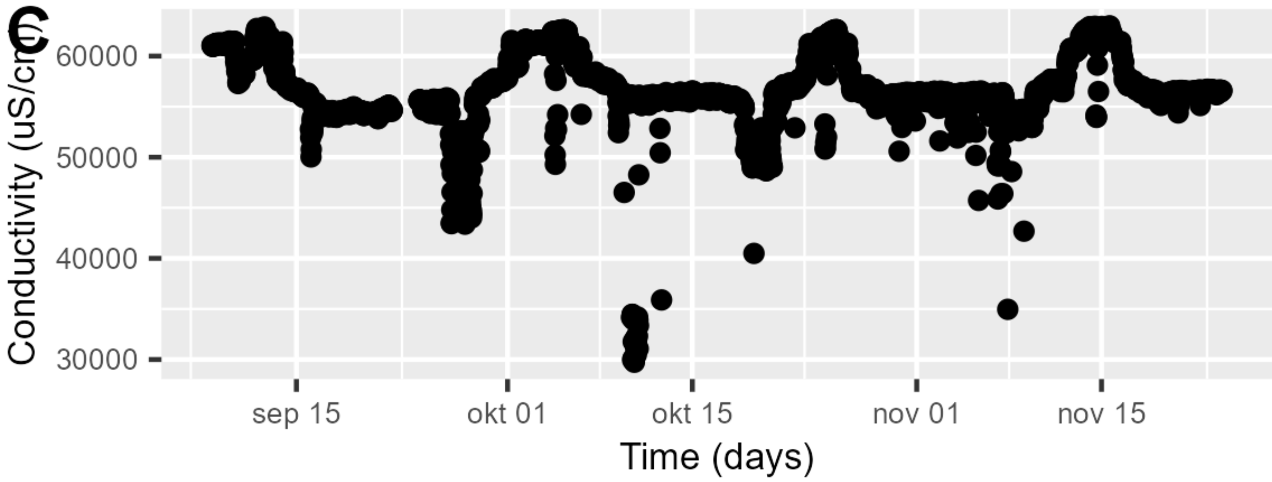


Figure 36: Timeplot conductivity Scuba data sea chest strainer.

- *pH-level*

The pH measurements (Figure 37) start with rather low pH values during the voyage from Sharjah to Ras Tanura, reaching a minimum of 8.25 during this period.

Overall, the pH values increase gradually from the beginning of the measurements to the end. At the beginning of the measurements, the pH values remain around 8.5, but towards the end of the measurements, the measurements are higher and more spread out.

While the ship is in the port of Kandla, the pH values decrease to lower values compared to when the ship is anchored near the port.

The pH values measured while anchored at Kandla are lower than those measured while sailing in the Arabian Sea and the Persian Gulf.

The pH values measured in the port of Ras Tanura are also lower than when the ship is underway. The pH values at the anchorage near Ras Tanura are also slightly lower than when the ship is underway, but still higher than when the ship is in the port of Ras Tanura.

The high pH values, up to 10.27, are probably not reflecting any real situation.

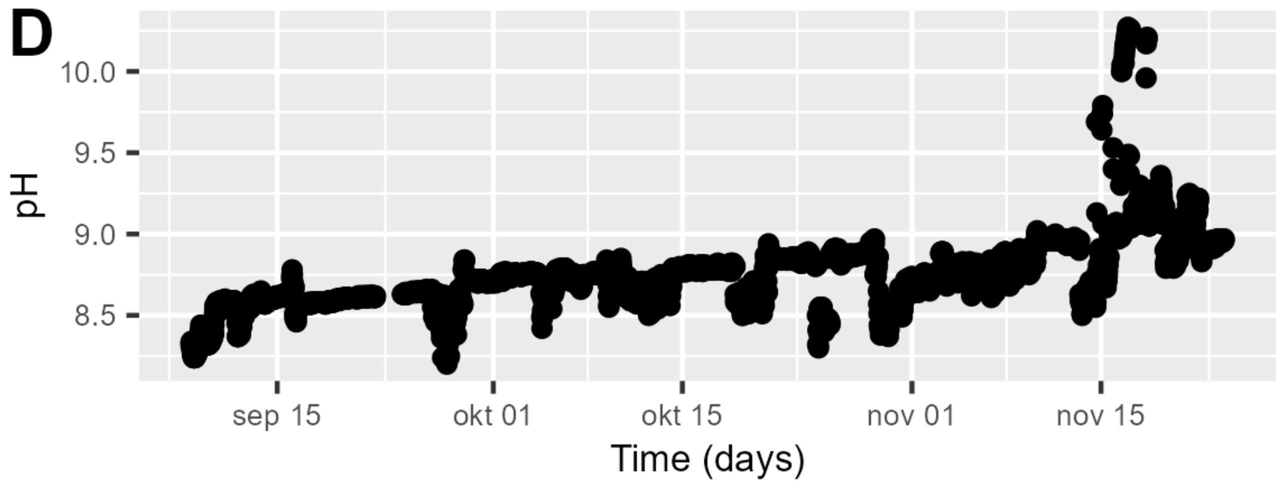


Figure 37: Timeplot pH-values Scuba data sea chest strainer.

- *Oxidoreduction potential*

The oxidoreduction potential (Figure 38) is initially lowest when the vessel is at anchor or in the harbors of Kandla and Ras Tanura. High values are often reached when the vessel is at anchor near Kandla. The highest values are measured when the vessel is in the port of Kandla.

Very low values are measured when the vessel is in the port of Ras Tanura. A minimum of -530.1 mV is reached. This occurs for the first time on October 25, 2022. As the ship departs for India, the values return to their initial range. At the same time, dissolved oxygen is reduced to almost zero. When the ship arrives at the Kandla anchorage on October 29, 2022, the values are very low again. After 2 days, the levels return to their initial range. The ship remains at anchor for another 7 days. The next drop is measured as the ship approaches the anchorage and port of Ras Tanura on November 13, 2022. Again, after about 1 day, the values return to their initial range.

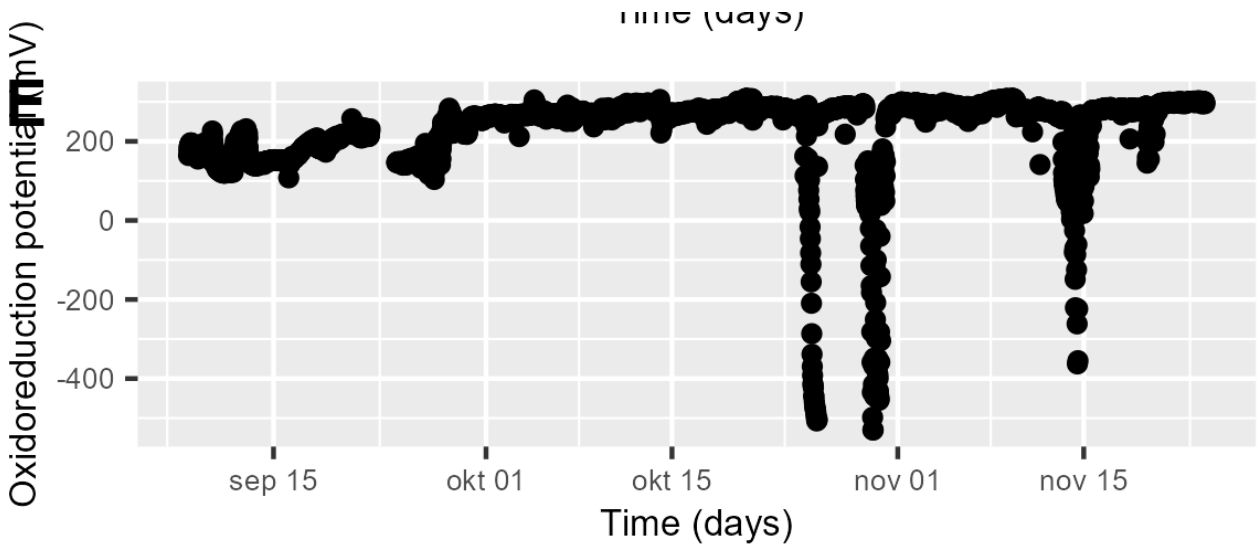


Figure 38: Timeplot oxidoreduction potential Scuba data sea chest strainer.

