Accident
Investigation Board
Norway

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REPORT Marine 2020/02

REPORT ON OCCUPATIONAL ACCIDENT ON BOARD THE FACTORY TRAWLER NORDSTAR ON 10 JUNE 2018

AIBN has compiled this report for the sole purpose of improving safety at sea. The object of a safety investigation is to clarify the sequence of events and root cause factors, study matters of significance for the prevention of maritime accidents and improvement of safety at sea, and to publish a report with eventually safety recommendations. The Board shall not apportion any blame or liability. Use of this report for any other purpose than for improvements of the safety at sea shall be avoided.

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This report has been translated into English and published by the Accident Investigation Board Norway (AIBN) to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Photo of ferry on the Norwegian west coast: Bente Amandussen

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NOTIFICATION OF THE ACCIDENT

The Accident Investigation Board Norway (AIBN) was notified of the accident by the Joint Rescue Coordination Centre for Southern Norway (JRCC-S) at 17.35 on 10 June 2018. A work accident had taken place on board the factory trawler Nordstar earlier that day when a crew member had collapsed during entering of a tank. The crew retrieved the man from the tank and administered CPR, but he was declared dead on the same day.

The AIBN decided to conduct a safety investigation into the accident. The first interviews with representatives of the shipping company and the crew who were on board Nordstar during the accident took place in Ålesund on 14 June 2018.

Figure 1: Nordstar had finished fishing in the Irminger Sea and was heading for Ålesund at the time of the accident. The position is marked with a red x. Map: Kystinfo, the Norwegian Coastal Administration

SUMMARY

On 10 June 2018, a crew member died on board the factory trawler Nordstar in connection with preparations for cleaning a silage tank. The tank had not been cleaned since unloading from the previous voyage, and there was some silage[1] residue in the tank.

The investigation has shown that methane gas as well as toxic hydrogen sulphide gas had probably formed as a result of a decomposition process in the silage tank. It is likely that the fisherman was quickly exposed to immediately lethal levels of gas as he climbed down to the bottom of the tank. It was a demanding job to get the fisherman up from the tank.

The risk of gas being formed during the production and storage of silage had not been identified as a hazard in the shipping company's safety management system. The hazards associated with gas formation were not mentioned in risk assessments, checklists or work procedures. Tanks with contents that represented a potential gas hazard were not sufficiently labelled, and equipment for detecting hazardous gas was lacking. This contributed to a situation where personnel carrying out work on storage tanks and those responsible for approving such work were unaware of the potential risks to which they were exposed.

The crew lacked sufficient emergency preparedness training and training in how to rescue people from a tank. It was somewhat unclear where the rescue equipment was located, and nor was the equipment adapted to efficient efforts to rescue personnel from a tank.

The shipping company has implemented several measures since the accident, including acquiring appropriate rescue equipment, conducting risk assessments of the ensiling work process, providing training for the crew, and introducing new work and operating procedures for silage production and storage.

Several parties took part in a project to establish a full-scale pilot plant for silage production on board Nordstar in 2015. The investigation has shown that knowledge of the hazards associated with the formation of gas when fish waste/silage decomposes was not transferred in an effective manner from the other parties in the project to the shipping company, and nor were they identified by the shipping company or the supervisory authority (the Norwegian Maritime Authority) during the operating phase of the project.

The requirement for a safety management system (ISM) for fishing vessels with a gross tonnage of more than 500 was introduced in 2016. The Norwegian Maritime Authority conducted audits of the shipping company and the ship's safety management systems on board Nordstar in 2017, after the vessel had been modified for silage production. The audit did not uncover that the management system did not mention the operational hazards associated with silage production and storage. The AIBN regards the supervisory process for this group of vessels as a work in progress, and expects it to become more capable of detecting such non-conformities in the safety management system in future.

The AIBN does not make any safety recommendations in connection with the investigation.

[1] The term ensilage refers to animal and plant material that has undergone enzymatic decomposition. Acid is usually added to the material during the ensiling process to stabilise it during long-term storage. Source: Arbeidstilsynet.no

1. FACTUAL INFORMATION

The factual information is based on interviews with the crew of the vessel, technical investigations on board the vessel, the JRCC’s operations log, the Norwegian Coastal Administration's Automatic Identification System (AIS) log, and information obtained from the shipping company, the Norwegian Maritime Authority, the police and relevant parties in connection with the vessel's modification for silage production.

Figure 2: The factory trawler Nordstar. Photo: Nordnes AS

1.1 Sequence of events

1.1.1 <u>The accident</u>

The factory trawler Nordstar was on its way to Ålesund after fishing in international waters west of the Reykjanes Ridge. The vessel was to be made ready for fishing for another type of fish (from redfish to white fish) during the voyage, and the crew had finished cleaning the factory on the morning of 10 June 2018.

Later in the morning, the skipper instructed the factory supervisor to prepare the silage tanks for cleaning. This meant flushing the tanks by filling them with seawater and emptying them several times, before lowering a fan (not explosion proof) into the tank to blow in fresh air and lead air out of the tank via the attached plastic hose. According to the skipper, he had given instructions that the fan was to be lowered using a rope in the same way as had been done on two previous occasions during the voyage when crew members entered diesel tanks in connection with cleaning.

The hatches to the two forward silage tanks were located inside on the main deck (see Figure 3), forward of the factory. The tanks had not been cleaned since the last voyage on 3 May 2018, and there was still silage residue at the bottom of the tanks. Normally, the tanks would have been cleaned when they were fishing for redfish, but during this voyage, the tanks had been filled with water and used as ballast tanks.

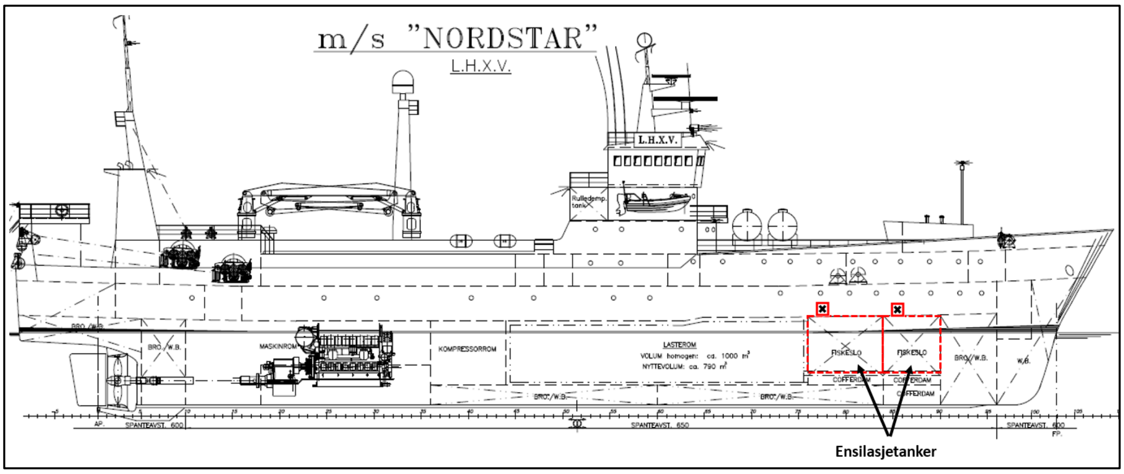

Figure 3: The vessel's four silage tanks were located in the foreship, indicated by red dotted lines. The access hatches were located on the factory deck, indicated by a red square with a black x. Source: GH Marine/AIBN

The factory supervisor started to prepare the tanks at about 11 o'clock. There was water in the tanks, but the amount is uncertain. He started by pumping all the water out of the forward starboard tank, then filled it with 40–50 m^3 of water, before emptying it again. The factory supervisor did not have time to finish before the watch changeover at 14.00, but the forward starboard tank had been emptied.

When the factory manager came on duty, he had a routine watch handover with the factory supervisor. The factory manager understood that he was to fill some water into the starboard tank and then empty it before lowering a fan into the tank to ventilate it. This was done, and shortly before 15.00 the factory manager and two fishermen went to start rigging the fan in the tank. The plan was to use a rope to lower the fan into the tank. In order not to blow the air from the tank directly into the factory and the ship's interior, an attached plastic hose would be used to lead the air back through the factory and out into the open air. The access hatches to the tanks are shown in Figure 4.

Figure 4: The access hatches for the two forward silage tanks were located forward of the factory, inside a confined space in the vessel's interior. There was a sign above the hatches with the text 'Danger lack of oxygen'. Photo: AIBN

The factory manager had previously found it challenging to prevent the hose getting twisted when the fan was lowered. He measured the oxygen level in the tank by lowering an oxygen detector on a string. The oxygen detector did not sound an alarm, and the factory manager therefore deemed it safe to enter the tank if necessary in order to place the fan correctly. Before the factory manager went down into the pump room, he left the oxygen detector with one of the two fishermen who took part in the work.

