Investigation report

D14/2008M

Loss of consciousness by two persons in the cargo tank of a tanker on 4 Nov 2008

Translation of the original Finnish report

Onnettomuustutkintakeskus
Centralen för undersökning av olyckor
Accident Investigation Board

Osoite / Address:	Sörnäisten rantatie 33 C FIN-00500 HELSINKI	**Adress:**	Sörnäs strandväg 33 C 00500 HELSINGFORS

Puhelin / Telefon: (09) 1606 7643
Telephone: +358 9 1606 7643

Fax: (09) 1606 7811
Fax: +358 9 1606 7811

Sähköposti: onnettomuustutkinta@om.fi tai etunimi.sukunimi@om.fi
E-post: onnettomuustutkinta@om.fi eller förnamn.släktnamn@om.fi
Email: onnettomuustutkinta@om.fi or first name.last name@om.fi

Internet: www.onnettomuustutkinta.fi

Henkilöstö / Personal / Personnel:

Johtaja / Direktör / Director	Tuomo Karppinen
Hallintopäällikkö / Förvaltningsdirektör / Administrative Director	Pirjo Valkama-Joutsen
Osastosihteeri / Avdelningssekreterare / Assistant	Sini Järvi
Toimistosihteeri / Byråsekreterare / Assistant	Leena Leskelä
Ilmailuonnettomuudet / Flygolyckor / Aviation accidents	
Johtava tutkija / Ledande utredare / Chief Air Accident Investigator	Hannu Melaranta (leave of absence) substitute Markus Bergman
Erikoistutkija / Utredare / Air Accident Investigator	Tii-Maria Siitonen
Raideliikenneonnettomuudet / Spårtrafikolyckor / Rail accidents	
Johtava tutkija / Ledande utredare / Chief Rail Accident Investigator	Esko Värttiö
Erikoistutkija / Utredare / Rail Accident Investigator	Reijo Mynttinen
Vesiliikenneonnettomuudet / Sjöfartsolyckor / Marine accidents	
Johtava tutkija / Ledande utredare / Chief Marine Accident Investigator	Martti Heikkilä
Erikoistutkija / Utredare / Marine Accident Investigator	Risto Repo
Muut onnettomuudet / Övriga olyckor / Other accidents	
Johtava tutkija / Ledande utredare / Chief Accident Investigator	Kai Valonen

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SUMMARY

After tank cleaning on a tanker on 4 Nov 2008, the crew was finalising the tanks for the next cargo. Two deck hands went into a cargo tank in order to sweep the bottom and drain the cargo pump well. At about 10.10 one of them alerted the watchman at the hatch by walkie-talkie and reported that the other had lost consciousness at the tank bottom. Shortly after this he also lost his consciousness. Both crew members were rescued from the tank by efficient crew action.

As a conclusion it can be mentioned that no definite and clear reason or causal connection was found. The MSDS of the 2-Ethylhexyl nitrate did not contain enough information. The investigation did prove that the actions of the crew were in accordance with their present knowledge and instructions. The company investigation brought up some deficiencies in the procedures, thus some internal recommendations were issued by the investigators. Insufficient ventilation and washing could be some of the contributing factors. According to the investigator, more attention should be paid on ventilation.

ABBREVIATIONS

EEBD	Emergency escape breathing device
IMO	International Maritime Organisation
ISGOTT	International Safety Guide for OIL Tankers and Terminals (prepared by the Oil Companies International Marine Forum, OCIMF)
LEL	Lower explosion limit
MAIIF	Marine Accident Investigation International Forum
MSDS	Material safety data sheet
PPM	Parts per million
O_2	Oxygen
HC	Hydrocarbon
CO	Carbon monoxide
H_2S	Hydrogen sulphide

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INTRODUCTION

The Accident Investigation Board Finland was informed of this work accident in an enclosed space in spring 2009, and a Maritime Accident Investigator from the Accident Investigation Board contacted the shipping company for initial oral information on the incident. The shipping company stated that the incident would be investigated in compliance with the company's Safety Management System. The shipping company's extensive investigation report was submitted to the Accident Investigation Board.

Prerequisites for working in an enclosed space include safety measures planned in advance and adequate ventilation in the enclosed space. Work in an enclosed space commonly takes place on vessels of nearly all types, which is why the Accident Investigation Board considers that making this incident public is relevant to public safety.

In late summer 2009, the Accident Investigation Board was given permission by the shipping company to tap on their report to draw up an investigation report in the Board's own format. The investigation report is mainly based on the internal report drawn up by the shipping company's internal investigators. Additionally, the shipping company made a tank ventilation study commissioned by it available to the investigators. Appendix 3.

The Marine Accident Investigators International Forum MAIIF has investigated 101 accidents in enclosed spaces, in which 93 people have lost their lives and 96 been injured since 1997. 25 of these accidents took place on tankers. This report was submitted to the International Maritime Organisation IMO's DSC Sub-committee (Dangerous goods, Solid cargoes and Containers), Appendix 2.

1 EVENTS AND INVESTIGATIONS

1.1 Chemical / product tanker

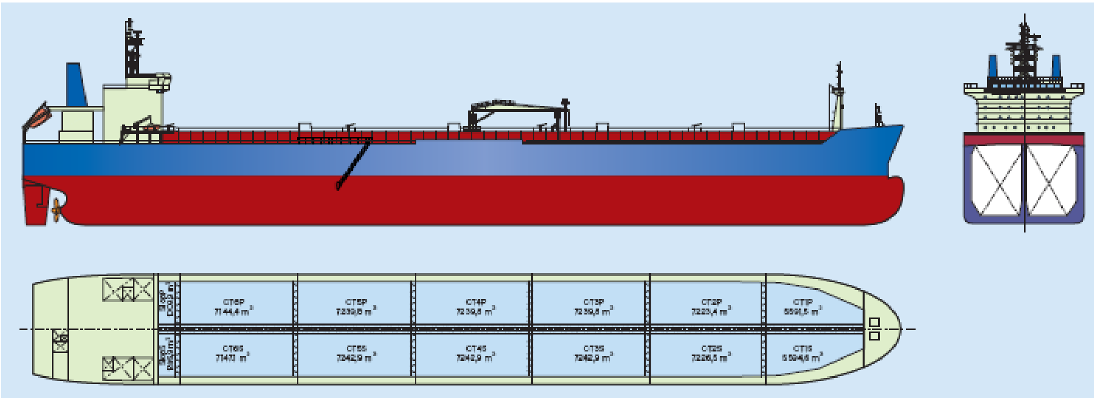


Figure 1 Vessel tank diagram.

1.1.1 General information

Year of completion	2007
Greatest length	228.50 m
Beam	32.24 m
Draught	14.70 m
Deadweight	74,999 t
Height keel to mast	53.48 m
Gt	42,810
Nt	21,999

1.1.2 Crew

For the work experience of crew members directly involved in the incident in the company, on this vessel type and in their positions, see Table below.

Table 1. Staff work experience (31 Oct 2008).

Position	Year of birth	Experience in company (years)	Experience on vessel (days)	Experience in position (days)
Master	1968	20.7	655	1355
Chief Mate	1952	3.8	310	310
Deck hand MM	1972	3.2	93	1133
Deck hand LL	1970	8.7	13	2203

According to the records, all those involved in the incident had had their more or less normal rest periods within the 24 hours preceding the incident. The day before, the crew members had been engaged in cleaning the tanks, which is why their working hours were longer than normal. Nothing exceptional emerged in the interviews or records as to the state of health or alertness levels of any of them.

1.1.3 Other systems

The fan capacity of the inert gas system, which is also used for the ventilation of cargo tanks, is 7,500 m^3/h.

1.1.4 Cargo

On 27 Sep – 6 Oct 2008, the vessel was loaded with low-sulphur diesel oil and gasoil in two different ports.

27-30.9	Low Sulphur Diesel		
	Ultra Low Sulphur Diesel	total	approx. 27,850 m^3
3-5.10	Gas Oil		approx. 48,100 m^3

According to the voyage order, the loads were evenly mixed in all cargo tanks (1-6 P&S), and in the latter port, the cargo was circulated during loading, in other words the loads were mixed together. The interviews indicate that loading operations went normally. In the second port of loading, 2 or 3 shore tanks were emptied out. This was reported to the vessel by the shore staff. The usual samples were taken from the cargo.

1.1.5 Introduction of an additive into tanks on the voyage

On its voyage, the vessel anchored on 21 Oct 2008, and two persons boarded the vessel from shore, who added an additive into the tanks. Additives are commonly used to increase the cetane rating[1] of diesel oil.

Additive	RV-100
Total volume	45,000 l

The additive was taken to the vessel on a barge in 1,000-litre containers and pumped in through the sampling port. The introduction of an additive into the cargo tanks started from the fore (tanks 1 P&S) and ended in the aft (tanks 6 P&S). After introducing the additive, the cargo in each tank was circulated for approx. 4 hours to ensure that the additive was mixed in. The circulation takes place by pumping the cargo from the tank into the pipe system and back. Both the suction outlet and return inlet are at the bottom of the tank. Based on interviews, these actions were carried out in a professional manner. The crew did not take part in the introduction of the additive. An amount corresponding with some 600 ppm of the additive was added to the cargo.

An introduction of an additive of this type had not been previously carried out on the vessel.

[1] A figure expressing the flammability rating of diesel oil

1.1.6 Unloading

The cargo was unloaded in two ports.

28–29.10.2008: volume of unloaded cargo approx. 37,969 m^3.

31.10–1.11.2008: volume of unloaded cargo approx. 37,122 m^3.

The interviews indicated that the cargo had been circulated after the introduction of an additive. In compliance with the voyage order, the cargo was also circulated for 5 hours before arrival in the first port of unloading.

According to the interviews, the unloading of the cargo took place normally. Problems emerged in the production of inert gas, which did not, however, play a role in this work accident.

1.2 The incident

1.2.1 Cleaning and ventilation of cargo tanks

After unloading, the vessel started preparing the cargo tanks (1 P&S, 3 P&S, 6 P&S) for the next loads. The charterer's cleaning instructions for tanks:

Table 2. Cleaning programme

Holds	Next cargo	Cleaning
1 P, 1 S	Mogas (Motor Gasoline)	2-hour cleaning cycle (washing programme 110° - 0° and 40° - 0°) sea water at 50°C, draining of lines, drying of tanks with squeegees (sweeping)
3 P, 3 S	Jet A-1 (jet fuel)	2-hour cleaning cycle (washing programme at 110° - 0° and 40° - 0°) sea water at 50°C, draining of lines, drying of tanks with squeegees (sweeping) 30-min freshwater rinsing
6 P, **6 S**	Jet A-1 (jet fuel)	2-hour cleaning cycle (washing programme at 110° - 0° and 40° - 0°) sea water at 50°C, draining of lines, drying of tanks with squeegees (sweeping) 30-min freshwater rinsing

The tanks were cleaned following the plan. The washing water was not circulated; in other words, clean water was used for the washing all the time.

Water volume used for washing (sea water) 200 m^3 (~33 m^3/tank)

Water volume used for washing (fresh water) 90 m^3 (~22.5 m^3/tank)

Cargo tank **6 S** volume (100 %) 7,147 m^3

For ventilation, water fans (ventilation driven by pressurized water) were only used in tanks 1 P&S, 3 S and the inert gas system fan in tanks 3 P, 6 P, **6 S**. The tanks ventilated using the inert gas system were ventilated through the cargo line, whereby fresh air enters the tank through the drop line at the bottom of the tank. On the deck, the inert gas line was joined to the cargo line using a so-called ”spool piece”. Water fans were not used in the three final tanks (3 P, 6 P, **6 S**), as the vessel was in the vicinity of a coastal state, and it was not desirable to let water flow visibly from deck to the sea.

Table 3. Hold ventilation times

Hold	Ventilation started	Ventilation ended
3 P	2.11 at 1810	4.11 at 0755
6 P	2.11 at 2400	4.11 at 0905
6 S	**2.11 at 2400**	**5.11 at 1205**

Once a tank was finished with, its inlet valve was shut off; for example, the ventilation of tank 3 P was switched off on 4 Nov at 07.55, after which the ventilation continued with tanks 6 P ja 6 S etc.

The ventilation was only turned off while measurements were being taken.

The inert gas system capacity was **7,500** m^3 / h.

Work in cargo tanks 1 P&S and 3 S was completed (washing, ventilation, finishing) on 3 Nov, and a decision was made to continue the finishing of the remaining tanks (3 P, 6 P, **6 S**) later.

According to the interviews, one of the deck hands remembered feeling a slight stinging in his eyes when entering tank 3 S on 3 Nov. He had also asked the other deck hand, ”What's the reading?”, to which the other one replied, ”LEL 15”[2]. This reading was too high, and the deck hands immediately left the tank. This reading should be less than 1%.

The inert gas system fan was used to ventilate cargo tank **6 S**. Ventilation air was directed to this tank simultaneously with two other tanks. Ventilation air was directly exclusively to tank **6 S** for no more than 50 minutes before entering the tank.

[2] LEL = Lower Explosion Limit.

1.2.2 Work areas on the day of the incident

The vessel lay at anchor on 4 Nov 05:15 a.m., and a decision was made to continue the finishing of tanks 3S, 6P and **6S** the same morning.

Table 4. Hold entry log 4 Nov 2008

Hold	Enclosed space permit granted	Work started in tank	Entered tank	Exited tank
3P	07:00	07:10	07:10 (deck hand MM) 07:14 (deck hand LL)	07:50 07:45
6P	08:10	08:15	08:15 (deck hand MM) 08:35 (deck hand LL) 08:35 (deck hand MM)	08:25 09:00 08:55
6S	**09:10**	**09:55**	**09:55 (deck hand MM)** **09:55 (deck hand LL)**	**10:38** **10:47**

1.2.3 Meeting to assign jobs

The Chief Mate organised the usual meeting to assign jobs before work started. This meeting was attended by all deck ratings, excluding deck watchman 12-4. It should be noted that the motorman who assisted in work on the deck did not attend this meeting.

The meeting was conducted following the practices of the vessel.

1.2.4 Preparations for entry into the tank

Preparations for working in an enclosed space mainly proceeded in compliance with company guidelines. A "Plan for working in the tank" document template drawn up on the vessel was in use, in which the task had been planned. The enclosed space permit form had been filled in appropriately.

The shipping company's risk assessment form was not used when preparing for this task, as the two forms mentioned above were regarded as meeting the requirements. The risk assessment requirement is based on occupational safety and health legislation[3] and international regulations (IMO Resolution 864(20) Parag. 3 Assessment of risk) as well as tanker shipping companies' own guidelines (ISGOTT 9.2.1 Assessment of risk; International Safety Guide for Oil Tankers and Terminals).

[3] The Occupational Safety and Health Act 738/2002, Section 10 Analysis and assessment of the risks at work:
The employer shall, taking the nature of the work and activities into account, systematically and adequately analyse and identify the hazards and risks factors caused by the work, the working premises, other aspects of the working environment and the working conditions and, if the hazards and risk factors cannot be eliminated, assess their consequences to the employees' safety and health…

The preparations were directed by the Chief Mate. The Master was aware and had approved of all work in an enclosed space associated with this case.

Tank ventilation at the scene of the incident, tank **6S**, was continuously on for 34 hours 10 minutes, excluding the taking of measurements (see Cleaning and ventilation of cargo tanks). The inert gas system fans were used to ventilate tank **6S**. Ventilation air was directed to this tank simultaneously with two other tanks. Ventilation air was directed exclusively to tank **6S** for no more than 50 minutes before entering the tank.

Both employees were using personal protective equipment suitable for the task:

- hard hat
- overalls
- protective footwear (rubber boots)
- protective gloves (protective gloves for chemicals)
- half-mask with hydrocarbon filter (active carbon)
- personal fall protection harness

Both also had in their belts emergency escape breathing devices (Ocenco M-20.2 EEBD).

No information is available on whether eye protection was worn during this incident.

The hatch was guarded by an ordinary seaman, deck watchman 8-12. He had been assigned the task of watchman at the hatch and instructed to keep in contact with the crew members working in the tank.

Additionally, a motorman was positioned outside the tank to assist in the regulation of working air flow and to guide the compressed air driven diaphragm pump exhaust hose. He had not attended the initial meeting of the deck department; in other words, none of the actions relevant to the washing of tanks and work in an enclosed space had been explained to him.

1.2.5 Work in the tank

On the day of the incident, deck hands MM and LL entered the tanks (3P, 6P, **6S**) with the intention of drying (sweeping) any residual cleaning water at the bottom of the tank and draining the cargo pump well. The atmosphere in all tanks had been tested[4] before entering the tanks, and based on the readings, no reason was detected not to enter them.

Nothing exceptional was noted in connection with cargo tank 3P.

Work in cargo tank 6P proceeded normally, except that based on interviews with deck hand MM and the watchman at the hatch, deck hand MM felt a minor irritation in his

[4] ISGOTT 8.2.2.2 Enclosed space monitoring. IMO Resolution A 864(20) parag.6. Testing the atmosphere. Appendix 1.

throat and a slight stinging of the eyes. After the men exited tank 6P, ventilation air through the inert gas system fan was directed for 50 minutes exclusively into tank **6S**.

1.2.6 Incident

After a break, both deck hands went on to continue their work in the following, or final cargo tank (**6S**). Deck hand MM was draining the cargo pump well with a hose connected to a compressed air driven pump. He had a multi gas monitor on his wrist. Deck hand LL was engaged in the drying (sweeping).

Based on the interviews, there were cleaning residues (sediment) within a radius of approx. 3-5 m from the cargo pump well, and the thickness of the residue layer was approx. 1 mm. In the cargo pump well, a greater amount of sediment had naturally accumulated. The layer of residue was described as "sludgy". In a sample taken from the sediment after the accident, as the content of additive 2EHN (2-etyhylhexyl nitrate) was measured 70 ppm. (The concentration of the additive mixed in with the cargo was 600 ppm.)

The deck hands were in almost continuous contact with the watchman at the hatch through walkie-talkies.

After some 15 minutes in the tank, deck hand LL had "shoved" the other deck man, saying, "We've got to go." He managed to grab hold of the handrails before losing consciousness at the bottom of the cargo tank. Deck hand MM immediately alerted the 8-12 deck watchman who was watching the hatch and reported, "Deck man LL had a fall, we need help". He took deck man LL's emergency escape breathing device with the intention of giving him oxygen. He managed to open the device and then made an attempt to read the instructions, which were in English. He reported later that he could not understand the instructions. After this, he remembers nothing until regaining consciousness on the deck.

Based on interviews with both deck hands, the loss of consciousness took place extremely rapidly. According to the interviews, no alarm was sounded by the monitors.

1.2.7 Scene of the incident

The vessel lay at anchor on 4 Nov 2008 at 05.15–16.10.

1.2.8 Weather conditions

4 Nov 2008 at 06.00:

Clear
Light variable wind (Var 2 m/w)
Temperature +18 °C
Air pressure 1016 mbar

1.2.9 Personal injuries

Deck man MM was sent to the hospital for observation on 4 Nov. He flew to Finland on 5 Nov and back to the vessel together with the shipping company's investigation team on 9 Nov 2008.

Deck man LL remained on the vessel and, at his own request, resumed light work duties the following day.

1.2.10 Recording instruments

To test the atmosphere in the tank, the following instruments were used:

- Personal monitor RIKEN GX-2001A
  - detects the following gases: O_2, HC, CO, H_2S
  - instrument calibrated on 1 Aug 2008
- on the deck RIKEN RX-517
  - detects HC, O_2, H_2S
  - 30-m hose (enables the taking of readings from tank bottom)
  - instrument calibrated on 1 Aug 2008

The personal monitors take continuous measurements. Concentrations were tested with the instrument on the deck before entering the tank and while work was being carried out in the tank. A record was kept of the readings.

1.3 Rescue operation

1.3.1 Emergency operations

Approx. at 10.10, deck watchman 8-12 who was acting as the hatch watchman alerted by walkie-talkie the Chief Mate, who was supervising the work in the cargo control room and who, after the alarm was raised, immediately contacted the bridge. After this, the Chief Mate went to the scene of the incident.

1.3.2 Initiation of rescue operation, evaluation of the operation

The motorman who was assisting in the work was the first one to hear the alarm through the hatch watchman's walkie-talkie, after which he immediately and without a separate order put on a self-contained breathing apparatus and entered the tank. According to his own report, he reached the bottom of the tank in approx. 1.5 minutes. The motorman in question was an experienced breathing apparatus user. What is worth noting, however, is the fact that this was the first time he entered a cargo tank and that he had not been assigned the duties of a rescuer in any incidents. Despite this, he entered the tank in an extremely rapid and determined manner.

The Master of the vessel was alerted by telephone, and he immediately came to the scene of the incident via the bridge. At that time, the motorman with the breathing apparatus had already entered the tank.

Immediately after the Master was alerted, the Medical Officer of the vessel was woken up, and he came to the scene with first aid equipment. At the scene, it was agreed that he would put on a breathing apparatus and go to the assistance of the motorman in the cargo tank. He entered the cargo tank at 10.15.

The crew was alerted by a PA announcement.

After hearing the announcement (alert), almost the entire crew came to the scene of the incident. They started getting ready to hoist the deck hands from the tank and administer first aid.

According to the interviews, activities on the deck were directed by the Chief Mate.

The Master returned to the bridge and contacted the local agent (at 10.20) and the shipping company (at 10.30).

The motorman had attempted to equip both deck hands with the emergency escape breathing devices (EEBD) in the tank, however without success. The mouthpiece of the device, which is "shaped like a snorkel", needs to be held in the mouth and compressed with teeth, which the unconscious deck hands were unable to do. He managed to open the devices, however, and according to his report the deck hands "got at least a bit of air" from them.

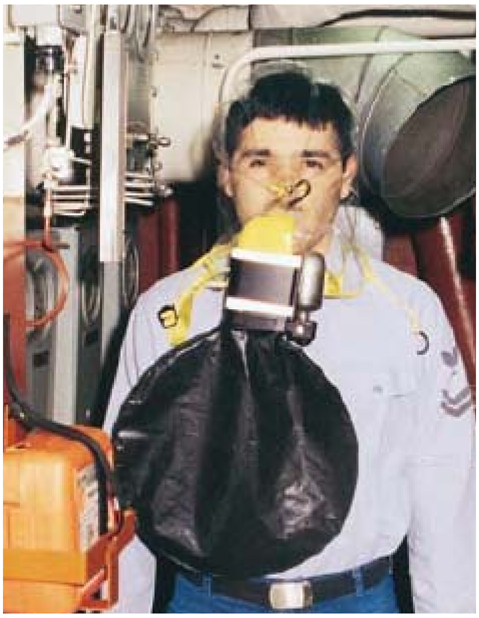


Figure 2. Wearing an EEBD Ocenco M-20.2 (figure from the manufacturer's website)

The personal fall protection harness of deck hand MM was first attached to the fall protection harness lanyard. This was discovered quickly, however, and replaced with the actual cable intended for hoisting. According to the interviews, this took "a couple of minutes" of additional time. The motorman's breathing apparatus sounded an alarm, and he left the tank. The motorman gave the apparatus to a repairman, who replaced the bottles and then went to the intermediate landing to help with the hoisting. Deck hand MM was lifted onto the deck at 10.38. The actual hoisting from the bottom to the deck took approx. 5 minutes.

The hoisting cable was re-lowered and attached to the fall protection harness of deck hand LL, who reached the deck at 10.47. In the second hoisting operation, the repairman assisted in attaching deck hand LL to the cable at the bottom of the tank, and the Chief Engineer assisted in the hoisting by pulling at the cable on the intermediate landing.

The last person exited the tank at 10.48.

The total time that elapsed from the alarm till both patients had been hoisted to the deck was approx. 37 minutes.

The interviews indicated that the crew members involved in the rescue did not hear alarms sounded by the instruments while in the tank. A person who was on the deck said in the interview, "An alarm was possibly heard from down there." Based on the available information, it is not possible to say if the gas monitor that was used sounded an alarm.