- *Boxplots*

As can be seen from the box plots, the data does not have any significant, unusual or noteworthy characteristics that stand out (Figure 39).

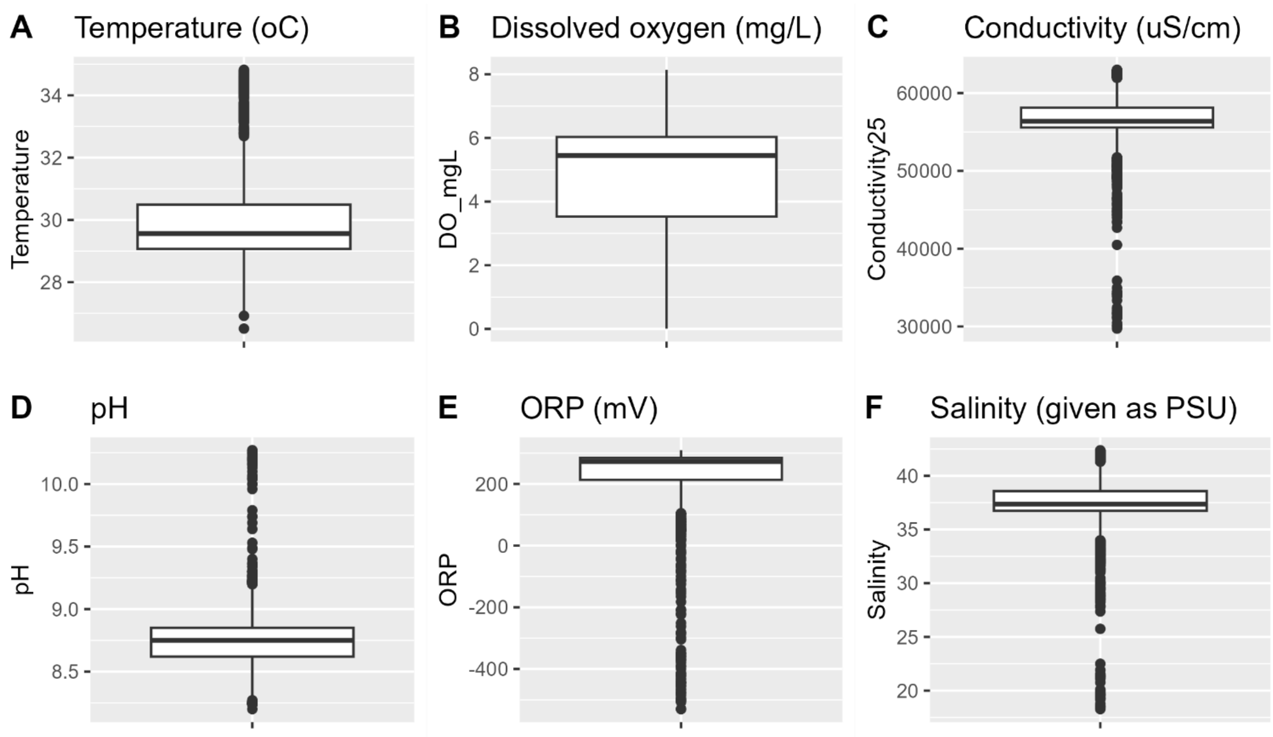


Figure 39: Boxplots Scuba data sea chest strainer.

- *Pairwise correlation matrix*

The pairwise correlation matrix (Figure 40) shows negligible correlation values, indicating a lack of significant relationships. There is a slight correlation between pH and temperature, but it should be noted that the readings from the pH sensors show irregular patterns.

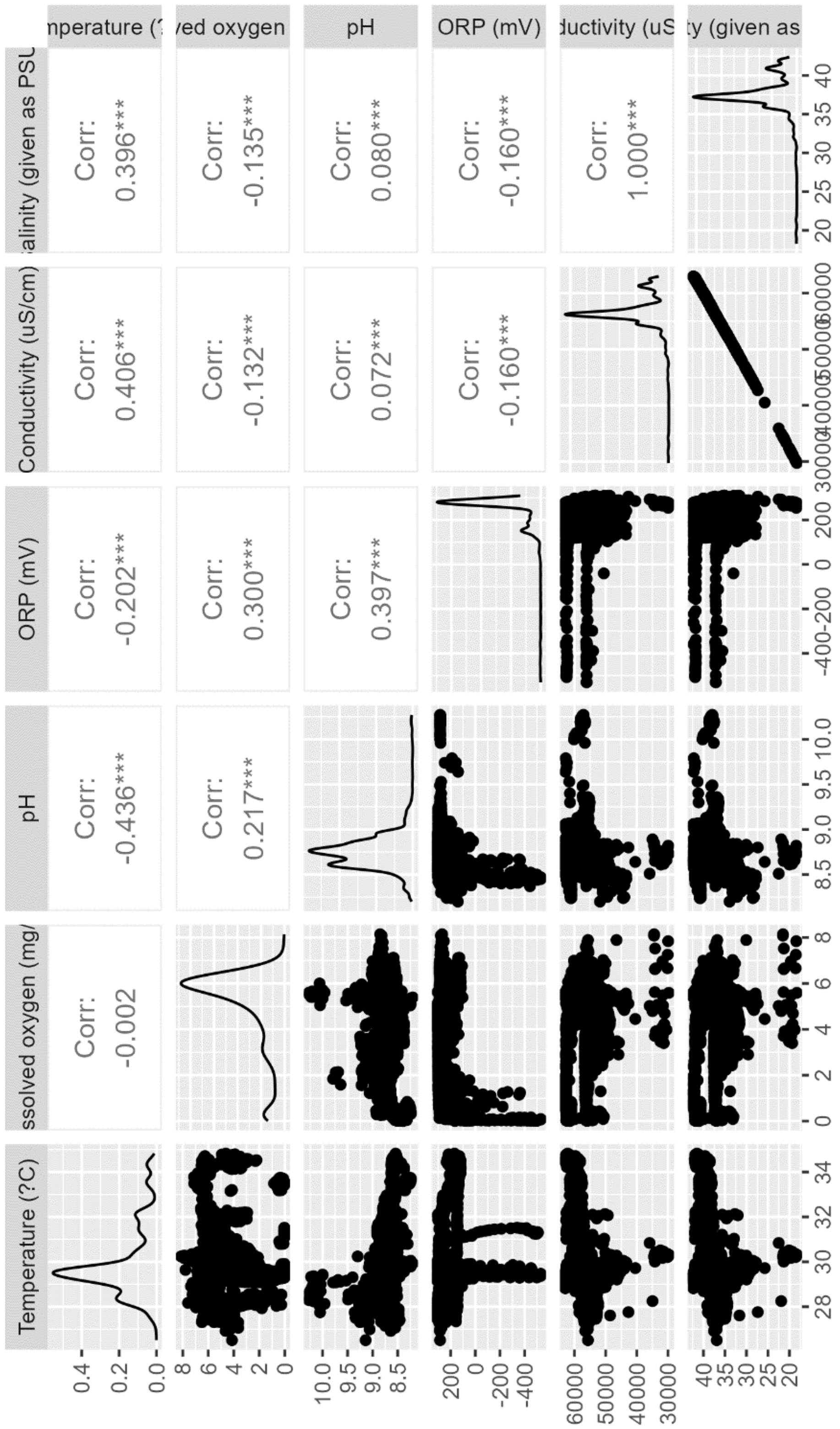


Figure 40: Pairwise correlation matrix Scuba data sea chest strainer.

- *Principal Component Analysis plot*

In the PCA plot analysis (Figure 41), dissolved oxygen and ORP show a significant correlation, while pH also shows some correlation with ORP, possibly because both have increased over time. There is also a slight negative correlation between temperature and both DO and ORP. Again, it should be noted that the readings from the pH sensors show irregular patterns.