The other fisherman started rigging the fan and hose. When the equipment was ready, the fisherman who had the oxygen detector said that he would go down into the tank to place the fan correctly. He had a torch and a portable oxygen detector with him when he entered the tank. After climbing part of the way down, the fisherman shouted to his colleague who remained on deck that there was a lot of silage residue left in the tank; he then proceeded down to the bottom of the tank. His colleague has stated that he could tell from the look on the face of the fisherman inside the tank that something was wrong, before he said that '*there is no air here*'. The fisherman inside the tank jumped back onto the ladder and climbed a few steps before he suddenly fell backwards and landed at the bottom of the tank, where he lay face-down in the silage residue.

Figure 5: The oxygen detector in use at the time of the accident was of the type Unitor OXY-MATE C. Photo: AIBN

1.1.2 Rescuing the injured person from the tank

The colleague on deck called out, and the factory manager immediately returned from the pump room. The factory manager was asked to fetch one of the vessel's sets of smoke-diving breathing apparatus, which was located on the trawl deck (the deck above). Several of the fishermen on duty understood that a serious incident had occurred and quickly arrived. The factory manager notified the mate, who had the bridge watch, via the vessel's PA system. The mate ran down to the scene of the accident, and notified the skipper on his way down.

The fisherman who witnessed the accident estimates that he donned a smoke-diving breathing apparatus and entered the tank in about four minutes. He turned over the fisherman who was lying face-down in the fish silage. Then he shouted up to the crew gathered at the hatch to throw down the end of a fire hose that he planned to use to hoist the other fisherman up. Another fisherman wearing a smoke-diving breathing apparatus soon entered the tank, and the two of them attempted to fasten the hose around the fisherman without succeeding.

When the vessel's lifting equipment was lowered into the tank, the first fisherman ran out of air and had to go up. A third fisherman wearing a smoke-diving breathing apparatus came down into the tank and, together with the second fisherman, tried to secure the strop around the injured person. It was a very challenging task, and the injured person repeatedly slipped out of the strop because he was unconscious.

It was also very challenging that the ladder cage on the entry ladder obstructed the hoisting operation (Figure 6). Another 20 minutes passed before they finally managed to get the injured person out of the tank.

Figure 6: The ladder cage on the ladder in the silage tank obstructed the hoisting operation. Photo: AIBN

1.1.3 Notification and lifesaving efforts

The mate notified the skipper about the accident at about 15.00. He first ran up to the wheelhouse to get an overview of the situation, and then proceeded to the factory. There were already several people at the scene of the accident, and the mate was leading the rescue efforts. The skipper fetched the rescue equipment that was kept in the storeroom next to the tank hatch.

He then ran back to the wheelhouse to notify JRCC-S of the accident and request assistance. He also contacted the Icelandic Coast Guard on VHF. At the same time, he set Nordstar's course for the nearest land. The Icelandic Coast Guard confirmed that it would send a helicopter. Afterwards, the skipper went back and forth between the bridge and the scene of the accident.

When the injured person had been brought up from the tank, the skipper took command at the scene of the accident and the mate returned to the bridge. CPR was immediately administered to the injured person, and attempts were made to resuscitate him using a defibrillator. This work continued non-stop, with most of the crew involved, until medical personnel from the Icelandic Coast Guard arrived at approx. 17.20. The medical personnel ascertained that the injured person had died, and CPR was discontinued. The defibrillator attached to the injured person did not register any sign of life and never delivered a shock.

Once the injured person had been declared dead, the shipping company, in consultation with the AIBN and the police, decided to bring the dead man ashore on Iceland. In the early hours of 11 June, Nordstar briefly called at Vestmannaeyjar in Iceland before continuing to Ålesund, where it arrived in the evening of 13 June.

1.2 Weather and sea conditions

There was a moderate westerly breeze and waves of 0.5 metres in the area in question on the morning of 10 June 2018.

1.3 Vessel and equipment

1.3.1 Introduction

The factory trawler Nordstar was built in 1969 at Aukra Bruk and has been modified several times since. The vessel has an overall length of 75.5 metres, a breadth of 13.0 metres and a gross tonnage of 2,053 tonnes.

1.3.2 Modification of the vessel for silage production

The shipping company carried out a pilot project for silage production in cooperation with SINTEF Fisheries and Aquaculture, Nofima and Aquarius/Hordafor AS (see Chapter 1.4.1 for a more detailed description). In 2015, the shipping company installed a full-scale pilot plant for silage production on board Nordstar and put it into operation. The shipping company bought a complete factory with pertaining pumps from Hordafor. The company first installed two silage tanks on board Nordstar, and a while later two more.

The production plant in itself does not affect the classification requirements, but four storage tanks for silage have been built, see Figure 7. In connection with the building of these tanks, a new inclining test was conducted and new stability calculations, a new tank plan and general arrangement (GA) were drawn up.

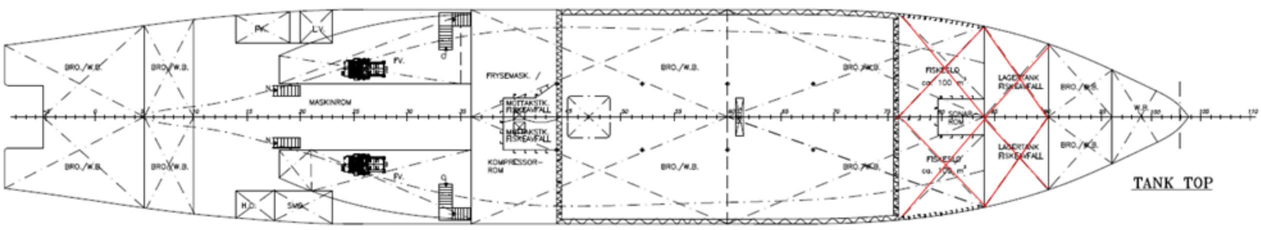

Figure 7: GA drawing showing the four storage tanks (indicated by red crosses) for silage. Source: Nordnes

The shipping company submitted drawings of the storage tanks to the classification society DNV GL for approval in connection with the modification. DNV GL inspected the vessel to verify the drawings in relation to the work carried out. It was not part of the classification society's job to consider operating conditions and procedures for the storage and production of silage.

1.3.3 Gas detectors and rescue equipment

1.3.3.1 *Oxygen detector*

The detector used before the fisherman entered the tank was of the Unitor OXY-MATE C type, which measures oxygen only – no other gases. The oxygen detector had last been serviced in October 2015 by a manufacturer's representative. The service included calibration of the meter. According to the certificate issued after the service, the next calibration of this instrument was scheduled to take place within a year (16 October 2016). The O_2 detector had not been serviced since 2015.

The AIBN has been informed by the shipping company that the O_2 detector was functioning on the day of the accident, but it has not carried out its own examination of the instrument.

1.3.3.2 *Rescue equipment*

The vessel had prepared hoisting equipment for rescuing persons from confined spaces or other relevant spaces, such as the cargo hold. It comprised a ‘helicopter harness’, ropes, block and tackle, torches and some first aid equipment.

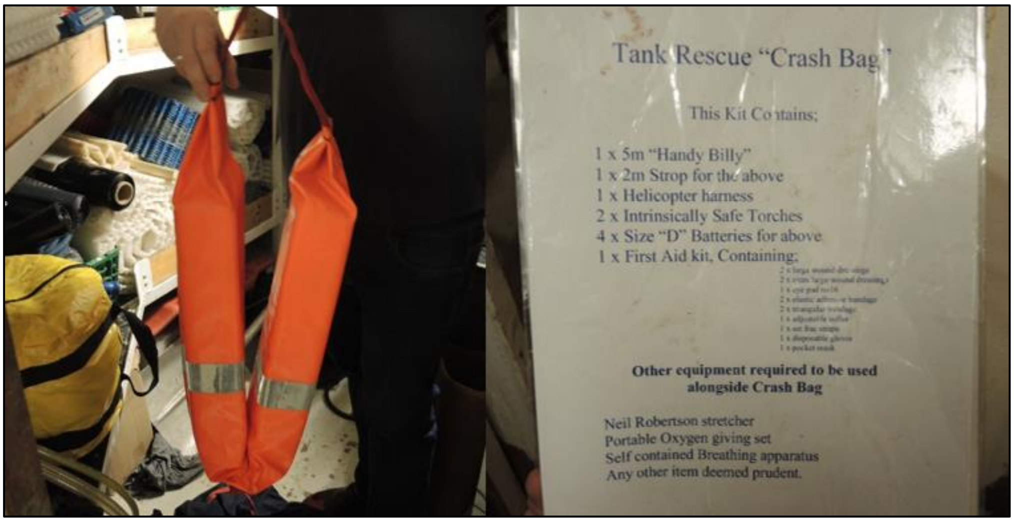

Figure 8: The rescue equipment included a lifting strop. The equipment was kept in a storeroom by the entrance to the forward starboard silage tank. Photo: AIBN

There was no lifting eye in the ceiling above the silage tank's access hatches. On the day of the accident, the crew therefore used extra rope and pipes in the room where the hatches were located to attach the hoisting equipment.

The lifting strop was of a type intended for hoisting persons who are conscious and capable of keeping their arms by their sides. The fact that the person was unconscious made it challenging to securely attach the lifting strop, and it consequently took several attempts for the crew to get him out of the tank. They have also described that the ladder cage complicated the rescue effort.

