

DEMONSTRATION AT BASF ANTWERP

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The demonstrator

Why this location

BASF, an observer partner in the SOCORRO project (OP 27), has a peculiar corrosion issue. To cool their cooling tower pumps, they use surface water from a nearby source. This water is treated by Evides Industriewater (OP1) and distributed over the site. The water quality transported through the two water circuits feeding the pumps is identical. However, visual inspection has shown that a different degree of corrosion is observed in the pumping station, depending on which circuit the water comes from. After treatment by Evides Industriewater, the process water doesn't undergo any further treatment. MCA (monochloroacetate) is dosed at the BASF site to avoid microbiological corrosion.

Within the project, two identical sensor units were placed at BASF, one on each of the water circuits (called F100 and G500).

Demonstrator design

Designing, building and maintaining two installations that meet the requirements of both the project and BASF presented many challenges. The big difference with other demonstrations within the project is that it is not possible to simply immerse the sensors and metal coupons in the process water. It was therefore decided to let the water flow from a tap point through a circuit of PVC hoses, pipes and flow cells, so that it can make contact with the sensors and metal coupons, after which the water is discharged. All parts are mounted on a wooden panel, which is supported by a metal structure. The final setup is about 1.2 meters wide, 0.5 meters deep and 1.5 meters high (Figure 1). Furthermore, a lot of tinkering was done in the lab of the Antwerp Maritime Academy to make the setup watertight. For example, the PVC hoses that connect the various parts were attached using clamping rings. Teflon tape (PTFE tape) was used to make the threaded connections watertight.



Figure 1. Demonstrators 1 and 2 installed at the BASF site

The path taken by the water can be divided into three zones, namely: the Cosasco pipe system, the flow-through cell with Eijkelkamp's environmental probe and the PVC tray with the metal coupons and the CCube sensor. There is also an electricity box. In what follows, the various components and sensors of the set-up will be discussed (Figure 2).

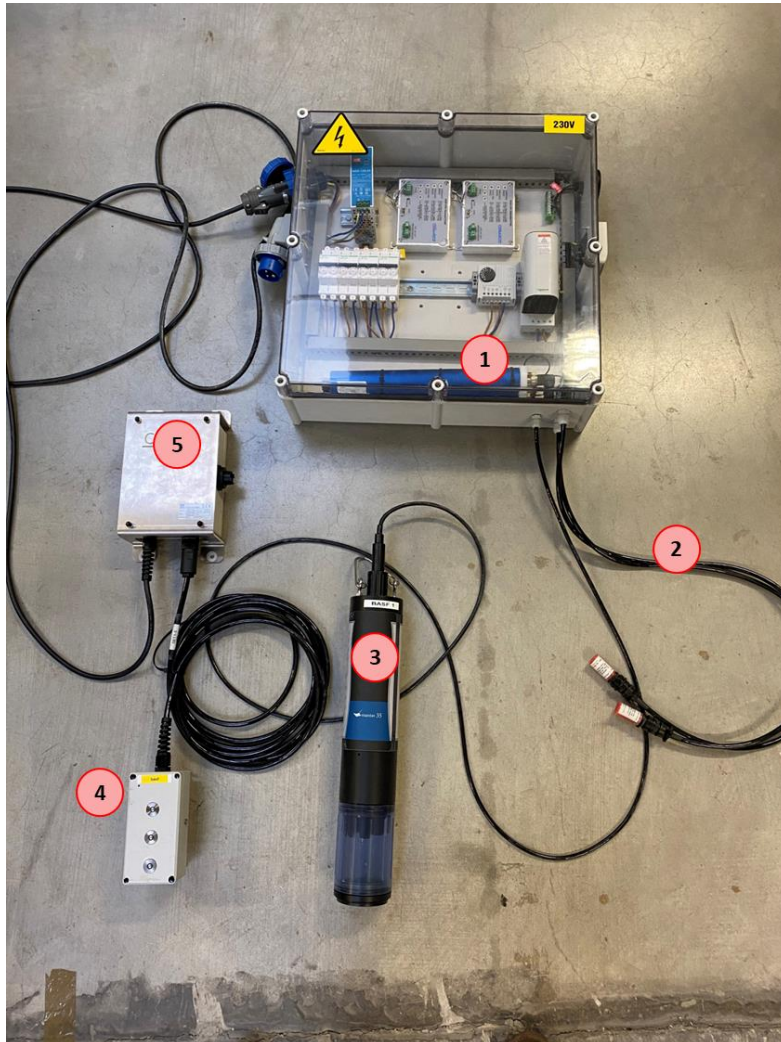


Figure 2. Functional components of the BASF demonstrators.

1: Box protecting the electronic equipment; 2: Cosasco LPR sensors; 3: Eijkelpamp Scuba 90 environmental sensor; 4: CCube LP sensor; 5: CCube modem

- *Pipe system from Cosasco with LPR probes*

Starting from a flange/drain point on BASF's installation, the water flows to Cosasco's Corrosion Monitoring LPR By-Pass Racks. This is a stainless steel tubing system designed to expose LPR probes and weight loss coupons to the process water via a side stream. The bypass rack contains two measuring points in which a coupon holder can be placed, two measuring points in which an LPR probe is installed, and a flow meter to measure the flow rate. The two mounted probes are the LPR Probe 7012/7022 from Cosasco. Electrodes are still mounted on the probes, one probe is equipped with 316L electrodes, the other with carbon steel electrodes. Each probe is coupled to a 9020 LPR Continuous Corrosion Rate Transmitter, located in the electrical cabinet, for monitoring the corrosion rate.

- *Environmental probe*

After the pipe system, the water flows past a flow cell on which the environmental probe (definition probe vs sensor) is mounted. The Scuba 90 is an Eijkelkamp water quality probe with room for 11 different sensors. The following sensors are mounted on the probe: a sensor for pH and ORP, a sensor for temperature, an optical sensor for dissolved oxygen, a sensor for conductivity and salinity, a fluorometer for measuring chlorophyll and an ISE sensor for measuring the chloride content. In the beginning of the measurements a custom flow cell was used. Eijkelkamp's flow cell was later used for practical reasons. The probe will be connected to a modem that will forward the data to an online platform.

The third part of the circuit is a PVC tray that houses corrosion coupons for mass loss measurements as well as the CCube sensor. The tray is completely filled and the water is continuously discharged into a nearby basin via an overflow system. 14 corrosion coupons can be hung on a rack in the tray. These will be removed at regular intervals for mass loss measurements. The general corrosion rate is measured using the C-cube sensor. The sensor in the tray connects to a transmitter located on the back of the panel. Later in the experiment, the BASF1 container was replaced by a stainless steel cylinder. This was placed horizontally on the back of the set-up using wall brackets.

Most importantly, of course, the electrical safety of the installation is guaranteed by incorporating protection against overloads and short circuits. In this respect, the electrical installation has also been officially inspected by a recognized inspection body and can therefore be installed throughout Belgian territory.

Sensor equipment

Both an environmental sensor (Scuba90) and a corrosion sensor (C-Cube) were used. By means of a specially designed distribution box, which was developed for the SOCORRO project, the uploading of data was optimized.

A **Scuba90 sensor**, manufactured by Royal Eijkelkamp Soil & Water B.V., was used to measure the environmental parameters. (Giesbeek, The Netherlands). In the context of the SOCORRO project, only Scuba sensors were used, which measure specific environmental parameters that influence the corrosion rate. The measured physiochemical factors include temperature, pH, specific conductivity 25°C, salinity, dissolved oxygen, dry matter content, redox potential and chlorine content.

The Scuba90 sensor is 450mm in length and 90mm in diameter. The operating temperature varies within a range of -50°C to +50°C. The maximum operational depth of the sensor is 200 m, while the ion-selective electrode (ISE) can reach a maximum depth of 15 m. The sensor is supplied with a 12 V power supply and has a memory for 1,000,000 measurements (Royal Eijkelkamp, n.d.).

It is a multi-sensor probe equipped with several sensors capable of determining eight parameters (Royal Eijkelkamp, 2022).

- The **temperature** (Figure 3, 1) was measured by means of a thermistor whose resistance changes with temperature. Thermistors are very stable over time and therefore do not require calibration.