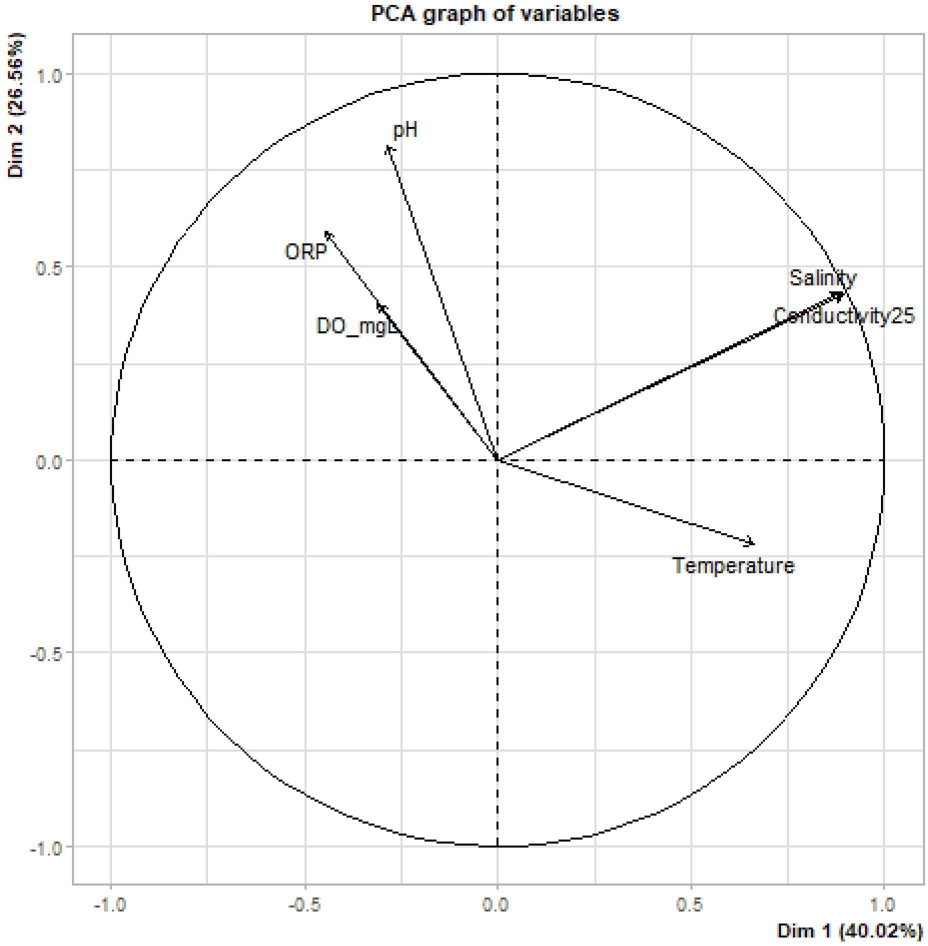


Figure 41: PCA plot Scuba data sea chest strainer.

Results: ballast water discharge line

The Scuba sensor in the ballast water setup started measuring on September 24, 2022. The last data retrieval was performed on May 3, 2023. The complete voyage has been described in Annex.

- *Temperature*

When ballast water is being discharged, the temperature measured by the Scuba depends primarily on the flow rate and temperature of the ballast water being discharged. When ballast water is not being discharged, the water in the flow cells and piping of the system is not being refreshed. Therefore, the temperature in this case is mostly dependent on the temperature of the air in the engine room. Overall, the temperatures measured in September and October are significantly higher than the temperatures measured in November, December, January and February.

When the vessel is at anchor and in a port of discharge, the temperature decreases over time. The engine is not running (kept at very low RPM) and no ballast is being discharged. The most significant decrease in temperature is observed when the vessel is at anchor for a longer period of time, which is clearly visible in the time plot of temperature (Figure 42) when the vessel is at anchor off Kandla from January 26, 2023 to February 3, 2023.

When the vessel is in a loading port, the temperature drops sharply. This is to be expected as deballasting is required when the ship is loaded and the engine is not running. When the vessel departs on a voyage, the temperature rises significantly, reaching a maximum of 39 °C. This is to be expected as the engine is running at high speed and the water in the system is not being refreshed.

The rise in temperature occurs on most voyages, but not on every voyage. This may be due to colder outside air temperatures or the engine running at a lower RPM. During some voyages, the temperature may suddenly drop sharply and then gradually rise again. This may be due to some limited deballasting during the voyage.

At certain times when the ship is in the port of discharge or at anchor, it is also seen that the temperature makes a significant drop. This could also be due to some limited deballasting operations being carried out at these times.

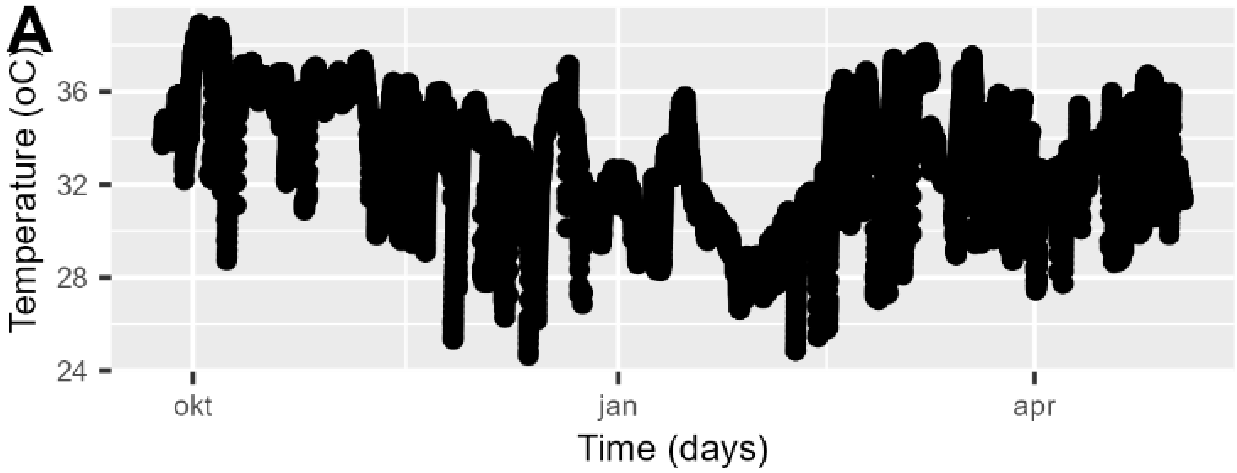


Figure 42: Timeplot temperature Scuba data ballast water setup.

- *Dissolved oxygen*

Each time the temperature drops sharply, the dissolved oxygen increases significantly. This supports the explanation that the sharp drops in temperature are caused by the discharge of ballast water. It is to be expected that after a period of time, the dissolved oxygen in the water present in the setup will decrease as it is depleted by corrosion processes. When ballast water is pumped through the discharge pipe, the ballast water that was present in the flow cells and piping of the installation is replaced by fresh ballast water. This fresh water contains more dissolved oxygen and has a lower temperature.

Oxygen depletion in the setup occurs quite rapidly. This may be due to the small size of the piping and flow cells. The data shows that the dissolved oxygen goes from 6 mg/L to 0 mg/L in 12 hours. The moment the ship supposedly discharges ballast water, the dissolved oxygen immediately increases from about 0 mg/L to 8 mg/L. This is clearly visible on the time plot (Figure 43).

Some very high dissolved oxygen readings were recorded continuously for 24 hours on December 26 and 27, 2022. However, no significant temperature changes were recorded, and it is likely that the ship was deballasting at this time, as it was anchored off Ras Tanura and entered port shortly thereafter.

After leaving the port of Ras Tanura, dissolved oxygen decreased rapidly. Low levels were recorded until the ship sailed from Porbandar to Sohar on February 8, 2023. During this period, the vessel had only visited Indian ports, which are likely to be ports of discharge. It had entered the port of Sohar on January 22, 2023. However, no change in dissolved oxygen was observed on this date. It is possible that only a small amount of cargo was loaded at that time, or that only spare parts or supplies were taken on board. After this period, the dissolved oxygen measurements were as expected, according to the evolution of the temperature and the position of the vessel.