1.4 Operating conditions

1.4.1 Silage production

1.4.1.1 *Pilot project*

According to the Norwegian Seafood Research Fund,[2] the annual quantity of residual raw material (heads, offal, liver, roe etc.) produced by the Norwegian fishing fleet amounts to more than 200,000 tonnes (white fish). In order to ensure optimal utilisation of fish resources, the shipping company started silage production on board Nordstar through a pilot project in cooperation with other parties.

Hordafor AS was one of the parties that sold and delivered equipment to the shipping company in connection with the silage plant. Hordafor's core activities are handling and processing by-products from the fisheries and aquaculture industries. The company uses specialist vessels to collect silage from fish farms, harvesting plants and fish landing and processing facilities along the entire coast of Norway. Hordafor has stated that it provided information about the risk of gas formation, and that this information was communicated to the shipping company both orally and in writing in a memo on 'safe production of high-quality silage', which was sent to the shipping company in 2017. This memo stated, among other things, that it was important that the shipping company carry out a risk assessment of the plant and maintain good control of tank cleaning and ventilation.

SINTEF Fisheries and Aquaculture was also involved in the project. Among other things, SINTEF was to map HSE conditions as part of the review of the pilot project for ensiling residual raw materials on board Nordstar. According to SINTEF's report, the plant had been assessed with respect to process technology and HSE.

The report also states that the evaluation included:

- A review of the pilot plant on board Nordstar
- An evaluation of the pilot plant (based on the review)
- If relevant, proposing improvements to the pilot and full-scale plant
- HSE assessments

The report makes no mention of issues relating to gas hazards in connection with silage production and storage. According to information from SINTEF, the work focused on its functioning and suitability as a production plant. The HSE assessment did not include the plant's operation.

Nofima and the Norwegian Food Safety Authority also contributed to the project. Nofima is a leading institute for business-oriented research and development for the aquaculture, fisheries and food industries. According to the final report[3] prepared by the shipping company, Nofima had evaluated and analysed silage as a product of the process. The requirements set by the Norwegian Food Safety Authority were also met.

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[2] Norwegian Seafood Research Fund, www.fhf.no
[3] Nordnes report: 'Prosjekt: Pilotanlegg – fullskala ensilasjeproduksjon, 100% utnyttelse av fangsten fra MS Nordstar', dated 17 February 2017.

1.4.1.2 *Work process for silage production*

During the ensiling process, "Helm FS+" (including formic acid) is added to minced fish.[3] The acid initially remains on the surface of the particles, but will penetrate the individual particles with time. The smaller the particles and the better the circulation, the more quickly the acid will penetrate and be distributed in the mixture. The most difficult particles for the acid to penetrate are the bones. As the silage becomes increasingly liquefied, the bones, which are heavy, will start to sink to the bottom of the tank. If they are not preserved all the way through, the bones that have settled at the bottom of the tank can start to rot, and there is a high risk that the whole content of the tank will spoil.[3]

On board Nordstar, fish heads and offal are collected on a conveyor belt. They go through two grinders, one course and one fine, and are collected in a tank in the factory. The fish mass continues down to a tank in the engine room where acid is added. The acid used in silage production is stored in tanks in the forecastle and led down to the factory through pipes. Acid is added until the right pH level has been achieved (3–4% acid).

The silage is circulated between the tank in the engine room and the tank in the factory in a continuous process. When the tanks in the factory and engine room are full, the factory manager checks that the acid level in the mixture is correct before it is pumped to the forward storage tanks. According to the shipping company, no significant changes should occur in the mixture after the mixing process has been completed and the mixture is pumped forward. The shipping company has focused on avoiding 'boiling' in the tanks, a reaction that can occur if too little acid is added. In such case, the tanks will be closed, and ventilation in the forecastle should be sufficient to deal with 'boiling'. If the correct amount of acid is added, the silage should be stable and not rot.

The silage is unloaded via a hose to a tanker at the same time as the frozen cargo is unloaded to a frozen storage facility. The silage produced on board Nordstar will then be processed to make oil and protein concentrate, which are used as ingredients in feed for farmed fish. Figure 9 shows an illustration of a typical silage plant.

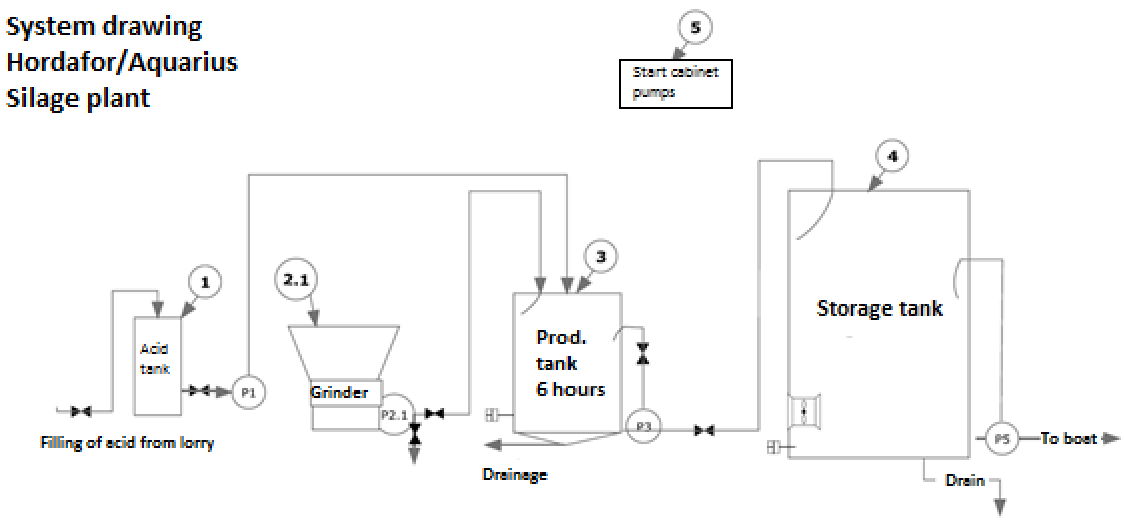

Figure 9: Illustration of a typical silage plant. Source: Hordafor

Silage production takes place more or less all year round, except for the redfish voyage during the summer. After the end of the last voyage, the silage was routinely unloaded to a tanker. The procedure was to then fill the tanks with seawater and empty them a few times. The tanks would then be opened to check whether there was a lot of bone residue left in them, and, if that was the case, the residue would normally be flushed towards the cargo pump to get the tanks as clean as possible before the next voyage.

A cargo pump placed in the pump room between the two aft silage tanks is used to unload cargo from the tanks. The fire-water lines are used to fill the tanks. Both the cargo pump and the fire-water lines have a capacity of 40–50 m^3 per hour.

According to the shipping company, the crew would not normally enter the storage tanks unless special work was to be carried out in them. There were agitators (propellers) in the bottom of the two forward tanks to maintain circulation of the silage, if necessary. The agitators were maintained by the engine crew when necessary.

1.4.1.3 *Use of the silage tanks since the last unloading*

After finishing its last voyage, Nordstar unloaded 205 m^3 of silage to a tanker while moored in Gangstøvika on 3 May 2018. There was some residue left in the tanks after the silage had been unloaded, and probably, as was usual, bones that had settled on the bottom of the tank. A crew starting a new voyage will normally clean the tanks of silage and bone residue before they start producing another batch of silage. No silage was to be produced on the voyage when the accident occurred, so the cleaning of the tanks was not a priority. Attempts had been made in previous years to produce silage from redfish, but they were discontinued because of the problems caused by too many bones in the redfish.

According to the crew, seawater was pumped into the forward starboard tank on 5 May 2018. This was done to use it as a ballast tank to keep the vessel's trim right during the voyage. Seawater was pumped both into and out of the tank during the voyage, but no record was kept of the amounts and times. The access hatch was probably open while the tank was being filled and emptied.

On the day of the accident, the work on flushing the tank started at about 11.00. There is some uncertainty about how much water was in the tank when the process of emptying it began. The figure below shows the assumed water content and times when the tank was filled and emptied. The oxygen content of the atmosphere in the tank was checked approx. 10 minutes after the tank was last emptied. Both the permanent ventilation pipes and the access hatch to the tank remained open throughout the emptying and filling period.