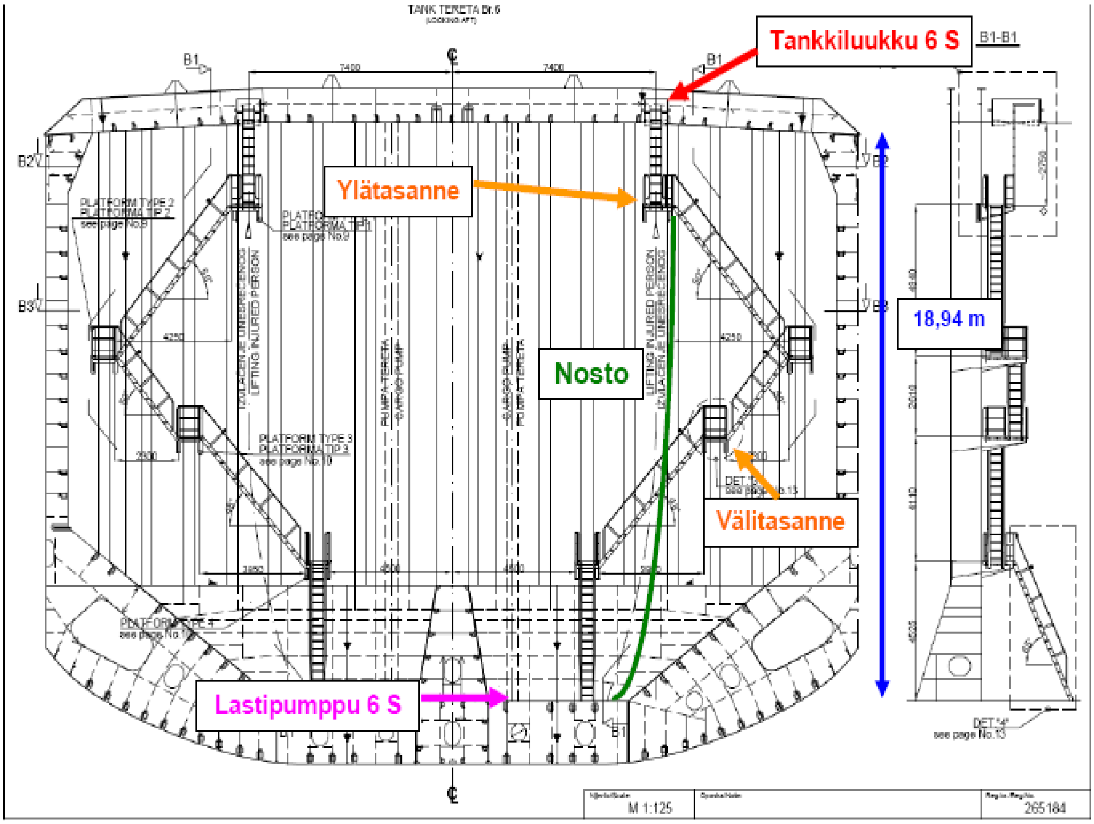


Figure 3. Hoisting from the tank.

Tankkiluukku 6 S – Tank hatch 6 S

Ylätasanne – Top landing

Nosto – Hoisting

Välitasanne – Intermediate landing

Lastipumppu 6S – Cargo pump 6 S

Figure 4. Tripod and winch on tank hatch of cargo tank 6S

Figure 5. Winch used in the hoistings

1.3.3 First aid

Administration of first aid started immediately after the first deck hand had been hoisted out of the tank. After hoisting, the patients were immediately moved into shade, and oxygen was administered to them. The vessel ran out of medicinal oxygen at 10.50, 12 minutes after the first patient had been hoisted to the deck.

The vessel attempted to request medical help through a coastal station, which did not respond. The supervisor of local boatmen came to assistance and finally managed to contact the coastal station at 10.50.

- At 10.50, the shipping company's contract doctor contacts the vessel for the first time and gives instructions for the treatment and monitoring of the patients. The status of the patients is continuously monitored, and the doctor is consulted.
- At 11.03, a message is received from shore to say that a local doctor is coming onboard.
- At 11.52, the status of the patients is variable, and the contract doctor advises that they should be given "a bronchodilatory medicine, such as Abrovent Comp solution, through a steam inhaler mask."
- At 11.57, an attempt is made to obtain medicinal oxygen from other vessels.
- At 12.11, the vessel announces that no bronchodilatory medicines are found on the vessel.
- At 13.55 a local doctor boards the vessel.
- At 14.42, a decision is made to send deck hand MM to a hospital for observation.

1.3.4 Flow of information

Table 5. Flow of information in the incident

Time	Event
10.28	The officer on duty in the shipping company is informed of the incident
10.44	The officer contacts the shipping company's Designated Person[5] who acted as the deputy of the emergency team coordinator.
10.47	The company's Safety Manager involved in talking to the vessel.
10.50	After the seriousness of the situation emerges, the contract doctor of the shipping company is contacted, and the first contact with the vessel is made.
12.06	The duty officer alerts the shipping company management and Designated Person by a text message.
12.27	The shipping company's emergency team meets.
12.37	A decision is made to hold a briefing on the incident at 14.30.
14.30	Briefing
17.34	Emergency team discontinues its activities

5 Under the International Safety Management Code, a Designated Person is the contact person ashore for vessels in safety matters. This person also has direct access to the highest level of management in the shipping company.

Information on the incident was communicated in compliance with guidelines, all responsible persons were informed and emergency team operation was initiated.

1.4 Detailed investigations conducted

1.4.1 Investigation of the vessel and scene of the incident

The Designated Person made a decision to proceed to a more extensive investigation following company guidelines. The order to investigate was issued on 5 Nov 2008. Shipping company experts were appointed as investigators. The investigation visit to the vessel was ordered to take place in week 45-46. The investigation team conducted interviews and collected material on the vessel on 11-12 Nov 2008.

1.4.2 Lines of investigation followed by the shipping company experts

Table 6. Lines of investigation 1/2

Possible factor	Possibility (grounds)	Ruled out (grounds)	Source of information
Neglect of guidelines for working in enclosed spaces		As a rule, company guidelines were complied with on the vessel	Documentation, interviews
Inadequate ventilation	Is the inert gas system fan capacity at approx. 7,500 m^3/h adequate for three tanks with a capacity of approx. 7,200 m^3/tank. Only this fan was used to ventilate the holds.		Inert Gas Generator Manual, specifications of the vessel. Expert opinion.
Flow of inert gas into the tank		Inert gas not produced at that time. Inert gas in the atmosphere of SLOP tanks, inert gas lines blinded.	Interviews on board
O_2 (oxygen) shortage in the tank		Atmosphere tested with two independent monitors, neither showed an O_2 content below 20.9%. Skin colour of patients did not indicate symptoms of oxygen shortage.	Interviews on board
LEL content (hydrocarbon)	The day before, a 15% content had been measured in the tank. In the other cargo tank 6, the monitor read ”FAILURE”.	No LEL contents were not measured in tank 6 S where the incident took place.	Interviews on board

Table 7. Lines of investigation 2/2

Possible factor	Possibility (grounds)	Ruled out (grounds)	Source of information
CO content (carbon monoxide)	CO contents measured in the tank after accident	The measured CO contents not sufficient to induce loss of consciousness Skin colour of patients did not indicate symptoms of oxygen shortage.	Information from the vessel and the occupational health doctor.
2EHN content (2-ethylhexyl nitrate) Chemical added to the cargo to increase the cetane rating	According to information from the work hygiene unit and another oil company, a LEL display unit may pick up 2EHN.		MSDS information from two different oil companies Information from work hygiene unit Information from another shipping company.
Dehydration (drying out of the body as a result of insufficient quantity of liquids)		Breaks were taken, during which the employees drank bottled water and sports drinks.	Interviews on board
State of health of persons		Both had a valid seafarer medical certificate. Persons were in a normal state of health. Unlikely that both would have an episode of illness simultaneously. Physically fit.	Documentation, interviews
State of alertness	A tank cleaning operation lasting for several days may result in a shortening of rest periods	No **excesses** of rest periods were observed. The day before, work had been finished on time.	Monitoring of rest periods, interviews on board
Malaria medication		Neither of those who lost consciousness was on malaria tablets Expert does not consider possible even with medication.	Information from the vessel and the occupational health doctor.

In 2009, the shipping company commissioned a study modelling the ventilation of tanks on vessels, in which cargo tank 6S on this vessel was used as an example and in which tank hatch A was open (see Appendix 3).

1.5 Rules and regulations applicable to the operations

1.5.1 National legislation

The Occupational Safety and Health Act 23.8.2002/738 (709/2008)

Government decision on guidelines to be applied in work onboard ships 11.6.1981/418 Chapters 7 and 8.

Government Decree on protective equipment and monitoring instruments used on a vessel 27.9.2001/825

1.5.2 Operator's rules

The shipping company has a clear Safety Management System, which features instructions on entering an enclosed space and the associated safety measures.

1.5.3 International conventions and recommendations

IMO resolution A 864(20) Recommendations for entering enclosed spaces aboard ship was adopted at twentieth Assembly on 27 November 1997. Appendix 1

At the international level, majority of tanker shipping companies are committed to complying with the ISGOTT guidelines (International Safety Guide for Oil Tankers and Terminals, 5th edition). The shipping company in question is part of this group.

ISGOTT Chapter 10 contains clear instructions on entering an enclosed space and the associated safety measures. Guidelines on ventilation do not contain numeric definitions of the exchange air volume.

2 ANALYSIS

The following sections contain an analysis of the causes that resulted in the accident based on the so-called Reason model. The analysis starts with the accident and its immediate causes and ends with the hidden background factors. The Figure at the end of this Chapter contains an analysis of causes in a graph form.

2.1 Direct causal factors

The accident is assessed to have taken place as a result of the combined action of the following factors.

2.1.1 Additive bonded in the sediment

The additive introduced into the cargo to improve the cetane rating, 2EHN (2-ethylhexyl nitrate) has a higher density than the basic cargo, it is not water soluble and its vapour pressure is low; it is thus possible that the substance has locally bonded with the sediment at the bottom of the tank.

From this sediment, the substance had evaporated as the sediment was moved with a squeegee. Sediment was found at the tank bottom within a radius of approx. 3-5 m from the cargo pump well, with a layer thickness exceeding 1 mm. The evaporated additive and other gases evaporating from the sediment will rise to the respiratory area of those working in the tank.

Sediment and gases evaporating from it only occur locally in the tank.

2.1.2 The protective ability of the respiratory protective device was cancelled out because of a leak

The respiratory protective devices were a poor fit on the faces of the users. A leak in a protective device cancels out its filtering effect, as majority of the respiratory air is carried to the respiration system through the area of lower resistance (the leak). The filters that were used had not lost their filtering ability to a significant extent.

The persons working in the tank reported having sensed a smell in the tank, which indicates a significant leak in the mask.

2.1.3 Ventilation by inert gas system fan only

The plan for working in an enclosed space included the use of pressurized water driven movable tank fans and the fan of the inert gas system. The work in enclosed spaces was interrupted the day before after three tanks, with the intention of continuing the next day following the plan.

Deviating from the plan, the work was continued without using the pressurized water driven fans, as it was not desirable to allow water to flow from the deck to the sea in the vicinity of a coastal state. The capacity of this fan at a pressure of 12 bar would have been approx. 12,500 m³/h.

The enclosed space was only ventilated by the inert gas system fan, the capacity of which was 7,500 m^3/h, while the tank capacity is 7,147 m^3 (1,049 exchanges of air volume in an hour, evenly divided between the last three tanks 0.35 times an hour). The tank in which the incident took place was only ventilated with the entire capacity of the fan for 50 minutes before the tank was entered (see Table 3, Tank ventilation times). Theoretically, the air in the tank where the incident took place was exchanged 13.2 times within the last 35 hours (in this calculation, air flowing into the tank at a low flow resistance was not taken into consideration); in other words, the air was exchanged approx. 0.38 times an hour. The tank hatch was located in the route of the air flow from the dropline to the work area, which is why even a significant share of the ventilation air would have escaped this way without reaching the work area (see Figure 6). In addition to the tank hatch, the tank also has two manholes, but based on the information received from the vessel, these were not open.

The air exchange rate was low in the tank where the incident took place while ventilation was in progress, especially as the same fan was also used to ventilate other tanks at the same time. According to the expert, the air exchange rate in a contaminated space similar in size to the this tank should be at least 3,960 m^3/h. As an example could also be cited the requirement for a pumproom, which is 20 air exchanges an hour.

Inadequate ventilation will enable the formation of local gas pockets in the tank; in the tank in question, the employees may have been in a shadow zone of ventilation, as they were working on the far side of the tank hatch seen from the dropline.

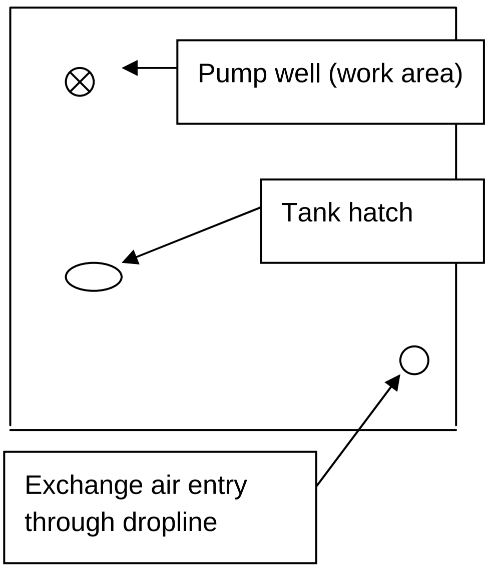


Figure 6. Tank seen from above

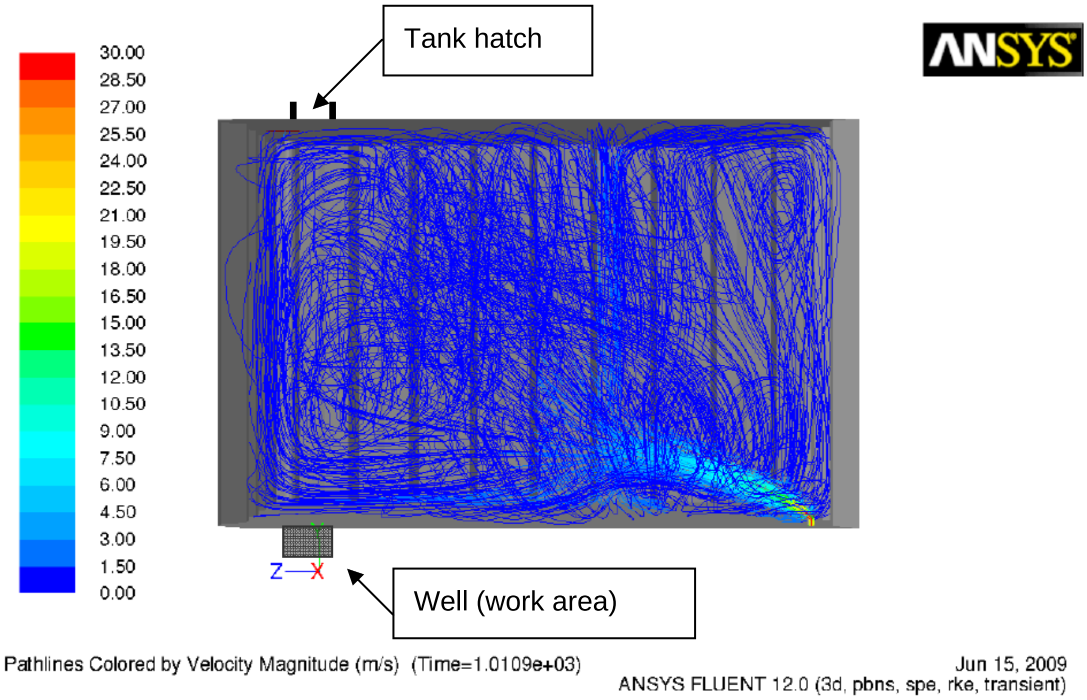


Figure 7. Figure from study commissioned by the shipping company on tank ventilation. It describes the situation on the vessel while the tank hatch was open. With this method of ventilation using the inert gas fan only, the reference ventilation time is some 6 hours.

2.2 Hidden causes

2.2.1 Additive bonded with the sediment

The risk of the additive being mixed with the sediment was not identified, because preparations for tank cleaning were made as for normal diesel with additives added at the refinery. It is probable that sediment was found at the tank bottom, as when the diesel was loaded, the shore tanks had been pumped empty, and there was lose material in the bottom layers of the tanks. This was also the first time the tanks of a newish vessel were washed. The crew had no experience of introducing additives to the cargo and the washing of tanks after the introduction of an additive on this vessel.

The Safety Management System or operative guidelines of the shipping company do not contain clear instructions on introducing additives into the vessel's tank and its impacts on tank cleaning. The introduction of an additive is comparatively rare on vessels, and more detailed instructions had not been found necessary. This risk is not described in the reference documentation (e.g. ISGOTT).

2.2.2 The protective ability of the respiratory protective device cancelled out because of a leak

The protective device used was of the half mask type, in which the area around the nose is prone to leaks. The devices used may not have been the correct size for their users. The tightening mechanism of the devices was experienced as awkward, and it was not possible to fit the masks closely against the face.

The respiratory protective device that was in use was included in a list of standard protective equipment.

When this model was selected for the list of standard protective equipment, more attention was focused on user feedback favouring a half-mask than on proneness to leaks.

2.2.3 Ventilation by inert gas system fan only

The inert gas system fan only was used to ventilate the tanks, because an exception was made in the work plan prepared in advance. The exception was made as the ship lay at anchor for several hours during the voyage, and the crew wished to make use of the time.

The crew did not wish to use fans driven by water pressure, as letting water flow from the deck to the sea would have attracted unpleasant attention.

It was assumed that the inert gas system fan would have adequate capacity for tank ventilation to produce sufficient and even air exchange in the work area.

There are no guidelines for ventilating an enclosed space that would unambiguously show the required air exchange rate per time unit. When preparing the ventilation plan, it was difficult for the Chief Mate to find reference documentation for this decision. No information was available either in the Safety Management system or ISGOTT.

Information on the air exchange rate needed for working in tanks was not available when preparing the instructions.

In the study commissioned by the shipping company on tank ventilation (Appendix 3), the starting point for the calculations was that the cargo in the tank was diesel and that after the tank washing cycle and inerting, a concentration of flammable gases remained in the cargo tank that was within 2% of the LEL limit. The oxygen content of the cargo tank before ventilation was initiated is 8% by volume, and the cargo tank has 50 ppm of 2EHN (2 ethylhexyl nitrate) originating from the diesel additive. Case 2. Figure 9 describes air circulation in the tank when the tank hatch is open and the inert gas fan is working at a capacity of 7,000 m^3/h through the dropline. The adequate ventilation period using this fan only is estimated at approx. 6 hours. On the day of the accident, the fan was used exclusively in tank 6S for approx. 50 minutes.

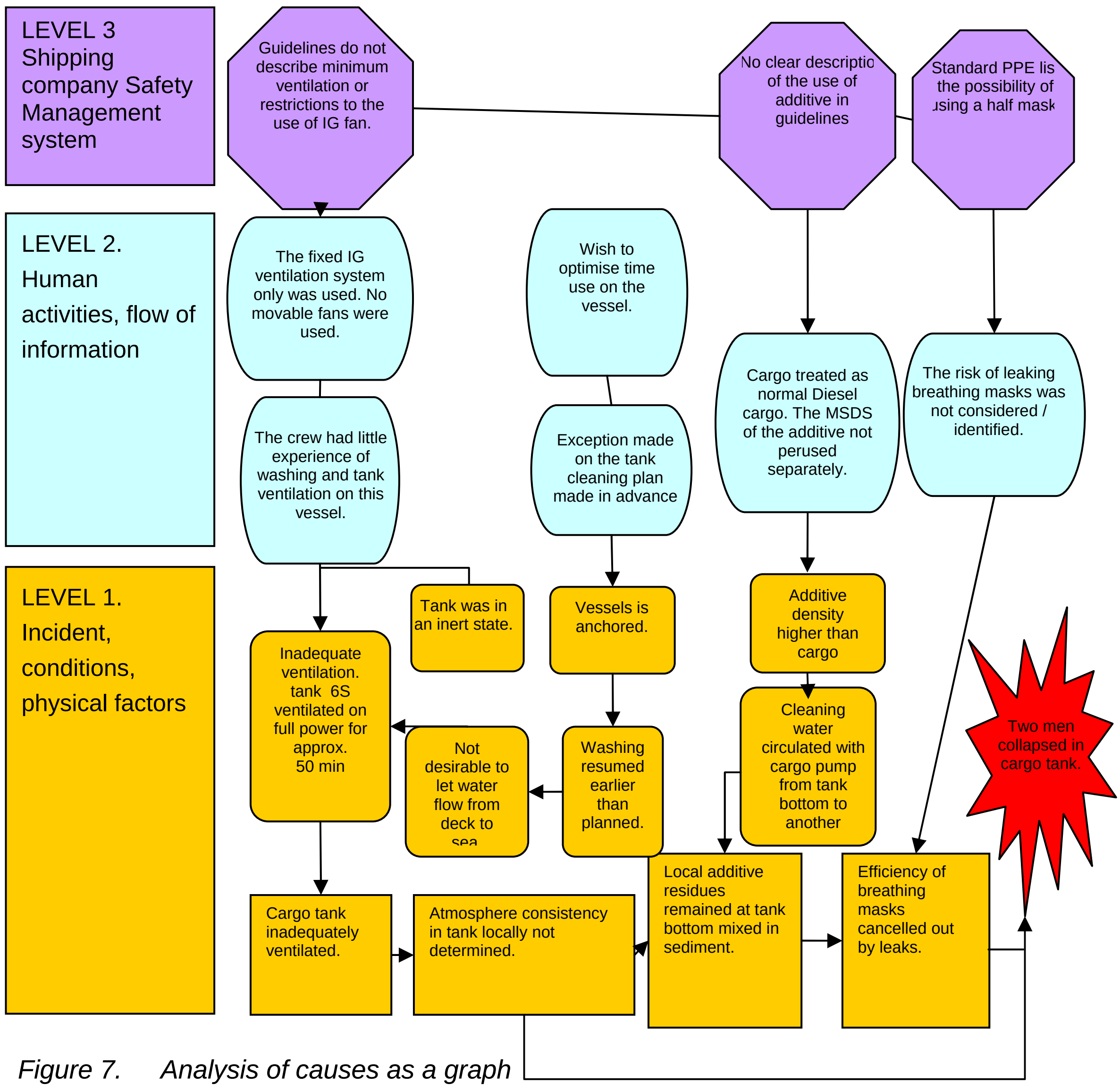


Figure 7. Analysis of causes as a graph

3 CONCLUSIONS

After unloading, the crew was instructed to prepare the vessel's cargo tanks for the next load. The preparations included washing the tanks with warm sea water, rinsing with fresh water, ventilation and drying the tank bottom with squeegees. In connection with the drying, two persons went down into the tanks to dry the tank bottoms with a squeegee and to drain the cargo pump well with a compressed air driven diaphragm pump. While performing this work, these two persons lost consciousness in cargo tank number 6S. According to the plan, this was the last tank in which work was to be carried out.

It was planned that the tanks would be cleaned on the way to the next port of loading. During this voyage, the tanks had been washed. However, the vessel lay at anchor for a longer period than was originally envisaged in vicinity of the coast, where a decision was made to continue drying the tanks. The day before, three tanks had been dried. At the end of the day, the persons engaged in the drying experienced mild irritation in their throat and eyes. In addition, the multi gas monitor carried by the employees during the day had shown a reading of 15% LEL level (2EHN used as an additive is known to give LEL indications). The LEL reading in a work area should be less than 1%.

According to the plan for the day of the incident, three tanks would be dried. As an exception to the plans, the inert gas system fan only was used to ventilate the tanks. The air produced by the fan was divided between three tanks. Pressurised water driven fans were not used as planned, as the crew did not wish to let the water flow into the sea. The persons engaged in the drying again felt mild irritation symptoms when working in the first two tanks. Even at this stage, it can be noted that the washing and/or ventilation had been inadequate, but the deck hands apparently did not bring their symptoms to the attention of their superiors. In the third tank (6S), the employees started work similarly to the other five tanks. After a while, the employee drying the tank bottom with a squeegee announced to his colleague who was operating the pump that everything was not all right and that they should leave the tank. Before reaching the stairs, he lost consciousness, after which the other employee called for help and tried to put on an emergency escape breathing device, however not succeeding. After an instant he, too, lost consciousness at the tank bottom. They were subsequently lying in the sediment at the bottom of the tank, and consequently may have continued being exposed to the substance that had caused them to lose consciousness.

According to the Material Safety Data Sheet, the agent added to the cargo in order to increase the cetane reading 2EHN (2-ethyhexyl nitrate) may cause irritation to mucous membranes and even induce loss of consciousness.