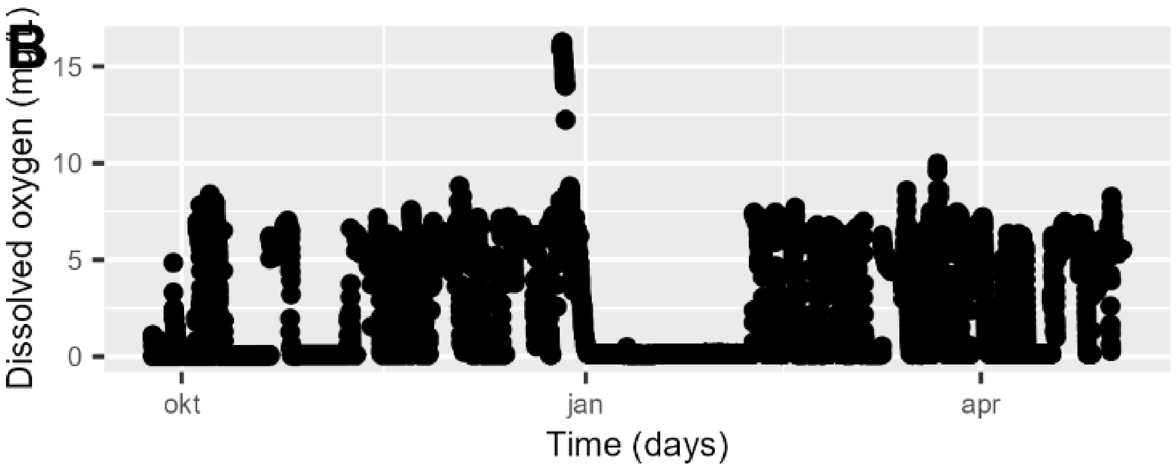


Figure 43: Timeplot dissolved oxygen Scuba data ballast water setup.

- *Conductivity*

Overall, the changes in conductivity coincide with times when deballasting operations are likely to have occurred based on changes in temperature and dissolved oxygen.

The highest conductivity values are measured in the 48 hours after deballasting is likely to have ceased. This may be due to the high level of corrosion products present in the water as the conductivity increases while the dissolved oxygen decreases to near zero. After 48 hours, the conductivity will drop to a more average level.

After the sensor was cleaned, the measured conductivity decreased to almost zero. However, the next time deballasting likely occurred, the conductivity returned to a more average level. This can be seen in the time plot of the conductivity (Figure 44) on November 22 to 24, 2022.

On December 26, 2022, the measured conductivity suddenly dropped to a very low level. This happened about 5 hours before the sharp increase in dissolved oxygen described before. These low levels persisted until January 9, 2023. This could be due to the contents of the discharged ballast water, as the ship was likely undergoing deballasting at the time of the sharp drop in conductivity. The time when the conductivity level increased again is unlikely to be during deballasting, as no other markers significantly changed and the ship was in a port of discharge.

After this period of high volatility, conductivity levels rise back to a more average level, but there are some very low readings that are not to be expected. All of these low readings occur very suddenly and the levels continue to average out just as suddenly. At the time of these readings, the other markers do not change significantly.

On February 8, 2023, the Scuba sensor was cleaned by the crew. After that, the readings were more in line with what would be expected. The erratic readings were probably caused by the sensor being contaminated. The sharp increase in conductivity was measured after the deballasting operation had probably taken place. At the time, the vessel was anchored off Kandla.

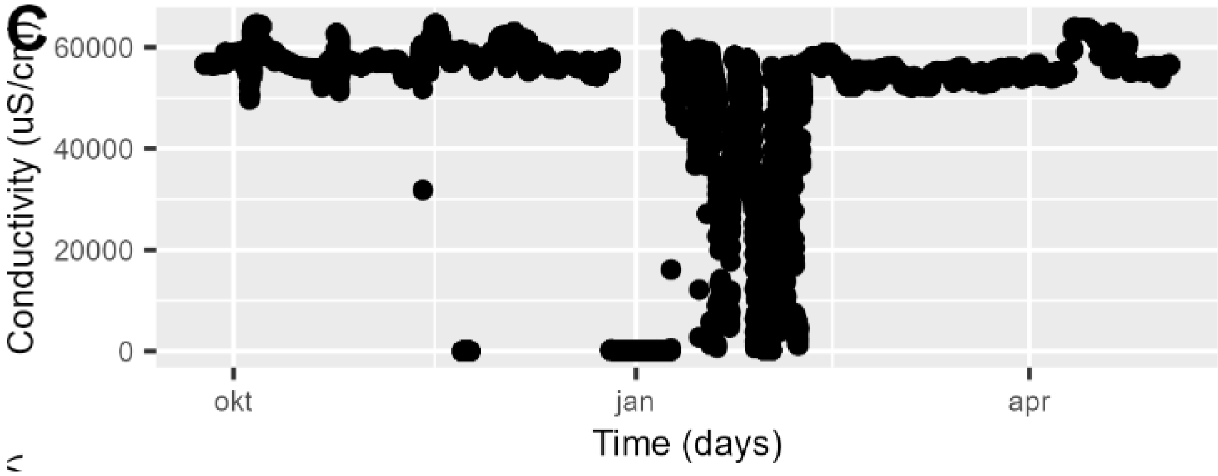


Figure 44: Timeplot conductivity Scuba data ballast water setup.

- *pH-level*

The pH generally varies between 7.19 and 8.44. A minimum of 6.45 was recorded. This is clearly visible on the time plot (Figure 45). Overall, the pH level increases when deballasting operations are assumed to be taking place. After these operations have ceased, the level gradually decreases and remains constant around 7.5 to 8.

A sudden drop was measured when the sensor was cleaned on February 22, 2022. The readings remained low until the next deballasting operation, as explained earlier for the conductivity level. A sudden change was also measured when the sensor was cleaned on February 8, 2023.

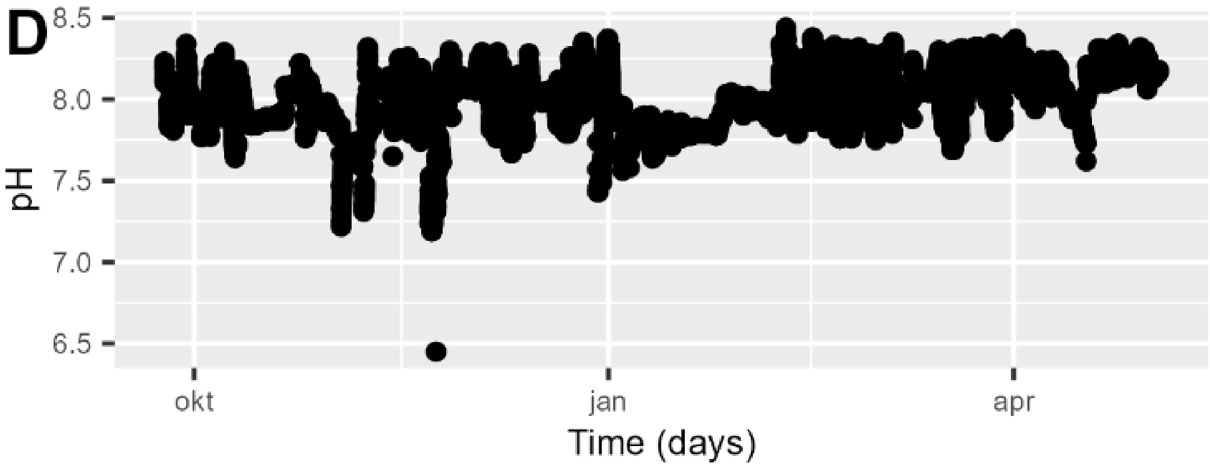


Figure 45: Timeplot pH-values Scuba data ballast water setup.