- **Dissolved oxygen** was measured using an optical sensor (Figure 3, 2). This sensor consists of a blue light source, a detection surface and a red-light receiver. When the detection surface is exposed to seawater, a reaction occurs between the oxygen in the seawater and the detection surface. The measurement principle is based on the phenomenon of fluorescence, where the detection surface absorbs light of a specific wavelength and then emits light of a different wavelength. In this case, the surface absorbs blue light and emits red light. During a measurement cycle, the blue light is turned on for a short time, after which the red-light receiver measures the time it takes for the fluorescence to extinguish. This length of time is proportional to the amount of dissolved oxygen in the seawater. It is important to emphasize that the presence of an oxygen active coating on the optical sensor can lead to inaccurate measurements. This is comparable to situations in which photosynthetic algae create a specific microenvironment of oxygen.
- The specific conductivity of water is determined by the four-electrode method. The sensor (Figure 3, 3) is equipped with two sets of graphite electrodes carefully positioned for stable measurement. A constant voltage is applied to one pair of electrodes and the current required to maintain this voltage is measured. The current strength increases as the conductivity of the water increases. The Scuba usually displayed specific conductivity, which is standardized to 25°C, representing the conductivity of the water as if the water had been heated or cooled to exactly 25°C. Conductivity can be expressed in different units, such as total dissolved solids (TDS) and salinity, expressed in Practical Salinity Unit (PSU). The values of either parameter were always derived from the specific conductivity.

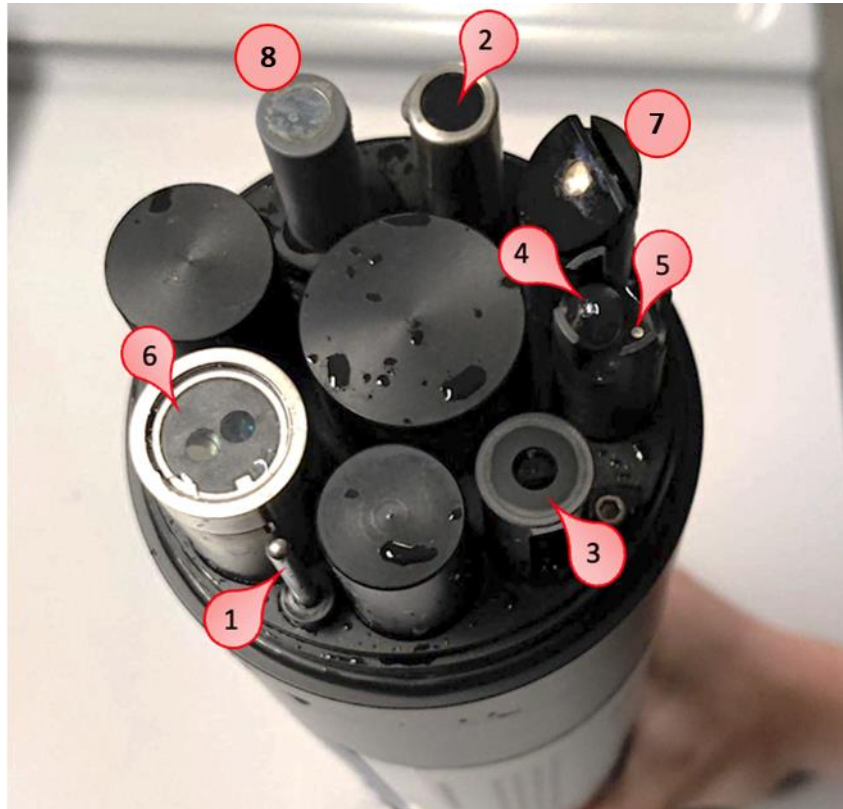


Figure 3. Different sensors of the Scuba Probe.

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.

- The acidity was determined by means of a pH glass electrode (Figure 3, 4). As a result of the ion exchange between the water and the pH glass membrane, a charge separation occurs across the glass. This charge separation creates a voltage difference that can be measured and corresponds to the pH value of the solution.
- The redox potential is measured using an oxidation-reduction potential (ORP) sensor (Figure 3, 5). This sensor is located next to the pH sensor and can be noticed as a gray dot of 1 mm diameter. The redox potential is determined by measuring the voltage drop between the platinum membrane of the ORP electrode and the reference electrode. Because platinum does not react with the ions in the water, the redox potential can be derived from this voltage drop.
- An extra fluorimeter (Figure 3, 6) can be used to measure the chlorophyll concentration in the water. This is a measure of the presence of microalgae and therefore an indicator of the biological activity of the marine ecosystem.
- A reference electrode (supporting the other electrode measurements; (Figure 3, 7) and a chloride sensor (Figure 3, 8) complete the setup.

The Scuba probe furthermore comes with two different attachments that serve to protect the sensors. These attachments can be securely attached to the sensors using threads. A sealed capsule is available to store the probe. Since the sensors must be stored in a humid environment, the sealed capsule is partially filled with water before being attached to the probe.

The Scuba is connected to a 4G modem that uploads the data to the Telecontrolnet platform. Telecontrolnet is a platform where all data from the Scuba sensors come together. Here specific filters were applied to select only the sensors and parameters relevant for this project. Subsequently, a dataset was exported in the form of an Excel file. This Excel file was converted to a CSV file so that it was functional with the R program for the correlation analysis.

Calibration of the environmental sensors

When the secondary Scuba's readings differ from the in-water Scuba's readings, it was replaced or calibrated. The calibration procedure involves instructing the Scuba with the values it should indicate in a specific calibration situation, where the correct parameter value is known (Table 1). This practically implies the use of a liquid with a known value, which is indicated to the Scuba during immersion in this liquid.

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 μ S (brackish – salt water) CD standard, 0.1 M, 12856 μ S (brackish water) CD standard, 0.01 Molar, 1412 μ S (freshwater) CD standard, 0.001 Molar, 147 μ S (fresh/glacial water)
Dissolved oxygen	1 point	100% saturated distilled water (shaken heavily to saturate water with O ₂)

Corrosion probes

For the SOCORRO project, a specific corrosion measurement system has been developed which measures corrosion of three different steel grades (S355, 316L and S235) and a micro-electrochemical cell that measures the rate of corrosion. These measurements are performed every 4 hours.

The linear polarisation (LP) sensor from CCube (Delft, the Netherlands) has dimensions of 150 mm (length) x 60 mm (height) x 50 mm (width). The working and reference electrodes are housed in a plastic housing filled with epoxy adhesive for protection against sea water.

The sensor is connected to a separate CCube control box located in an easily accessible position. A potentiostat and a data logger are installed in the control cabinet. In addition, the

control box contains a mobile antenna that transmits the measured data to the CCube network. The company collects all sensor data and sends it to an online database that is accessible to all researchers of the SOCORRO project.