Before starting the work, the persons who lost consciousness had put on personal fall protection harnesses, which could be used to evacuate them from the tank. Before starting the work, a hoist had been set up on the tank hatch, which was used to hoist the unconscious persons from the tank. It should be noted that the personal fall protection harnesses played a significant role in the hoisting operation, and this method of operation should be introduced on all vessels through the Safety Management System. The vessel crew members who were wearing the harnesses on a voluntarily basis deserve a special commendation (a recommendation in the Safety Management system at the time of the incident). As to the hoisting equipment, it can be noted that its setup may not have been thoroughly thought out, and the tackle was hanging in the middle of the tripod on a rope, allowing the tackle to swing around and get entangled around the rope. In addition, the use of a pulley to make the hoisting lighter had not been taken in consideration. The model used does not comply with the company's current standard.

The employees were rescued from the tank by the crew, and first aid was organised for them. It took 37 minutes from the alarm till the employees were rescued from the tank. In the first aid administered to the patients, the vessel was supported by a private doctor of the flag state, who consulted the vessel crew by telephone. The vessel crew found consultation obtained in their working language vitally important when administering first aid.

As a conclusion it must be stated that no unambiguous and clear cause or causal relationship can be pinpointed for the loss of consciousness. The shipping company investigation team takes the following view of the events:

Additive was introduced into the tank, the density of which is higher than that of the cargo. This addition was carried out by means of a pump through the sampling port in the top part of the tank. It is possible that some of the additive has flown through the cargo to the tank bottom in a "bubble". When loading, the vessel was informed that the shore tank would be emptied into the vessel tank. In this type of situation, such as rust usually ends up at the tank bottom. The additive may have become mixed with this sediment locally. The cargo was circulated using the cargo pump in connection with the introduction of the additive and before unloading. In the circulation process, cargo is sucked out of the tank bottom and returned into the hold bottom to the corner diagonally opposite the outlet point. The circulation is thus not complete but allows the possibility of unmixed zones remaining in the tank.

When the tank was washed, additive-containing sediment may have been left at the bottom. The person drying the tank had stirred that sediment and possibly released the 2EHN in it into his respiratory air. The inadequate ventilation in the tank did not dilute the gas compound fast enough, and the person had inhaled the additive-containing air. The half-mask type respiratory protective devices that were used had leaks, which enabled the entry of additive-containing air into the respiratory organs. The compound that was inhaled was concentrated enough to induce loss of consciousness.

Or

There were residues of the inert gas and/or the carbon monoxide contained in it in the tank. The carbon monoxide content of the inert gas may have been higher than normal because of a fault in the inert gas system. The inadequate ventilation of the tank did not dilute the gas compound fast enough, and the persons had inhaled low-oxygen air containing carbon monoxide. The half masks in use do not protect against a lack of oxygen. The lack of oxygen in blood circulation resulted in a loss of consciousness. (The skin colour of the victims did not indicate symptoms of oxygen insufficiency, however, Table 7.)

Or

The combined effects of the above.

4 SAFETY RECOMMENDATIONS

The **shipping company investigation team** recommends to the company the introduction of the following measures based on this incident investigation:

1. The use of half-mask type respiratory protective devices is discontinued. These are replaced by full masks or fresh air breathing apparatuses, in which leaks around the nose and exposure of eyes to hazardous substances are eliminated.
2. In the Safety Management System, instructions on introducing additives into the vessel tank are clarified.

   The necessary changes will be made in the enclosed spaces guideline concerning the risks of introducing additives.
3. Enclosed space rescue drills are to be carried out on the vessels following the guidelines. In training, attention will be focused on crew members transferring from one vessel to another, with vessel group specific training. In case a new employee comes in from a different vessel group, s/he shall take part in the relevant training before participating in work in an enclosed space. All those involved in the work must have training in their tasks.
   The focus in training should be on learning to use life-saving and emergency equipment and to observe and remedy any defects in them before they are needed in a real-life rescue. Those coming to work on the vessel should practice using EEBD's with a practice apparatus.
4. In the Safety Management system, a rule is added that bans the Master and Chief Engineer from entering conditions known to be hazardous without permission of the shipping company. This will ensure that the risks inherent in the situation are mapped with adequate accuracy, and in the event that an accident nevertheless occurs, the unit will not be left without effective leadership in the midst of a special situation.

Of the internal recommendations of the shipping company, recommendation no. 3 has been implemented, while the others are being processed.

In addition, the shipping company is planning to draw up ship-specific ventilation recommendations, also relying on the calculations presented in Appendix 3 produced for the shipping company.

The **investigators of the Accident Investigation Board** feel that the issuing of numeric reference values should be carefully considered. Adequate ventilation is influenced by a number of factors, such as the quality of the cargo in the tank before cleaning, the washing results, water quantity used and the water temperature, fans used for ventilation, time used for ventilation and the number of hatches that are open. If reference values are issued, in their determination an attempt should be made to take these factors into consideration, as well as **adequate safety margins**.

As regards work in tanks, the investigators would like to highlight the following safety considerations:

1) Accurate MSDS's should be available for all substances handled, to make it possible to plan for the safe cleaning and ventilation of tanks. If it is necessary to act relying on deficient information, however, ***work in an enclosed space should be interrupted once any physical symptoms occur****. Before carrying on the work, the crew should proceed to an additional washing and ventilation operation.*

2) In addition to a single reference value, or fan capacity, a requirement concerning the quantity of water used for washing and the ***number of times the air is exchanged*** *in the space to be ventilated (****time used on ventilation****) should be introduced.*

3) In case it is necessary to enter the tank to drain the pump well after washing, careful ventilation and testing of the atmosphere, a so-called "air sock" should be used to target the ventilation to this work area, because any cargo residues in the well may emit gases harmful to health when moved.

Helsinki 11 February 2010

Juha Sjölund

Risto Repo

SOURCES

1. Shipping company report 30 Jan 2009

2. Occupational Safety and Health Act 738/2002

3. Government decision 1981/418 on guidelines on work onboard vessels

4. Government Decree on protective equipment and monitoring devices used on a vessel

5. IMO Resolution A 864(20) Recommendations for entering enclosed spaces aboard ship was adopted at twentieth Assembly on 27 November 1997.

6. ISGOTT International Safety Guide Of Tankers and Terminals 5th edition

APPENDICES

1. IMO Resolution A 864(20) Recommendations for entering enclosed spaces aboard ship was adopted at twentieth Assembly on 27 November 1997.

2. DSC 14/INF.9 17 July 2009 Revision of the recommendations for entering enclosed spaces aboard ships

3. Study commissioned by the shipping company on tank ventilation AI9000 (in Finnish)

Appendix 1. IMO Resolution A 864(20) Recommendations for entering enclosed spaces aboard ship was adopted at twentieth Assembly on 27 November 1997.

A 20/Res.864
5 December 1997
Original: ENGLISH

ASSEMBLY
20th session
Agenda item 9

RESOLUTION A.864(20)
adopted on 27 November 1997

RECOMMENDATIONS FOR ENTERING ENCLOSED SPACES ABOARD SHIPS

THE ASSEMBLY,

RECALLING Article 15(j) of the Convention on the International Maritime Organization concerning the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

BEING CONCERNED at the continued loss of life resulting from personnel entering shipboard spaces in which the atmosphere is oxygen-depleted, toxic or flammable,

BEING AWARE of the work undertaken in this regard by the International Labour Organization, Governments and segments of the private sector,

NOTING that the Maritime Safety Committee, at its fifty-ninth session, approved appendix F to the Code of Safe Practice for Solid Bulk Cargoes concerning recommendations for entering cargo spaces, tanks, pump-rooms, fuel tanks, cofferdams, duct keels, ballast tanks and similar enclosed spaces,

NOTING FURTHER the decision of the Maritime Safety Committee at its sixty-sixth session to replace appendix F referred to above with the recommendations annexed to this resolution,

HAVING CONSIDERED the recommendation made by the Maritime Safety Committee at its sixty-sixth session,

1. ADOPTS the Recommendations for Entering Enclosed Spaces Aboard Ships set out in the Annex to the present resolution;

2. INVITES Governments to bring the annexed Recommendations to the attention of shipowners, ship operators and seafarers, urging them to apply the Recommendations, as appropriate, to all ships;

3. REQUESTS the Maritime Safety Committee to keep the Recommendations under review and amend them, as necessary.

ANNEX

RECOMMENDATIONS FOR ENTERING ENCLOSED SPACES ABOARD SHIPS

PREAMBLE

The object of these recommendations is to encourage the adoption of safety procedures aimed at preventing casualties to ships personnel entering enclosed spaces where there may be an oxygen deficient, flammable and/or toxic atmosphere.

Investigations into the circumstances of casualties that have occurred have shown that accidents on board ships are in most cases caused by an insufficient knowledge of, or disregard for, the need to take precautions rather than a lack of guidance.

The following practical recommendations apply to all types of ships and provide guidance to seafarers. It should be noted that on ships where entry into enclosed spaces may be infrequent, for example, on certain passenger ships or small general cargo ships, the dangers may be less apparent, and accordingly there may be a need for increased vigilance.

The recommendations are intended to complement national laws or regulations, accepted standards or particular procedures which may exist for specific trades, ships or types of shipping operations.

It may be impracticable to apply some recommendations to particular situations. In such cases, every endeavour should be made to observe the intent of the recommendations, and attention should be paid to the risks that may be involved.

1 INTRODUCTION

The atmosphere in any enclosed space may be deficient in oxygen and/or contain flammable and/or toxic gases or vapours. Such an unsafe atmosphere could also subsequently occur in a space previously found to be safe. Unsafe atmosphere may also be present in spaces adjacent to those spaces where a hazard is known to be present.

2 DEFINITIONS

2.1 *Enclosed space* means a space which has any of the following characteristics:

.1 limited openings for entry and exit;

.2 unfavourable natural ventilation; and

.3 is not designed for continuous worker occupancy,

and includes, but is not limited to, cargo spaces, double bottoms, fuel tanks, ballast tanks, pump-rooms, compressor rooms, cofferdams, void spaces, duct keels, inter-barrier spaces, engine crankcases and sewage tanks.

2.2 *Competent person* means a person with sufficient theoretical knowledge and practical experience to make an informed assessment of the likelihood of a dangerous atmosphere being present or subsequently arising in the space.

2.3 *Responsible person* means a person authorised to permit entry into an enclosed space and having sufficient knowledge of the procedures to be followed.

3 ASSESSMENT OF RISK

3.1 In order to ensure safety, a competent person should always make a preliminary assessment of any potential hazards in the space to be entered, taking into account previous cargo carried, ventilation of the space, coating of the space and other relevant factors. The competent person's preliminary assessment should determine the potential for the presence of an oxygen-deficient, flammable or toxic atmosphere.

3.2 The procedures to be followed for testing the atmosphere in the space and for entry should be decided on the basis of the preliminary assessment. These will depend on whether the preliminary assessment shows that:

.1 there is minimal risk to the health or life of personnel entering the space;

.2 there is no immediate risk to health or life but a risk could arise during the course of work in the space; and

.3 a risk to health or life is identified.

3.3 Where the preliminary assessment indicates minimal risk to health or life or potential for a risk to arise during the course of work in the space, the precautions described in 4, 5, 6 and 7 should be followed as appropriate.

3.4 Where the preliminary assessment identifies risk to life or health, if entry is to be made, the additional precautions specified in section 8 should also be followed.

4 AUTHORIZATION OF ENTRY

4.1 No person should open or enter an enclosed space unless authorised by the master or nominated responsible person and unless the appropriate safety procedures laid down for the particular ship have been followed.

4.2 Entry into enclosed spaces should be planned and the use of an entry permit system, which may include the use of a checklist, is recommended. An Enclosed Space Entry Permit should be issued by the master or nominated responsible person, and completed by a person who enters the space prior to entry. An example of the Enclosed Space Entry Permit is provided in the appendix.

5 GENERAL PRECAUTIONS

5.1 The master or responsible person should determine that it is safe to enter an enclosed space by ensuring:

.1 that potential hazards have been identified in the assessment and as far as possible isolated or made safe;

.2 that the space has been thoroughly ventilated by natural or mechanical means to remove any toxic or flammable gases, and to ensure an adequate level of oxygen throughout the space;

.3 that the atmosphere of the space has been tested as appropriate with properly calibrated instruments to ascertain acceptable levels of oxygen and acceptable levels of flammable or toxic vapours;

.4 that the space has been secured for entry and properly illuminated;

.5 that a suitable system of communication between all parties for use during entry has been agreed and tested;

.6 that an attendant has been instructed to remain at the entrance to the space whilst it is occupied;

.7 that rescue and resuscitation equipment has been positioned ready for use at the entrance to the space, and that rescue arrangements have been agreed;

.8 that personnel are properly clothed and equipped for the entry and subsequent tasks; and

.9 that a permit has been issued authorizing entry.

The precautions in .6 and .7 may not apply to every situation described in this section. The person authorizing entry should determine whether an attendant and the positioning of rescue equipment at the entrance to the space is necessary.

5.2 Only trained personnel should be assigned the duties of entering, functioning as attendants, or functioning as members of rescue teams. Ships' crews should be drilled periodically in rescue and first aid.

5.3 All equipment used in connection with entry should be in good working condition and inspected prior to use.

6 TESTING THE ATMOSPHERE

6.1 Appropriate testing of the atmosphere of a space should be carried out with properly calibrated equipment by persons trained in the use of the equipment. The manufacturers' instructions should be strictly followed. Testing should be carried out before any person enters the space, and at regular intervals thereafter until all work is completed. Where appropriate, the testing of the space should be carried out at as many different levels as is necessary to obtain a representative sample of the atmosphere in the space.

6.2 For entry purposes, steady readings of the following should be obtained:

.1 21% oxygen by volume by oxygen content meter; and

.2 not more than 1% of lower flammable limit (LFL) on a suitably sensitive combustible gas indicator, where the preliminary assessment has determined that there is potential for flammable gases or vapours.

If these conditions cannot be met, additional ventilation should be applied to the space and re-testing should be conducted after a suitable interval. Any gas testing should be carried out with ventilation to the enclosed space stopped, in order to obtain accurate readings.

6.3 Where the preliminary assessment has determined that there is potential for the presence of toxic gases and vapours, appropriate testing should be carried out using fixed or portable gas or vapour detection equipment. The readings obtained by this equipment should be below the occupational exposure limits for the toxic gases or vapours given in accepted national or international standards. It should be noted that testing for flammability does not provide a suitable means of measuring for toxicity, nor vice versa.

6.4 It should be emphasized that pockets of gas or oxygen-deficient areas can exist, and should always be suspected, even when an enclosed space has been satisfactorily tested as being suitable for entry.

7 PRECAUTIONS DURING ENTRY

7.1 The atmosphere should be tested frequently whilst the space is occupied, and persons should be instructed to leave the space should there be a deterioration in the conditions.

7.2 Ventilation should continue during the period that the space is occupied and during temporary breaks. Before re-entry after a break, the atmosphere should be re-tested. In the event of failure of the ventilation system, any persons in the space should leave immediately.

7.3 In the event of an emergency, under no circumstances should the attending crew member enter the space before help has arrived and the situation has been evaluated to ensure the safety of those entering the space to undertake rescue operations.

8 ADDITIONAL PRECAUTIONS FOR ENTRY INTO A SPACE WHERE THE ATMOSPHERE IS KNOWN OR SUSPECTED TO BE UNSAFE

8.1 If the atmosphere in an enclosed space is suspected or known to be unsafe, the space should only be entered when no practical alternative exists. Entry should only be made for further testing, essential operation, safety of life or safety of a ship. The number of persons entering the space should be the minimum compatible with the work to be performed.

8.2 Suitable breathing apparatus, e.g. of the air-line or self-contained type, should always be worn, and only personnel trained in its use should be allowed to enter the space. Air-purifying respirators should not be used as they do not provide a supply of clean air from a source independent of the atmosphere within the space.

8.3 The precautions specified in 5 should also be followed, as appropriate.

8.4 Rescue harnesses should be worn and, unless impractical, lifelines should be used.

8.5 Appropriate protective clothing should be worn particularly where there is any risk of toxic substances or chemicals coming into contact with the skin or eyes of those entering the space.

8.6 The advice in 7.3 concerning emergency rescue operations is particularly relevant in this context.

9 HAZARDS RELATED TO SPECIFIC TYPES OF CARGO

9.1 Dangerous goods in packaged form

9.1.1 The atmosphere of any space containing dangerous goods may put at risk the health or life of any person entering it. Dangers may include flammable, toxic or corrosive gases or vapours that displace oxygen, residues on packages and spilled material. The same hazards may be present in spaces adjacent to the cargo spaces. Information on the hazards of specific substances is contained in the IMDG Code, the Emergency Procedures for Ships Carrying Dangerous Goods (EMS) and Materials Safety Data Sheets (MSDS). If there is evidence or suspicion that leakage of dangerous substances has occurred, the precautions specified in 8 should be followed.

9.1.2 Personnel required to deal with spillages or to remove defective or damaged packages should be appropriately trained and wear suitable breathing apparatus and appropriate protective clothing.

9.2 Bulk liquid

The tanker industry has produced extensive advice to operators and crews of ships engaged in the bulk carriage of oil, chemicals and liquefied gases, in the form of specialist international safety guides. Information in the guides on enclosed space entry amplifies these recommendations and should be used as the basis for preparing entry plans.

9.3 Solid bulk

On ships carrying solid bulk cargoes, dangerous atmospheres may develop in cargo spaces and adjacent spaces. The dangers may include flammability, toxicity, oxygen depletion or self-heating, which should be identified in shipping documentation. For additional information, reference should be made to the Code of Safe Practice for Solid Bulk Cargoes.

9.4 Oxygen-depleting cargoes and materials

A prominent risk with such cargoes is oxygen depletion due to the inherent form of the cargo, for example, self-heating, oxidation of metals and ores or decomposition of vegetable oils, animal fats, grain and other organic materials or their residues. The materials listed below are known to be capable of causing oxygen depletion. However, the list is not exhaustive. Oxygen depletion may also be caused by other materials of vegetable or animal origin, by flammable or spontaneously combustible materials, and by materials with a high metal content:

.1 grain, grain products and residues from grain processing (such as bran, crushed grain, crushed malt or meal), hops, malt husks and spent malt;

.2 oilseeds as well as products and residues from oilseeds (such as seed expellers, seed cake, oil cake and meal);

.3 copra;

.4 wood in such forms as packaged timber, roundwood, logs, pulpwood, props (pit props and other propwood), woodchips, woodshavings, woodpulp pellets and sawdust;

.5 jute, hemp, flax, sisal, kapok, cotton and other vegetable fibres (such as esparto grass/Spanish grass, hay, straw, bhusa), empty bags, cotton waste, animal fibres, animal and vegetable fabric, wool waste and rags;

.6 fishmeal and fishscrap;

.7 guano;

.8 sulphidic ores and ore concentrates;

.9 charcoal, coal and coal products;

.10 direct reduced iron (DRI)

.11 dry ice;

.12 metal wastes and chips, iron swarf, steel and other turnings, borings, drillings, shavings, filings and cuttings; and

.13 scrap metal.

9.5 Fumigation

When a ship is fumigated, the detailed recommendations contained in the Recommendations on the Safe Use of Pesticides in Ships* should be followed. Spaces adjacent to fumigated spaces should be treated as if fumigated.

10 CONCLUSION

Failure to observe simple procedures can lead to people being unexpectedly overcome when entering enclosed spaces. Observance of the principles outlined above will form a reliable basis for assessing risks in such spaces and for taking necessary precautions.

* Refer to the Recommendations on Safe Use of Pesticides in Ships, approved by the Maritime Safety Committee of the Organization by circular MSC/Circ.612, as amended by MSC/Circ.689 and MSC/Circ.746.

APPENDIX

EXAMPLE OF AN ENCLOSED SPACE ENTRY PERMIT

This permit relates to entry into any enclosed space and should be completed by the master or responsible officer and by the person entering the space or authorized team leader.

General

Location/name of enclosed space..

Reason for entry..

This permit is valid from:................hrs Date..................
to :................hrs Date...................
(See note 1)

Section 1 - Pre-entry preparation

(To be checked by the master or nominated responsible person) Yes No

- Has the space been thoroughly ventilated ? ❒ ❒
- Has the space been segregated by blanking off or isolating all connecting pipelines or valves and electrical power/equipment ? ❒ ❒
- Has the space been cleaned where necessary ? ❒ ❒
- Has the space been tested and found safe for entry ? (See note 2) ❒ ❒
- Pre-entry atmosphere test readings:
  - oxygen.......................% vol (21%) By:...................
  - hydrocarbon.............% LFL (less than 1%)
  - toxic gases................ppm (specific gas and PEL) Time:................

  (See note 3)
- Have arrangements been made for frequent atmosphere checks to be made while the space is occupied and after work breaks ? ❒ ❒
- Have arrangements been made for the space to be continuously ventilated throughout the period of occupation and during work breaks ? ❒ ❒
- Are access and illumination adequate ? ❒ ❒

	Yes	No
● Is rescue and resuscitation equipment available for immediate use by the entrance to the space ?	❒	❒
● Has a responsible person been designated to be in constant attendance at the entrance to the space?	❒	❒
● Has the officer of the watch (bridge, engine room, cargo control room) been advised of the planned entry ?	❒	❒
● Has a system of communication between all parties been tested and emergency signals agreed ?	❒	❒
● Are emergency and evacuation procedures established and understood by all personnel involved with the enclosed space entry ?	❒	❒
● Is all equipment used in good working condition and inspected prior to entry ?	❒	❒
● Are personnel properly clothed and equipped ?	❒	❒

Section 2 - Pre-entry checks
(To be checked by the person entering the space or authorized team leader)

	Yes	No
● I have received instructions or permission from the master or nominated responsible person to enter the enclosed space	❒	❒
● Section 1 of this permit has been satisfactorily completed by the master or nominated responsible person	❒	❒
● I have agreed and understand the communication procedures	❒	❒
● I have agreed upon a reporting interval of.......................minutes	❒	❒
● Emergency and evacuation procedures have been agreed and are understood	❒	❒
● **I am aware that the space must be vacated immediately in the event of ventilation failure or if atmosphere tests show a change from agreed safe criteria**	❒	❒

Section 3 - Breathing apparatus and other equipment
(To be checked jointly by the master or nominated responsible person and the person who is to enter the space)

	Yes	No
● Those entering the space are familiar with the breathing apparatus to be used	❐	❐
● The breathing apparatus has been tested as follows:		
- gauge and capacity of air supply	....	
- low pressure audible alarm	....	
- face mask - under positive pressure and not leaking	....	
● The means of communication has been tested and emergency signals agreed	❐	❐
● All personnel entering the space have been provided with rescue harnesses and, where practicable, lifelines	❐	❐

Signed upon completion of sections 1,2 and 3 by:

Master or nominated responsible person..................... Date.................. Time................

Responsible person supervising entry .... Date.................. Time................

Person entering the space or authorized team leader .... Date.................. Time................

Section 4 - Personnel entry
(To be completed by the responsible person supervising entry)

Names	Time in	Time out
....	....	....
....	....	....
....	....	....
....	....	....

Section 5 - Completion of job
(To be completed by the responsible person supervising entry)

● Job completed Date.......................... Time......................

- Space secured against entry Date............................ Time.......................
- The officer of the watch has been duly informed Date.............................

Time.........................

Signed upon completion of sections 4 and 5 by:

Responsible person supervising entry .... Date................... Time................

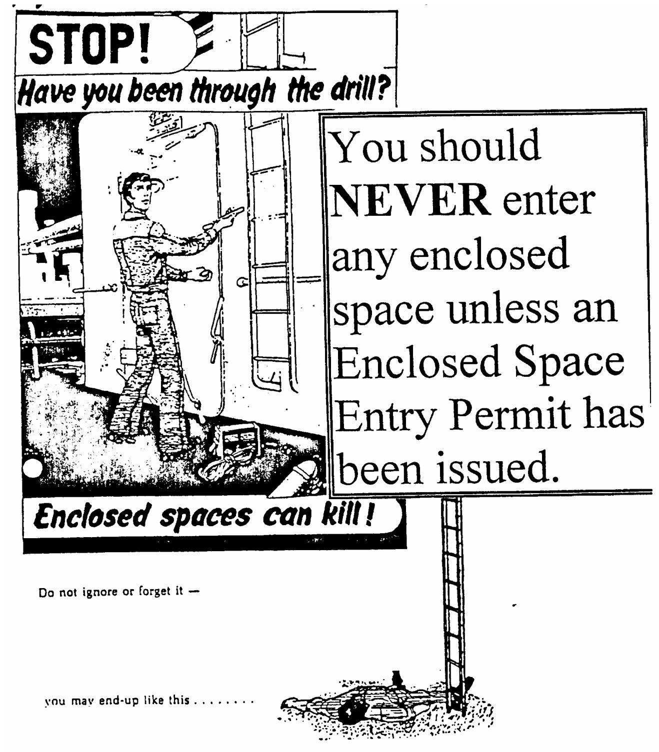
THIS PERMIT IS RENDERED INVALID SHOULD VENTILATION OF THE SPACE STOP OR IF ANY OF THE CONDITIONS NOTED IN THE CHECKLIST CHANGE

Notes:

1 The permit should contain a clear indication as to its maximum period of validity.

2 In order to obtain a representative cross-section of the space's atmosphere, samples should be taken from several levels and through as many openings as possible. Ventilation should be stopped for about 10 minutes before the pre-entry atmosphere tests are taken.