- *Oxidoreduction potential*

As can be seen from the Principal Component Analysis plot (Figure 46), the ORP is strongly correlated with dissolved oxygen. Since the ORP of seawater depends on the concentration of dissolved oxygen, this is to be expected. Dissolved oxygen acts as an oxidant by accepting electrons in chemical reactions. Higher concentrations of dissolved oxygen increase the redox potential, indicating a greater potential for oxidation reactions. On the other hand, lower concentrations of dissolved oxygen decrease the redox potential (Speight, 2020). Therefore, ORP generally follows the same trend as dissolved oxygen (described earlier).

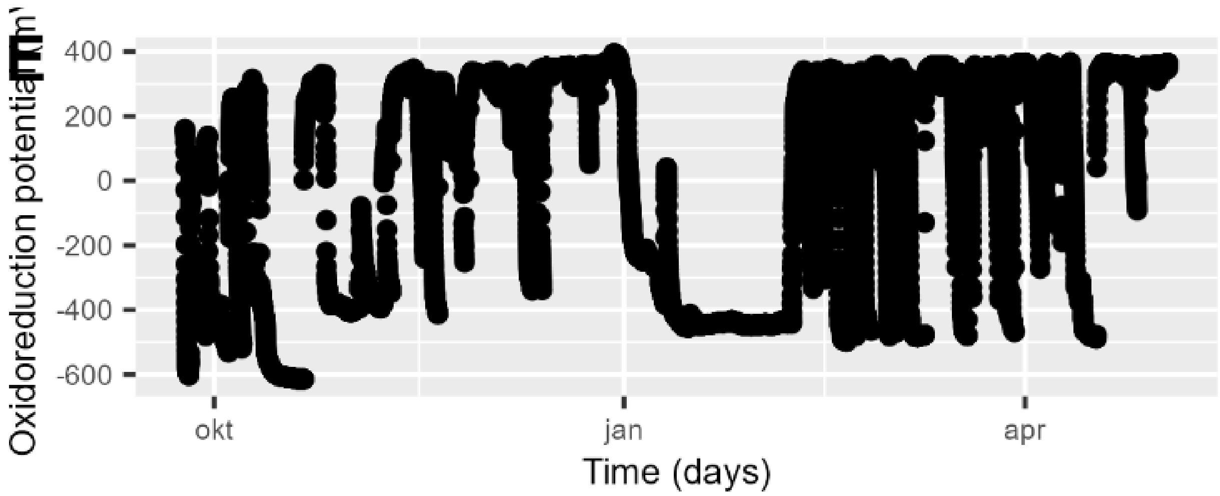


Figure 46: Timeplot oxidoreduction potential Scuba data ballast water setup.

- *Chloride*

Overall, the chloride concentration increases when deballasting is assumed to occur. When the operation is ceased, the chloride concentration gradually decreases and then slowly increases again.

After the sensor is cleaned on November 22, 2022, the chloride concentration is 0 mg/L, as clearly shown in the time plot (Figure 47). When the next deballasting is likely to take place, the concentration rises again to a more average concentration.

On November 26, 2022, at the same time as the conductivity drops sharply, the chloride concentration also drops significantly. In the following days, the concentration fluctuates significantly, ranging from 30730 mg/L to 83810 mg/L.

At about the same time on January 8, 2023, the conductivity returns to more average levels, and the chloride concentration does the same.

The chloride concentration readings continue to fluctuate excessively until the sensor is cleaned on February 8, 2023. After that, the readings show a more expected trend.

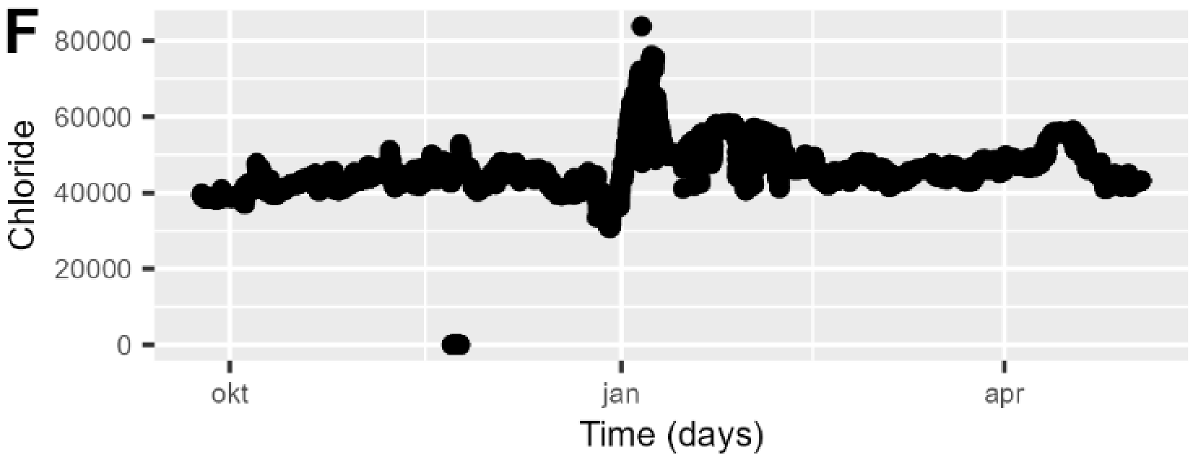


Figure 47: Timeplot chloride Scuba data ballast water setup.

- *Boxplots*

As can be seen from the box plots, there are no significant, unusual, or noteworthy characteristics of the data that stand out (Figure 48).

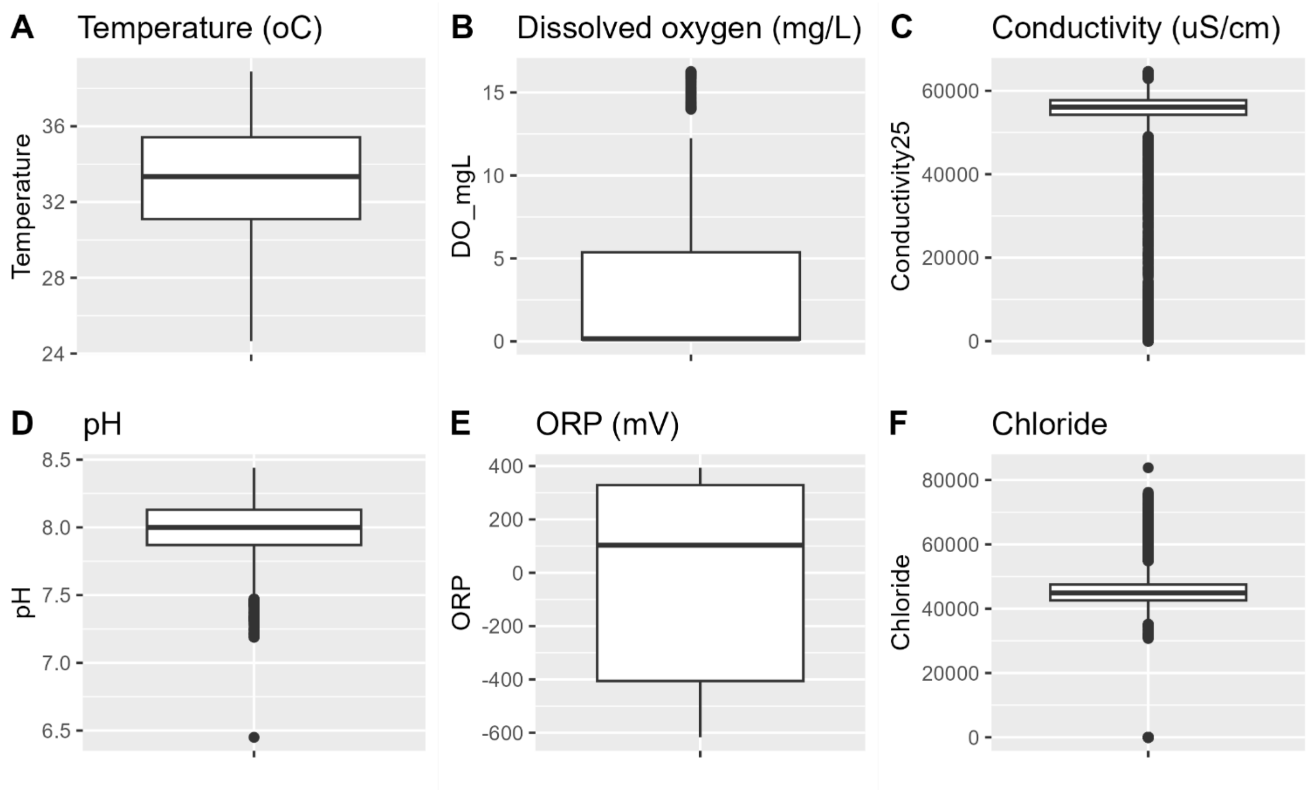


Figure 48: Boxplots Scuba data ballast water setup.