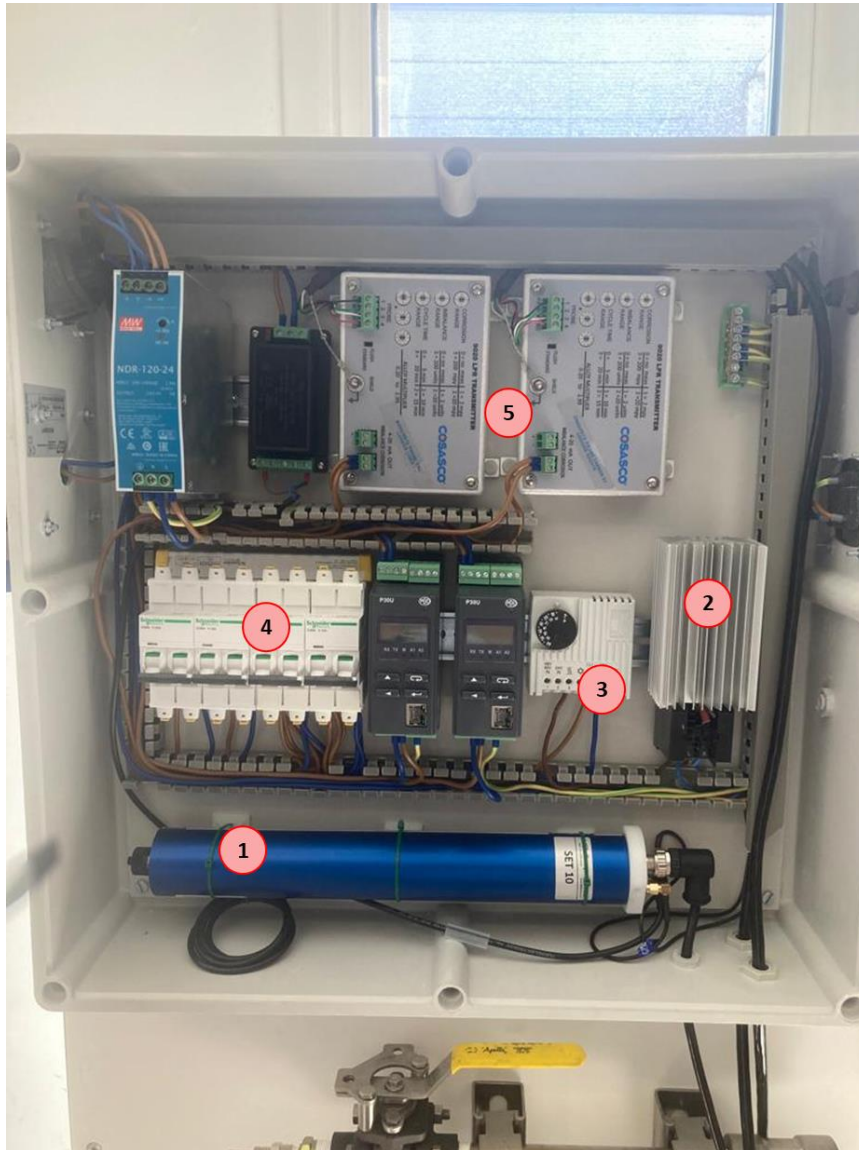


Figure 4. Electrical distribution box for sensors.

1: 4G modem, 2: internal heating, 3: thermostat, 4: circuit breakers, 5: data transmitters for Cosasco LPR probes

Sensor box

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 4, 2) to maintain a constant temperature of approximately 15-20 degrees Celsius. This heating element is connected to a thermostat (Figure 4, 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 4, 4). The box also contains two data loggers/transmitters for data from the Cosasco corrosion sensors (Figure 4, 5).

Data upload

For this purpose, a 4G modem (Figure 4, 1), namely the GDT-S Prime Plus, is integrated in the system. This allowed the data generated by the Scuba sensors to be initially stored and then forwarded to the GDT server at time intervals set by the user. Via this server, users not only had the possibility to view the data via the internet, but also to adjust the settings of the modem and sensors. This could be done via the Eijkelpark web portal.

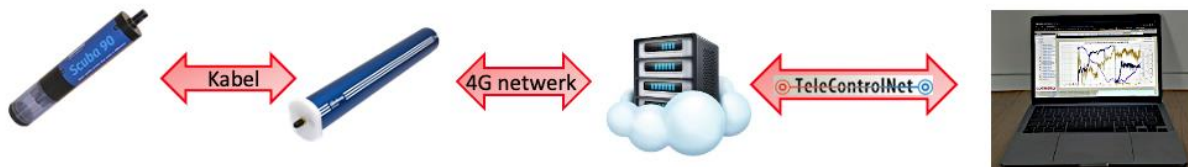


Figure 5. Overview of how data flows from sensor to web portal

Sensor maintenance

To ensure the accuracy of the measurements, it was essential to carry out a thorough maintenance of the sensors. At each visit to the rigs, the sensors were removed from the water and subjected to a thorough visual inspection. It was frequently found that the sensors suffered from biological fouling, which required careful and thorough cleaning. The cleaning process had to be carried out with extreme care to avoid possible damage to the sensors. It was crucial to clean specifically around the sensors and to avoid direct contact with the sensors. For the CCube corrosion probe, it was extremely important to have absolutely no contact with the LPR sensors, as this would disturb the corrosion layers already present on the sensor, which could affect the measurements.

For the maintenance of the Scuba, the initial concern is the external condition of the device. In particular, the copper protective cover, intended to limit biological growth on the sensors, may need to be replaced. Then the Scuba's current readings were analyzed using a secondary Scuba. A bucket was used to carefully collect a sample of water from the immediate vicinity of the setup, at a depth of about 1 meter. The bucket should be handled with care to minimize unwanted oxygen entry into the water. The Scuba was carefully placed in the bucket, to a distance of approximately 10 cm from the bottom, and then connected to a laptop computer running the Scuba Control Software. The direct measurement values could be observed via this software. After a certain period of time, the values stabilized. The software provided the option to copy a data series.

This data set was then compared to the data received from the Scubas in the water, allowing to calibrate or replace the Scuba to be determined. After the calibration procedure, the secondary Scuba was thoroughly rinsed with distilled water to remove any contaminants, and it was then safely stored, fitted with its protective cap, to maintain the integrity of the device.

Baseline measurements of environmental parameters

The composition of the Biesbosch water, used to feed the cooling water circuit, was monitored regularly in another project (Aquaspice¹, Horizon 2020). The average composition over a 1.5 month period is given in Table 2. Within this project, the lines were also sampled separately to ensure the quality between both water circuits was the same. As the results in

¹ <https://aquaspice.eu/>

Table 3 show, there is indeed no discernible difference between both water circuits.

Table 2. Average composition Biesbosch water

Parameter	Unit		
Br	mg/L	0.13	± 0.09
Ca	mg/L	45.16	± 3.51
Cl	mg/L	50.67	± 1.96
Cr	µg/L	0.00	± 0.00
Cu	µg/L	1.41	± 0.58
Fe	µg/L	38.49	± 33.08
F	mg/L	0.26	± 0.14
Conductivity	µS/cm	424.00	± 23.89
K	mg/L	8.86	± 6.29
Mg	mg/L	6.43	± 1.43
Na	mg/L	40.11	± 3.88
NH ₃	mg/L	0.26	± 0.07
Ni	µg/L	2.05	± 1.26
NO ₂	mg/L	0.05	± 0.10
NO ₃	mg/L	10.20	± 5.20
pH	-	8.04	± 0.09
PO ₄	mg/L	0.00	± 0.00
SiO ₂	mg/L	4.92	± 0.33
SO ₄	mg/L	54.01	± 33.57
TOC	mg/L	3.83	± 2.19
Zn	µg/L	12.34	± 18.51

Table 3. Measured parameters on the two separate water circuits

Parameter	Unit	Circuit 1		Circuit 2	
Cl	mg/L	59.79	± 0.86	59.23	± 1.55
SO ₄	mg/L	54.52	± 0.28	53.77	± 0.47
F	mg/L	0.18	± 0.01	0.18	± 0.01
B	mg/L	0.03		0.03	± 0.01
NO ₃	mg/L	8.41	± 0.72	8.36	± 0.26
NO ₂	mg/L	1.72		1.74	
TOC	mg/L	3.38	± 0.1	3.52	± 0.01
TC	mg/L	23.69	± 0.27	23.51	± 0.29
IC	mg/L	20.31	± 0.37	20.00	± 0.29

To further investigate the potential differences that could cause the difference in observed corrosion, a more detailed analysis of the organic material in the water was performed through HPSEC. This method divides the organic material into 3 fractions; high molecular weight (HMW), medium molecular weight (MMW) and low molecular weight (LMW). For both circuits, duplicate samples were taken, but one was lost before analysis was possible. This results in the chromatograms as overlaid in Figure 6 and the concentrations mentioned in Table 4. Again, no discernible difference can be observed between both circuits in terms of organics composition.