3 Tests for specific toxic contaminants, such as benzene or hydrogen sulphide, should be undertaken depending on the nature of the previous contents of the space.


STOP!
Have you been through the drill?
You should **NEVER** enter any enclosed space unless an Enclosed Space Entry Permit has been issued.
Enclosed spaces can kill!
Do not ignore or forget it —
you may end-up like this ....

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Appendix 2. DSC 14/INF.9 17 July 2009 Revision of the recommendations for entering enclosed spaces aboard ships. (MAIIF information paper)

INTERNATIONAL MARITIME ORGANIZATION

IMO

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SUB-COMMITTEE ON DANGEROUS GOODS, SOLID CARGOES AND CONTAINERS
14th session
Agenda item 16

DSC 14/INF.9
17 July 2009
ENGLISH ONLY

REVISION OF THE RECOMMENDATIONS FOR ENTERING ENCLOSED SPACES ABOARD SHIPS

Enclosed space entry issues

Submitted by the Marine Accident Investigators' International Forum (MAIIF)

SUMMARY

Executive summary:	This document provides information on enclosed space entry incidents that have occurred since 1998, and which have given MAIIF serious cause for concern and discussion at recent meetings
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	-
Action to be taken:	Paragraph 8
Related documents:	IMO resolution A.864(20); DSC 13/20, annex 4; MSC 85/26, paragraph 23.7; FSI 17/20, paragraphs 6.6 and 6.7 and MSC 86/26, paragraphs 10.18 and 13.22

Background

1 IMO resolution A.864(20) on Recommendations for entering enclosed spaces aboard ship was adopted at the twentieth Assembly on 27 November 1997. It invites Governments to bring the recommendations to the attention of shipowners, ship operators and seafarers, urging them to apply the recommendations, as appropriate, to all ships.

2 The object of the Recommendations is to encourage the adoption of safety procedures aimed at preventing casualties to ships personnel entering enclosed spaces where there may be an oxygen deficient, flammable and/or toxic atmosphere. They are practical recommendations that apply to all types of ships and provide guidance to seafarers, which are intended to complement national laws or regulations, accepted standards or particular procedures which may exist for specific trades, ships or types of shipping operations.

3 A preliminary survey of MAIIF members (attached at annex) reveals that there have been at least 101 enclosed space incidents resulting in 93 deaths and 96 injuries, since the Recommendations were adopted in November 1997.

4 Areas of concern identified in the reports include, *inter alia*:

.1 lack of knowledge, training and understanding of the dangers of entering enclosed spaces;

.2 Personal Protective Equipment (PPE) or rescue equipment not being used, not available of inappropriate type, improperly used, or in disrepair;

.3 inadequate or non-existent signage;

.4 inadequate or non-existent identification of enclosed spaces on board;

.5 inadequacies in Safety Management Systems; and

.6 poor management commitment and oversight.

5 MAIIF believes that the investigations show that, from many of the casualties investigated, it is evident that training was inadequate, and that the necessary drills were not carried out in the procedures for safe entry and safe rescue from enclosed spaces. Training may remain ineffective if not backed up by a positive management level commitment to managing safety, assessing competence and training needs on board, and developing a safety culture from the company head-office to the master, the officers and the ratings.

6 MAIIF notes from the report of the MSC 85 the new work programme item to revise, as necessary, the specific provisions of the Recommendations for Entering Enclosed Spaces Aboard Ship, under the coordination of the DSC Sub-Committee.

7 At the eighty-sixth session of the Maritime Safety Committee, the Committee agreed to invite MAIIF to provide the Organization with the outcome of its work on deaths in enclosed spaces, as the findings thereof may be relevant to the consideration of the issue of explosions on small chemical tankers. However, it is clear from the work already done by MAIIF, that some of the provisions of the Recommendations for Entering Enclosed Spaces Aboard Ship are not being universally applied. MAIIF therefore considers that the information provided will assist the work of the Sub-Committee in coordinating the revision of the Recommendations for entering enclosed spaces aboard ship, and will provide any additional information as may become available.

Action requested of the Sub-Committee

8 The Sub-Committee is invited to note the contents of this document in the context of consideration of agenda item 16 and to take action as appropriate.

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PRELIMINARY SURVEY REPORT ON ENCLOSED SPACE INCIDENTS

Incident	Approx. Date	Ship Type	Reporting Authority	Confined Space	Condition of Space	Deaths	Injuries	Comments	Notes on Investigation	Vessel Flag (if other than reporting authority)
1	01/03/1998	Cargo	Cyprus	Tunnel	Tunnel, below loaded cargo holds	3	0	The vessel carried wheat and the cargo had been fumigated with Aluminum phosphide - Phostoxin. Water was observed in Hold No.1 and in the duct keel. Three crew members entered tunnel for inspection, but they lost their lives due to the presence of phosphire gas. A Fumigation notice stated that the above product generates phospire gas (PH3) and that the fumigated spaces must be completely sealed for ten days. The presence of water was due to minor hull damage.		
2	28/04/1998	RoRo Vehicle/ Passenger ferry	UK MAIB	Deck locker		0	1	Young female passenger, who was under the influence of alcohol, crossed security chains and entered restricted space on small ferry. She was located after vessel had shut down for the night in a small deck locker. She was suffering from smoke inhalation having inadvertently placed clothing on a heater.		
3	14/05/1998	Aggregates Dredger	UK MAIB	Engine Room	Unknown	0	1	Using a burning torch to cut a pipe ring in the engine room caused a vapor to be given off. Work stopped and both the personnel involved with the task moved away. One of them experienced breathing difficulty. it is thought that the burner vaporized sealant of some other substance trapped below the pipe ring. The work was completed using a grinder.		
4	02/10/1998	Fishing Vessel	U S C G	Pipe Tunnel Void	Low O2 and Toxic Environment, Access Procedures	1	4	Crewman was asphyxiated by lethal levels of hydrogen sulfide, carbon monoxide, and depleted oxygen when he entered a pipe tunnel void researching an odor and clam hold drain leak onboard moored clam dredge vessel. The following rescue personnel were also treated for hydrogen sulfide exposure: 1 crewman from the same vessel, 2 crewmen from an adjacently moored F/V, and 1 police officer.		
5	05/01/1999	Bulk/oil carrier	UK MAIB	Duct Keel	Unknown	0	1	Seaman overcome by fumes while working in duck keel of tanker. All proper precautions taken and other crew with him were not effected.		Bahamas
6	16/01/1999	Oil tanker	UK MAIB	Cargo Oil Tank	Gasoline	0	1	Crewman entered cargo oil tank. After placing eductor pump in suction well he collapsed. Atmosphere had been tested before entry. Tested immediately after incident and found gas free. Presumed cause was isolated pocket of gas in tank.		Gibraltar
7	03/02/1999	Tug/anchor handling vessel	UK MAIB	Store Space	Carbon monoxide	0	1	Use of petrol driven salvage pump in store space caused one crew member to suffer minor carbon monoxide poisoning .		
8	18/02/1999	General cargo multi-deck	UK MAIB	Hold	Oxygen depletion	1	0	Crew member entered partitioned area of hold during carriage of steel turnings. He died of asphyxiation.	Investigated by Bahamas Maritime Authority	Bahamas
9	23/04/1999	Chemical Tanker	IOM	Cargo Tank - previous cargo HMD and Nitrogen blanket	Nitrogen, Oxygen depletion	2	0	Very similar to Bow Wind comments. There was a practice on board of taking a deep breath and going to first platform to see if clean, cutting corners to save time. Pumpman died, cadet tried to rescue wearing a filter mask and also died. Subject of "Silent Assassin" video.		

10	19/07/1999	Barge	U S C G	Cargo Tank	Low O2 and Toxic Environment, Access Procedures	1	0	At a Barge Cleaning Facility, a shipyard worker entered the #1 cargo tank. He was later found by co-workers lying unconscious on the bottom of the hold and was extracted from the hold, and personnel conducted CPR until an ambulance arrived. He was transported to Hospital where he was pronounced dead. Apparent cause of death was asphyxiation due to exposure to an oxygen deficient environment. Investigation found that he had received the safety training Respirator fit test and training, Confined space entry, Workplace safety training (hazardous communications) and concluded that cleaning facility had inadequate enforcement of their confined space entry and securing procedures.		
11	26/08/1999	Naval support	UK MAIB	Unknown	Sodium metabisulphite	0	1	Accidental release of sodium metabisulphite vapor during cleaning of reverse osmosis plant. Injured crew member was not wearing sufficient personal protective equipment.		
12	25/09/1999	RoRo Vehicle/ Passenger ferry	UK MAIB		Ammonia	0	1	Crew member suffered injury due to accidentally inhaling ammonia gas while moving a faulty refrigerator. Ammonia refrigerators to be removed from vessel.		
13	03/02/2000	Tanker	Latvia	Cargo tank	Ventilated. cargo fumes	1	0	While climbing up the stairs after cargo tank cleaning sailor fell back to the tank bottom from five meter height and lost his life. The causes of the accident: 1) lack of the tank-working permit; 2) lack of the safety line while climbing up.		
14	01/04/2000	Dry Cargo -Reefer	Liberia	Cargo Hold	Oxygen Deficiency	1	0	Cocaine Smuggler found dead in Cargo Hold.		
15	05/04/2000	Ore carrier	UK MAIB	Hold	Bulk coal	2	1	Military intelligence decided to search vessel using combined naval, marine and specialized army search team. Holds to be searched if ventilated/time allowed. 2 army entered hatch, no pre-entry tests. Both men became unconscious, corporal entered space without pre-testing, became unconscious.	Investigated by MAIB http://www.maib.gov.uk/publications/investigation_reports/2001/mv_diamond_bulker.cfm	Philippines
16	18/05/2000	Tank Ship	U S C G	Cargo Tank	Entering Toxic Environment without protective clothing, access procedures	1	0	Vessel enroute Houston, TX after discharging a cargo MTBE. Two days after departure the pumpman entered number #1 center cargo tank for cleaning with a respirator & EEBA. The pumpman retrieved from inside the tank by ships crew. CPR was administered but was unsuccessful. Autopsy concluded the pumpman died of "toxic fumes intoxication secondary to MTBE exposure."		
17	10/06/2000	Fish Catching	UK MAIB	Engine Room	Carbon Monoxide	1	0	Portable petrol-engined pump being used to pump bilges of fishing vessel. Pump and engine placed in engine room with no ventilation. Engineer was fatally affected by carbon monoxide fumes from engine's exhaust.	Investigated by MAIB http://www.maib.gov.uk/publications/investigation_reports/2001/fv_mariama_k_fr242.cfm	
18	10/09/2000	General cargo - single deck	UK MAIB	Cargo hold	Carbon monoxide	1	0	Seaman found lying at bottom of no.2 hold access shaft. Atmospheric tests on access shaft to hold showed very low levels of oxygen & high levels of carbon monoxide. Apart from distinctive smell, chemical reaction in shaft or in timber in hold. Tests on timber sample showed no evidence of preservatives or any apparent reason for low oxygen & high carbon monoxide atmosphere.	Investigated by MAIB http://www.maib.gov.uk/publications/investigation_reports/2001/baltyskiy.cfm	Russia
19	19/10/2000	Tanker/ combination carrier	UK MAIB	Cargo tank	Inert gas	0	1	Crew member entered a cargo tank after cleaning to retrieve a pair of gloves despite being aware of the dangers from inert gas. He collapsed, a rescue using "SCBA SEDS" was carried out and the man rescued.		
20	29/10/2000	General cargo single deck	UK MAIB	Cargo hold	Oxygen depletion, Carbon Monoxide	1	0	Master entered cargo hold on coaster, whilst at anchor sheltering and was overcome by fumes from coal cargo. Oxygen content found to be below 3.5% and carbon monoxide found present.		Holland

21	24/11/2000	General Dry Cargo Ship	NOR NMD	Cargo Hold	Probably low O2-level in cargo hold	2	1	OS painted access hatch for cargo hold. The hatch was open. Observed unconscious. Two persons entered the cargo hold without BA to rescue the OS. One of them survived due to resuscitation.		
22	01/12/2000	Chemical tanker (Inland)	Netherlands	Cargo tank	Low O2 environment, Access Procedures	1	0	After discharging a naphtha cargo, the cargo inspector declared the cargo tank unfit for the intake of different chemical load, remains of the naphtha still being present. The master decided to clean the tank himself. Although all the right equipment was available and the master was well informed and experienced, he nevertheless entered the tank relying on a full face mask with filter for naphtha vapors. He did not take a possible low oxygen level into account and died of oxygen deficiency.		
23	10/05/2001	Oil tanker	Latvia	Ballast tank	Insufficient ventilation during spray-painting	1	1	During spray painting with toxic paint in the ballast tank safe working regulations were violated – air respirators were used instead of breathing apparatus. As a result one worker lost his life and another got toxic poisoning. The accident was facilitated by prolonged evacuation of victims from the tank (almost 5 hours).		Liberia
24	04/09/2001	Chemical Tanker	IOM	Cargo tank- previous cargo Naphtha	30% LEL and no O2 checks	1	1	Educting tank residues all day, occasionally checking atmospheres, crew refusing to wear SCBA only filter masks, condoned by C/O - lucky they didn't all die! Cutting corners to save time and effort in port. Master died of a heart attack during rescue.		
25	05/10/2001	Oil Tanker	Liberia	Ballast tank	Oxygen Deficiency	1	1	One Ship yard Worker died due to asphyxiation while painting ballast tank and one Ship yard Worker injured due to intoxication by hydrocarbon gas.		
26	02/11/2001	Pelagic Fishing Vessel	SAMSA	Fishhold	Oxygen depletion	2	0	2 crew members entered the fishhold to clean, 2 days after a catch of pelagic fish had been discharged. Oxygen content too low to sustain life.		
27	30/11/2001	Tanker	Latvia	Double bottom fuel tank	Ventilated	1	0	Severance was performed in ships double bottom fuel tank (DB FT). Gas cylinders were located on the main deck and gas hoses were put through openings down into DB FT. In same time the electrical welding was performed in the pump room above the DB FT. After a short break, steel cutting works were being recommenced and fire in DB FT broke out. As a result the worker lost his life. The probable causes of accident were: gas hose damage after contact with hot metal surface inside DB FT or hose contact with drops of melted steel from the pump room.		

28	17/11/2001	Bulk Carrier	Australia ATSB	Ballast Tank	ntilated, non-intrinsi	8	0	With the ship waiting at anchor off Dampier to load, the crew were preparing and painting the interior of no.1 port topside ballast tank. At about 1430 on a hot Sunday afternoon, the eight-man deck crew started work painting the steelwork inside the tank. One man was spray painiting inside the empty tank while the rest of the deck crew maintained the paint reservoir and tended a cargo light lowered into the tank through the after manhole. An open-ended compressed air hose was led from the forecastle, along the deck and down through this after manhole, while an electrically driven fan was positioned over the after manhole to ventilate the tank. The paint being used was a two-part epoxy mix, excessively thinned because of the hot day. At about 1640 a large explosion ripped through the tank. It is likely that the cargo light was inadvertently dropped into the tank which caused the incandescent bulb to break which then ingnited the heavier-than-air paint fumes trapped in the frames spaces at the bottom of the tank. The tank was ruptured and three men were blown down the length of the main deck, killing them all instantly. The explosion also blew four other men over the ship's side. One man, who had been inside the tank, still alive although severely burned was assisted out of the tank, through the ruptured maindeck plating, and airlifted ashore. He died 18 days later in hospital.		Hong Kong
29	17/12/2001	Bulk Carrier	Liberia	Cargo Hold	Oxygen Deficiency	1	0	Chief Mate died due to lack of oxygen in the cargo hold		
30	04/01/2002	Oil/chemical tanker	UK MAIB	Cargo Tank	Gasoline fumes	0	1	AB developed problem with BA mask and removed/lost his face mask, became unconscious. Enclosed spaces checklist and company procedures were not followed.		Gibraltar
31	10/01/2002	Oil tanker	UK MAIB	Cargo or other tank space	Unknown	0	1	Bosun entered untested enclosed space and collapsed as a result		Gibraltar
32	08/02/2002	Prawn Freezer Trawler	SAMSA	Machinery space	Oxygen depletion	1	0	Chief Engineer found dead in machinery space after working on refrigeration system.		
33	31/03/2002	Ro-Ro Cargo Ship	U S C G	Engineroom	Low O2 Environment, Fire fighting and recovery procedures	2	0	The vessel had a fire in the engine room. At approx 0645, the vessel master released CO-2 to extinguish the fire. At approx 0745, a team led by the Chief Mate entered the engine room and reported that the fire was out. At approx 0815, the team made a second entry to further evaluate the extent of the damage and the ability of the ship to get underway. During this entry, the Chief Engineer fell unconscious down a stairwell near the start-air tanks to the lower engine room deck. He was assisted by the Chief Mate, 1st Asst Engineer and 3rd Asst Engineer. The 3rd Asst Engineer exited to get help.The Chief Engineer awoke alone at the bottom of the stairwell wearing an emergency air pack (ELSA). He departed the engine room through a nearby escape trunk. A rescue team, entering to assist, found the Chief Mate and 1st Asst Engineer aft of the MDE. It appears they were in the process of exiting the engine room when they ran out of air. After extracting them from the engine room, the crew initiated CPR efforts but were unable to revive them. The autopsies ruled that the crewmembers died of asphyxia due to oxygen deficiency combined with carbon dioxide inhalation.		

34	20/04/2002	Freezer Trawler	SAMSA	Machinery Space	Oxygen depletion/refrigeration gas	2	0	Greaser was instructed to clean the filter on a refrigeration system. Filter not isolated. R22 entered the compartment displacing the oxygen, being heavier than air. Chief Engineer went to check on progress noted the Greaser collapsed on the plates and entered the compartment. Both died.		
35	06/08/2002	Hopper Barge	MAI Hong Kong	Void Space adjacent to cargo hold	Oxygen depletion, Carbon Monoxide	2	0	Two local seamen died after entering the void space adjacent of a cargo hold. Carbon monoxide gas had accumulated in the space and depletion of oxygen took place inside the space due to rusting of vessel structure. The space had not been ventilated before they entered into it.	Investigated by MAI Hong Kong http://www.mardep.gov.hk/en/publication/pdf/mai020806.pdf	Locally licensed barge in Hong Kong
36	06/08/2002	Tanker	NOR NMD	Cargo tank	Low O2 Environment, Methane atmosphere	0	2	AB entered the Tank in connection with tank cleaning. The tank was not ventilated and the atmosphere was not tested. The AB lost consciousness due to Methane poisoning.		
37	29/08/2002	Offshore	U S C G	Leg of drilling rig, void spaces	Low 02 environment	2	0	2 shore staff were working on the rig. They were sent into a leg of the rig to install ventilation and lights. According to findings the leg was Oxygen deficient. The two personnel who entered the compartment died of "Asphyxiation".		
38	01/09/2002	General dry Cargo Ship	U S C G	Cargo Hold	Low O2 Environment, Access Procedures	0	1	While in a cargo hold collecting stacking cones, an AB fell approximately 10 feet to the level below. He was found by a shipmate several minutes later in a pool of blood. There were no witnesses to the actual fall, and the victim does not remember what happened. He sustained several injuries, including a fractured skull, a broken rib, a punctured lung, and a broken left wrist. Inestigating officer theorized that oxygen deficiency in the space may have caused the mariner to pass out and fall.		
39	09/09/2002	Fishing Vessel	U S C G	Engineroom	Refrigerant leak	0	1	In the Pacific Ocean, 112 nm west of point St. George, a refrigeration leak occurred in the engine room. Crew member attempted to repair the leak but was overcome by freon gas in the enclosed space and lost consciousness for 20-25 seconds. The victim was medevaced and transported to hospital. Vessel ventilated the engine room and the leak was repaired.		

40	02/12/2002	Bulk Carrier	U S C G	Cargo Hold	Low O2 and Toxic Environment, Access Procedures	1	1	At Dar Es Salaam, Tanzania hatches to #3, #5, #6 and #7 were opened for discharge of cargo. At about 0935 two Tanzanian Agricultural inspectors arrived to inspect holds #5 and #7 for quality of cargo. At about 1030 another inspector arrived aboard with 24 Agricultural trainees, requesting they be allowed to observe the inspection process. Although the master refused initially he eventually relented and referred the matter to the Chief Officer who instructed the students to view the cargo operations from the deck level only. At about 1125 the master was notified a man collapsed in cargo hold #3. A rescue team was formed. Deck crew responded with a first aid kit and noticed an individual lying about six feet below on top of the cargo inside the #3 cargo hold trunk hatch. The Chief Mate return with a gas mask, used for fumigant whcih had been used to fumigate the carge after loading, and an EEBD. The Chief Mate put on the gas mask and entered the space. The Chief Mate attempted to put the EEBD on the down person but collapsed. When the master arrived on scene he instructed AB to get an SCBA who then entered the space with a rescue line and block. At about 1135 the Chief Mate was recovered. The master checked the Chief Mate for vitals, found no pulse or respiration, and immediately started CPR. At about 1137 the Chief Mate responded to CPR, breathing on his own. At about the same time the original man down was brought up. The master checked for vitals, found no pulse or respiration. and immediately started CPR. He did not respond to CPR and the master then used the vessel's portable AED to defibulate the patient. He did not respond and CPR was continued until paramedics arrived at about 1215. At about 1230 the Chief Mate was removed to an awaiting ambulance and was taken to the hospital in critical condition. At about 1240 the original person found in the hold was removed to an awaiting ambulance but was pronounced dead. At 1330 atmospheric readings were taken from the #3 cargo hold trunk and found to be 3% Oxygen. The post-Mortem Examination stated that the primary cause of death was due to head injury. The deceased was not authorized entry into the #3 cargo hold. The Chief Mate did not follow proper procedures for confined space entry.		
41	12/04/2003	Pair trawler	UK MAIB	Cargo – fishroom	Hydrogen sulphide fumes	0	2	Two crew who were working in the fish hold ended up with very sore eyes and extremely bad head aches. A study following a similar accident suggested that hydrogen sulphide fumes were to blame. The problem was eventually solved by removing the concrete floor, and replacing it, sealing it correctly.		
42	21/05/2003	Scallop/ queenie dredger	UK MAIB	Cargo - fishroom	R409A	0	1	A shoreside engineer was overcome by gas R409A while working on the refrigeration system. In future the skipper intends to open all the fish room hatches when the refrigeration system is being worked on.		