- *Pairwise correlation matrix and PCA analysis*

The pairwise correlation matrix (Figure 49) shows a strong correlation between ORP, dissolved oxygen and pH. There is only a slight correlation between ORP and temperature,as well as a slight correlation between conductivity and salinity. No correlation is observed between chloride and salinity or between chloride and conductivity.

As shown in the principal component analysis plot (Figure 50), pH, ORP, and dissolved oxygen show a strong correlation. There is a negative correlation between conductivity and chloride concentration.

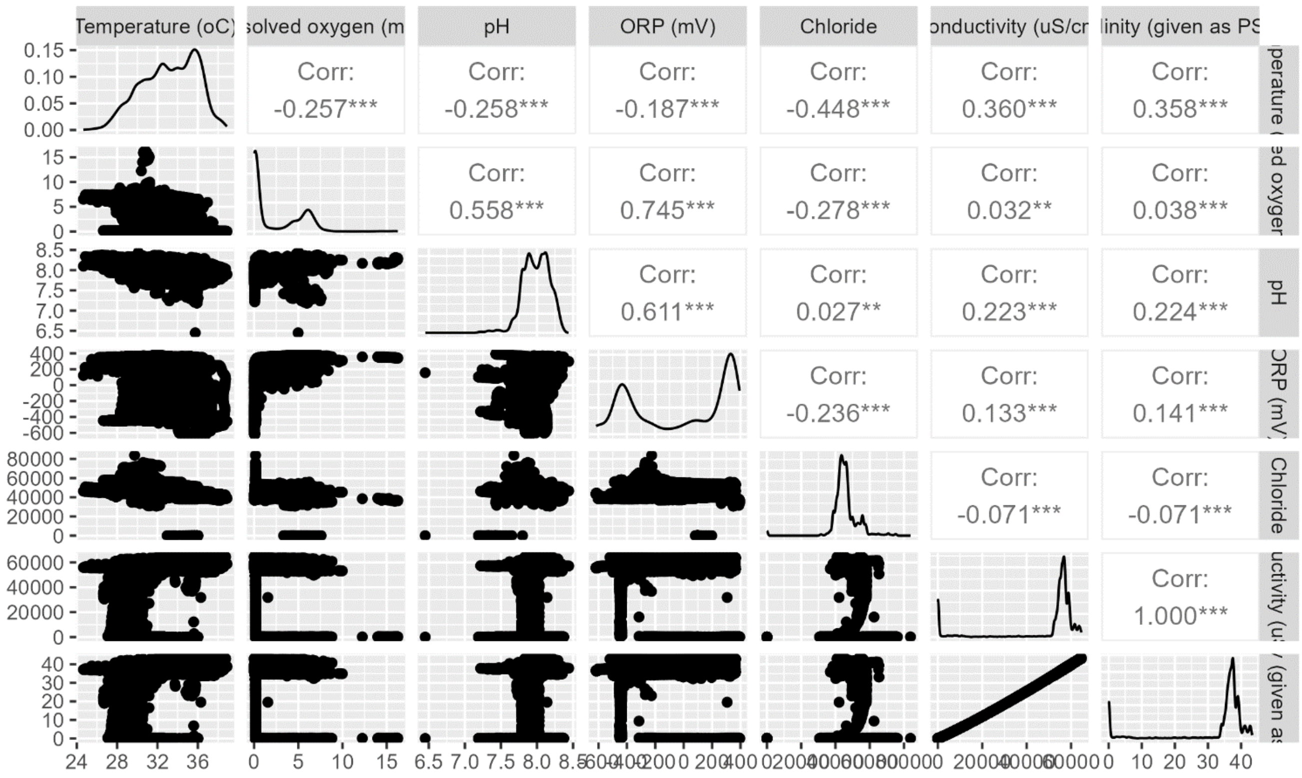


Figure 49: Pairwise correlation matrix Scuba data ballast water setup.

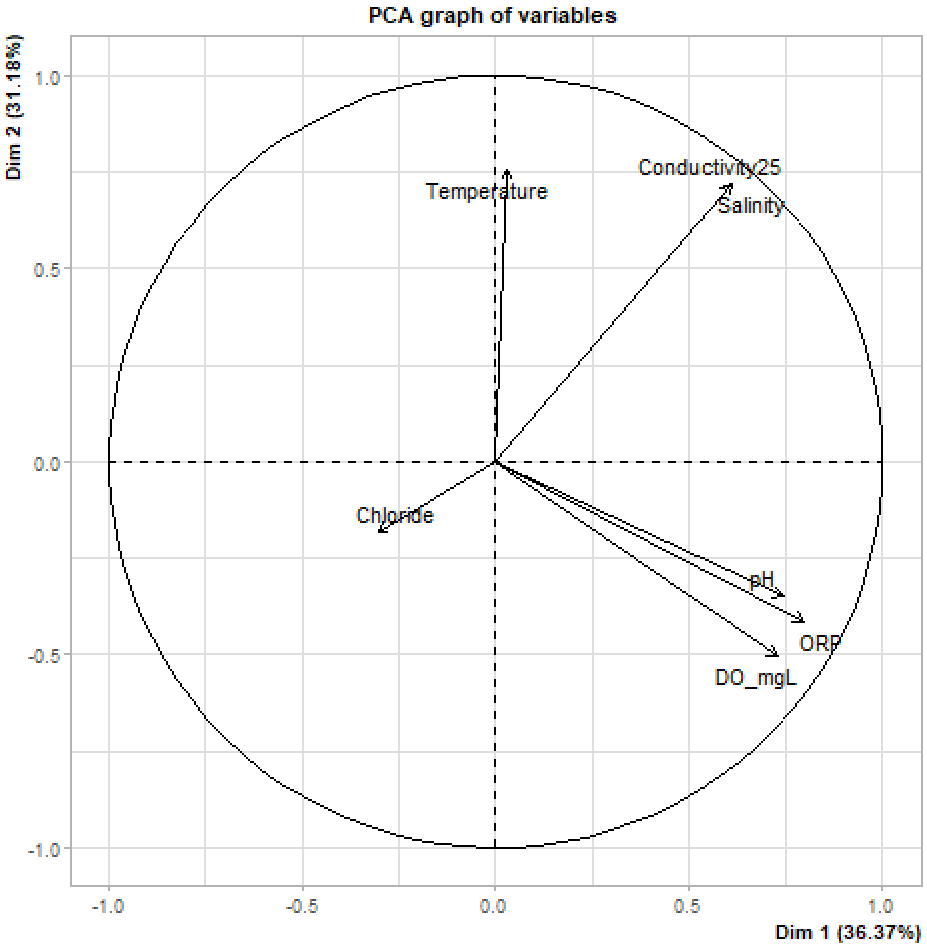
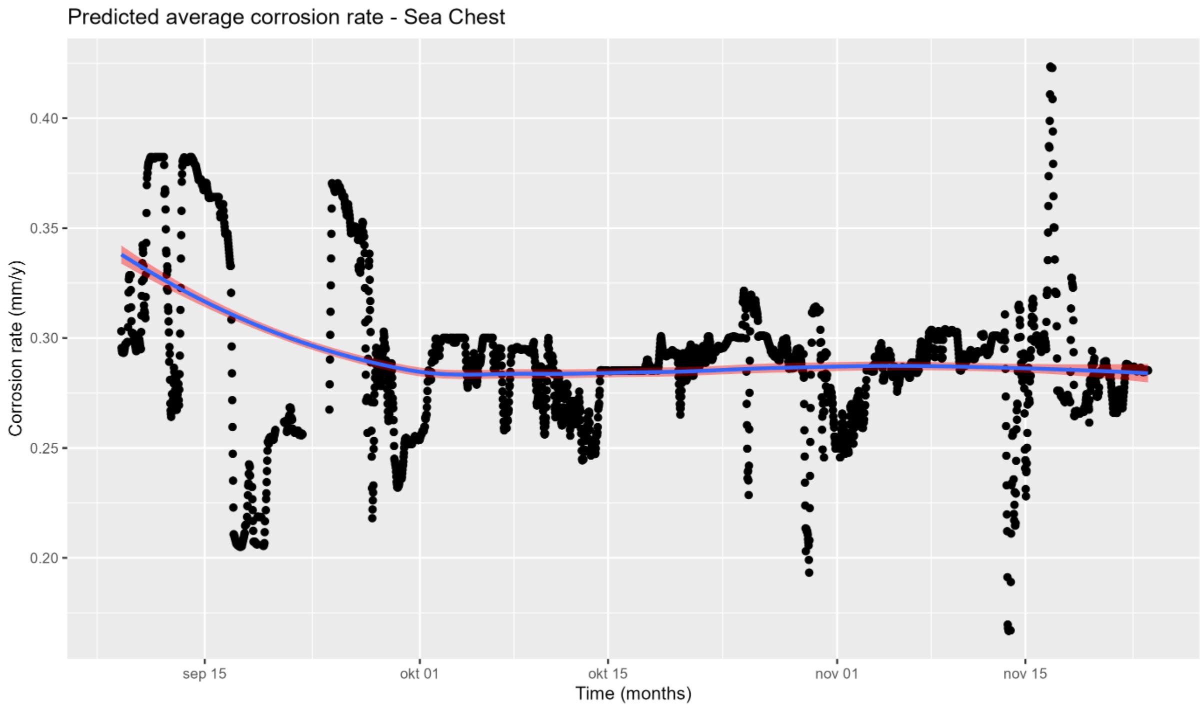