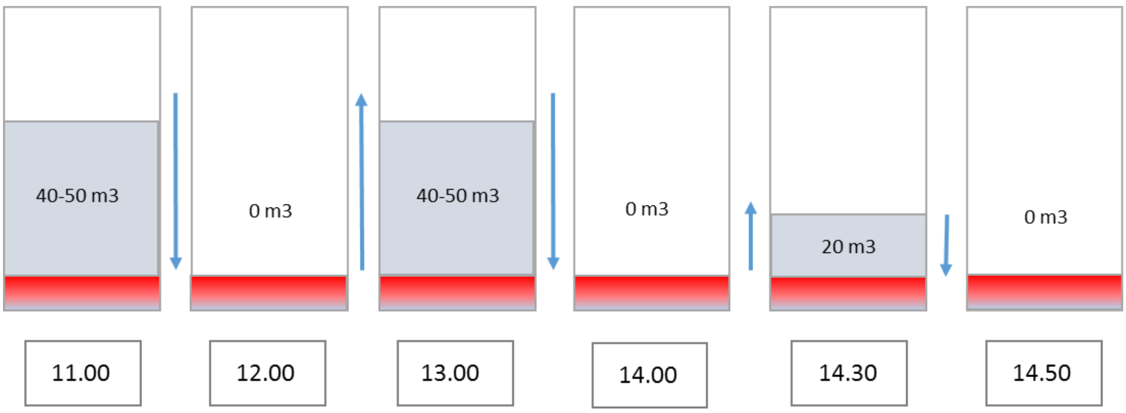

Figure 10: The process of flushing the tank began at 11.00 and was completed at approx. 14.50. Seawater is illustrated in blue and the sediment in red. The illustration is not to scale and gives an indication of the flushing process. Illustration: AIBN

1.4.2 Gas formation in connection with the production and storage of silage

1.4.2.1 *Introduction*

If a decomposition process occurs during the production and storage of silage, this may lead to the formation of gases (CO_2, H_2, H_2S and CH_4) that could represent a threat to the safety of personnel. Based on information received from the shipping company, CO_2 and H_2 were the only gases mentioned as hazards in the shipping company's final report[3] on the pilot project.

1.4.2.2 *Carbon dioxide (CO_2) and hydrogen gas (H_2)*

Carbon dioxide is a non-flammable gas that does not contribute to combustion. Its density is about 1.5 times that of air, so the gas will settle at the bottom of spaces where such gas is formed. Carbon dioxide is formed through aerobic (with O_2) bacterial decomposition of organic compounds, meaning that the oxygen is used up.

Breathing air with a CO_2 content of 4–5% over a prolonged period of time can render people unconscious. A CO_2 content of 8% will cause unconsciousness and death in 30–60 minutes. CO_2 is not toxic as such, but it has an asphyxiating effect because there is not enough oxygen left to breathe.[4]

Hydrogen gas is colourless, odourless and tasteless. It conducts heat more effectively than any other gas. For example, its thermal conductivity is five times higher than that of air. The gas is not soluble in water.[5]

The following is quoted from the final report prepared by the shipping company after the pilot project:

> *The CO_2 gas which is formed during the ensiling of raw material rich in bones can displace oxygen from the tank and give rise to dangerous situations if crew members enter the tanks without an adequate air supply. If the amount of acid is not sufficient in relation to the bone content of the raw material, there is a risk that the pH level will be too high, which increases the risk of the silage 'boiling'.*
>
> …
>
> *There is also a risk that gas, which has been proven to contain hydrogen (H_2), could ignite.*

1.4.2.3 *Hydrogen sulphide (H_2S)*

At room temperature, hydrogen sulphide (H_2S) is a colourless, toxic, flammable gas with a characteristic foul odour of rotten eggs. The odour is volatile and will decrease with high concentrations. The gas is somewhat heavier than air. It is formed by anaerobic (without O_2) bacterial decomposition of organic compounds containing sulphur (bacterial decomposition in an oxygen-poor environment) of, for example, fish and fish waste.[6]

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[4] https://snl.no/karbondioksid
[5] https://snl.no/hydrogen
[6] https://www.kyst.no/article/mikrobiell-kontroll-i-ras-og-utfordringer-ved-bruk-av-sjoevann

1.4.2.4 *Methane (CH_4)*

Methane is formed through anaerobic decomposition of organic material.[7] It is lighter than air and explosive.

1.5 The crew

The crew consisted of 25 persons in all. Some of the fishermen were of Polish or Lithuanian origin, and some crew members did not speak Norwegian.

The master of the vessel had a maritime education and had come up through the ranks on board as a fisherman, factory manager, deck bosun, mate and skipper.

The factory manager was a qualified engineer who had worked on fishing vessels for 17 years (including 15 years with the company) and had been factory manager for 10 years.

The fisherman who died had been working for the company for 9 years. In recent years, he had worked in the company's onshore operations, including on a number of yard stays for the company's vessels, and thus had experience of work in tanks. He started working on Nordstar two and a half weeks before the accident.

The fisherman who witnessed the accident had worked for the company for ten years on other vessels, and was on his second voyage with Nordstar.

The mate had been a permanent employee of the shipping company for 12 years, and for the past five years he had been a mate and skipper on one of the company's other vessels.

The factory supervisor had worked for the company on board Nordstar for 10 years, including 5 years as factory supervisor

1.6 The shipping company

1.6.1 General information

The shipping company Nordnes AS was formed in 1997 and is part of the Nordnes Group. At the time of the accident, the company operated three trawlers: the freezing trawler Nordstar, the trawler Nordbas, and the shrimp trawler/training vessel Vollerosa. The company sold the freezing trawler Nordørn in autumn 2017.

In addition to the fishing vessels, the company also runs its own workshop and a net-mending workshop. The company has approx. 100 employees, comprising fishermen and a small onshore administration. The company have fishing rights for white fish, argentine, redfish and shrimps.

1.6.2 The shipping company's safety management

1.6.2.1 *Introduction*

The shipping company has established a safety management system for Nordstar that is designed to meet the requirements set out in Regulations of 5 September 2014 No 1191

[7] https://www.arbeidstilsynet.no/tema/kjemikalier/ensilasje/

on safety management systems for Norwegian ships and mobile offshore units. The safety management system uses the CCOM platform.

The shipping company's safety management system states that, in order to comply with the above-mentioned regulations and the company's goals, the company wishes, among other things, to focus on:

- Compliance with the applicable regulations, guidelines and standards issued by IMO and other industry organisations, the authorities and classification societies

- Establishing sufficient protective measures against all identified hazards

The following are some of the examples the company provides of functional elements in the safety management system:

- Procedures to identify, assess and minimise all risks that could give rise to hazardous situations, errors and incidents

- Procedures to prepare for and respond to any emergencies

1.6.2.2 *Risk assessments*

According to the safety management system, any work on deck, in the engine room, galley, factory etc. with which a distinct risk is associated is covered by procedures and risk assessments that analyse how the job should be carried out.

The shipping company had carried out and documented risk assessments of several operations on board. Among other things, risk assessments had been carried out of work in the factory, but not of silage production and storage, and the cleaning of tanks.

1.6.2.3 *The procedure 'Work in enclosed spaces'*

The procedure for work in enclosed spaces has undergone minor changes since the accident (text in *italics* indicates updates as of 30 June 2018) and sets out the following requirements:

- The space must be well ventilated *by means of a fan*.
- The atmosphere must be tested and found to be safe.
- Rescue and resuscitation equipment must be easily accessible.
- An attendant must be present at the entrance.
- Sufficient communication must be established between the attendant at the entrance point and the person who enters the space.
- Sufficient lighting.
- Respiratory protective equipment (BA) must be available, tested and found satisfactory.

In addition to this, a checklist for work in enclosed spaces had been prepared ('Entering an enclosed space F/T Nordstar LHXV'). The checklist was to be filled in and signed before work commenced. The following is quoted from the checklist:

> *All double bottom tanks, cofferdams etc. that have been closed for a period shall be considered unsafe. Personnel must never enter these areas until oxygen and, if*

relevant, gas measurements have been carried out. The checklist must be completed and signed before entry. A personal oxygen monitor must always be worn when entering an enclosed space.

The checklist must show which space/tank is to be entered and describe the work to be done. The tasks described in the 'Work in enclosed spaces' procedure are ticked off on the checklist to show that they have been performed. Finally, gas measurements are carried out when necessary, and the oxygen and explosive gas readings must be recorded.

According to the skipper, the intention was that no one would enter the tank until it had been ventilated for 24 hours. The checklist was therefore not filled in before the crew member entered the silage tank.

1.6.2.4 *The procedure 'Work on board'*

Use of personal protective equipment is described in the 'Work on board' procedure. Among other things, the procedure includes information about the vessel's breathing apparatuses. The report states:

It is mandatory to use a breathing apparatus when entering unsecured tanks or other enclosed spaces where there is a possibility of:

- *Lack of oxygen*
- *Toxic gases*
- *During fire-fighting efforts*

Necessary risk assessments must be carried out or repeated as required in connection with work that entails risk. A brief review of the work to be done must be carried out before the work commences. The purpose of such a review is to ensure that the job is understood, including the need to work safely, and that the environment is protected.

It also states that fall protection equipment is mandatory for all work at heights, including when entering silage tanks. The fisherman who entered the tank was not wearing such equipment.

1.6.2.5 *The procedure 'Work in the factory'*

This procedure concerns work in the factory and freezer hold. It points out several concrete factors with a bearing on safety, and dangerous conditions relating to such work are described. The procedure also deals with the use of personal protective equipment. Work on silage production and work in and around the silage tanks are not mentioned.

1.6.2.6 *The procedures 'Rescuing casualties from cargo holds/enclosed spaces'*

A checklist had been prepared for rescuing personnel from cargo holds/enclosed spaces. The list includes several items about notification as well as items about the actual rescue work.