43	26/06/2003	Barge	U S C G	Cargo Tank	Low O2 and Toxic Environment, Access Procedures	0	2	2 collapsed while working in the barge. The first crew member entered the barge to pump out the water when he was overcome by the lack of oxygen in the space. He fell approximately 10 ft, injuring his head. The second crew member went in to provide assistance. He was also overcome by the lack of oxygen. A third person was lowered into the tank via rope and was also overcome but was able to be pulled out. The owner of the cleaning company notify Emergency Response and then placed a ventilator into the space. A Good Samaritan provided assistance, holding his breathe went down into the tank placing a rope around both individuals. Both crew members were pulled safely out of the barge and transferred to Hospital. Both men were breathing but unconscious when they arrived at the hospital. They since recovered.		
44	08/07/2003	Bulker	RMI	#6 Fwd Cargo Hold	Oxygen Deficiency	0	2	Fitter and Chief Officer fainted in the first platform of No.6 Fwd Cargo Hold entry due to lack of oxygen.		
45	10/09/2003	Surface craft	UK MAIB	Other internal deck/space	Hydrogen sulphide	0	1	Whilst conducting planned maintenance cleaning of a sewage treatment plant with two assistants the engineer officer was overcome by hydrogen sulphide after disturbing the sludge with a fire hose. The plant had been shut down previously for several days but the hose was required to break up the heavy sludge.		
46	13/10/2003	Liquid gas carrier	UK MAIB	Engine room	Hydrogen gases	1	1	2 shore workers chemically cleaning a main boiler, the steam drum door had been opened to allow for inspection of the clean. As the contractors approached the drum a non-intrinsically safe halogen lamp was passed into the drum. There immediately followed an explosion which caused fatal injuries to the UK worker and serious 30% burns to a Danish national. The chemical used to remove the boiler scale and corrosion was nitro's descalex. This inhibited Sulphamic acid cleaner also contained a coloring agent to indicate the acid strength. The inhibitor Provided a protective coating on the internal steel surfaces of the boiler so that it was protected From acid attack, which produces hydrogen gas.	Investigated by MAIB http://www.maib.gov.uk/publications/investigation_reports/2007/hilli.cfm	
47	24/10/2003	Container	Germany	Scavenge Air Receiver	The autopsy report revealed cardiovascular failure due to hyperthermia as cause of the death	1	0	Engineer entered scavenge air receiver again after work was completed, no safety watch was posted; he got locked inside due to construction of "dogs" used for locking the access hatch; inappropriate search measures were applied when it became known that the engineer was missing; time/commercial pressure and relationship between crew members might had contributed; even though the scavenge air receiver was known to be the last working place of the engineer it had not been opened before departure as the main engine had already been started and opening of the access hatch would had required to shut down the main engine again; the engineer was found dead two days later in the next port of call.	Investigated by BSU; http://www.bsu-bund.de/	
48	18/11/2003	Bulk Carrier (Carrying lumber)	MAI Hong Kong	Access passage to cargo hold	Oxygen depletion, Carbon Monoxide	1	0	A seaman died after entering the access passage. The space had not been ventilated before entry. The bio-deterioration characteristic of lumber absorbed the oxygen from the surrounding atmosphere and through the access door into the access passage.	Investigated by MAI Hong Kong	

49	24/11/2003	Tank Ship	U S C G	Forepeak Tank	Low O2 and Toxic Environment, Access Procedures	0	1	A shipyard worker was incapacitated by paint fumes when he entered the forepeak tank. The tank had been recently painted and everyone was told not to enter the tank, however when the job supervisor returned from locating an extension cord for the forced air blower, he found the worker lying at the bottom of the tank unconscious. He immediately notified the Master, who had the ship's emergency evacuation detail don SCBAs and remove the individual from the tank. EMS and ship's medical personnel administered oxygen to the victim until he was evacuated to a nearby hospital, treated and released.		
50	12/12/2003	Oil Tanker	Liberia	Cargo Tank	Oxygen Deficiency	1	0	Death of Ordinary Seaman by asphyxiation due to explosion inside the cargo tank during repair works at Lisnave shipyard.		
51	03/01/2004	Tanker/combinatio n carrier	UK MAIB	Engine Room	Carbon monoxide	0	2	While discharging gas oil, an engineer became unconscious. About 55 minutes later, a motorman who had been working him also lost consciousness. Engine room was vented. Higher levels of CO, were detected and the IG plant, which had been kept working to provide a positive pressure on the tanks, was immediately shut down. A high concentration of co was found aft of the funnel, where the plant's atmospheric outlet valve is sited. This was due to the low discharge rate. It was assessed that the co was carried into the engine room by a vent fan.		Germany
52	25/01/2004	General cargo	Finland	Cargo Hold casing	Low O2 Environment, Access Procedures	2	1	Young OS, new on board went look for brushes to clean hatchcovers after deck cargo (logs) discharge. Fell down to bottom of the casing. Chief officer went to help, fell down. Third man tried to go down to help, felt dozy…managed to climb back to deck.		
53	01/04/2004	Bulk Carrier	MAI Hong Kong	Bilge space enclosure beneath cargo hold	Oxygen depletion	2	0	A Chief Officer and a Cadet died inside a bilge space enclosure after entry. The space had not been opened for some time and was not ventilated before entry. The Chief Officer was likely to have consumed more alcohol than he was allowed under the prescribed limit.	Investigated by MAI Hong Kong http://www.mardep.gov.hk/en/publication/pdf/mai040104.pdf	
54	02/04/2004	Bulker	Vanuatu	Cargo hold	Oxygen deficiency	1	1	AB entered the hold to take cargo samples without standby personnel and without PPE. Cadet attempted to rescue him.		
55	27/05/2004	Oil tanker	CHILE	Cargo Tank	Gasoline	0	5	Crew members were manually cleaning the cargo tanks, which had been ventilated previously. Fuel leaks in the waste disposal hoses polluted the environment. Oil gases were detected by safety teams, however the crew did not notice this fact. There was no autonomous breathing system available.		
56	12/06/2004	Chemical Tanker	MAI Hong Kong	Cargo Tank	Nitrogen, Oxygen depletion	1	0	A pumpman died after taken a quick dash to the upper ladder platform of a cargo tank in an attempt to retrieve the helmet for the cargo surveyor. The tank had been purged with nitrogen.	Investigated by MAI Hong Kong http://www.mardep.gov.hk/en/publication/pdf/mai040612.pdf	
57	15/09/2004	Naval support	UK MAIB	Store space	Formaldehyde	0	1	Leaking cans of fluid for chemical toilets created noxious fumes, which were inhaled by this crew member. The data sheet on board was for the chemical toilet fluid that did not contain formaldehyde, however the fluid actually carried did contain formaldehyde.		
58	29/03/2005	General Dry Cargo Ship	U S C G	Cargo Hold	Low O2 Environment, Access Procedures	0	3	Vessel sailed from Oakland. A day later while approximately 150 miles West of LA, 3 crew members went into a hold (with wood pellets) to try to secure some cargo that had broken loose and were overcome by oxygen depravation. They were removed, treated and have recovered..		

59	29/04/2005	Stern trawler	UK MAIB	Machinery space	R22	0	1	Contractor inadvertently drilled into a R22 refrigerant liquid line, thinking it to be gas free. This immediately released liquid/gas into the machinery space. Four contractors were taken to hospital to be checked over and one remained in hospital for 2 Nights for observation and was then released.	Investigated by UK Health and Safety Executive	
60	21/05/2005	Tanker	RMI	Tank #5- Port COT	Oxygen Deficiency	2	0	While removing the suction hose, one AB said to another he felt bad, then his eyes rolled up and he collapsed. . The Chief Mate exited the tank to put on a SCBA and returned the tank to find another AB was motionless. The two A.B.s were unable to be revived. The autopsy revealed the 2nd individual to collapse had abrasions on his head, which could have been consistent with hitting it as a result of a fall.		
61	01/06/2005	Fishing	Sweden	Hold entry.	Non vent.	2	1	Was going to clean the hold from rotting herring		Lithuania
62	01/08/2005	Gen.cargo	Sweden	Hold entry.	Non vent.	1	0	Entered without breathing app. when fetching tools for hold cleaning	Investigated by SMSI Sweden http://www.transportstyrelsen.se/Global/Sjofart/Dokument/Haverirapporter/E_2005/2005_08_19_torrlastfartyget_eken_sbji_olycka_med_dodlig_utgang.pdf (In Swedish)	
63	24/10/2005	Oil Tanker	Liberia	Cargo Tank	Oxygen Deficiency	1	0	Ordinary Seaman asphyxiated while cleaning liquid residue from the cargo tank during vessel's passage from Mangalore, India to Dubai, UAE.		
64	10/12/2005	Fish catching	UK MAIB	Cargo – fishroom	Carbon monoxide	0	2	A portable engine driven pump was lowered into the fish room to relieve flooding. Two crewmen were overcome by the pump's exhaust fumes, one of them losing consciousness.		
65	30/01/2006	Fish catching (25gt)	UK MAIB	Cabin	Carbon monoxide	1	0	Crew member using vessel as temporary accommodation placed portable petrol driven generator in fish hold adjacent to cabin area to provide power to cabin area. The bulkhead between the spaces was not gas tight and the crewman died from inhaling exhaust fumes.	Preliminary examination carried out by MAIB http://www.maib.gov.uk/publications/comlpleted_preliminary_examinations/completed_preliminary_examinations_2006/pamela_s.cfm	
66	04/03/2006	General cargo	CHILE	Ballast tank/ Cargo hold	Sulfuric Acid	1	1	Crew members entered a tank in which fish oil had been transported and which afterwards had been filled with ballast water. They worked inside for several hours without any problems. A pocket of sulphuric acid that was formed inside the tank intoxicated them. There was no autonomous breathing system available.		
67	26/04/2006	Bulker	RMI	#4 Cargo Hold Manifold	Oxygen Deficiency	1	1	While the vessel was discharging coal one A.B. died and another A.B. was injured due to lack of oxygen in #4 Cargo Hold Manhole.		
68	10/07/2006	Container	UK MAIB	Tank container	Hydrochloric acid	0	8	8 people, 6 dock workers and two crew, were slightly injured when a cargo of titanium tetrachloride, which was being carried in a tank container, was contaminated by water in the container's steam heating system. The subsequent reaction cause hydrochloric acid to escape in vapor form and it was breathing this that caused the injuries.	German investigation carried out http://emsa.europa.eu/Docs/accidents/10-212.pdf	Korea
69	27/08/2006	Container	RMI	Hold #4	Oxygen Deficiency	1	0	While the vessel was enroute to Istanbul, Turkey, the engine cadet was engaged in entry into hold #4 in order. He consequently lost consciousness due to oxygen deficient atmosphere due to leakage of tank container containing liquid argon IMO 2.2 U.N. 1951.		

70	25/09/2006	Bulker	RMI	Cargo Hold	Oxygen Deficiency	1	1	The O/S and Bosun went down into the cargo hold for taking cargo sample without specific instruction not received from Master nor Chief Officer. The crew members went down into cargo hold #5 in order to retrieve a cargo sample, and suffocated while in the cargo hold.		
71	12/10/2006	Chemical Tanker	NOR NMD	Cargo tank	Not ventilated. Nitrogen atmosphere, Low O2	1	0	Cleaning the tank. Chief officer entered tank without Breathing Equipment. The Tank had less than 2 % O2.		
72	16/11/2006	Bulk Carrier (Carryingwooden pellets)	MAI Hong Kong	Access passage to cargo hold	Oxygen depletion, Carbon Monoxide	1	4	A seaman died and a shore worker seriously injured after entering the access passage. The space had not been ventilated before entry. The bio-deterioration characteristic of lumber absorbed the oxygen from the surrounding atmosphere and transferred to the access passage. (According to Sweden 7 others were sent to hospital but were released.)	Investigated by MAI Hong Kong and SMSI Sweden http://www.mardep.gov.hk/en/publication/pdf/mai061116_f.pdf. http://www.transportstyrelsen.se/Global/Sjofart/Dokument/Haverirapporter/D_2006/2006_11_16_bulkfartyget_saga_spray_vrww5_dodsfall.pdf (In Swedish)	Sweden
73	01/12/2006	Gen.cargo	Sweden	Hold entry.	Non vent.	1	0	Entered without breathing app.		
74	01/12/2006	Tanker	Sweden	Deck	Open air	0	2	Opened a pipe to take cargo sample	Investigated by SMSI Sweden http://www.transportstyrelsen.se/Global/Sjofart/Dokument/Haverirapporter/D_2006/2006_12-27_oljetankfartyget_stoc_regina_sgox_peronskada.pdf (In Swedish)	
75	06/12/2006	Fish catching	CHILE	Fishhold	Sulfuric Acid	1	0	A crew member entered the fish cargo hold, without previously measuring the gas conditions, after which he fell down inside the hold as he lost consciousness because of the sulphuric acid released from decomposing fish. □		
76	13/12/2006	Chemical Tanker	NOR NMD	Cargo tank	Not ventilated. Cargo atmosphere (hexene-1)	0	2	Deck cadet entered tank on bosun's order without PE, lost consciousness. Bosun entered tank without PE to assist, lost consciousness. AB stationed at hatch raised alarm, AB and Chief Officer. entered tank with PE and rescued cadet and Bosun.		
77	01/01/2007	River launch (15 gt)	UK MAIB	Wheelhouse	Carbon monoxide	0	2	Over a period of up to two months several crew from a river launch were exposed to carbon monoxide in the wheelhouse. The air intake to the heater was located in the engine compartment. The possibility of exhaust leaks in the trunking or of engine exhaust re-entering through the engine vents considered the most likely source of co.		
78	07/02/2007	Fish catching liner	UK MAIB	Shark oil storage/ cargo tank	Unknown	1	3	Shore contractors at non UK port boarded the vessel to clean the shark oil storage/cargo tank. The atmosphere was not tested before entering; no breathing apparatus was being worn and no forced ventilation was provided. One worker succumbed to the fumes (& later died). Three other workers also suffered from the effects while rescuing their colleague.	Investigated by Spanish authorities (Capitnaeria Maritime) from Vigo.	

79	04/03/2007	Oil Tanker	Liberia	Slop Tank	Oxygen Deficiency	2	0	Death of OS and AB due to entry into VOID spaces and inhalation of toxic gases. OS and AB (to rescue the OS) entered into slop tank without carrying breathing apparatus and wearing only a portable dust mask which was not appropriate. The OS and the AB did not receive the Chief Officer's permission and they apparently ignored three other crew members' protests forbidding them to enter the slop tank.		
80	15/03/2007	Refrigerated Cargo Ship	U S C G	Cargo Hold	Low O2 Environment, Access Procedures	2	0	Investigation conducted jointly with Liberia. Vessel is constructed to carry fruit concentrate. Cargo tanks are clustered independently in segregated cargo holds with typical cargo and nitrogen gas supply piping. During cargo operations, 2 officers were found unconscious in the number cargo hold and were extracted by the crew. The first responders began CPR before EMS paramedics arrived but officers were pronounced dead at the scene. The deck officer entered the cargo hold for routine pre-departure checks. When he didn't return topside, the Chief Mate entered the cargo hold to look for him. It was determeind that the rupture disk (safety device) installed on the cargo tanks, overfill tank, failed allowing nitrogen gas to be released into the cargo hold. The date and time of the breach of the rupture disc is unknown.		Liberia
81	Apr-07	Tanker	Cyprus	Cargo Tank	Empty, last cargo was naphtha, not inerted.	1	0	Pumpman carried out stripping of the tanks. Flow rate was slow, so he entered the tank without permission, without proper equipment and without notifying anybody. It was his first day as Pumpman.		
82	23/05/2007	General Cargo	IOM	Cargo hold - completed laden voyage with pulp logs	No Oxygen and carbon monoxide	2	1	Bosun entered hold via access hatch to collect equipment. Discovered missing and Master entered tank without SCBA during search. Crew aware of dangers of O2 depletion with timber cargo. Hold not treated as enclosed space and entry was quick attempt to save time.		Sweden
83	31/05/2007	Pelagic Fishing Vessel	SAMSA	Fishhold	Low O2 Access Procedures	1	3	Skipper died after entering fishold to rescue 2 crew members who had been overcome while trying to rescue another crew member who had entered to clean the hold.		
84	20/09/2007	Bulker	RMI	Cargo Hold #5	Pet Coke Fumes	1	0	While retrieving samples of the Pet Coke cargo from Cargo Hold #5 through the forward manhole, the boatswain lost consciousness while equipped with an EEBD.		
85	23/09/2007	Offshore supply	UK MAIB	Starboard chain locker	Oxygen depletion	3	0	2 persons entered chain locker to secure noisy anchor chain & collapsed, likely 2nd person entered in an attempt to recover 1st. 3rd person donned breathing apparatus & carried 10 minute Emergency Escape Breathing Device (EEBD) to place on casualty. 3rd person of large build unable to fit down hatch wearing BA so donned EEBD. EEBD became removed.		
86	27/09/2007	Tug	RMI	Barge Tank	Oxygen Deficiency	2	1	Despite the Chief Officer instructing the Bosun to not enter the tank, the Bosun went inside and shortly thereafter fell unconscious. Immediately, the A.B. went to rescue the Bosun and also fell unconscious. After witnessing the two men descend into the tank, the Messboy rushed to enter the tank and also fell unconscious. The A.B. and Bosun died inside the tank. The only survivor was the Messboy, who was hospitalized and recovered from his injuries.		

87	14/10/2007	Workboat	UK MAIB	Other internal deck/space	Carbon monoxide	0	2	Vessel flooding, 2 crew members moved portable, petrol driven, pump into the confined space adjacent to accommodation space. The pump later lost suction and one of the crew members went into the space to investigate. His colleague then joined him in the space to assist. The first crewman to enter the space then reported feeling dizzy and collapsed and lost consciousness. The second man then stopped the pump and left the space to get a rope to pull his colleague out.	Preliminary examination carried out by MAIB http://www.maib.gov.uk/publications/comlpleted_preliminary_examinations/completed_preliminary_examinations_2007/panurgic_II.cfm	
88	29/10/2007	General cargo - single deck	UK MAIB	Accommodation	Phosphine poisoning	1	0	Vessel carrying feed wheat into her two holds. Once loading was complete, the cargo was fumigated by applying aluminum phosphide pellets loose into the cargo. The fumigation process was intended to progress during the voyage, as the tablets decomposed and gave off phosphine gas. The following morning, crewman found dead in his cabin. No obvious leakage path for the fumigant gas was located, even after smoke testing the hold and stripping back the bulkhead linings. However, following de-scaling of the area, some pin holes were discovered in the underside of the cabin deck that overhung the cargo hold.	Preliminary examination carried out by MAIB http://www.maib.gov.uk/cms_resources/Fumigated_cargo_Flyer.pdf http://www.maib.gov.uk/publications/completed_preliminary_examinations/completed_preliminary_examinations_2008/monika.cfm	Antigua & Barbuda
89	13/01/2008	Chemical Tank Ship	U S C G	Cargo Tank	Low O2 Environment, Access Procedures	1	0	3rd Officer fell into one of the tanks, was exposed to nitrogen, was extracted and taken to hospital. Investigation found the 3rd Officer was taking oxygen content readings of nitrogen tank during purging operations at 15 to 30 minute intervals. The purging operation commenced at 0600. At approximately 0645-0650 3rd Officer went to take his second set of readings. After several minutes the Chief Officer tried to radio the 3rd Officer to get the readings but the 3rd Officer never responded. The Chief Officer sent an AB to check on the 3rd Officer. The AB discovered the oxygen monitoring equipment and hardhat on deck but the 3rd Officer was missing. He immediately looked into the cargo tank and saw the 3rd Officer lying on the deck. The alarm was sounded @ 0700 and the crew removed the 3rd Officer from the cargo tank. The 3rd Officer apparently dropped part of the air testing equipment into the tank and he went in to retrieve it wearing only an air purifying respirator. Once in the tank, the 3rd Officer was overcome with nitrogen. There were no signs that he fell into the tank. He remained on life-support but died 11 days later.		
90	17/01/2008	Fishing Vessel	UK MAIB	Fish Hold	Carbon Monoxide	0	1	Bilge system became blocked and pump put in fish hold to clear water. Crew member lay down to clear blockage and became unconscious. 3 other crew in hold had 12, 14 and 16% CO in their blood stream. In future pump will only be used on open deck.		UK
91	18/01/2008	Fish catching	UK MAIB	Fishhold	Carbon monoxide	0	1	Flooding. Bilge pump suction pipe blocked in fish hold. Purchased petrol driven pump which was eventually placed in hold with 4 crew standing in hold. 1 person injured. 3 others admitted to hospital for less than 24 hours, the carbon monoxide levels in their blood were 12%, 14% and 16%.		

92	18/01/2008	General Cargo	UK MAIB	Forward Store	IMDG Code Class 4.2 ferrous metal turnings had been in a nearby hold and depleted oxygen levels.	2	0	Prohibited cargo self-heated causing reduced levels of oxygen inside the forward store, resulting in the death of 2 crewmen.	http://www.maib.gov.uk/publications/investigation_reports/2008/sava_lake.cfm	Latvia
93	21/02/2008	Ro-Ro Passenger Ferry		Funnel	Carbon Monoxide	0	1	Crew member suffered carbon monoxide poisoning while cleaning inside of funnel. Fans to be left on in future, permit to work to be introduced, and gas alert micro clip to be worn.		
94	25/02/2008	Fishing Vessel	Vanuatu	Engine Room	Ammonia leak	1	0	During a blackout caused by an ammonia leak from the refrigeration plant which displaced all the oxygen in the engine room, the chief engineer attempted to enter the engineroom without breathing apparatus and succumbed in the ammonia rich/oxygen poor atmosphere.		
95	24/03/2008	General Cargo	UK MAIB	Forepeak	Tested to approx 19.6% oxygen no CO or hydrocarbons	0	1	Hydrochloric acid had been released in area. Same crew member entered on two successive days. First day had minor eye and skin irritation. Second day became unconscious and stopped breathing. No harmful substances detected	Isle of Man believed to have conducted investigation	Isle of Man
96	10/04/2008	Bulk Carrier	Liberia	Cargo Hold	Oxygen Deficiency	1	0	Cargo receiver's surveyor lost consciousness, after entering into cargo hold No. 8 to conduct survey during discharge operation at Bilbao, Spain. Extensive emergency efforts to revive him failed.		
97	11/06/2008	Cruise Ship	UK MAIB	Ballast Tank	Insufficient oxygen due to corrosion of steel	1	1	Asphyxiation in ballast tank		Bahamas
98	25/07/2008	Tanker-Gas Carrier	Liberia	Cargo Tank	Oxygen Deficiency	2	0	Two men hired by subcontractor in the shipyard died after falling into a tank on board the vessel at St. Marine Shipyard.		
99	16/10/2008	Bulker	Norway AIBN	Cargo hold	Probable oxygen deficiency	0	2	Under investigation		
100	06/04/2009	Naval Support	UK MAIB	Deep Freeze	Ozone	0	5	Seven crewmen were loading frozen meat in to the deep freeze when they displayed symptoms of respiratory distress. They immediately evacuated the refrigeration compartment. The atmosphere was tested the presence of refrigeration gas and oxygen depletion. The results appeared to be normal and the work party returned to the space. The symptoms reappeared and work was stopped again. On investigation it was found that the compartment was fitted with an ozone generator which had been commissioned a week earlier, at the end of a refit period. The compartment had remained empty for the week and ozone had accumulated within the deep freeze and food handling spaces.		

101	06/05/2009	Chemical Tanker	UK MAIB	cargo tank	Hydrogen Sulphide	0	2	AB overcome by release of hydrogen sulphide as he prepared to remove the water wash hose from the open hatch. The Ch Officer attempted a rescue and he too was overcome. Both were hospitalised in ICU. Ch Officer was released after one day and the AB after 6 days. To note that the fixed cleaning system was defective which required use of the portable cleaning system.	As at 17 June 2009 Investigation underway, vessel name is Jo Eik. Progress can be monitored at http://www.maib.gov.uk/latest_news/current_investigations.cfm	Norway
					TOTAL	**93**	**96**			

Appendix 3. Study commissioned by the shipping company on tank ventilation AI9000

(in Finnish)

LAIVOJEN TANKKITUULETUSTEN MALLINTAMINEN
LASTITANKIN MALLINTAMINEN

1 YLEISTÄ

Laivojen lastitankit tuuletetaan ennen niiden tarkastus tai korjaustöiden vaativaa sisään menoa. Tuuletuksen avulla pyritään varmistamaan mahdollisesti pesun jäljiltä jääneiden myrkyllisten yhdisteiden poistuminen tankin sisältä ulkoilmaan. Tuuletuksen toisena tarkoituksena on myös saattaa tankin sisällä olevan ilmaseoksen happipitoisuus säiliössä oleskelun kannalta turvalliselle rajalle.

Tankkien tuuletus toteutetaan normaalisti kiinteällä tai liikutettavalla tuuletusjärjestelmällä. Tuuletusilma johdetaan tankin sisälle, joko tankin ylä- tai alaosaan riippuen käytetystä tuuletusjärjestelmästä. Vastaavasti tuuletusilma poistetaan tankin äärimäisestä päästä ilman syöttöpisteestä katsoen.