Figure 50: PCA plot Scuba data ballast water setup.

Corrosion experiment



Technical issues?

Demonstrator construction issues

When **designing the sensor systems**, the importance of considering all scenarios and designing the sensor system accordingly was always kept in mind. The risk of unstoppable leakage and damage to on-board systems due to sensor fragments had to be avoided at all costs. Therefore, the design process was lengthy and several versions of the sensor setups were developed.

For the next installation of a similar demonstrator, the following recommendations should therefore be considered.

- When relying solely on technical drawings of the ship's system, it is more likely that essential elements will be overlooked. Recent photographs of the elements of the system in which the demonstrator is to be installed can be of great value.
- It is more effective to arrange a face-to-face meeting with the crew well in advance of the planned installation than to communicate only by e-mail. During this meeting, it is important to explain the intentions and current plan in detail. By explaining this in real life, it will be more practical and clear. The crew will also be able to brainstorm and give their expert advice during the meeting. In addition, they will have a better understanding of what needs to be done and will provide you with valuable suggestions.
- During the design process, remember that everything on the ship will vibrate intensely when the engine is running. Always try to make everything as robust as possible, as this will also reassure the crew and other staff that the setup will not break and damage the ship's equipment.
- Always check the work of the yard workers very carefully, as they do not always fully understand all expectations, even if they say they do.
- Be aware that any part can break, and provide sufficient spare parts so that the crew can repair any damage.

Data retrieval problems

- *Scuba sensor sea chest strainer setup*

On 7 February 2023, an email was received from the Kruibeke's chief engineer stating that the crew had attempted to perform a data retrieval from the Scuba sensor in the sea chest strainer as described in the manual. However, they reported that when the USB cable from the sensor was connected to the laptop, a successful connection could not be established. Several solutions were tried, but the problem could not be solved. Therefore, the last successful data retrieval was performed on 24 November 2022.

- *C-Cube sensors both setups*

When the C-Cube sensors were installed on board in August 2023, no power cable was provided for the logger boxes. Therefore, it had to be shipped to the vessel. This adapter was delivered to Exmar, but it was never confirmed that the adapter was delivered on board. As a result, the ship's crew were unable to transmit the C-Cube data. On 3 May 2023, the ship's crew reported that they had managed to adapt the logger boxes so that they could be plugged into a power socket on the bridge. However, due to other technical problems the data measured by the C-Cube has not been received at the time of writing.

Additionally, in April 2023 it was discovered that when C-Cube sensors are installed in seawater, fouling or corrosion very quickly creates a conductive connection between the sensor's electrodes. This causes the data collected by the sensors to be incorrect.

- *Corrosion coupons*

The ship's crew was requested to retrieve some of the corrosion coupons. However, the coupons did not arrive at the Antwerp Maritime Academy in time for analysis.

Plans for further use of these demonstrators?

The Output on board of the Kruibeke, after having been active for 9 months, has been dismantled. The corrosion sensors and the coupons are on their way to Antwerp for further analysis and data retrieval. It was deemed technically too demanding to keep it up, especially since it is impossible for the researchers themselves to take care of the installation (and while the crew is very willing to perform necessary maintenance, proper follow-up, let alone new tests and experiments, would be too much to ask or to direct.

However, the information obtained from this output and during the installation on board have been enlightening and support a useful way to provide interesting information and test management procedures on corrosion prevention for the shipping sector.

1. The measurements / dataset (as described in the Output report) will still be exploited to learn more about the corrosion processes on board and to optimise the SOCORRO algorithm.
2. Participation in inspections of the ship while in drydock has taught the LP1 team that we are only touching the surface of the corrosion problems on board of a tanker, and that the list at the beginning of this report is certainly not complete. Due to the difficulties to study corrosion ob board of a ship, we are planning to set up a new technical installation, where we use all that we learned onboard. LP1 will join forces with PP2, PP3 and PP5 to work out a shipping corrosion lab in Belgium.
3. A brief analysis of the expenses incurred by the tanker while in drydock indicate that corrosion is responsible for at least 16% of the total cost (and probably a lot more). Further development of this line of analysis may be what is needed to find more support in the shipping sector for a complete overhaul of corrosion management procedures.

Annex: The voyage of the MV Kruibeke

From September 24, 2022 to November 24, 2022, the vessel sailed as described in section 0. On November 24, 2022, the vessel was in the port of Kandla (India). The vessel then sailed to Ras Tanura (Saudi Arabia), after which it returned to Kandla Port (India) and then proceeded to New Mangalore Port (India). The vessel then sailed back to Ras Tanura Port (Saudi Arabia). The vessel then proceeded to Kandla Port (India), Mumbai Port (India) and New Mangalore Port (India). It then proceeded to an anchorage near Fujairah (UAE) where it remained for 1 day before proceeding to an anchorage near the port of Sohar (Oman) where it entered after 1 day at anchor.

After leaving the port of Sohar (Oman), the vessel anchored near the port for 1 day before proceeding to the anchorage of Kandla (India). After entering the port of Kandla (India), the vessel proceeded to anchor near Porbandar (India) and entered port. The vessel then sailed back to Sohar (Oman).

After anchoring off Sohar (Oman) and entering port, the vessel proceeded to New Mangalore (India). It entered port here and then spent 4 days at a nearby anchorage before re-entering port. The vessel then proceeded to Mumbai (India) where it anchored before entering port. After this port call, the vessel proceeded to the port of New Mangalore (India). The vessel then sailed to an anchorage near Tuticorin (India) before entering port. The vessel then made several voyages between the Indian ports of Mumbai, New Mangalore, Kandla and Porbandar.

The longest anchorage was off Kandla, where the vessel spent up to 10 days at anchor. At the time of the last data collection, the ship was anchored off Porbandar (India).

During the measurement period of the Scuba sensor of the ballast water system, the vessel sailed according to Table 5.

Table 5: Positions of the vessel during measurement period of ballast water Scuba.