1.6.2.7 *Crew training*

The shipping company has drawn up checklists for reviewing safety instructions for all new personnel. When this review of safety instructions is completed, the crew member must ensure that he/she is fully aware of his/her own responsibilities, company policy, the ship's procedures, and where equipment is located and how it is used. The shipping company has also drawn up a checklist for the training of new fishermen.

The factory manager is responsible for safety in the factory and for ensuring that crew working in the factory have received the necessary training and are competent to carry out the duties assigned to them. The factory manager is also responsible for reviewing the safety and training list for new employees before production starts.

1.6.2.8 *Drills*

Emergency response drills are among the topics covered by the management system's chapter on emergency preparedness. It is pointed out that all crew members must participate in at least one man overboard drill and one fire drill per month. In addition, the skipper is required to organise regular exercises to train the crew in how to deal with engine failure and blackouts, collisions, fires, grounding, evacuation and serious injuries/deaths. Separate checklists have been drawn up for the different types of emergencies.

Nordstar has a checklist for rescuing casualties from cargo holds/enclosed spaces, but no training needs were described. The AIBN has not found any documentation showing that drills have been carried out for entering of tank.

1.7 Relevant rules and regulations

1.7.1 <u>Regulations on the working environment, health and safety of persons working on board ships</u>

The Regulations of 1 January 2005 No. 8 on the working environment, health and safety of persons working on board ships are important when it comes to ensuring that the working environment on board a ship is safe. The Regulations apply to all persons working on board a Norwegian ship, including fishing vessels.

As regards the working environment, in general, and work in enclosed spaces and tanks, in particular, the following is emphasised from the Regulations:

> *Section 11-5 Arrangement and organisation of work, etc.*
>
> *(1) Where a risk to the safety or health of persons working on board is identified, necessary measures to remove or reduce such risk shall be taken before work has begun. Steps shall be taken to ensure, inter alia:*
>
> *a) the availability of written instructions to ensure safe routines for the storage, handling and carriage of chemicals and biological agents on board;*
>
> *b) the use of suitable methods of measurement and measuring equipment that will identify possible chemical exposure risks;*
>
> *c) the availability of necessary protective arrangements and personal protective equipment and that such arrangements and equipment are in good working order and adapted to the working situation in each case*
>
> *d) the implementation of necessary technical control measures;*

e) the availability of first-aid equipment and other equipment to prevent or mitigate injuries to persons working on board in the event of incidents and accidents.

(2) Work in narrow and confined spaces, tanks and similar spaces shall be according to instructions which shall always be reviewed before commencing work. The instructions shall ensure that, inter alia:

a) the oxygen content of the atmosphere is measured before commencing work;

b) there is a person standing guard during the work operation at the entrance of the space and that this person is provided with necessary and approved communication equipment and protective and rescue equipment.

1.7.2 Regulations on a safety management systems for Norwegian ships and mobile offshore units

The Regulations of 5 September 2014 No. 1191 on a safety management system for Norwegian ships and mobile offshore units are also a key piece of legislation. These regulations incorporate the International Safety Management (ISM) Code into Norwegian law. The Regulations applied to Nordstar with effect from 1 January 2016. The following is quoted from the Regulations:

The following is stated in Section 7 Shipboard operations:

The company should establish procedures, plans and instructions, including checklists as appropriate, for key shipboard operations concerning the safety of the personnel, ship and protection of the environment. The various tasks should be defined and assigned to qualified personnel.

1.7.3 The Regulations on fishing vessels of 15 m and upwards

Regulations of 13 June 2000 No 660 on the construction, operation, equipment and surveys of fishing vessels of 15 m in overall length (LOA) and upwards apply to both new and existing fishing vessels unless otherwise specified). Among other things, the Regulations describe requirements for inspections to ascertain gas hazards and safety measures.

The following description of inspections to ascertain gas hazards is quoted from Section 6-13:

(1) Before any person enters tanks, cargo holds, narrow enclosed spaces, tunnels or other spaces presenting a risk of gas or insufficient oxygen, without wearing approved or accepted breathing protection, the necessary checks shall be carried out to ascertain that the air in those spaces is safe. Measurements shall be taken at various heights and repeated measurements shall be taken if necessary.

(2) Vessels engaged in fishing for industrial raw material shall have at least one approved or accepted instrument for measurement of the oxygen content in the air.

Section 6-14 describes how gas-hazardous spaces or spaces presenting a risk of insufficient oxygen are to be marked.

(1) All doors, hatches, manhole covers etc. providing access to gas-hazardous spaces or spaces presenting a risk of insufficient oxygen shall be clearly marked with signs or adhesive notices giving warning of the hazard of gas poisoning or lack of oxygen to which a person may be exposed in the space in question. In places where the sign or adhesive notice can easily be damaged or dirtied the actual hatch, cover or similar shall also be painted in the same colour as the signs. The colour of the warning signs and adhesive notices shall be in accordance with the requirements specified in appendix 4 and have the following Norwegian text:

FARE OKSYGEN MANGEL	(Symbol)	DANGER LACK OF OXYGEN
FARE GIFTIG GASS	(Symbol)	DANGER POISON GAS
FARE EKSPLOSIV ATMOSFÆRE	(Symbol)	DANGER EXPLOSIVE ATMOSPHERE

Section 6-15 describes safety measures in connection with inspections, work etc. It reads as follows:

(1) Work in cargo holds, tanks or other spaces presenting a risk of poisoning or lack of oxygen is permitted only on the condition that an approved or accepted self-contained breathing apparatus is used. Such spaces shall be thoroughly ventilated before work is started in them, and larger spaces shall be provided with mechanical ventilation. There shall be continuous ventilation while work is in progress.

(2) Special caution shall be shown when entering a tank or cargo hold in connection with the delivery of raw fish materials to factories, and during cleaning of such spaces. Special caution shall also be shown when entering unventilated tanks or spaces which have been closed or which have considerable rust formation.

(3) While inspection or work is in progress in tanks and spaces referred to in paragraphs (1) and (2) the oxygen content and any gas concentration shall be measured at short intervals. The work or inspection shall be supervised by two persons, one of whom shall have easy access to a self-contained breathing apparatus and be trained in its use.

1.7.4 Requirements for work in tanks for shore-based undertakings

Undertakings subject to the Norwegian Labour Inspection Authority's supervision must meet the requirements set out in the following regulations.

Regulations of 6 December 2011 No 1357 concerning the performance of work, use of work equipment and related technical requirements – Chapter 29: Work in or on tanks, pipelines, rooms etc. where flammable products or hazardous substances could be present.

Regulations of 6 December 2011 No 1360 concerning administrative arrangements within the area of application of the Working Environment Act, Section 11-1: Registration of inspectors that issue work certificates.

The Act of 17 June 2005 No 62 relating to the working environment, working hours and employment protection etc. Section 3-2(1) letter c) on expert assistance when necessary in order to implement the requirements of the Act.

The following is quoted from the Norwegian Labour Inspection Authority's website:[8]

> *Inspections may only be conducted by a competent person who has received special training for the task. A competent person is a skilled chemist or other person who*
>
> - *has the required general technical and chemical knowledge*
> - *is familiar with the most important physical and chemical properties of flammable goods and substances hazardous to health*
> - *has the required practical experience of using measuring equipment and performing relevant gas measurements*
> - *has sufficient practical experience and experience from the type of undertaking in question and knowledge of the structure in question and its design*
>
> *The inspector shall:*
>
> - *conduct inspections and necessary measurements*
> - *issue work certificates to workers when the working atmosphere is safe*
>
> *The employer must notify the Norwegian Labour Inspection Authority about who fills the function of inspector at all times.*
>
> *The employer must obtain a work certificate for any work carried out, including cleaning and other preparatory and subsequent tasks.*
>
> *Once the working atmosphere is deemed to be safe, it is the inspector who issues the work certificate permitting the work to be carried out. The work certificate must be posted in a clearly visible location near the work site.*
>
> *The work certificate must contain the following information:*
>
> - *Information about the previous content of the structure*
> - *What work is permitted*
> - *Where the work is permitted*
> - *Which special safety measures are required*
>
> *The inspector must also assess how often new inspections should be carried out and which measures must be implemented.*

1.8 Supervision of the shipping company and vessel

The Norwegian Maritime Authority (NMA) conducted a first-time audit of Nordstar's safety management system in January 2017, followed by a supplementary audit in June 2017 to follow up non-conformities noted in January that year. The first-time audit was partly carried out as interviews on board the vessel and partly as a review of safety

[8] https://www.arbeidstilsynet.no/tema/arbeid-i-tank/

management system documents. The NMA's established checklists[9] were used in the review of the safety management system during the audit.

Among other things, the audit report states that the general impression was that the crew on board the vessel had a strong focus on safety. It goes on to say that there was a particular potential for improvement in '*helping to ensure that the safety management system is in accordance with the shipboard operations and regulatory requirements*'. It also states that the shipping company should '*focus on procedures, plans and instructions and, if relevant, checklists for key shipboard operations as regards the safety of the vessel and personnel and environmental protection, and that such tasks should be defined and assigned to qualified personnel, including an understanding of risk mapping and assessment, as well as risk-reduction measures*'.

The report describes the shipowner's and master's responsibility for ensuring that the safety system complies with the requirements of the ISM Code, although the Authority verifies that the ISM Code requirements are largely met.