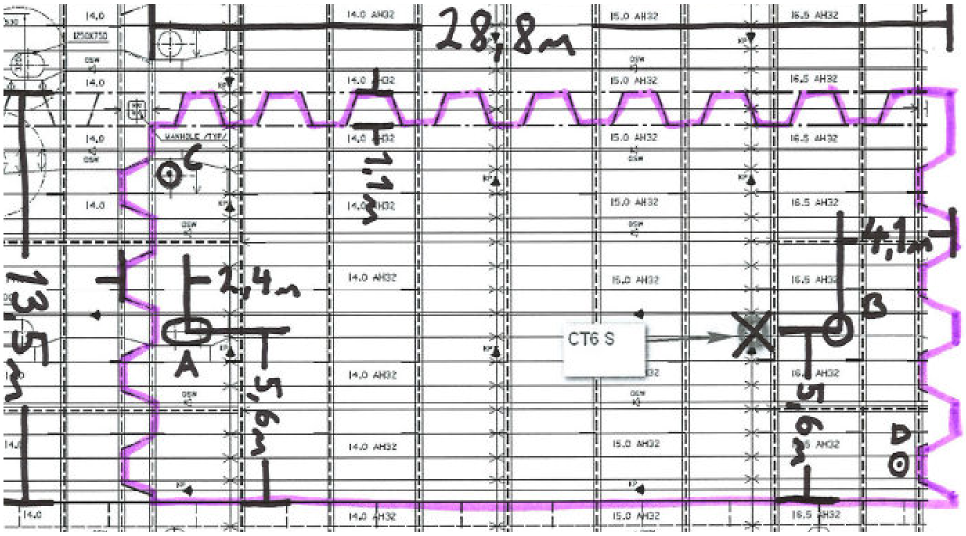
Laivojen lastitankkien tuuletus suoritetaan yleensä kokemukseen perustavan rutiinin perustella. Lastitankkeja tuuletetaan yleensä tietyn ajanjakson ajan, jonka jälkeen säiliön happi sekä hiilivetypitoisuutta mitataan analysaattoreilla ja tuuletusta jatketaan tarpeen vaatiessa lisää.

Projektin tarkoituksena on selvittää varustamon laivojen lastitankkien tuuletusjärjestelmien ja käytetyn tuuletusajan vaikutusta ilmanvaihtumiseen, sekä myrkyllisten kaasujen poistumiseen laivojen lastitankeista. Mallinnuksen tulosten perusteella saadaan tarkempi kuva tarvittavista tuuletusajoista ja tuuletusilman käyttäytymisestä lastitankin sisällä.

Lastitankit mallinnettiin kaupallisella CFD (Computational Fluid Dynamics) virtauslaskentaohjelmalla. Mallin pohjaksi valittiin onnettomuusalus, jonka lastitankkien geometrioiden perusteella tehtiin CFD mallit.

2 LASTITANKIN MALLINTAMINEN

Lastitankin mallin pohjana käytettiin onnettomuusaluksen lastitankin geometriaa. Mallinnetun lastitankin pituus on 28.8 m, leveys 13.5 m, korkeus 19.0 m ja kokonaistilaavuus 7174 m^3. Tankin molemmat päädyt sekä toinen sivu ovat ”aalto” kuviollisia ja muut tankin osat oletettiin sileäpintaisiksi. Kuvassa 1 on esitetty piirros lastitankin geometriasta.

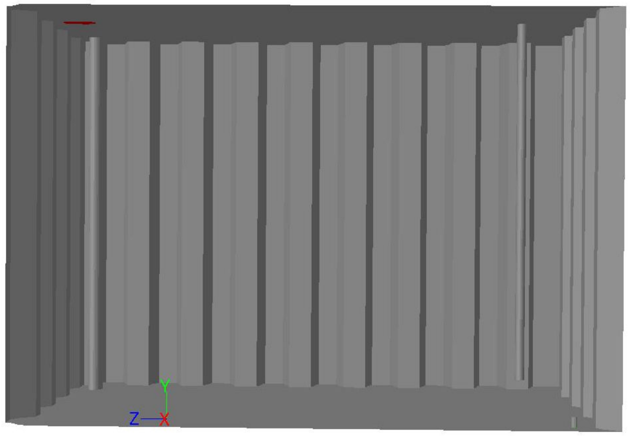


Kuva 1. Onnettomuusaluksen lastitankin geometria.

Kuvaan 1 lastitankin sisäänmenoluukku (1800x700mm) on merkitty A kirjaimella. Sisäänmenoluukku toimii tuuletusprosessissa ilmanpoistoluukkuna, jonka kautta tuuletusilma poistuu lastitankista ulkoilmaan. Tuuletusluukku on merkitty kuvaan B kirjaimella, jonka kautta liikutettavan tuuletusjärjestelmän tuuletusputkisukka lasketetaan lastitankin sisälle. Tuuletusputkisukka lasketaan noin 1.5 m etäisyydelle lastitankin pohjasta. Lastitankin sisällä oleva lastiputki C on otettu myös malliin mukaan sen aiheuttaminen virtausvastusten selvittämiseksi. Lastitankin kiinteä tuuletusjärjestelmä on merkitty kuvaan D kirjaimella. Kohdassa D sijaitsee kiinteän tuuletusjärjestelmän syöksypuhallus, jonka kautta tuuletusilma johdetaan lastitankin pohjalle (0.5 m tankin pohjasta). Kiinteän tuuletusjärjestelmän avulla voidaan myös puhaltaa tuuletusilmaa lastitankin yläosaan. Tämä kohta sijaitsee aivan B tuuletusluukun vieressä.

Lastitankin muut pienet paikallisvastukset ja geometria muutokset jätettiin huomioimatta CFD mallinnuksessa, sillä niiden katsottiin aiheuttavan vain marginaalista muutosta tuloksiin.

Kuvan 1 pohjalta laadittiin CFD malli, jonka perusteella toteutettiin tuuletussimuloinnit eri tuuletus olosuhteilla. Kuvassa 2 on esitetty lastitankin laskentageometria.



Kuva 2. Lastitankin geometriakuva Fluent CFD ohjelmasta.

3 CFD laskenta

Laskenta verkko on tehty Gambit 2.4.9 ohjelmalla ja CFD laskenta Ansys Fluent 12 ohjelmalla. Laskenta tehtiin ajastariippuvana ja käytetty turbulenssimalli oli realizable k-epsilon malli. Väliaine oletettiin kokoonpuristamattomaksi ideaalikaasuksi vakio-ominaisuuksilla. Lämpötilaeroja ei otettu huomioon. Laskennassa käytettiin 5 x 3.0 GHz:n prosessoreita rinnakkain jolloin yhteen tapaukseen kului noin kaksi päivää (yksinkertaistettuna, katso 4.1) laskenta-aikaa.

3.1 Laskenta tapaukset

Jokaisen lasketa tapauksen pohjana on käytetty seuraavaa tilannetta. Lastitankin lastina on ollut dieseliä ja tankin pesuohjelman sekä inertoinnin jäljeltä palavia kaasuja on jäänyt lastitankkiin, siten että LEL (Lower Explosive Limit) rajaan alle 2 %. Lastitankin happipitoisuus ennen tuuletuksen aloittamista on 8 V-% ja lastitankissa on 50 ppm dieselin lisäaineesta peräisin olevaa 2EHN (2 ethylhexyl nitrate).

Laskenta toistettiin viidellä eri lasketa tapauksella, joissa vaihdeltiin käytettävissä olevaa tuuletuskapasiteettia sekä käytettävissä olevaa tuuletusjärjestelmää. Taulukossa I on esitetty eri laskentatapausten tuuletus kapasiteetit ja lähtötiedot.

Taulukko 1. Laskentatapausten tuuletus kapasiteetit.

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	
Lastitankin Tilavuus	7174	7174	7174	7174	7174	m^3
Tuuletus Kapasiteetti	7000	7000	17000	17000	10000	m^3/h
O_2 Pitoisuus	8	8	8	8	8	V-%
LEL	2	2	2	2	2	%
2EHN Pitoisuus	50	50	50	50	50	ppm

Case 1

Tuuletukseen käytetään lastitankin kiinteää tuuletusjärjestelmää D ja tuuletusilma syötetään lastitankin yläosaan B luukun vieressä sijaitsevasta tuuletus yhteestä. Tuuletuksen kapasiteetti on 7000 m^3/h.

Case 2

Tuuletukseen käytetään myös kiinteää tuuletusjärjestelmää D, mutta tuuletusilma syötetään kiinteän tuuletusjärjestelmän syöksyputken kautta säiliön pohjalle. Tuuletuksen kapasiteetti on 7000 m^3/h.

Case 3

Tuuletukseen käytetään 1 case:n mukaista tuuletusjärjestelmää sekä liikutettavaa tuuletusjärjestelmää B. Tuuletus ilmaa ohjataan lastitankin ylä- ja alaosaan. Tuuletuksen kapasiteetti on yhteensä 17000 m^3/h.

Case 4

Tuuletukseen käytetään 2 case:n mukaista tuuletusjärjestelmää sekä liikutettavaa tuuletusjärjestelmää B. Tuuletus ilmaa ohjataan vain lastitankin alaosaan. Tuuletuksen kapasiteetti on yhteensä 17000 m^3/h.

Case 5

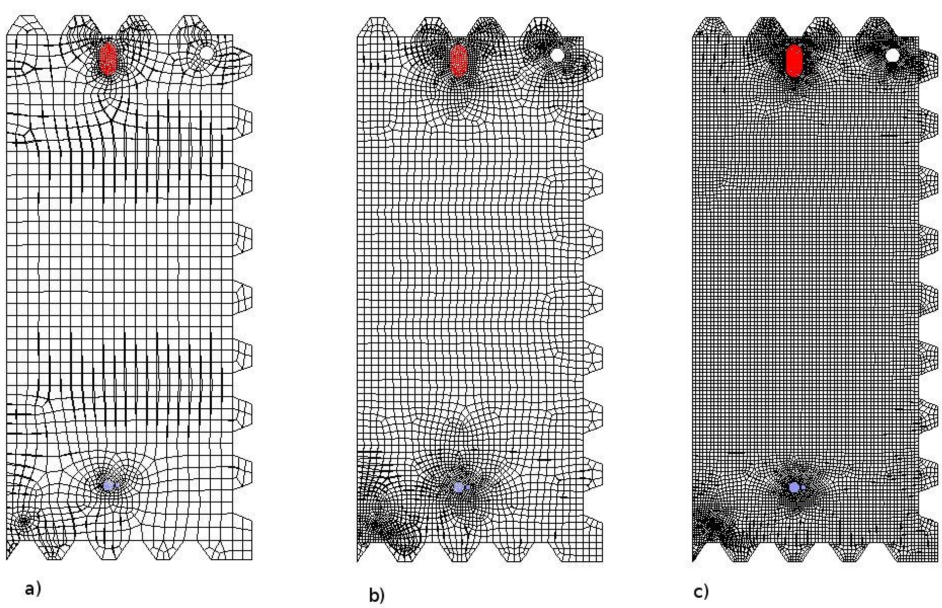
Tuuletukseen käytetään liikutettavaa tuuletusjärjestelmää B ja tuuletus ilma syötetään lastitankin alaosaan. Tuuletuksen kapasiteetti on 10000 m^3/h.

4 Laskennan verifiointi

4.1 Verkkoriippuvuustesti

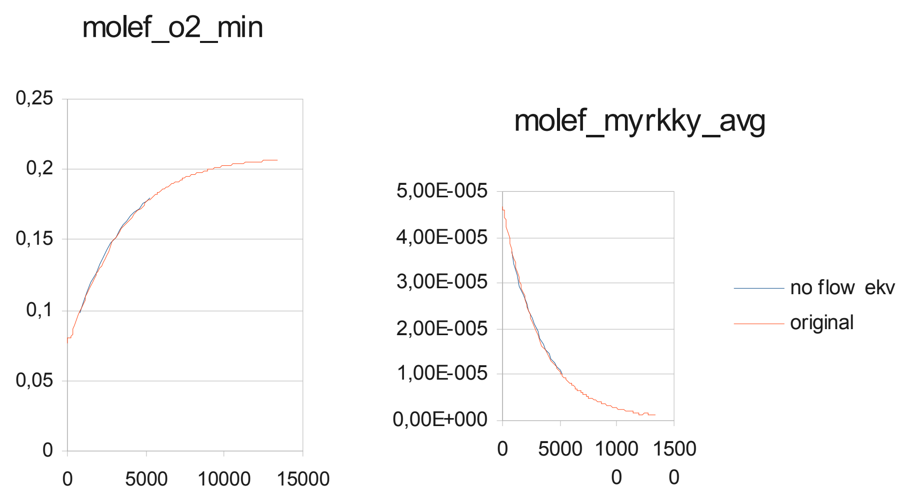
Laskentaverkon vaadittavaa tiheyttä testattiin laskemalla samaa tapausta kolmella eri verkolla. Pienin verkko koostui 63 000 laskentakopista, keskikokoinen verkko koostui 242 000 kopista ja suurimmassa tarkastetussa verkossa oli 685 000 koppia. Laskenta-aikaan nämä kokoerot vaikutti suhteessa noin 1:7. Suurimman ja keskikokoisen verkon simulointitestit olivat hyvin samanlaisia, mutta pienimmän verkon tulokset erosivat näistä eikä pienintä verkkoa siten voitu käyttää näissä laskennoissa. Suurin verkko taas pidentäisi laskenta-aikaa melkein kuukauteen per laskenta (ilman yksinkertaistusta) ja oli turhan tarkka.

Yksi ongelma näissä laskennoissa oli että tankissa esiintyi sekä suuria että hyvin pieniä nopeusalueita ja laskenta-aika on riippuvainen suurimmasta nopeudesta. Sisääntulon nopeus vaatii pientä aika-askelta jotta laskenta konvergoisi, mutta sillä ajalla tankin muissa osissa ei tapahdu juuri mitään muutoksia.



Kuva 3. Laskentaverkot: a) pieni (harva) b) keskikoko ja c) suuri (tiheä)

Laskennan nopeuskenttä osoittautui pysyvän hyvin tasaisena 500 sekunnin jälkeen. Laskenta-ajan säästämisen vuoksi tehtiin vielä tarkastelu virtausyhtälöiden ja turbulenssiyhtälöiden poisjättämisestä 500 sekunnin jälkeen. Laskennassa ratkaistaisiin siis vain pitoisuuksien diffuusioyhtälöt jäädytetyssä virtauskentässä. Tulokset menivät hyvin yhteen alkuperäisen ratkaisun kanssa ja tapaukset 2-5 ovat laskettu tällä tavalla noin 500 sekunnin jälkeen. Laskenta-aika tippui tällä yksinkertaistuksella viidesosaan.



Kuva 4. Yksinkertaistuksen vaikutukset.

4.2 Laskentamallien verifiointi

Varustamon CFD-tutkimusprojektin puitteissa tehtiin rinnakkaislaskentoja OpenFOAM nimisen open-source CFD-ohjelman kanssa, millä pystyttiin verifioimaan tuloksia. Eri ratkaisija sekä eri turbulenssimallit antoivat hyvin samanlaisia tuloksia joten voi todeta että käytetyt mallit sopivat näihin tapauksiin hyvin. Kuvia OpenFOAM-simulointituloksista Liite 1:ssä.

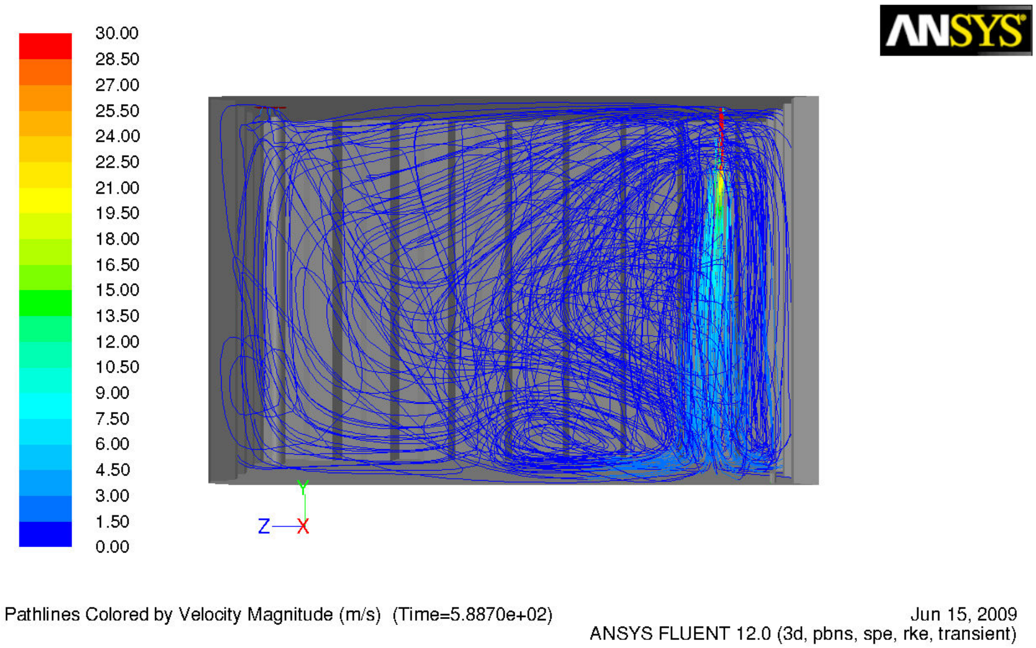
5 Tulokset

Tuloksista on selvinnyt että tankkiin syntyy tuuletuksen aikana voimakas ilmakierre, joka sekoittaa uuden ilman ja muut kaasut hyvin. Suurin vaikutus ilmalaatuun on siis käytetyllä ilmamäärällä sekä tuuletusajalla. Pienet virtausvastukset kuten nousuputki tankissa ei vaikuta oleellisesti tuuletusaikaan. Tuuletussukka on tässä tapauksessa mallinnettu kiinteäksi. Todellisuudessa sukan heiluminen tankissa todennäköisesti parantaisi sekoittumista vähän.

Tulosten arvioinnissa on huomioitava että 2EHN-kaasun pitoisuus on ppm-tasolla ja laskentavirheet näkyvät tuloksissa. Silloin kun pitoisuudet menevät 1 ppm:n alle niin laskennan resoluutio ei enää riitä. Keskiarvokäyrissä nämä pienet virheet kumoavat toisensa paremmin eivätkä näy samalla tavalla. 2EHN-pitoisuuden maksimiarvon suuruusluokka on kuitenkin oikein ja siitä voi jo tehdä tarpeelliset johtopäätökset.

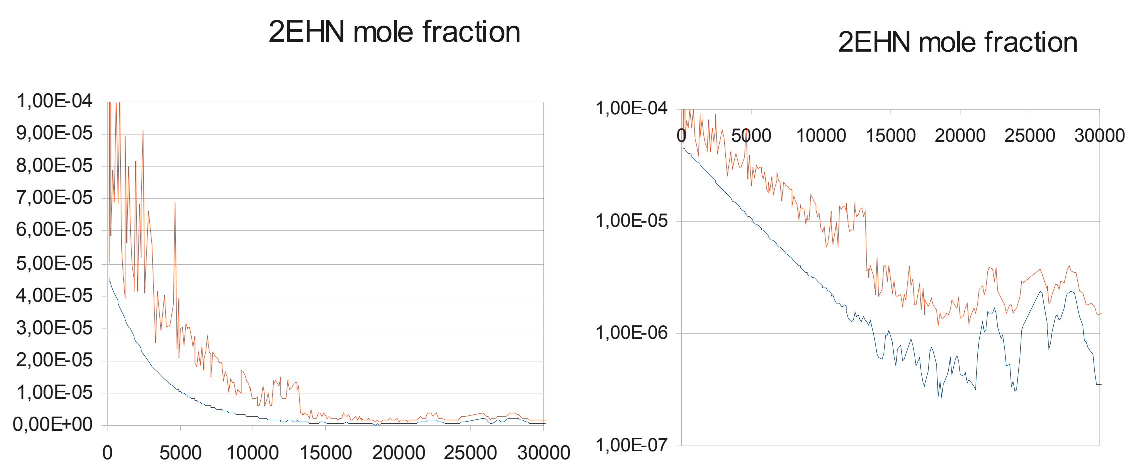
5.1 Case 1

Tässä tapauksessa inertgas tuuletin puhaltaa katon kautta. Tässä tapauksessa tehtiin tarkastelu voidaanko virtausyhtälöt jättää pois nopeuttaakseen laskentaa ja kuvat ovat tehty siitä ajosta missä kaikki yhtälöt olivat mukana. Tämän takia esitetyt käyrät ovat hieman epätasaisempia kuin seuraavissa tapauksissa.



Kuva 5. Case 1:n virtauskenttä väritettynä virtausnopeuden mukaan (m/s).

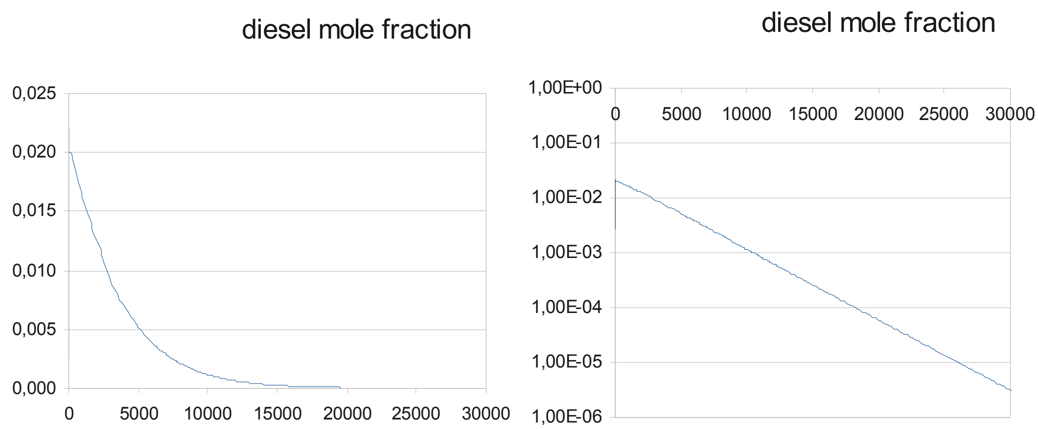
Kuvan 5 mukaan ilma sekoittuu hyvin tankissa vaikkakin suurimmat virtausnopeudet pysyvät lähellä sisääntuloa. Miesluukun lähellä virtaus on hidasta, mutta pitkällä tuuletusajalla ilma sekoittuu melko hyvin.



a) b)

Kuva 6. a) 2EHN:n mooliosuus tankissa ajanfunktiona (sekunteina) b) logaritmisella skaalalla. Maksimiarvo on punaisella ja keskiarvo sinisellä.

Kuvassa 6 2EHN:n maksimiarvo on simuloinnin alkuvaiheessa hieman heiluva ja ajoittain syntyy maksimiarvoja. Nämä saattavat osittain riippua laskennan tarkkuudesta, mutta koska kaasut sekoittuvat melko hyvin tankissa, niin pitkä tuuletusaika poistaa haitallisen kaasun varmasti. Ajanfunktio logaritmisessa skaalassa on hyvin lineaarinen, niin sitä voi jatkaa riippuen miten pieni pitoisuus on toivottu. Ekstrapoloiden kuvaa 6 maksimipitoisuuden raja-arvo 1 ppm saavutetaan noin kuudessa tunnissa.



a) b)

Kuva 7. Dieselin konsentraatio tankissa ajan funktiona (sekunteina). b) logaritminen skaala

Räjähdyskaasun, tässä tapauksessa diesel-ilmaseoksen, pitoisuus vähenee hyvin tasaisesti ajan funktiona. Kolmessa tunnissa ja 45 minuutissa mooliosuus tippuu suunnilleen 500 ppm:ään, eli räjähdysvaaraa ei ole.

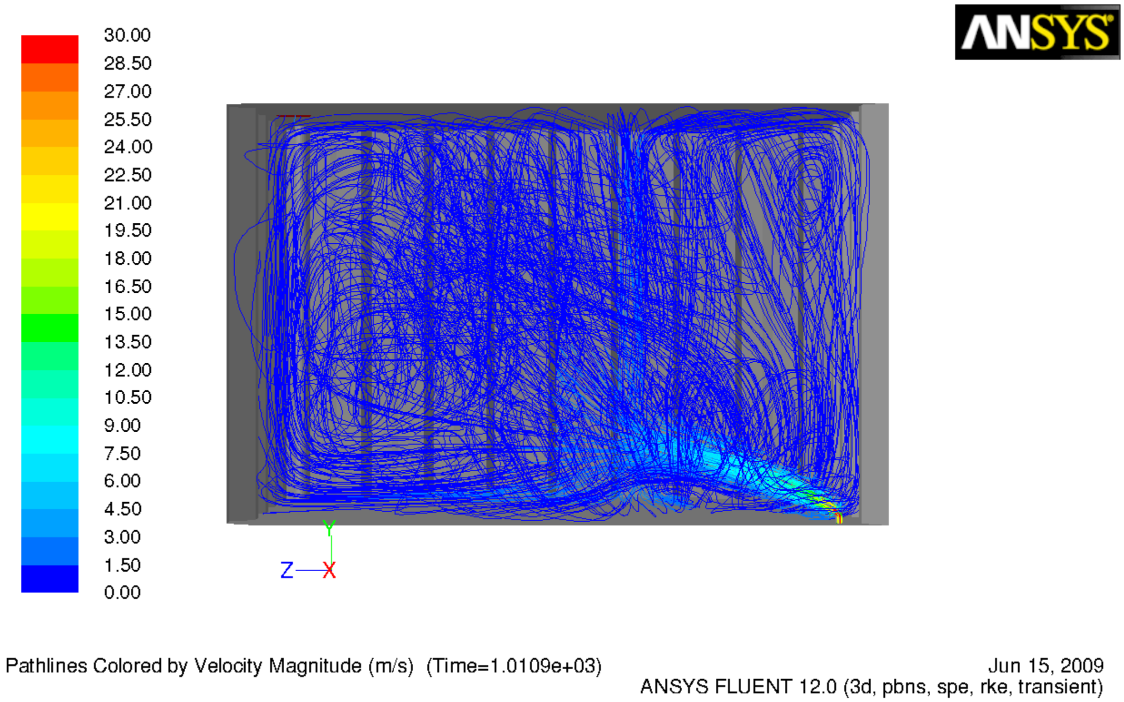
Kuva 8. Hapen mooliosuus tankissa ajan funktiona (sekunteina).