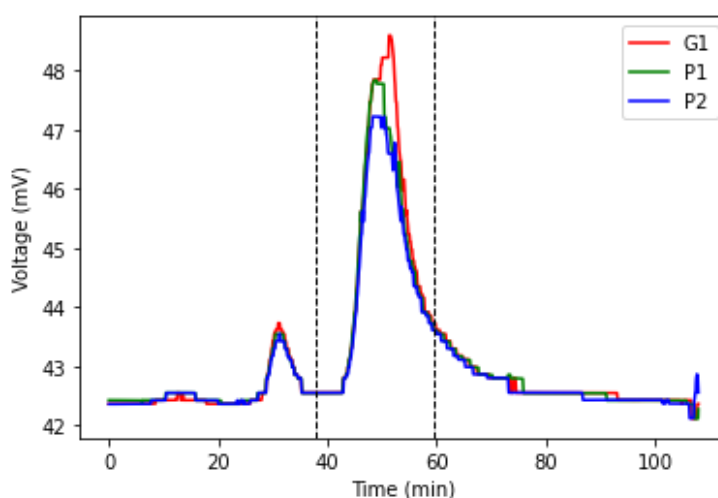


Figure 6. HPSEC chromatogram of the three samples

Table 4. Concentration HMW (high molecular weight), MMW (medium molecular weight) and LMW (low molecular weight) organic compounds in both circuits.

Parameter	Unit	Circuit 1		Circuit 2	
HMW	mgC/L	0.18		0.16	± 0.01
MMW	mgC/L	2.12		1.83	± 0.12
LMW	mgC/L	0.31		0.30	± 0.03

Corrosion measurements: experimental methodology

Steel types

Three specific steel types were selected for conducting the experiments: S235, S355 and 316L. In the following paragraphs, these individual steel types will be briefly described, explaining their characteristics and composition.

The first material is **S355 carbon steel**, which meets the European EN 10025:2 standard. This is a structural steel type (indicated by the "S" in the designation, which refers to "structural"). The value "355" stands for the minimum tensile strength of the material (355 MPa, for a sheet thickness of 16 mm). S355 can be classified as "mild steel" because of its relatively low carbon content, which makes it more suitable for welding work (de Jesus et al., 2012). The chemical and mechanical properties of the steel can be compared to those of the American standard variant ASTM A572/A709 (Igwemezie, Mehmanparast, & Kolios, 2018). S355 is widely used in various construction applications, including shipbuilding, bridge components, offshore structures and wind towers (Igwemezie et al., 2018).

S235 carbon steel follows the guidelines of the European Committee for Iron and Steel Standardization (ECISS), with a minimum tensile strength that is slightly lower than that of S355 for an equal thickness.

Both aforementioned structural steels belong to the category of low-carbon steels. The carbon limit for this category has been set at 0.30%, with both S235 with a maximum value of 0.22% C and S355 with a maximum value of 0.23% C more than comply. In addition to the carbon content, the American Iron and Steel Institute (AISI) also looks at the alloying elements in the steel. Since both S235 and S355 have a manganese content of up to 1.60%, they are classified as "plain carbon steel" (Singh, 2020). These classifications and limit values provide insight into the composition and properties of the steels. It is important to note that these low carbon steels will not perform optimally in terms of corrosion resistance. The material does not contain the crucial elements such as copper, chromium or nickel, which are of great importance for corrosion resistance. In the past, this material was available in a pickled and oiled form, which offered some degree of corrosion resistance.

Alloy 316L is a stainless steel with an austenitic structure containing chromium, nickel and molybdenum. The molybdenum improves corrosion resistance and resistance to pitting corrosion caused by chloride ion solutions, which often occur in water. In addition, it also increases strength at high temperatures. To provide protection against corrosion, a thin layer of metal oxides is applied to the surface, which acts as a barrier against corrosive substances. Typically, alloy 316L contains approximately 2-3% molybdenum, 16-18% chromium, 10%-14% nickel, 16-18% chromium, and 0.08% carbon. Other elements can be added to this alloy to modify the properties of the steel. Alloy 316L is widely used in marine equipment, refineries and chemical plants because of its excellent corrosion resistance, especially in highly corrosive environments.

Use of coupons for corrosion measurements

14 metal coupons could be hung in each tray, five of which were 316L, five S235 and four S355 (Figure 7), on which mass loss measurements will be performed (see below). The coupons are approximately 2 cm wide and 8 cm long. After being weighed and labelled, they were immersed in the process water for a certain period of time. Afterwards they were etched and weighed again. The corrosion rate could be calculated on the basis of the mass difference.



Figure 7. Coupon box at the BASF demonstrators

Due to the limited number of coupons that could be hung in the tray, a sampling protocol had to be written in which a coupon that was removed was immediately replaced by a newly labeled coupon. In this way it was possible to have one or more measurement points for each type of steel for a period of 1, 2, 3, 6, 9 and 12 months.

After collection, coupons were thoroughly cleaned with water, dried with paper towels, wrapped in paper towels and placed in a sealed freezer bag with silica gel to prevent further corrosion. One coupon was not cleaned and was placed in a freezer bag without touching it. The purpose of this action was to perform a visual inspection on the coupon in the future. The date and location of sampling were documented on the pouch, after which the pouch was carefully sealed.

The coupons were cleaned in accordance with the guidelines set forth in the ASTM G1 standard. After cleaning, the weight loss and corrosion rate of the coupons were evaluated to understand their corrosion behaviour. Measuring the weight loss and corrosion rate provides valuable information about the interaction between the coupon material and the environment in which they are exposed and can serve as an indicator of the durability and performance of the material in corrosive conditions. To determine the corrosion rate based on the mass loss, the corrosion products were first removed from the coupons. For this purpose, the metal coupons were placed in 200 ml 23% hydrochloric acid in glass beakers for 15 minutes. After

the acid treatment, the coupons were thoroughly rinsed with demineralized water and dried with paper. To ensure the accuracy of the measurement, it was ensured that the coupons were completely dry before being weighed. At the start and after the cleaning process, the coupons were photographed with the corresponding tags.

Use of the Cosasco and CCube LP(R) sensor

For the SOCORRO project, bespoke sensor systems been developed for corrosion measurement CCube (Delft, the Netherlands). The sensor is based on linear polarization (LP) theory to measure the rate of corrosion. This is achieved by applying small voltages (less than ± 30 mV) to the metal just above and below the corrosion potential. Within this voltage range, the resulting current response is linear if the anodic and cathodic regions are equal (Campos-Silva & Rodríguez-Castro, 2015; Ropital, 2011). This makes it possible to determine the polarization resistance (R_p), which is defined as the slope of the current-potential curve according to the Stern-Geary equation (Stern & Geary, 1957):

$$I_{corr} = \frac{1}{R_p} * \frac{\beta_a * \beta_c}{2.303(\beta_a * \beta_c)}$$

with

$$B = \frac{\beta_a * \beta_c}{2.303(\beta_a * \beta_c)}$$

B is a constant that depends on the anodic and cathodic table diagram (β_a and β_c) obtained from polarization curves. In most cases, the values of β are between 60 and 120 mV (García-Galvan, Fajardo, Barranco, & Feliu, 2021).

$$I_{corr} = \frac{B}{R_p}$$

Faraday's law can then be applied to calculate the corrosion rate as follows:

$$CR = K_1 * \frac{I_{corr}}{dA} * EW$$

whereby CR = corrosion rate in mm/year, $K_1 = \text{constant of } 3.27 * 10^{-3}$, $d = \text{density in g/cm}^3$, EW = the equivalent weight, defined as the mass in grams oxidized by the passage of an electrical charge of 1 Faraday. EW values can be found for different metals in ASTM G102 (García-Galvan et al., 2021).

The CCube uses working electrodes made from the three different steel grades in the project (S355, 316L and S235) and a micro-electrochemical cell that measures the rate of corrosion. These measurements are performed every four hours. The working and reference electrodes are housed in a plastic housing filled with epoxy adhesive for protection against sea water, with dimensions of 150 mm (length) x 60 mm (height) x 50 mm (width).

The sensor is connected to a separate CCube control box located in an easily accessible position. A potentiostat and a data logger are installed in the control cabinet. In addition, the control box contains a mobile antenna that transmits the measured data to the CCube network.

The company collects all sensor data and sends it to an online database that is accessible to all researchers of the SOCORRO project.