The audit did not identify any particular shortcomings relating to ISM Code Section 7 'Shipboard operations' or shortcomings in procedures and/or risk assessments relating to the storage and production of silage. The audit report nevertheless contains a comment that the system should be adapted to the vessel and its operations.

The vessel's most recent safety management certificate was issued in January 2017.

The NMA published an article on hazardous unloading operations on its website in autumn 2019 (after the accident) in which silage tanks were a topic. The article described chemical health hazards associated with the gases that can form, and pointed out, among other things, the importance of taking measurements before entering tanks and ensuring good evacuation possibilities and holding drills in how to carry out an evacuation.

1.9 Medical factors

1.9.1 Post-mortem examination of the deceased

According to the post-mortem report, the injuries of the deceased were consistent with the sequence of events and the rescue operation. The cause of death was found to be asphyxiation due to lack of oxygen.

1.9.2 Physiological effects of reduced oxygen levels in the atmosphere

A normal atmosphere will contain approximately 20.9% oxygen. In general, lack of oxygen leads to impairment of mental functions, impaired judgement and reduced task performance. This occurs in a short space of time, and without the person being aware of it.

Table 1 shows the effects of O_2 deficient atmospheres on individuals. The values in the table are approximate and can vary from person to person. Exposure to an atmosphere

[9] KS-1250B Sjekkliste – Sertifikat for sikkerhetsstyringssystem Fartøy – Obligatorisk and KS-1251B Sjekkliste – SMC utvidet sjekkliste ISM fartøy

containing less than 18% oxygen poses a risk, and there is a risk of death at oxygen concentrations of less than 11%.

Table 1: Asphyxia – effect of oxygen concentration.[10]

Asphyxia – Effect of O_2 Concentration	
O_2 (volume %)	Effects and symptoms
18–21	No discernible symptoms in the individual.
11–18	Reduction of physical and intellectual performance without the sufferer being aware of this.
8–11	Possibility of fainting within a few minutes without prior warning. Risk of death at concentrations below 11% by volume.
6–8	Fainting occurs after a short time. Resuscitation possible if carried out immediately
0–6	Fainting almost immediately. Brain damage may occur, even if rescued.

1.9.3 Hazards associated with residues of organic material

Hydrogen sulphide is one of the gases that can be formed during bacterial decomposition of fish waste etc. in an oxygen-depleted environment.

According to the Norwegian Electronic Health Library's website Helsebiblioteket.no, H_2S has a characteristic smell of rotten eggs that gradually decreases at concentrations of more than approx. 150 ppm. Toxic doses are shown in Table 2. The sense of smell is paralysed from concentrations of between 20 and 100 ppm.

Table 2: Toxic concentrations of hydrogen sulphide. Source: Helsebiblioteket.no

Toxic concentrations of H_2S	
Concentration	Effect
From 1–5 ppm	Local irritation of the eyes, skin and the mucous membranes in the mouth, throat and nose. May cause coughing and breathing difficulties.
From approx. 50 ppm	Risk of pulmonary oedema, neurotoxic signs and symptoms, respiratory failure.
Approx. 500 ppm	Severe eye and lung damage. Loss of consciousness and death within 30–60 minutes.
Approx. 1,000 ppm	Respiratory arrest and collapse within 1–2 breaths.

1.10 Relevant previous accidents

1.10.1 Introduction

Relevant previous accidents are described in this chapter.

1.10.2 Work accident on board Star Ismene

On 16 December 2008, an accident occurred on board the cargo ship Star Ismene while the ship lay at anchor in Nantong, China. During measuring of the fuel and ballast tank levels, two crew members lay unconscious on a platform leading down to one of the

[10] Source: University of Oxford http://www.admin.ox.ac.uk/safety/s403.shtml.

cargo holds. Readings taken following the accident showed an oxygen content of 5.9% in the room where the accident occurred.

The AIBN made four safety recommendations following this investigation, two of which are deemed to be of relevance to this accident.

Safety recommendation MARINE No 2010/29T

The AIBN recommends that the shipping company review its safety management system so that it can be adapted to each specific ship. This could include risk analyses on the basis of the design. Based on the risk analyses, it should be considered whether the design needs to be changed or whether operating procedures and other measures can be introduced to ensure the safety of the crew.

Safety recommendation MARINE No 2010/31T

The AIBN recommends that Det Norske Veritas consider the process whereby it issues and verifies ISM certificates with a view to identifying and implementing measures that will put DNV, as the supervisory authority, in a better position to identify non-conformities with the requirement that safety management systems shall be adapted to each individual shipping company and ship.

1.10.3 Work accident on board Solstraum

On 4 February 2011, a work accident occurred on board the chemical tanker Solstraum. During tank cleaning work while the ship was sailing to Rotterdam, the pumpman died when he entered one of the cargo tanks before it had been cleaned and ventilated. Nitrogen had been introduced to the cargo tanks in question as an inert gas in connection with the transport of ethylene dichloride (1,2-dichloroethane), and the cargo had been unloaded earlier that day. At the time of the accident, the oxygen content of the atmosphere at the bottom of the tank was probably less than 7%, and the AIBN assumed that the pumpman died as a result of lack of oxygen.

The investigation identified underlying safety problems relating to failure to comply with the procedures in the safety management system. The deceased pumpman who entered the cargo tank without complying with the procedures for entering an enclosed space was not the only example. On the voyage in question, the procedures for conducting a pre-arrival conference, the procedures for holding a tank cleaning meeting and the procedures for logging nitrogen inerting were not complied with.

Based on the shipping company's follow-up after the accident, the AIBN did not deem it necessary to make any safety recommendations.

1.10.4 Work accident on board Key Fighter

On 1 September 2018, a work accident occurred on board the oil/chemical tanker Key Fighter, which was registered in Malta and en route from Averøy in Norway to Erith in the UK. Two crew members involved in cleaning a cargo tank died after falling inside a tank. The tank’s content, a mixture of tank wash water and vegetable oil, had been pumped out at sea before the crew members entered the tank. While the content was being loaded, several crew members had noticed a smell of ‘rotten eggs’. The post-mortem report could not confirm the presence of H_2S. The injuries sustained in the fall were fatal, but, considering other circumstances relating to the accident, the report did not exclude the possibility that the cause of death could have been H_2S poisoning or asphyxiation due to lack of oxygen.

The investigation uncovered the following, among other things:

- Inadequate knowledge of the content of the tank.
- No pre-cleaning meeting was held, and it is likely that monitoring of the atmosphere in the tank during the cleaning process was not raised during the toolbox talk.
- There was no effective supervision of the cargo tank cleaning and ventilation operations. There was no continuous atmosphere monitoring for toxic gas.
- The crew members who died had not signed the risk assessment document.
- The cargo tank entry permit was not signed by everyone who was supposed to sign it.
- The crew members who entered the tank were not wearing personal gas detectors.

Based on the shipping company's follow-up after the accident, which included more frequent visits on board by company representatives to observe and discuss shipboard operations, providing additional training for crew members, analysing all the ship’s procedures and holding crew conferences on board for the purpose of improving safety, the Maltese Marine Safety Investigation Unit did not propose any safety recommendations.

1.11 Measures implemented

The shipping company has informed the AIBN that several measures have been implemented as a result of the accident. They are as follows:

- Two new gas detectors for measuring O_2, H_2S, LEL, and CO have been acquired.
- The procedure and checklists for tank entry have been revised. The company has obtained an entry procedure from a tank entry provider and compared it with the company's own procedure. Improved checklist “Entering of enclosed space”, were among others the skipper or another officer shall review the checklist with the person who is to enter a tank and sign it.
- Developed and implemented “Checklist for opening of hatches to enclosed spaces”
- A risk assessment has been carried out of the silage production. It describes the risks associated with the storage tanks and the risk-reduction measures implemented by the shipping company.
- A procedure for cleaning silage tanks has been drawn up. Among other things, it describes how to fill the tanks in preparation for cleaning. The procedure also describes hazardous conditions that can arise in the tank, and it refers to both the procedure and the checklist for entering an enclosed space. Reference is also made to a separate risk assessment for silage production. Among other things, it states that fans should not be lowered into tanks due to the risk of explosion.

- The tank cleaning procedures have been amended. The tanks must always be cleaned after unloading, regardless of whether or not silage is to be produced on the next voyage.

- Better and more informative signs on tanks about the risk of gas forming in the tank.

- The shipping company has purchased fall protection equipment adapted for tank rescue, and equipment to enable more efficient rescues from tanks. It is also stated in the risk assessment that everyone who enters the silage tanks must wear fall protection equipment.

- Theoretical drills in using the rescue equipment have been included in the management system and will be carried out on a regular basis.

- Supplied-air respirators with a constant air supply have been procured and are deemed to be considerably better suited to use in confined spaces than oxygen cylinders.

- Padlocks have been fitted on all the silage tanks, and the keys are kept on the bridge and must be collected there for it to be possible to open the silage tank hatches.

- Maintenance and control of new equipment must be registered in the safety management system CCOM.

- Extra safety meetings including a review of all implemented changes/measures have been held for both shifts.