Kuva 8 mukaan happikonsentraatio saavuttaa normaalilukemia noin 13500 sekunnin kuluttua, mikä tarkoittaa 3 tuntia ja 45 minuuttia. Tämän jälkeen muutokset ovat hyvin pieniä.

Eri tarkastetuista arvoista 2EHN:n pitoisuus on kriittisin ja määrittää vaadittavan tuuletusajan, mikä tässä tapauksessa on noin kuusi tuntia.

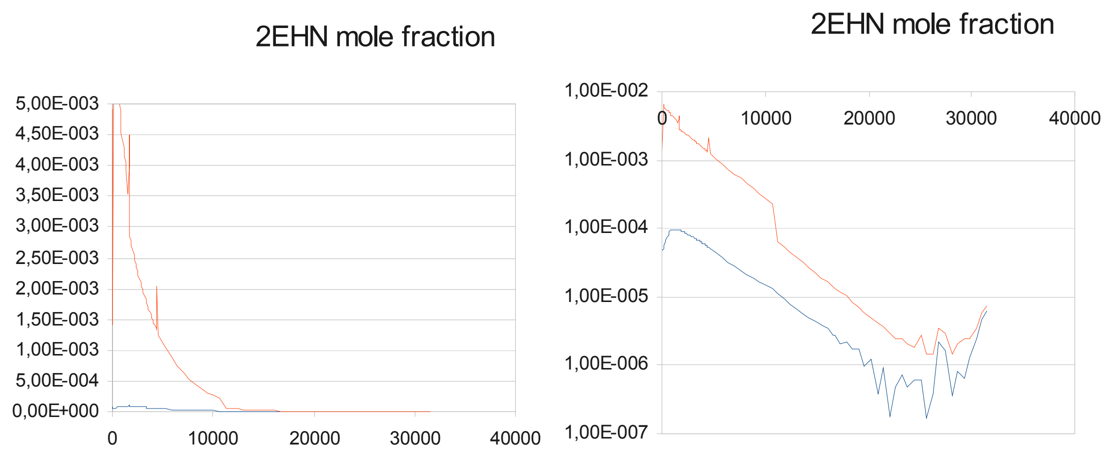
5.2 Case 2

Tässä tapauksessa inertgas tuuletin puhaltaa syöksyputken kautta.



Kuva 9. Case 2:n virtauskenttä väritettynä virtausnopeuden mukaan (m/s).

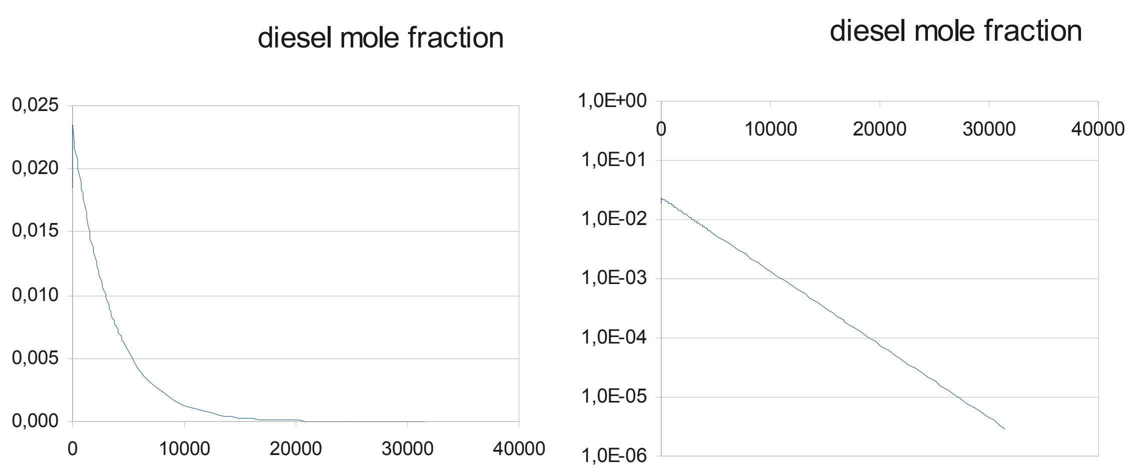
Kuvan 9 mukaan ilma sekoittuu hyvin tankissa vaikkakin suurimmat virtausnopeudet pysyvät lähellä syöksylinjan sisääntuloa. Miesluukun lähellä virtaus on hidasta, mutta ilma kiertää joka paikassa.



a) b)

Kuva 10. a) 2EHN:n mooliosuus tankissa ajanfunktiona (sekunteina) b) logaritmisella skaalalla. Maksimiarvo on punaisella ja keskiarvo sinisellä.

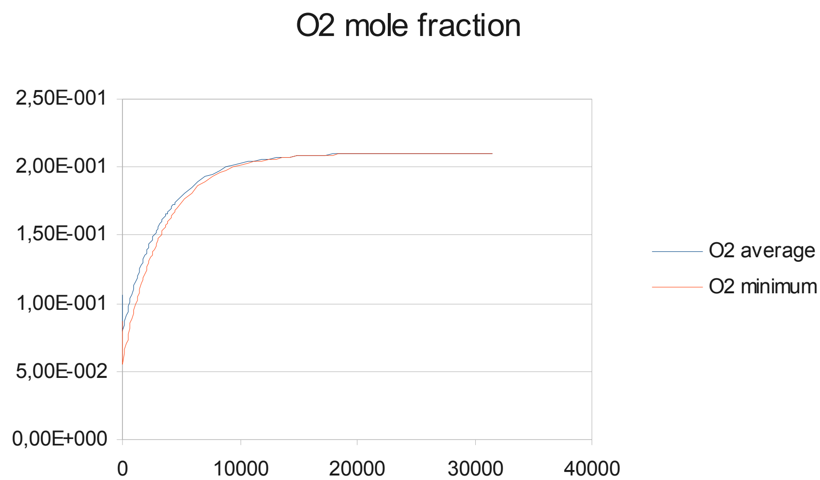
2EHN:n maksimiarvo nousee simuloinnin alkuvaiheessa. Tuloksista nähdään että uuden ilman virratessa sisään se työntää tankissa olleen kaasun syrjään ja syntyy hetkellisiä maksimiarvoja. Pitkää tuuletusaikaa tarvitaan poistamaan haitallinen kaasu, ekstrapoloidessaan tässäkin tarvitaan noin 6 tuntia että maksimipitoisuus saavuttaa raja-arvon 1 ppm.



a) b)

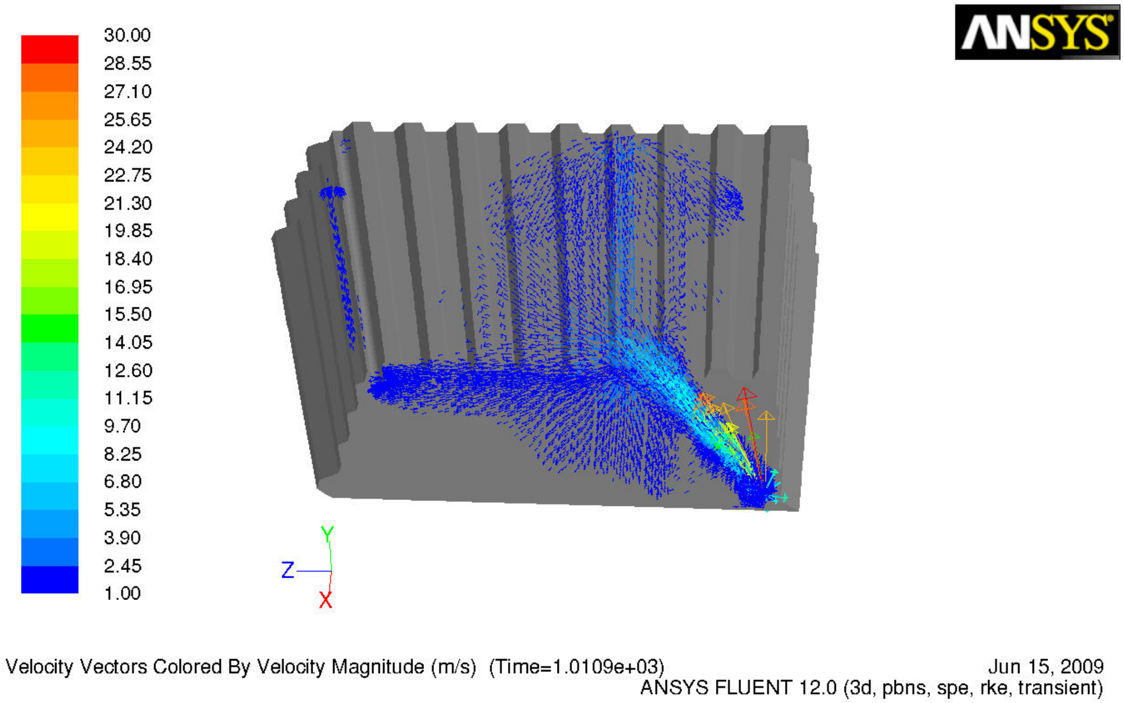
Kuva 11. Dieselin konsentraatio tankissa ajan funktiona. b) logaritminen skaala

Räjähdyskaasun pitoisuus vähenee hyvin tasaisesti ajan funktiona. Siinä ajassa kun 2EHN:n on tuuletettu pois, niin räjähdysvaaraa ei enää ole.



Kuva 12. Hapen mooliosuus tankissa ajan funktiona.

Kuva 12 mukaan happikonsentraatio saavuttaa normaalilukeman samassa ajassa kuten edellisessä tapauksessa. Tämän jälkeen muutokset ovat hyvin pieniä. Koska sekoittuminen on hyvä, niin tuuletusaika ratkaisee. Tässä tapauksessa vaadittava tuuletusaika on noin 4 tuntia hapen osalta.



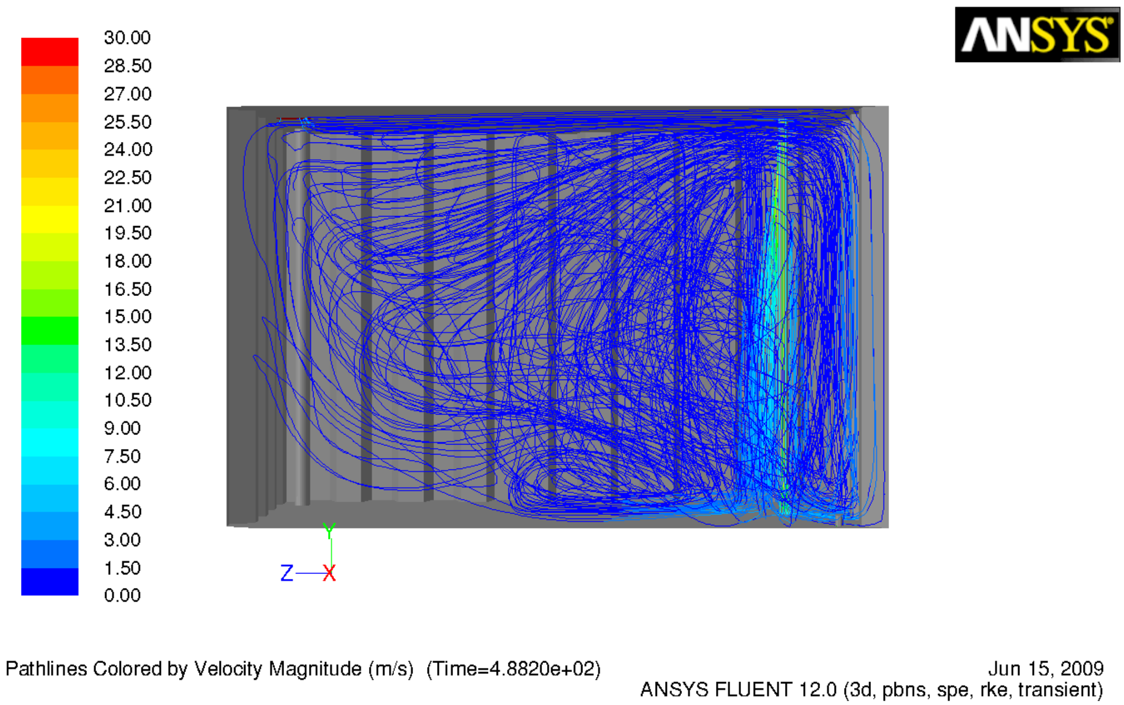
Kuva 13. Case 2:n virtauskenttä vektoreina väritettynä virtausnopeuden mukaan (m/s).

Kuvassa 13 nopeusvektorikenttä on rajattu niin että näkee miten suurin osa ilmasta leviää tässä tapauksessa.

Eri tarkastetuista arvoista 2EHN:n pitoisuus on kriittisin ja määrittää vaadittavan tuuletusajan, mikä tässä tapauksessa on noin kuusi tuntia.

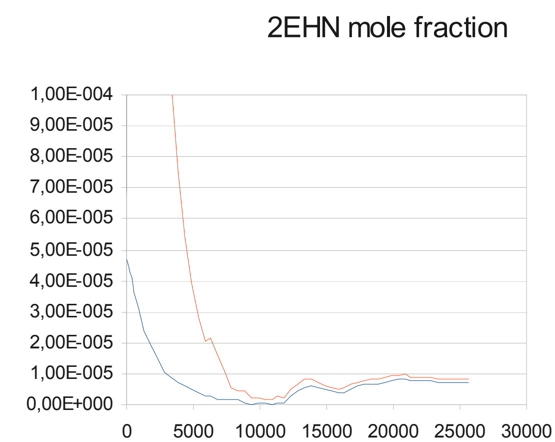
5.3 Case 3

Tässä tapauksessa inertgas tuuletin puhaltaa katon kautta, sekä kannettava tuuletin puhaltaa sukalla.

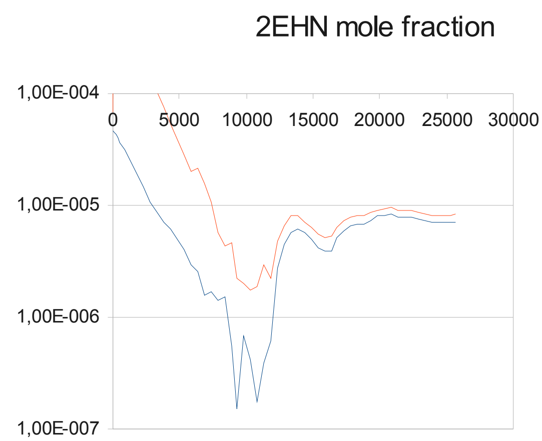


Kuva 14. Case 3:n virtauskenttä väritettynä virtausnopeuden mukaan (m/s).

Kuvan 14 mukaan suurimmat virtausnopeudet pysyvät lähellä sisääntuloa. Miesluukun alla virtaus on hyvin hidasta, mutta pitkällä tuuletusajalla ilma sekoittuu melko hyvin. Tässä tapauksessa kun ilmamäärä on suurempi niin pitoisuudet tippuvat nopeammin.



a)

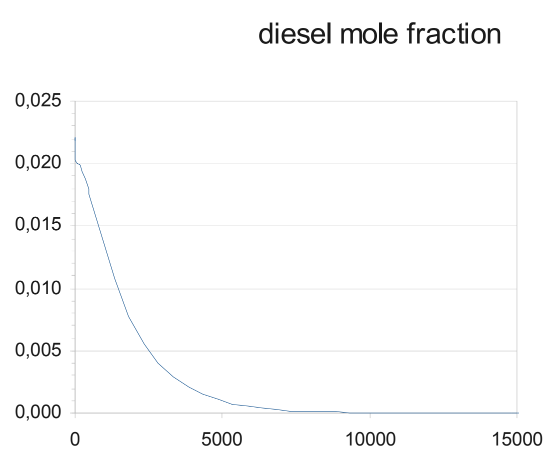


b)

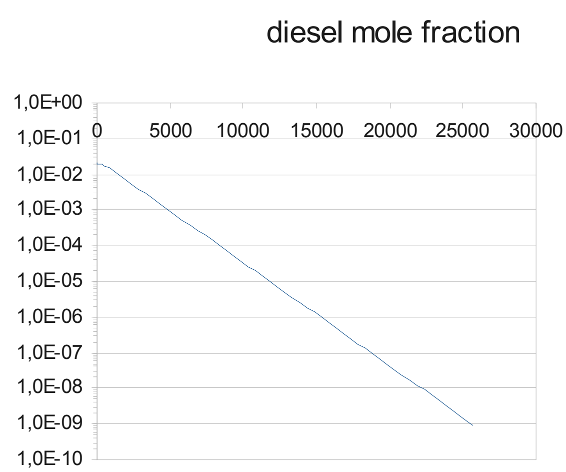
Kuva 15. a) 2EHN:n mooliosuus tankissa ajanfunktiona b) logaritmisella skaalalla. Maksimiarvo on punaisella ja keskiarvo sinisellä.

2EHN:n maksimiarvo nousee simuloinnin alkuvaiheessa, niin kuin edellisessä laskennassakin. Laskennan puolivälissä näkyy selvästi milloin laskennan tarkkuus ei enää riitä hyvin pienille pitoisuuksille ja käyrät rupeavat heilumaan. Koska on tiedossa että pitoisuudet laskevat ajan funktiona loputtomiin niin uutta tarkempaa laskentaa ei tässä vaiheessa tehty, vaan pitää vain jättää virheellisen loppuosa huomioimatta.

Tarvittava tuuletusaika tässä tapauksessa on huomattavasti lyhyempi kuin edelliset. Periaate on kuitenkin sama että 5-6 viipymäaikaa tarvitaan. Tässä tapauksessa 1 ppm:n raja-arvo saavutetaan noin 3.5 tunnin jälkeen.



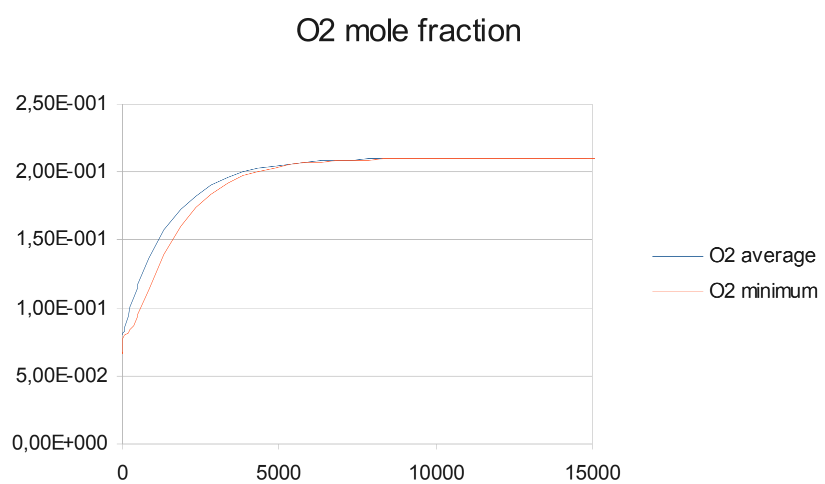
a)



b)

Kuva 16. Dieselin konsentraatio tankissa ajan funktiona. b) logaritminen skaala

Räjähdyskaasun pitoisuus vähenee hyvin tasaisesti ajan funktiona. Siinä ajassa kun 2EHN:n on tuuletettu pois, niin räjähdysvaaraa ei enää ole.



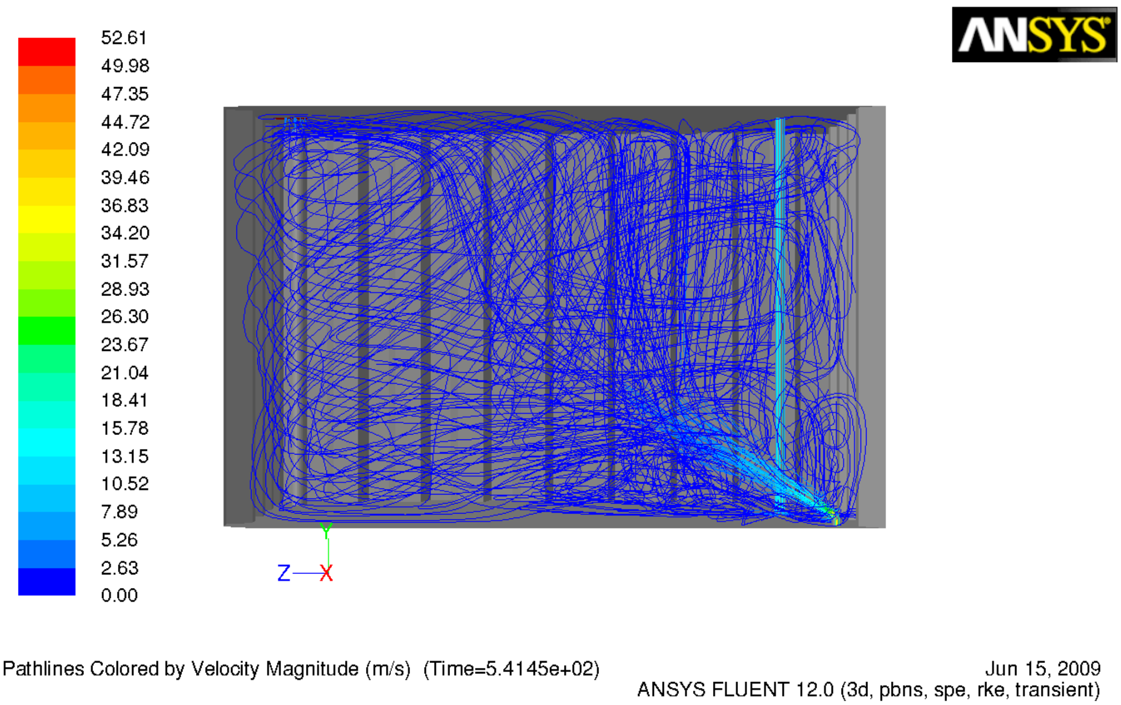
Kuva 17. Hapen mooliosuus tankissa ajan funktiona.

Kuva 17 mukaan happikonsentraatio saavuttaa normaalilukemia noin kahdessa tunnissa. Tämän jälkeen muutokset ovat hyvin pieniä.

Eri tarkastetuista arvoista 2EHN:n pitoisuus on kriittisin ja määrittää vaadittavan tuuletusajan, mikä tässä tapauksessa on noin kolme ja puoli tuntia.

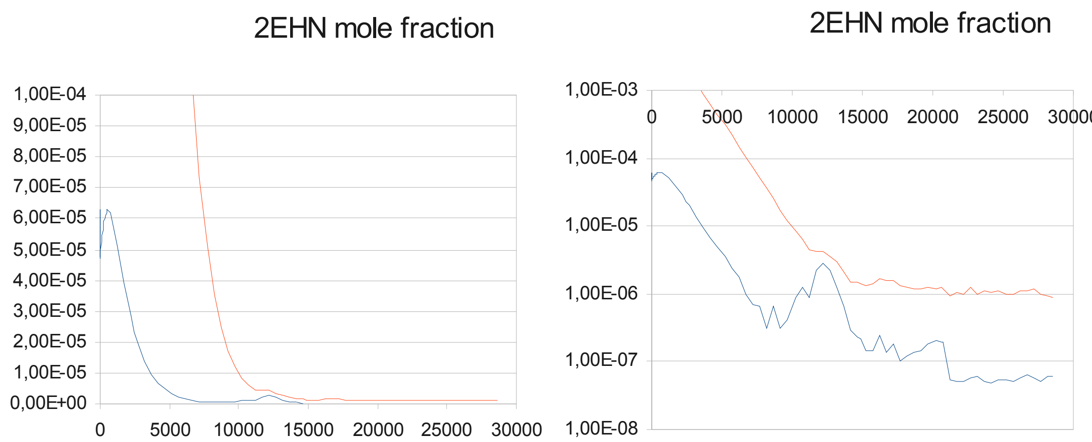
5.4 Case 4

Tässä tapauksessa inertgas tuuletin puhaltaa syöksyputken kautta, sekä kannettava tuuletin puhaltaa sukalla.