The two cosasco LPR probes are connected to the two LPR transmitters in the electrical cabinet. The probes are used to measure the corrosion rate. These consist of two electrodes that are brought into contact with the water. The 9020 LPR transmitter is able to measure the polarization resistance between the two electrodes and calculates the corrosion rate based on this measurement. The transmitters are in turn connected to a Lumel brand P30U transducer. A transducer converts a physical quantity, in this case current, into an electrical signal so that it can be further processed electronically. The P30U also functions as a logger in this case, as the measured values appear on the screen/interface and are also stored in the internal memory. Both the transmitters and transducers must be preconfigured.

The corrosion data must be downloaded manually. This is done using a File Transfer Protocol (FTP) whereby the logger is connected to a PC with an Ethernet cable. For this, the IP address, user name and password of the loggers must be known.

Environmental data: results

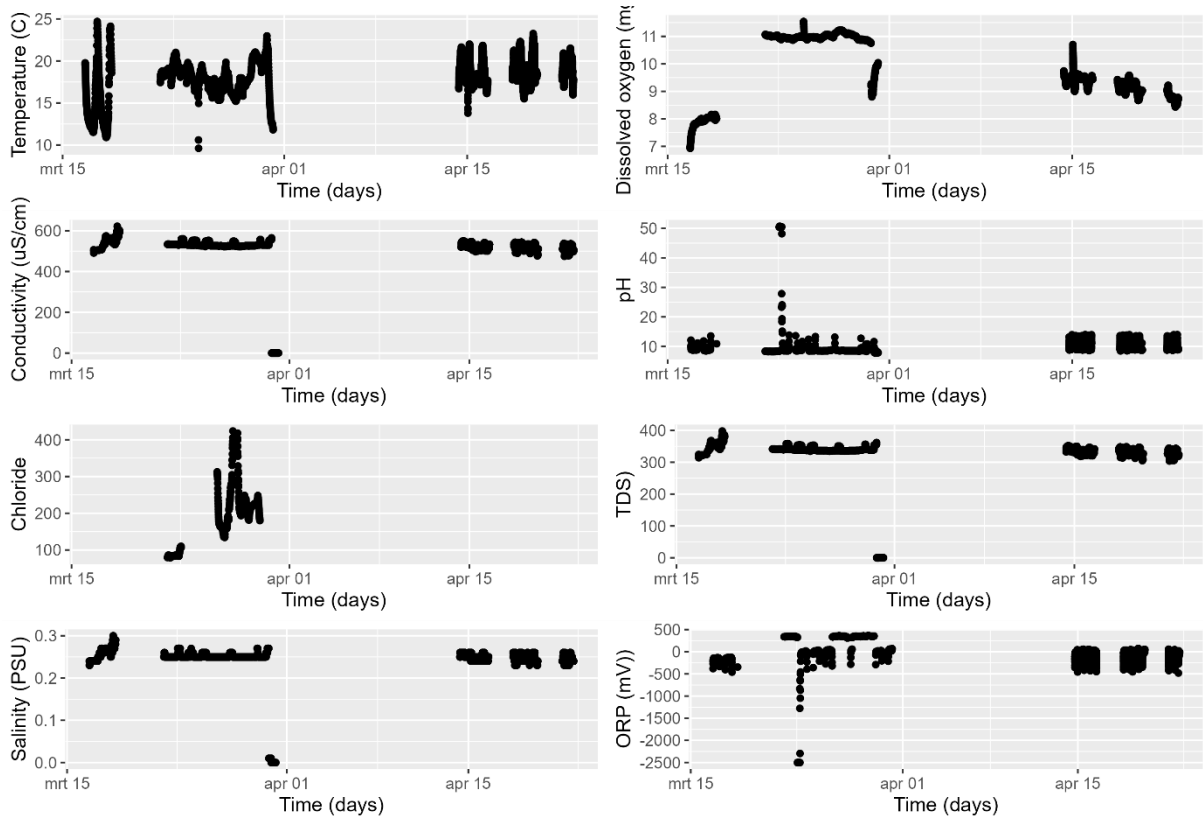


Figure 8. Time plots for environmental data for the BASF 1 demonstrator

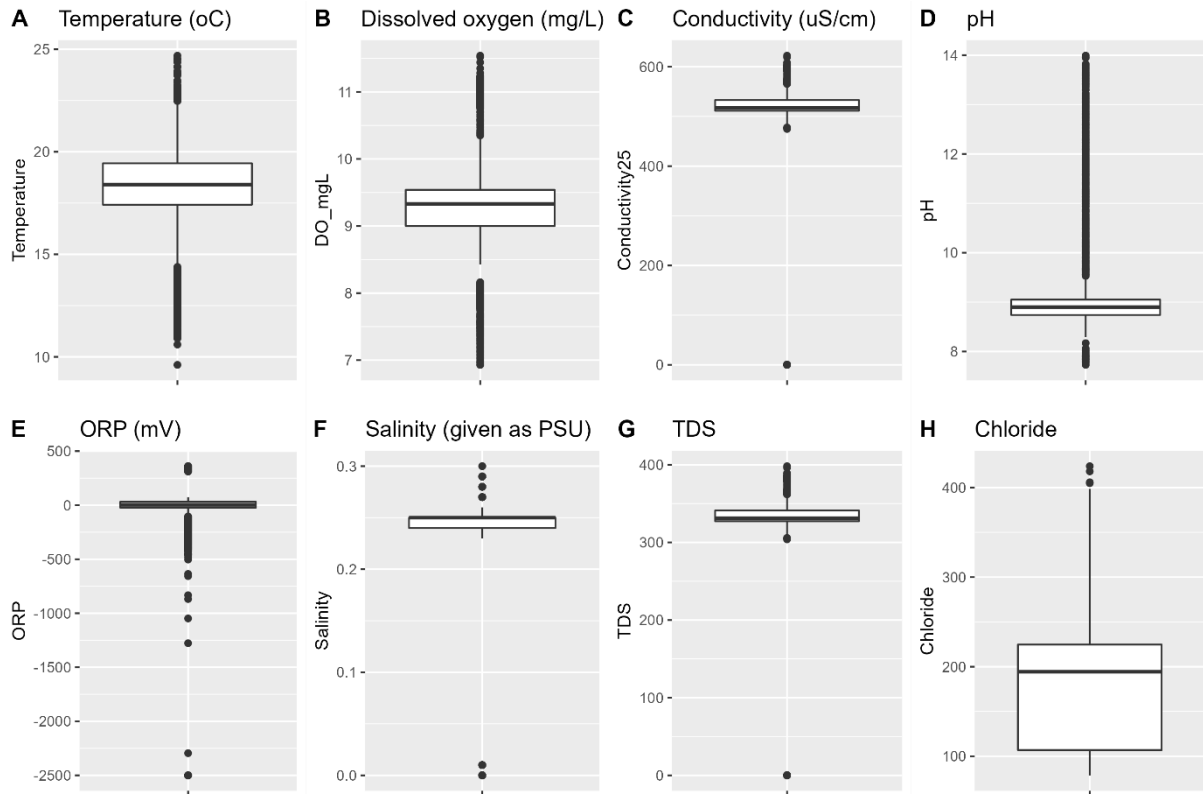


Figure 9. Boxplots for the different parameters measured at BASF 1

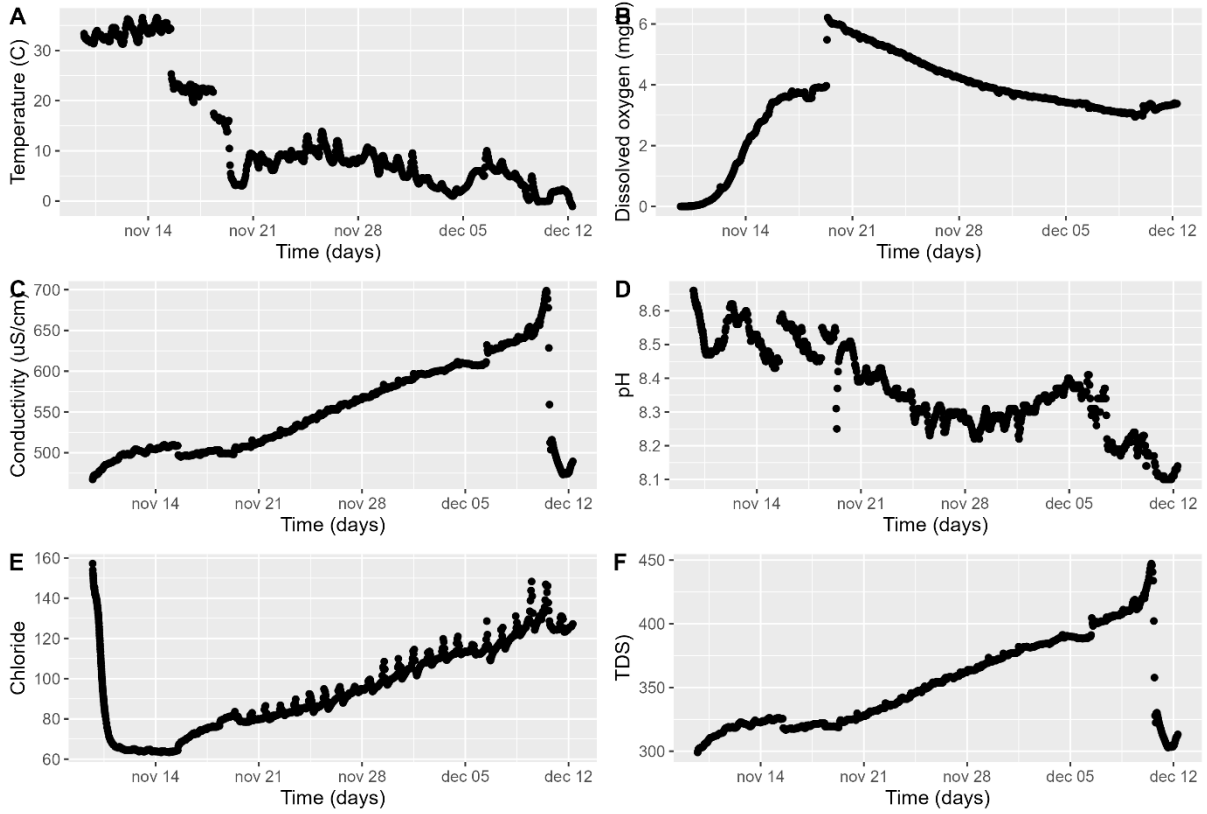


Figure 10. Time plots for environmental data for the BASF 2 demonstrator

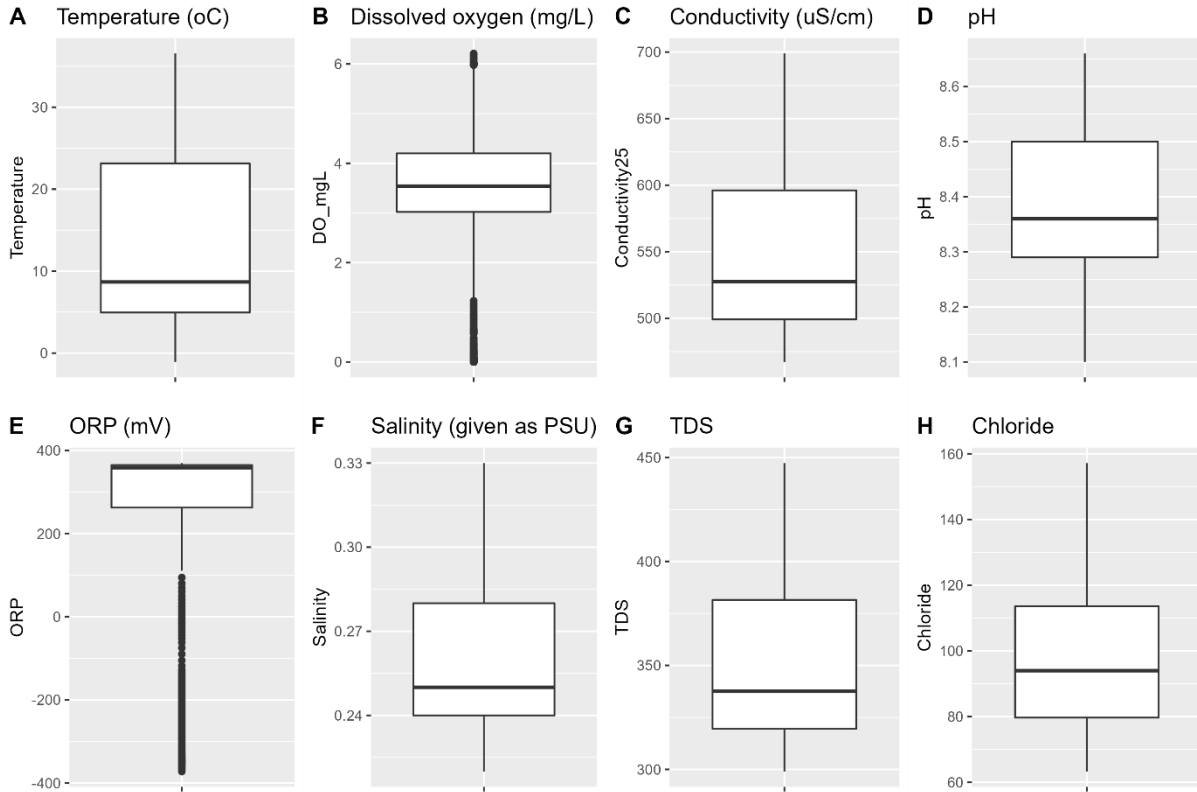


Figure 11. Boxplots for the different parameters measured at BASF 2

Corrosion: results

Corrosion rates for coupons

At this moment, only a limited number of coupons were analysed, representing 2 months of corrosion at either demonstrator. There are, however, no significant differences ($P = 0.05$) in corrosion between the two demonstrators, neither for S235 nor for S355. This may indicate that the difference of the corrosion as indicated before may be due to the steel type used in the installation itself.

Steel type	BASF 1 corrosion rates (mm/y)	BASF 2 corrosion rates (mm/y)
S235	0.080 ± 0.008	0.090 ± 0.004
S355	0.077 ± 0.003	0.068 ± 0.011