2. ANALYSIS

2.1 Introduction

The analysis consist of an assessment of the sequence of events relating to entering the silage tank in connection with tank cleaning. The shipowners' safety management and risk control will then be considered in more detail. Knowledge of the hazards of gas formation in connection with the storage and production of silage, procedures for entering tanks and emergency preparedness for accidents in tanks will be discussed in this section. Finally, the role played by other parties in connection with the pilot silage production project on board the vessel will be discussed.

2.2 The sequence of events relating to entering the tank

2.2.1 Preparations for cleaning and entering the tank

The skipper had instructed the factory supervisor to prepare the silage tanks for cleaning. This meant flushing the tanks by filling them with seawater and emptying them several times, before lowering a fan into the tank to blow in fresh air and lead air out of the tank via the attached plastic hose.

The fisherman, who was wearing a personal oxygen detector, decided to enter the tank to set up the fan, since the O_2 measurement did not show that there was insufficient oxygen inside the tank. The fisherman probably knew too little about the risk of hazardous gas forming in the tank over time. The silage tanks were normally cleaned by the crew departing on a new voyage, which meant that it was not normal for silage and bone residue to remain in the tanks over time. However, since they were not going to produce silage on the voyage in question, the tanks had not been cleaned prior to departure. Risks associated with the decomposition of silage and bone residue in the tanks, and thereby the formation of hazardous gases such as hydrogen sulphide and methane, were therefore not something Nordstar's crew had experience of.

The fisherman who entered the tank took an O_2 detector with him, but no alarm was triggered while he was descending the ladder. As the tanks had been flushed several times just before he entered the tank, the oxygen level in the tank above the ensilage residue was probably within acceptable O_2 limits.

The detector that was used only measured the level of oxygen, not other gases. It was therefore not possible for the fisherman to determine whether the atmosphere was safe, which the shipping company’s procedures (ref. Chapter 1.6.2.3) state should be ascertained before entering a tank.

When the fisherman stepped down into the silage residue in the tank, he shouted that there was no air and attempted to make his way back up the ladder. On his way up, he fell backwards and ended up lying in the silage residue at the bottom of the tank. The silage residue had been there for more than a month, and it is highly likely that a decomposition process had produced methane and hydrogen sulphide gas. This happens when bacteria use sulphate from seawater to break down organic material.

Methane is a light gas. Since the top of the tank had open ventilation to above deck, the methane gas was probably diluted in the atmosphere above the water level inside the tank and disappeared through the ventilation. Hydrogen sulphide is a heavy gas, and has probably settled on the water's surface, gradually displacing the oxygen in the air.

Because the tanks were not completely filled up with seawater, the free H_2S gas that settled on top of the seawater did not disappear, see the illustration of the possible tank atmosphere conditions in Figure 11. Since H_2S gas is heavier than air, it is also likely to have remained encapsulated in the silage residue. It is also probable that, when the fisherman stepped down into the bottom of the tank, the pockets of H_2S gas in the silage residue were released, rapidly exposing him to the gas.

The decomposition process has most likely taken place over a long period from May to June, and a high concentration of H_2S has probably developed in the silage residue. This probably caused immediately fatal exposure. The crew that went down the tank during the rescue operation wore breathing apparatuses.

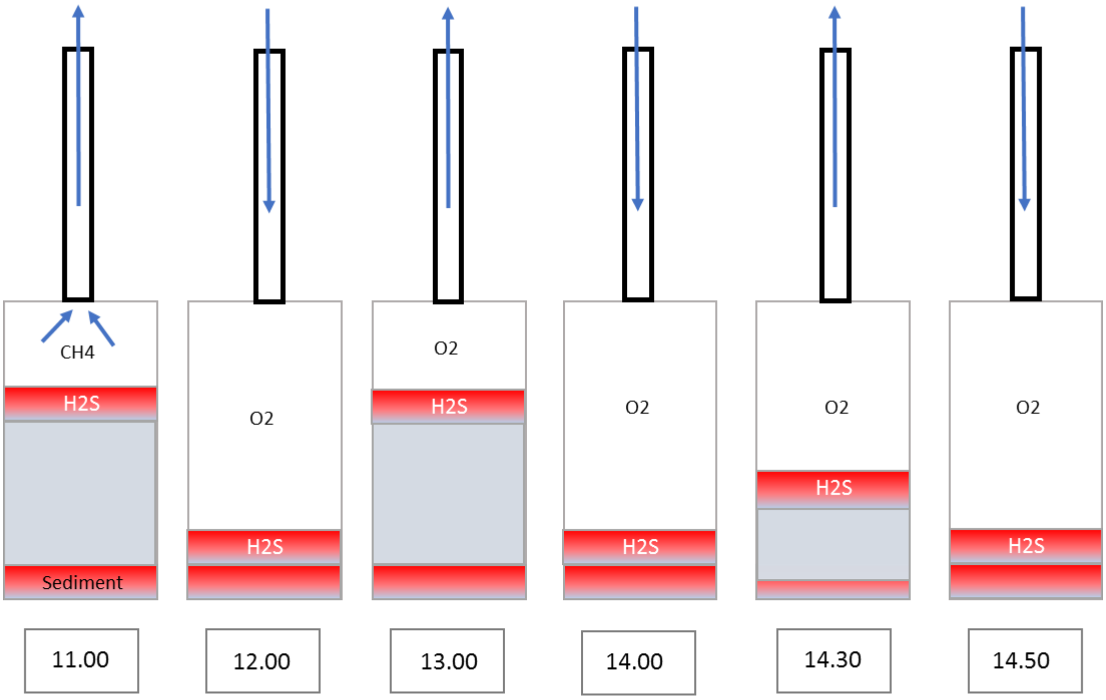

Figure 11: Illustration of possible tank atmosphere conditions during the flushing process. The illustration is not to scale and gives an indication of the probable tank atmosphere conditions. Illustration: AIBN

2.3 The shipping company’s safety management

2.3.1 Inadequate knowledge of the danger of gas forming in connection with silage production

The investigation has shown that the risk of gas being formed during the production and storage of silage had not been identified as a hazard in the shipping company's safety management system. Neither risk assessments nor checklists or operating procedures made any mention of the hazards associated with gas formation. The hatches to the silage tanks were marked ‘Danger – lack of oxygen’, but not as a gas hazard.

This resulted in a situation where personnel carrying out work on storage tanks and those responsible for approving such work were unaware of the potential risks they were exposed to. The crew therefore did not have the information required to determine which measures and precautions were necessary to ensure that there were no hazardous gases in the storage tanks when work was to be carried out inside them.

Following the accident, Nordstar has conducted a risk assessment of the silage production, also including factors relating to the hazards that work in storage tanks entails. A procedure for cleaning silage tanks has been added to the safety management system, and the checklist for tank entry has been updated. The shipping company has also stated that information about the risks associated with silage production and storage will be covered at regular safety meetings on board the vessel. The tanks are now secured by padlocks, the keys to which are kept on the bridge. In addition, the tanks are marked with warnings of gas hazards in the tank.

The AIBN sees no particular reason to submit a safety recommendation to the company for the above circumstances, as this is expected to be followed up in connection with future supervisory activities.

2.3.2 Procedures for cleaning and entering silage tanks

This was the first voyage during which Nordstar was not going to produce silage because they were fishing for redfish. Therefore, cleaning the tanks, as was normally done before every voyage, was not a priority.

The skipper had communicated to the factory supervisor how he envisaged that the flushing and preparation of the tanks for cleaning was to be done. This was communicated orally to the factory supervisor, and when the factory supervisor's watch ended, he told the factory manager that work remained to be done. There were no documented risk assessments and/or work procedures for cleaning the silage tanks.

The sequence of events shows that several things were unclear to the crew members who were to carry out the work. The crew had different ideas about how the tanks should be flushed to get rid of as much of the silage residue and potentially hazardous gases as possible. They also had different perceptions of how the tanks were to be ventilated and when they were safe to enter.

However, Nordstar did have a work procedure for work in enclosed spaces, which stated that the ‘the space must be well ventilated’ and that ‘the atmosphere must be tested and found to be safe’. The shipping company had also prepared a checklist that was to be filled in and signed before anybody entered an enclosed space. This checklist was not filled in on the day of the accident, since no work inside the tank was planned. The fact that the fisherman nevertheless entered the tank, suggests that he did not know much about the checklist and the procedure for work in enclosed spaces or the dangers of entering a tank. Other misunderstandings may also have contributed to him believing that it was safe to enter the tank, even though the purpose of entering the tank was to put a fan in place to ventilate it.

As mentioned above, since the accident, the shipping company has adopted a procedure for ‘cleaning of silage tanks’ and conducted a risk assessment for silage production. Among other things, it provides a step-by-step description of how the tanks are to be flushed and which preparations must be done before cleaning, including how ventilation should take place, and it states that fans should not be placed inside the tank due to the risk of explosion.