Action	Location	Date	Duration
Arrived at	Anchorage near Kandla (India)	16/09/2022	
			8 days
	Beginning of measurements.	**24/09/2022**	
			2 days
Arrived at	Port of Kandla (India)	26/09/2022	
			2 days
Departed from	Port of Kandla (India)	28/09/2022	
			4 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	2/10/2022	
			2 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	4/10/2022	
			1 days
Departed from	Port of Ras Tanura (Saudi Arabia)	5/10/2022	

			1 days
Arrived at	Anchorage near Fujairah (UAE) for bunkering	6/10/2022	
			1 days
Departed from	Anchorage near Fujairah (UAE)	7/10/2022	
			2 days
Arrived at	Anchorage near Kandla (India)	9/10/2022	
			10 days
Arrived at	Port of Kandla (India)	19/10/2022	
			2 days
Departed from	Port of Kandla (India)	21/10/2022	
			3 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	24/10/2022	
			1 days
Departed from	Port of Ras Tanura (Saudi Arabia)	25/10/2022	
			4 days
Arrived at	Anchorage near Kandla (India)	29/10/2022	
			9 days
Arrived at	Port of Kandla (India)	7/11/2022	
			2 days
Departed from	Port of Kandla (India)	9/11/2022	
			4 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	13/11/2022	
			1 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	14/11/2022	
			1 days
Departed from	Port of Ras Tanura (Saudi Arabia)	15/11/2022	
			2 days
Arrived at	Anchorage near Fujairah (UAE) for bunkering	17/11/2022	
			12 hours
Departed from	Anchorage near Fujairah (UAE)	17/11/2022	
			2 days
Arrived at	Anchorage near Kandla (India)	19/11/2022	
			5 days
Arrived at	Port of Kandla (India)	24/11/2022	
			2 days
Departed from	Port of Kandla (India)	26/11/2022	
			5 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	1/12/2022	
			1 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	2/12/2022	

			1 days
Departed from	Port of Ras Tanura (Saudi Arabia)	3/12/2022	
			5 days
Arrived at	Anchorage near Kandla (India)	8/12/2022	
			3 days
Arrived at	Port of Kandla (India)	11/12/2022	
			2 days
Departed from	Port of Kandla (India)	13/12/2022	
			3 days
Arrived at	Anchorage near New Mangalore (India)	16/12/2022	
			4 days
Arrived at	Port of New Mangalore (India)	20/12/2022	
			1 days
Departed from	Port of New Mangalore (India)	21/12/2022	
			5 days
Arrived at	Anchorage near Ras Tanura (Saudi Arabia)	26/12/2022	
			1 days
Arrived at	Port of Ras Tanura (Saudi Arabia)	27/12/2022	
			1 days
Departed from	Port of Ras Tanura (Saudi Arabia)	28/12/2022	
			4 days
Arrived at	Anchorage near Kandla (India)	1/01/2023	
			7 days
Arrived at	Port of Kandla (India)	8/01/2023	
			2 days
Departed from	Port of Kandla (India)	10/01/2023	
			1 days
Arrived at	Anchorage near Mumbai (India)	11/01/2023	
			1 days
Arrived at	Port of Mumbai (India)	12/01/2023	
			1 days
Departed from	Port of Mumbai (India)	13/01/2023	
			1 hour
Arrived at	Anchorage near Mumbai (India)	13/01/2023	
			1 days
Arrived at	Port of New Mangalore (India)	14/01/2023	
			1 days
Departed from	Port of New Mangalore (India)	15/01/2023	
			4 days
Arrived at	Anchorage near Fujairah (UAE)	19/01/2023	

			1 days
Departed from	Anchorage near Fujairah (UAE)	20/01/2023	
			7 hours
Arrived at	Anchorage near Sohar (Oman)	20/01/2023	
			2 days
Arrived at	Port of Sohar (Oman)	22/01/2023	
			1 days
Departed from	Port of Sohar (Oman)	23/01/2023	
			1 hour
Arrived at	Anchorage near Sohar (Oman)	23/01/2023	
			1 days
Departed from	Anchorage near Sohar (Oman)	24/01/2023	
			2 days
Arrived at	Anchorage near Kandla (India)	26/01/2023	
			8 days
Arrived at	Port of Kandla (India)	3/02/2023	
			1 days
Departed from	Port of Kandla (India)	4/02/2023	
			1 days
Arrived at	Anchorage near Porbandar (India)	5/02/2023	
			1 days
Arrived at	Port of Porbandar (India)	6/02/2023	
			1 days
Departed from	Port of Porbandar (India)	7/02/2023	
			2 days
Arrived at	Anchorage near Sohar (Oman)	9/02/2023	
			3 days
Arrived at	Port of Sohar (Oman)	12/02/2023	
			1 days
Departed from	Port of Sohar (Oman)	13/02/2023	
			4 days
Arrived at	Port of New Mangalore (India)	17/02/2023	
			18 hours
Departed from	Port of New Mangalore (India)	17/02/2023	
			1 days
Arrived at	Anchorage near New Mangalore (India)	18/02/2023	
			4 days
Arrived at	Port of New Mangalore (India)	22/02/2023	
			1 days
Departed from	Port of New Mangalore (India)	23/02/2023	

			1 days
Arrived at	Anchorage near Mumbai (India)	24/02/2023	
			4 days
Departed from	Anchorage near Mumbai (India)	28/02/2023	
			2 days
Arrived at	Port of Tuticorin (India)	2/03/2023	
			2 days
Departed from	Port of Tuticorin (India)	4/03/2023	
			1 days
Arrived at	Anchorage near New Mangalore (India)	5/03/2023	
			3 days
Arrived at	Port of New Mangalore (India)	8/03/2023	
			1 days
Departed from	Port of New Mangalore (India)	9/03/2023	
			1 days
Arrived at	Anchorage near Mumbai (India)	10/03/2023	
			4 days
Arrived at	Port of Mumbai (India)	14/03/2023	
			1 days
Departed from	Port of Mumbai (India)	15/03/2023	
			1 days
Arrived at	Port of New Mangalore (India)	16/03/2023	
			1 days
Departed from	Port of New Mangalore (India)	17/03/2023	
			2 days
Arrived at	Anchorage near Tuticorin (India)	19/03/2023	
			2 days
Arrived at	Port of Tuticorin (India)	21/03/2023	
			1 days
Departed from	Port of Tuticorin (India)	22/03/2023	
			3 days
Arrived at	Anchorage near Mumbai (India)	25/03/2023	
			1 days
Arrived at	Port of Mumbai (India)	26/03/2023	
			1 days
Departed from	Port of Mumbai (India)	27/03/2023	
			1 days
Arrived at	Anchorage near New Mangalore (India)	28/03/2023	
			1 days
Arrived at	Port of New Mangalore (India)	29/03/2023	

			1 days
Departed from	Port of New Mangalore (India)	30/03/2023	
			3 days
Arrived at	Anchorage near Kandla (India)	2/04/2023	
			8 days
Arrived at	Port of Kandla (India)	10/04/2023	
			13 hours
Departed from	Port of Kandla (India)	10/04/2023	
			1 days
Arrived at	Anchorage near Kandla (India)	11/04/2023	
			6 days
Arrived at	Port of Kandla (India)	17/04/2023	
			1 days
Departed from	Port of Kandla (India)	18/04/2023	
			1 days
Arrived at	Port of Mumbai (India)	19/04/2023	
			4 days
Departed from	Port of Mumbai (India)	23/04/2023	
			1 days
Arrived at	Anchorage near New Mangalore (India)	24/04/2023	
			2 days
Arrived at	Port of New Mangalore (India)	26/04/2023	
			1 days
Departed from	Port of New Mangalore (India)	27/04/2023	
			1 days
Arrived at	Anchorage near Mumbai (India)	28/04/2023	
			2 days
Arrived at	Port of Mumbai (India)	30/04/2023	
			1 days
Departed from	Port of Mumbai (India)	1/05/2023	
			22 hours
Arrived at	Anchorage near Porbandar (India)	1/05/2023	
			2 days
	Last data retrieval performed.	**3/05/2023**	
			2 days
Arrived at	Port of Porbandar (India)	5/05/2023	