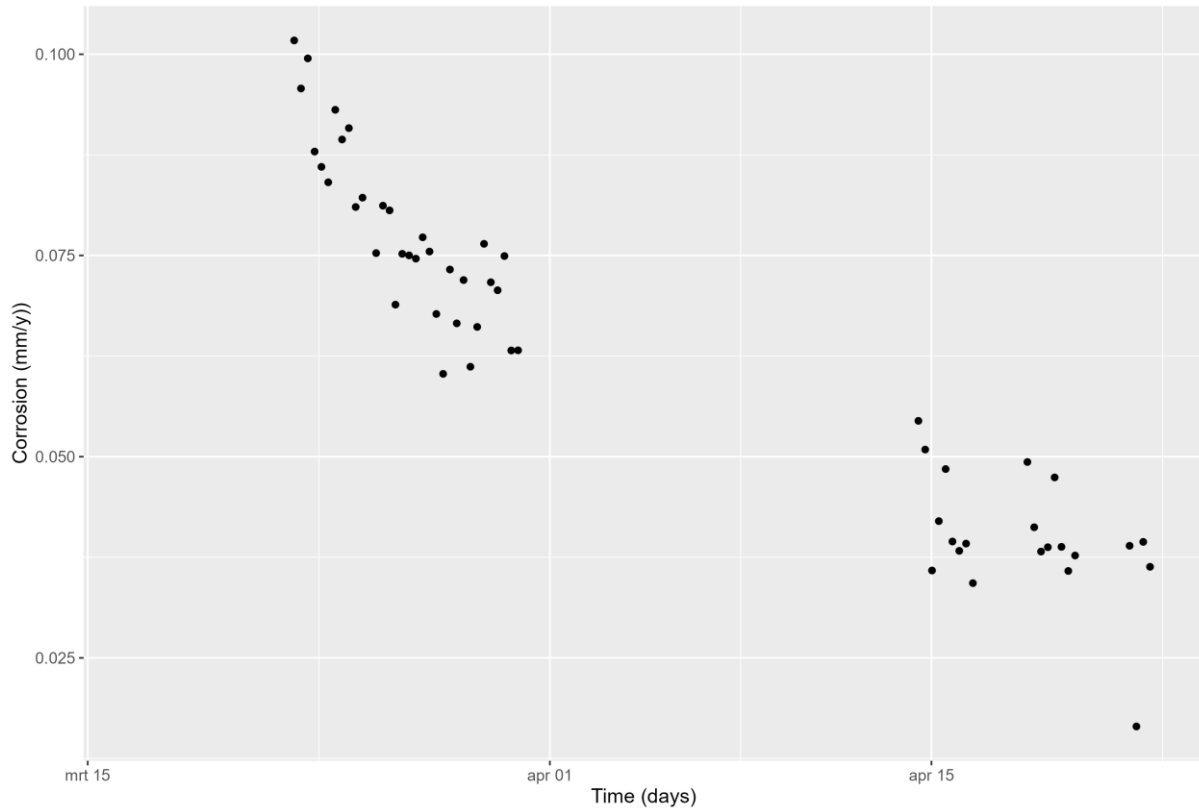


Figure 12. Corrosion rates obtained for S235 steel

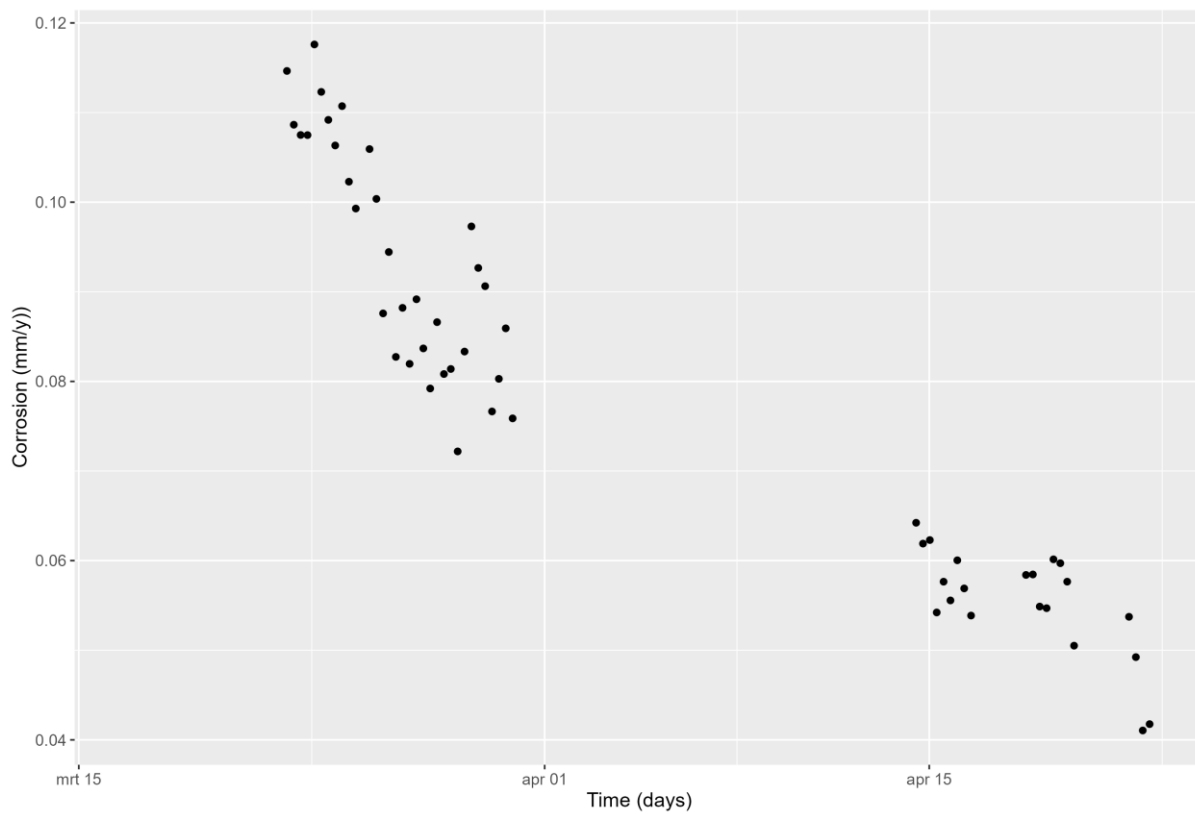


Figure 13. Corrosion rates obtained for S355 steel

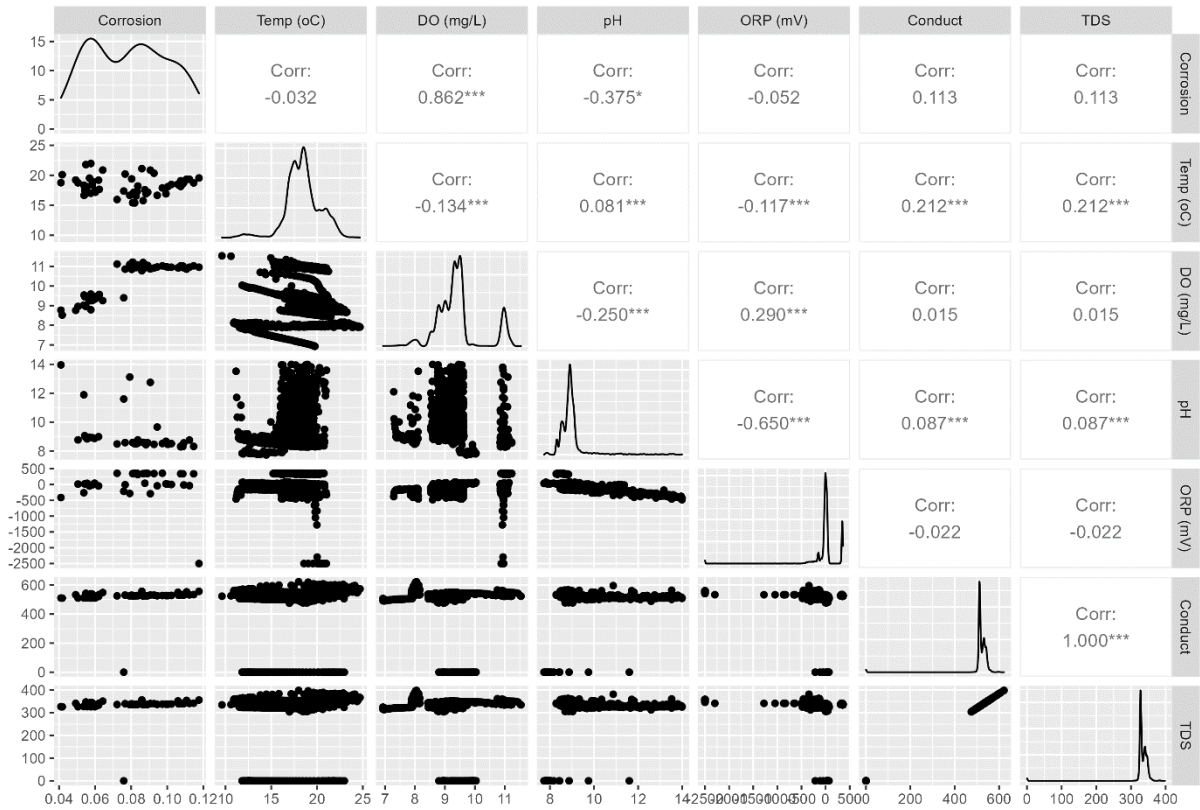


Figure 14. Pairwise correlations between the different environmental parameters and S355 steel