Before the fisherman entered the tank, O_2 readings were taken inside the tank by lowering a detector on a string. The shipping company had no equipment on board for detecting other gases, and it was therefore not possible for the crew to check whether the atmosphere in the tank was explosive or toxic gases were present. This means that it was not possible for the crew to comply with the requirements in the procedure for work in enclosed spaces to ensure that the atmosphere was tested and found to be safe. Since the accident, the shipping company has acquired new gas detectors that measure H_2S, O_2, LEL (Lower Explosive Limit) and CO. It has also updated the checklist for entering an enclosed space to include checkpoints for corresponding gas measurements.

The shipping company’s procedure for work on board includes a description of the requirements that apply to the use of personal protective equipment. It states that it is mandatory to use a breathing apparatus when entering unsecured tanks. It also points out that risk assessments/safe job analyses must be carried out as necessary in connection with work that entails risk.

The AIBN has not been able to clarify why the deceased did not use a breathing apparatus when entering the tank, but assumes that he was not aware of the gas hazard and that the satisfactory O_2 reading may have given him a sense of security. The new procedure for cleaning silage tanks describes hazardous conditions associated with the work operation, and it contains a clearer description of what personal protective equipment and measures are necessary.

The shipping company has informed the AIBN that it has changed its procedures so that, every time silage has been unloaded, the tanks are to be cleaned before the vessel's next voyage, regardless of what it will be fishing for.

Based on the above, the AIBN does not make any safety recommendations aimed at the shipping company.

2.4 Survival aspects and the shipping company's emergency preparedness

The colleague who saw the fisherman fall and remain lying inside the tank notified the factory manager. The demanding job of getting the fisherman up from the tank then started. It was somewhat unclear where the rescue equipment was located, and initially alternative solutions to try to hoist the casualty up was used. The rescue equipment, which included a ‘helicopter harness’, was subsequently used, but the lack of equipment and adaptation gave rise to several challenges:

- The absence of a lifting eye in the ceiling above the access hatches to the silage tanks made it challenging to fasten the hoisting equipment.
- It was difficult to fasten the lifting strop to an unconscious person.
- The ladder cage was an obstacle to rapid rescue and evacuation of the casualty.

The AIBN believes that the crew worked as efficiently as possible under the circumstances. However, the incident showed that it was somewhat unclear where the rescue equipment was stored and they did not have much training in how to use the equipment available on board to retrieve personnel from a tank. It also turned out that the rescue equipment on board was not adapted to rescuing personnel from a tank in an efficient manner.

Following the accident, the shipping company has acquired adapted rescue equipment that is stored beside the access hatches, and regular drills have been included in the company's maintenance and control system. The shipping company has also acquired breathing apparatuses with constant airflow, as they are considered to be better suited to work in confined spaces than oxygen cylinders.

Based on the shipping company’s follow-up of emergency preparedness on board the vessel, the AIBN sees no need to submit safety recommendations on this point.

2.5 Safety in the transition from design and construction to the operating phase

2.5.1 Introduction

Several parties were involved in the pilot project. Pursuant to the regulatory framework, the shipping company has a clear responsibility to control risks associated with the production and operation of a silage plant on board the company's own vessel. They nevertheless expected the other parties to help them by providing the necessary knowledge about the hazards associated with the plant, since the company was new to this type of activity. However, the investigation has shown that knowledge about the hazards associated with the formation of gas when fish waste/silage decomposes was not transferred in an effective manner to the shipping company, and nor were they identified by the shipping company or the supervisory authority (the Norwegian Maritime Authority) during the operating phase. This is elaborated on below.

2.5.2 The roles of the parties

Hordafor had mentioned hazards associated with the formation of gas in a memo to the shipping company, but the memo did not go into any detail about which gases could be formed, how they were formed and what measures could be implemented to prevent the formation of gas. The fact that the shipping company did not have any particular expertise about the atmosphere in silage tanks probably also contributed to the company not being able to identify the concrete hazards that the work process entailed.

SINTEF conducted an HSE survey, but since the survey, according to SINTEF, did not cover operation of the plant, the risk of gas formation was not identified in SINTEF's report either. The fact that the risk of gas formation was not mentioned in SINTEF's report may have resulted in the shipping company not understanding that there were hazards that the company had to take account of and identify itself.

The investigation has thus shown that the shipping company's expectations that other parties would assist by providing detailed information about the hazards associated with silage production and work in the tanks was not in agreement with the parties' own understanding of their role in the project. This resulted in risks associated with the production and storage of silage not being identified or taken into consideration in the plant's operation.

The NMA audited the shipping company's and the ship's safety management on board Nordstar after the vessel had been modified, without uncovering that the management system did not cover the operational hazards that accompany silage production and storage. Based on these audits, the shipping company and ship were issued with certificates that verified that the safety management system had been found to be in accordance with the requirements of the ISM Code, even though the system was not sufficiently ship-specific as regards silage production and storage.

The AIBN would like to mention that, in autumn 2019, the NMA published an article on its website about hazardous unloading operations and entering tanks containing fish raw materials.

The AIBN refers to section 1.7.4 of the article, which describes what land-based undertakings must do to safeguard life and health in connection with work in tanks. The regulatory framework that applies at sea has no corresponding provisions.

The requirement for a safety management system (ISM) for fishing vessels with a gross tonnage of more than 500 tonnes was introduced in 2016, and the NMA has stated that extensive resources have gone into implementing it in the different shipping companies. However, the supervisory process for ISM for this group of vessels appears to still have been under development at the time of the accident, and the process is still a work in progress. The AIBN regards the supervisory process for this group of vessels as a work in progress, and expects it to become more capable of detecting such non-conformities in safety management systems in future.

The AIBN therefore submits no safety recommendations to the NMA in this connection.

3. CONCLUSION

3.1 The sequence of events, operational and technical factors

a) The crew had different understandings of how to prepare for tank cleaning, with respect to both flushing and ventilation of the tank.

b) The fisherman, who was wearing a personal oxygen detector, decided to enter the tank to set up the fan, since the O_2 measurement did not show that there was insufficient oxygen inside the tank. The fisherman probably knew too little about the risk of hazardous gas being present in the silage tanks.

c) The available detector only measured the level of oxygen, not other gases. It was therefore not possible for the deceased to determine whether the atmosphere was safe, as the shipping company's procedures state should be ascertained before entering a tank.

d) Since no work inside the tank had been agreed in advance, the checklist for entering an enclosed space had not been filled in and reviewed before tank entry.

e) The fisherman was probably very quickly exposed to toxic hydrogen sulphide gas as he climbed down to the bottom of the tank. This probably lead to immediately fatal exposure.

f) Extensive efforts were required to get the fisherman up from the tank, and challenges were encountered relating to the availability of suitable equipment, a lack of hoisting equipment, and getting the fisherman up past the ladder cage.

3.2 Organisational and systemic factors

a) The risk of gas being formed during the production and storage of silage had not been identified as a hazard in the shipping company's safety management system. The hazards associated with gas formation were not mentioned in risk assessments, checklists or work procedures. This contributed to a situation where personnel carrying out work on storage tanks and those responsible for approving such work were unaware of the potential risks to which they were exposed.

b) The shipping company lacked a work procedure for silage tank cleaning and guidelines for when tanks were to be cleaned after unloading.

c) The shipping company had not put up signs warning of a potential gas hazard related to the tank content, and there was no detection equipment for hazardous gases.

d) The crew lacked sufficient emergency preparedness training and training in how to rescue people from a tank. It was somewhat unclear where the rescue equipment was located, and nor was the equipment adapted to enabling the efficient rescue of personnel from a tank.

e) Knowledge of the hazards associated with the formation of gas when fish waste/silage decomposes was not transferred in an effective manner from the other parties in the pilot project to the shipping company, and nor were they identified by the shipping company or the supervisory authority (the Norwegian Maritime Authority) during the operating phase.

f) The shipping company's expectations that other parties would assist by providing detailed information about the hazards associated with silage production and work in tanks was not in agreement with the parties’ own understanding of their role in the project. This resulted in risks associated with the production and storage of silage not being identified or taken into consideration in the plant's operation.

g) Nor did the NMA's audit detect that the operational hazards associated with silage production and storage were not mentioned in either the shipping company's or in the vessel’s safety management system.

4. SAFETY RECOMMENDATIONS

The investigation of the accident on board the Nordstar on 10 June 2018 has not identified new areas in which the Accident Investigation Board Norway deems it necessary to propose safety recommendations for the purpose of improving safety at sea.

Accident Investigation Board Norway

Lillestrøm, 26 March 2020

DETAILS OF THE VESSEL AND THE ACCIDENT

Vessel	
Name	Nordstar
Flag state	Norway
Classification society	DNV
IMO Number/Call signal	6920111/LHXV
Type	Trawler
Build year	1969
Owner	Nordnes AS
Operator / Responsible for ISM	Nordnes AS
Construction material	Steel
Length	75.5
Gross tonnage	2053
The voyage	
Destination port	Ålesund
Type of voyage	International
Cargo	Fish
Persons on board	25
Information about the accident	
Date and time	10 June 2018 13:00 UTC
Type of accident	Fatal accident. Entering an enclosed space.
Location/position where the accident occurred	International waters south of Iceland
Place on board where the accident occurred	Silage tank
Deaths	1
Ship operation	Preparation for tank cleaning
At what point in the voyage was the vessel	Under way