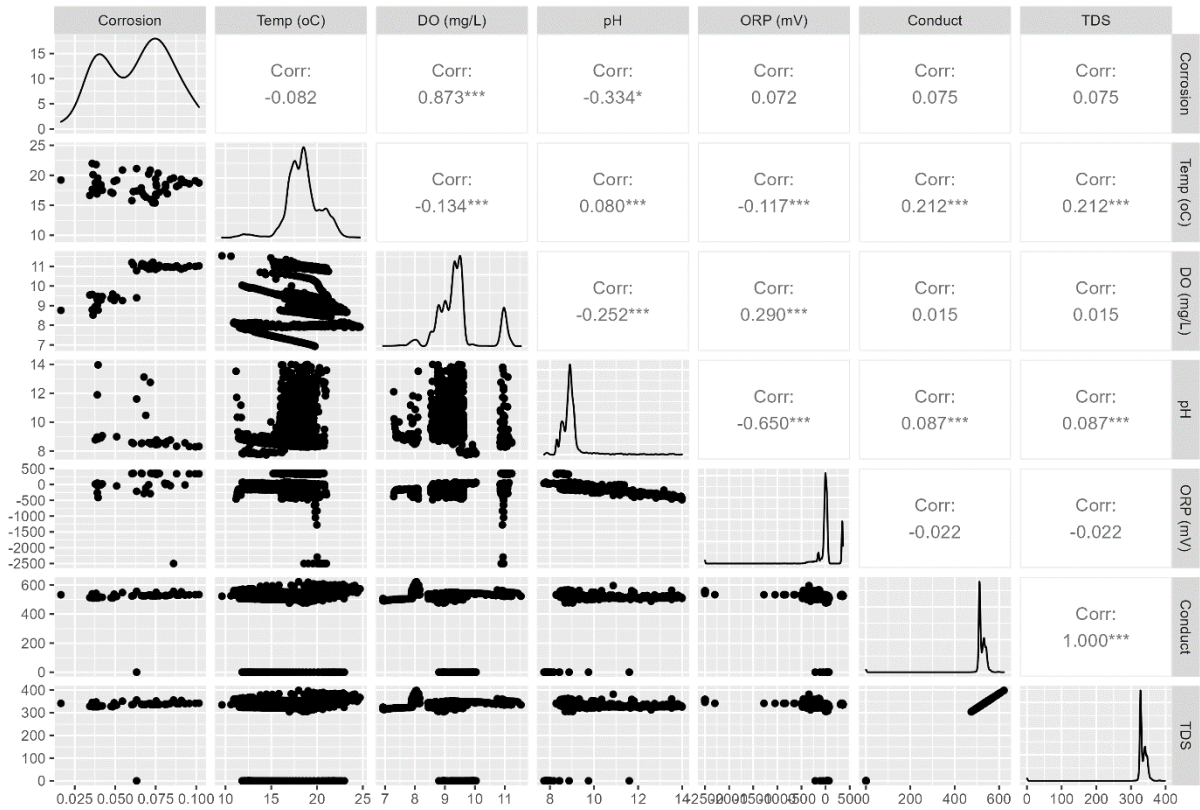


Figure 15. Pairwise correlations between the different environmental parameters and S235 steel

Correlations between environmental parameters and corrosion rates for BASF 1

Corrosion values taken from the LP measurements are shown in Figure 12 and Figure 13. Comparing these with the environmental parameters measured at BASF 1 (Figure 14 and Figure 15), we note that these values are closely correlated with the concentration of dissolved oxygen ($R = 0.862$ for S355 and 0.873 for S235) and slightly inversely correlated with pH (with R values of -0.375 for S355 and -0.334 for S235). No other significant correlations could be observed. These observations are in line with the PCA analyses (Figure 16, Figure 17).

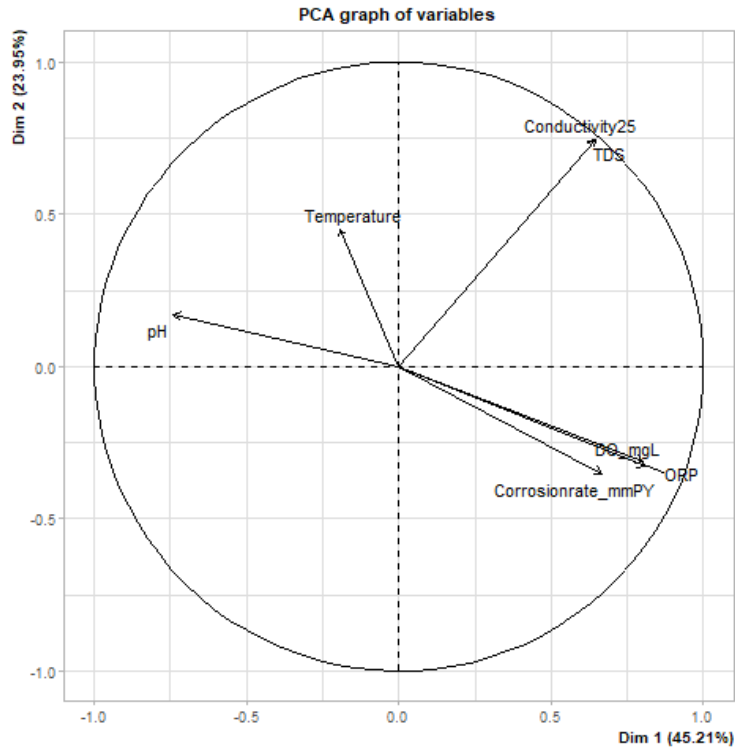


Figure 16. PCA graph for the BASF 1 S355 corrosion data in relation to the environmental parameters.

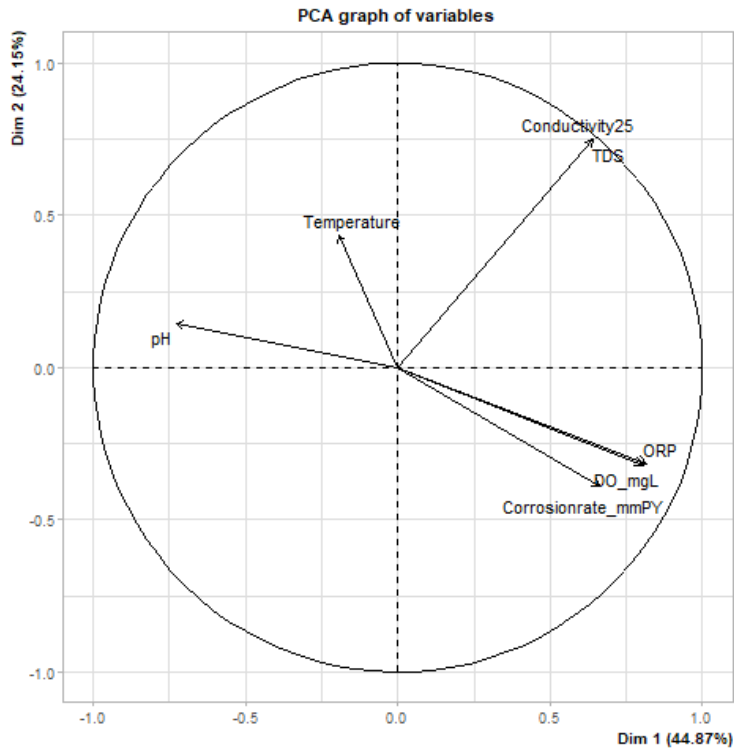


Figure 17. PCA graph for the BASF 1 S235 corrosion data in relation to the environmental parameters.

Technical issues

The two PVC trays turned out to be unsuitable for the experiment. Due to a sudden increase in pressure, the container on BASF1 broke because the glue no longer held. The other container began to leak over time. This can be explained by the regular opening and closing of the transparent lid when removing the coupons. Frost damage is another possible explanation. It was therefore decided to replace these containers with a stainless steel pipe later in the experiment. This pipe was originally intended for an arrangement of the project on board a ship (see report Output O4). By making some adjustments (making it watertight, buying the right connectors, etc.), this stainless steel pipe could be mounted on the BASF setup. The LP sensor could be fixed in the tube, in which a set of 15 coupons could be mounted as well.

Furthermore, temperature fluctuations and extreme temperatures must be taken into account. After a whole summer afternoon in the flat sun, temperatures can rise sharply. Frost is also always possible in winter. Appropriate materials must therefore be selected for this, which must also be resistant to mechanical loads such as wind or vibrations. For example, the transparent lid of the electrical box is also resistant to UV rays.

The data from the Ccube is sent online to the company itself. This will be processed and returned afterwards. However, the Ccube sensors were not yet on point at the beginning of the experiment. First they had to be updated. This by connecting to the sensor on site using a printer cable (USB B to USBA). The instructions to be followed can be found in Appendix X. It later turned out that the sensor was badly wired. This was therefore adapted from three counter electrodes to one counter electrode.