Kuva 18. Case 4:n virtauskenttä väritettynä virtausnopeuden mukaan (m/s).

Kuvan 18 mukaan ilma sekoittuu erittäin hyvin tankissa ja virtausnopeudet kasvavat muuallakin kuin lähellä sisääntuloa. Miesluukun lähellä havaitaan virtausta ja tämä puhallinjärjestely vaikuttaa sekoitusmielessä järkevältä.

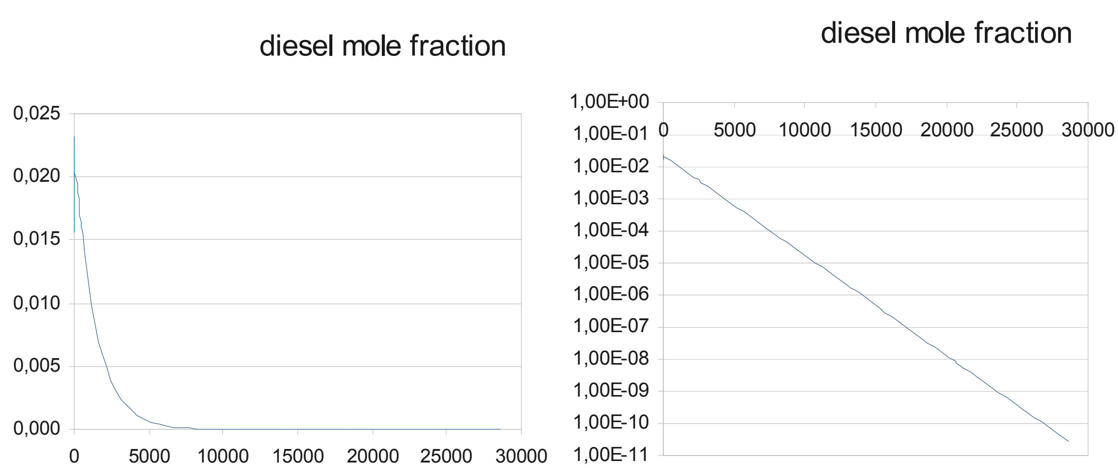


a) b)

Kuva 19. a) 2EHN:n mooliosuus tankissa ajanfunktiona b) logaritmisella skaalalla. Maksimiarvo on punaisella ja keskiarvo sinisellä.

2EHN:n maksimiarvo nousee simuloinnin alkuvaiheessa samalla tavalla kuten edellisissä tapauksissa. Laskennan puolivälissä näkyy taas selvästi milloin laskentatarkkuus loppuu kesken, eli loppuosan virheet pitää taas jättää huomioimatta.

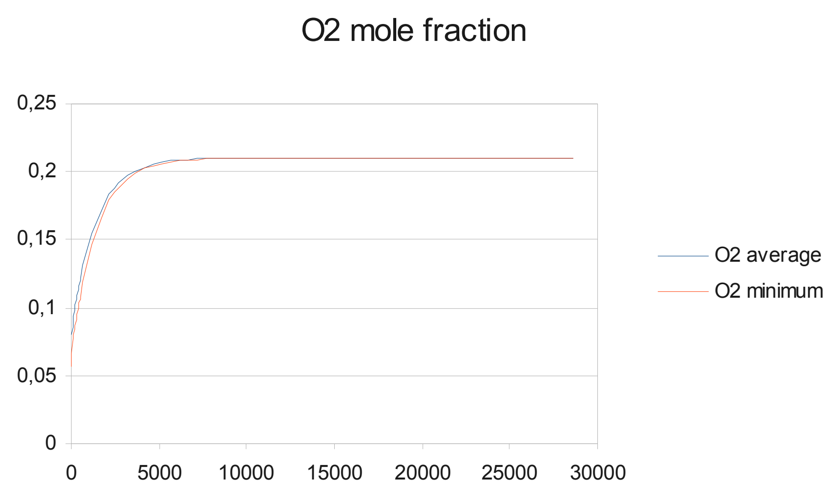
Tarvittava tuuletusaika tässä tapauksessa on hieman pitempi kuin edellisessä. Tässä tapauksessa 1 ppm:n raja-arvo saavutetaan vajaan 4 tunnin jälkeen.



a) b)

Kuva 20. Dieselin konsentraatio tankissa ajan funktiona. b) logaritminen skaala

Räjähdyskaasun pitoisuus vähenee hyvin tasaisesti ajan funktiona. Siinä ajassa kun 2EHN:n on tuuletettu pois, niin räjähdysvaaraa ei enää ole.



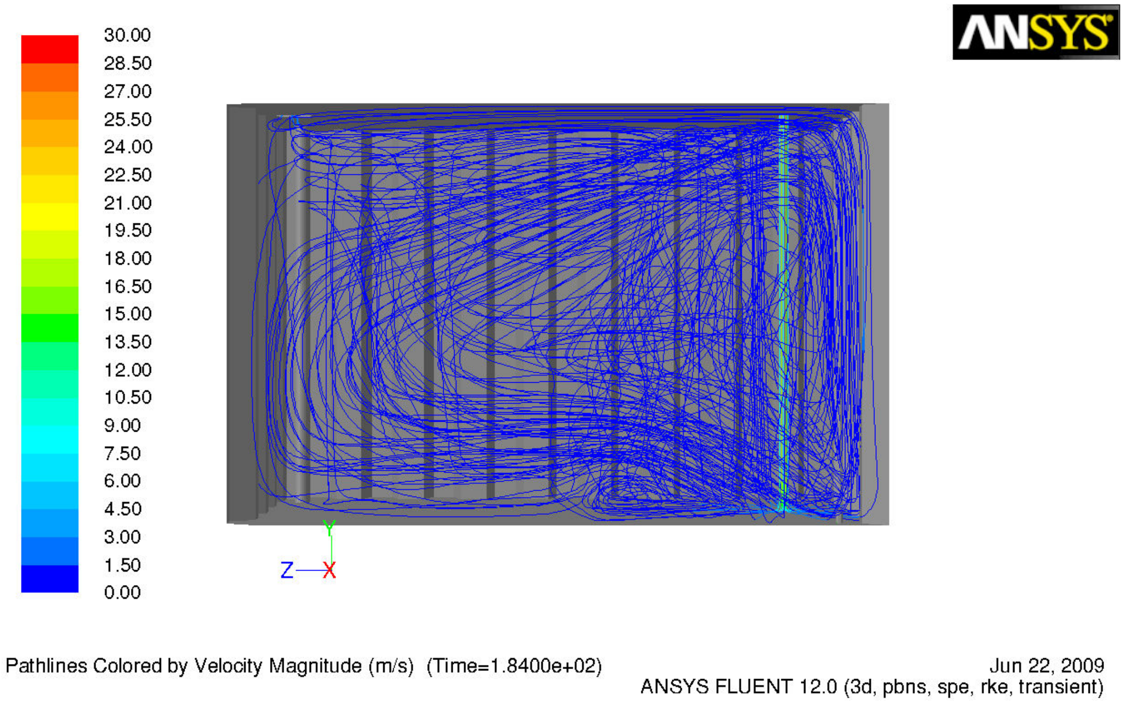
Kuva 21. Hapen mooliosuus tankissa ajan funktiona.

Kuva 21 mukaan happikonsentraatio saavuttaa normaalilukemia noin kahdessa tunnissa. Tämän jälkeen muutokset ovat hyvin pieniä.

Eri tarkastetuista arvoista 2EHN:n pitoisuus on kriittisin ja määrittää vaadittavan tuuletusajan, mikä tässä tapauksessa on noin neljä tuntia.

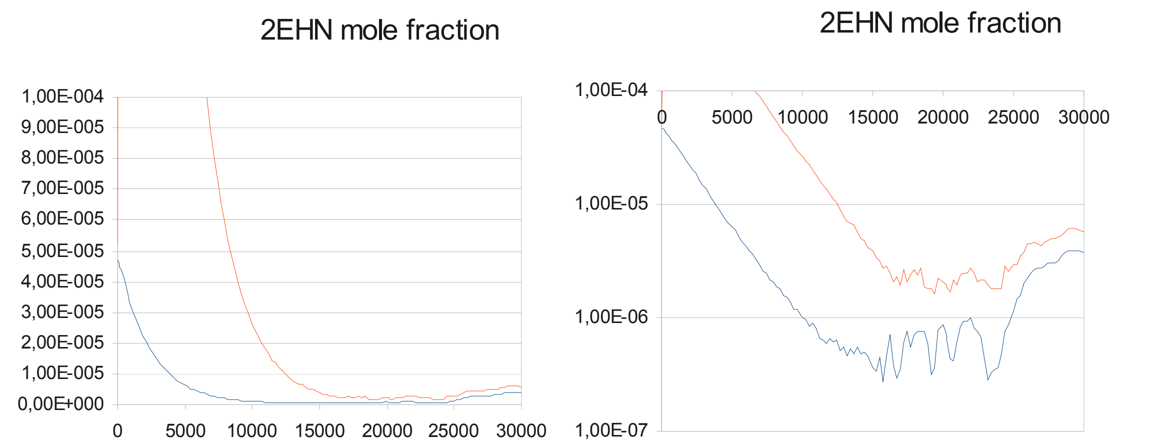
5.5 Case 5

Tässä tapauksessa käytetään kannettava tuuletin sukalla.



Kuva 22. Case 3:n virtauskenttä väritettynä virtausnopeuden mukaan (m/s).

Kuvan 22 mukaan ilma sekoittuu tankissa hyvin, mutta suurimmat virtausnopeudet pysyvät lähellä sisääntuloa. Miesluukun lähellä on virtausta, mutta hitaampaa ja tämä puhallinjärjestely vaatii vähän pidemmän tuuletusajan kuin parhaat tapaukset.

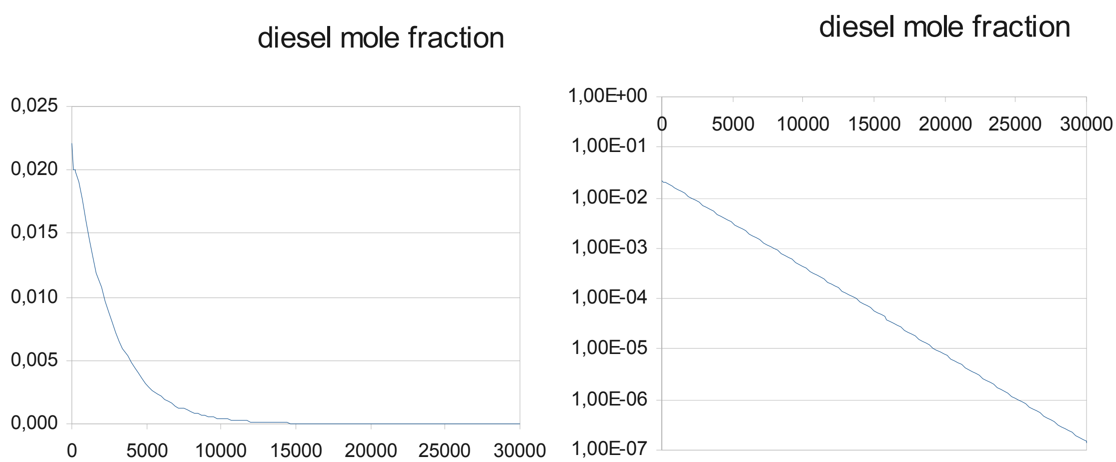


a) b)

Kuva 23. a) 2EHN:n mooliosuus tankissa ajanfunktiona b) logaritmisella skaalalla. Maksimiarvo on punaisella ja keskiarvo sinisellä.

2EHN:n maksimiarvo nousee simuloinnin alkuvaiheessa samalla tavalla kuten edellisissä tapauksissa. Tämä laskenta oli numeeristesti vähän stabiilimpi ja virheet vaikuttavat vasta lopussa.

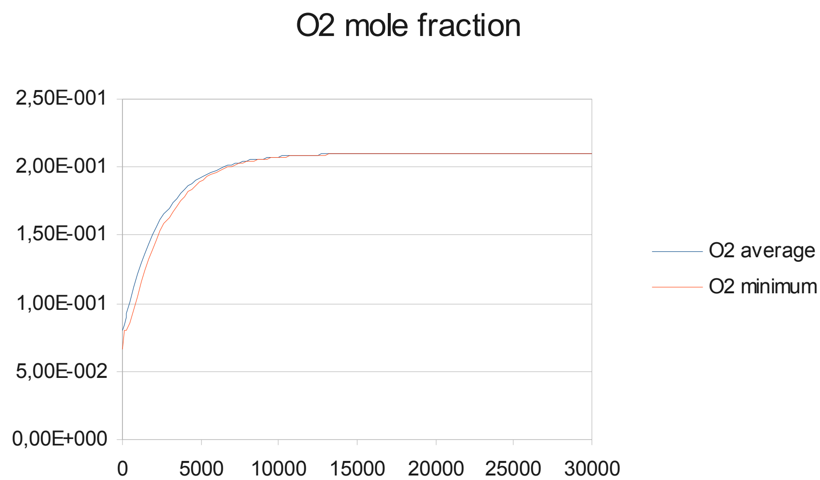
Tässä tapauksessa 1 ppm:n raja-arvo saavutetaan vajaan 5 tunnin jälkeen.



a) b)

Kuva 24. Dieselin konsentraatio tankissa ajan funktiona (sekunteina). b) logaritminen skaala

Räjähdyskaasun pitoisuus vähenee hyvin tasaisesti ajan funktiona. Siinä ajassa kun 2EHN:n on tuuletettu pois, niin räjähdysvaaraa ei enää ole.



Kuva 25. Hapen mooliosuus tankissa ajan funktiona.

Kuva 25 mukaan happikonsentraatio saavuttaa normaalilukemia noin neljässä tunnissa. Tämän jälkeen muutokset ovat hyvin pieniä.

Eri tarkastetuista arvoista 2EHN:n pitoisuus on kriittisin ja määrittää vaadittavan tuuletusajan, mikä tässä tapauksessa on noin viisi tuntia.

6 Johtopäätökset

Tulokset näyttävät että jokaisella tuuletustavalla saavutetaan hyviä tuloksia. Ilma sekoittuu niin hyvin että vain tuuletusaika on ratkaiseva. Suurempi ilmamäärä pienentää vaadittavaa tuuletusaikaa. Nyrkkisääntö hyvin sekoittuneissa säiliöissä on että pitäisi tuulettaa 6 viipymäaikaa. Näissäkin tapauksissa tämä sääntö pitää hyvin paikkansa, eli se on suositeltava minimituuletusaika.

Tarkastelussa huomaa että 2EHN:lle vaaditaan pitempi tuuletusaika kuin muille kaasuille. Pelkkä happimittari ei siis näytä onko turvallista mennä tankkiin sisään. Mikäli 2EHN:n pitoisuus tuuletuksen alkaessa on vielä suurempi kuin 50 ppm niin vaaditaan entistä pitempi tuuletusaika.

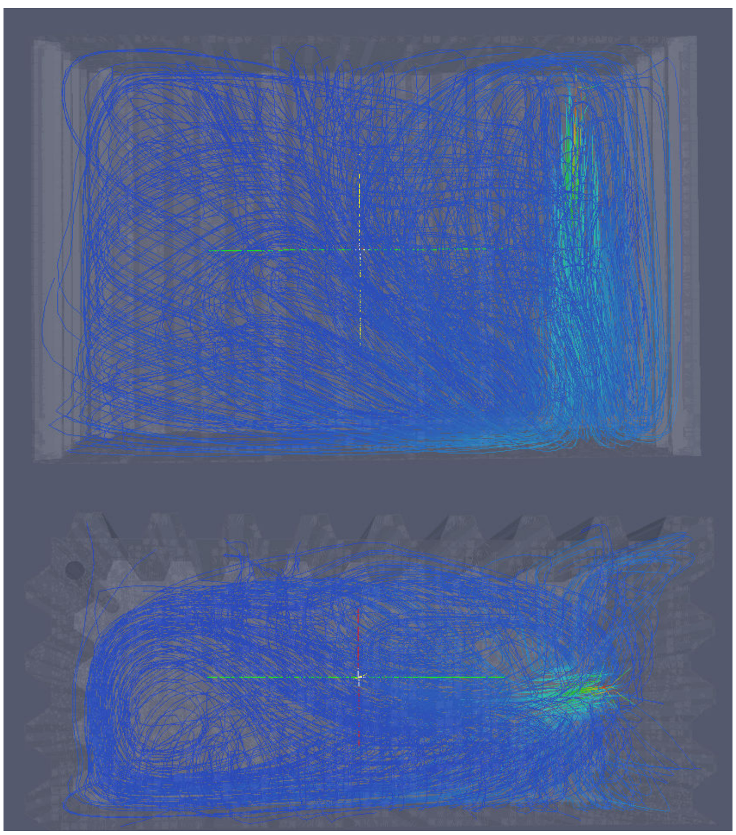
Taulukko 2.

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	
Lastitankin tilavuus	7174	7174	7174	7174	7174	m^3
Tuuletus kapasiteetti	7000	7000	17000	17000	10000	m^3/h
Minimi tuuletusaika	~6	~6	~3.5	~4	~5	h
O_2 pitoisuus minimituuletuksen jälkeen	21	21	21	21	21	V-%
Diesel pitoisuus minimituuletuksen jälkeen	36	51	5	<1	16	ppm
2EHN pitoisuus minimituuletuksen jälkeen	~1	~1	<1	<1	~1	ppm

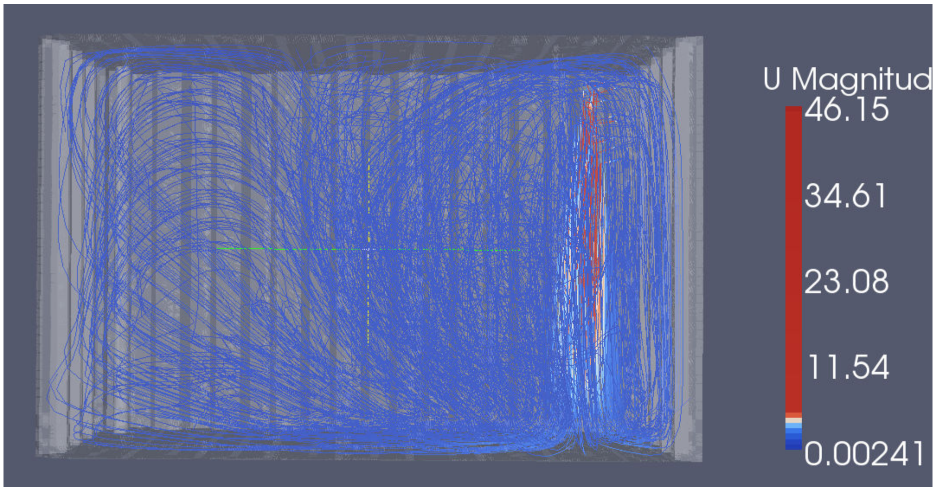
7 Liite 1 OpenFOAM tulokset

CFD-laskennan OpenFOAM-koodilla teki Juhani Aittamaa ja tarkoitus oli tarkistaa antavatko eri koodit samankaltaisia tuloksia. Vertailu tehtiin case1:lle.

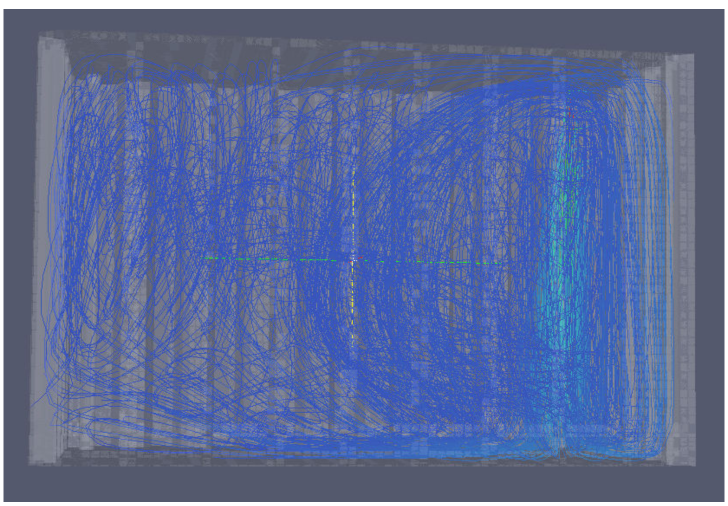
Näissä laskelmissa käytettiin samaa periaatetta että ensin laskettiin virtauskenttä ja tämän jälkeen komponenttien diffuusio. Näissä kuvissa näytetään pääosin virtauskenttää virtaviivoilla mutta lopussa on myös kuvasarjoja syöttöilman leviämisestä. Kuvat on tehty ParaView ohjelmalla.

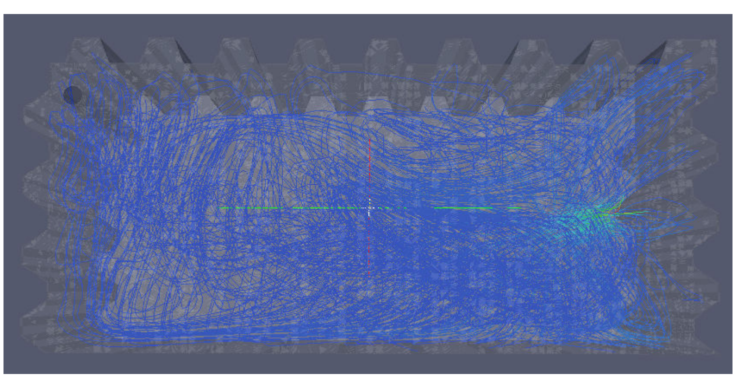


Kuva 26. Keskikokoisella verkolla ja k-omega SST turbulenssimallilla laskettu virtauskenttä sivulta ja ylhäältä.

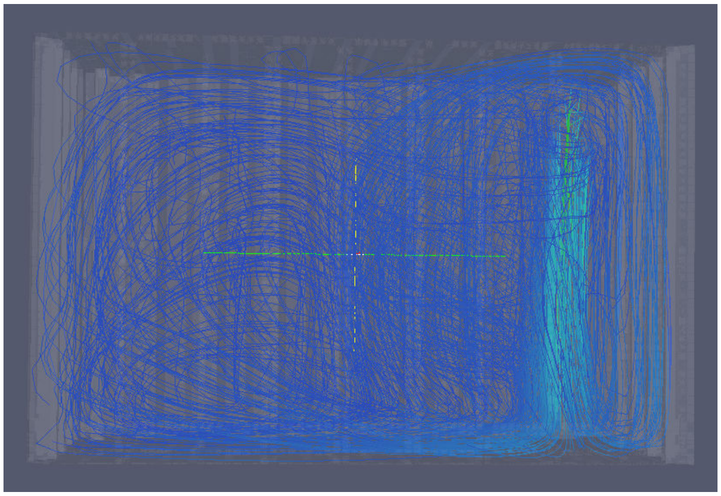


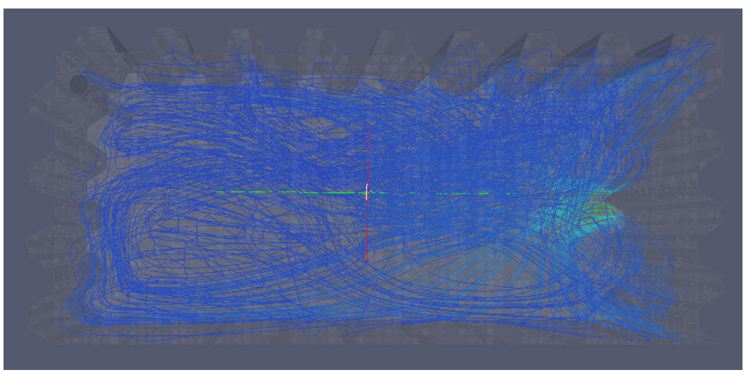
Kuva 27. Keskikokoisella verkolla ja realizable k-epsilon turbulenssimallilla laskettu virtauskenttä. Oikealla näkyy virtausnopeuksien väritysskaala.



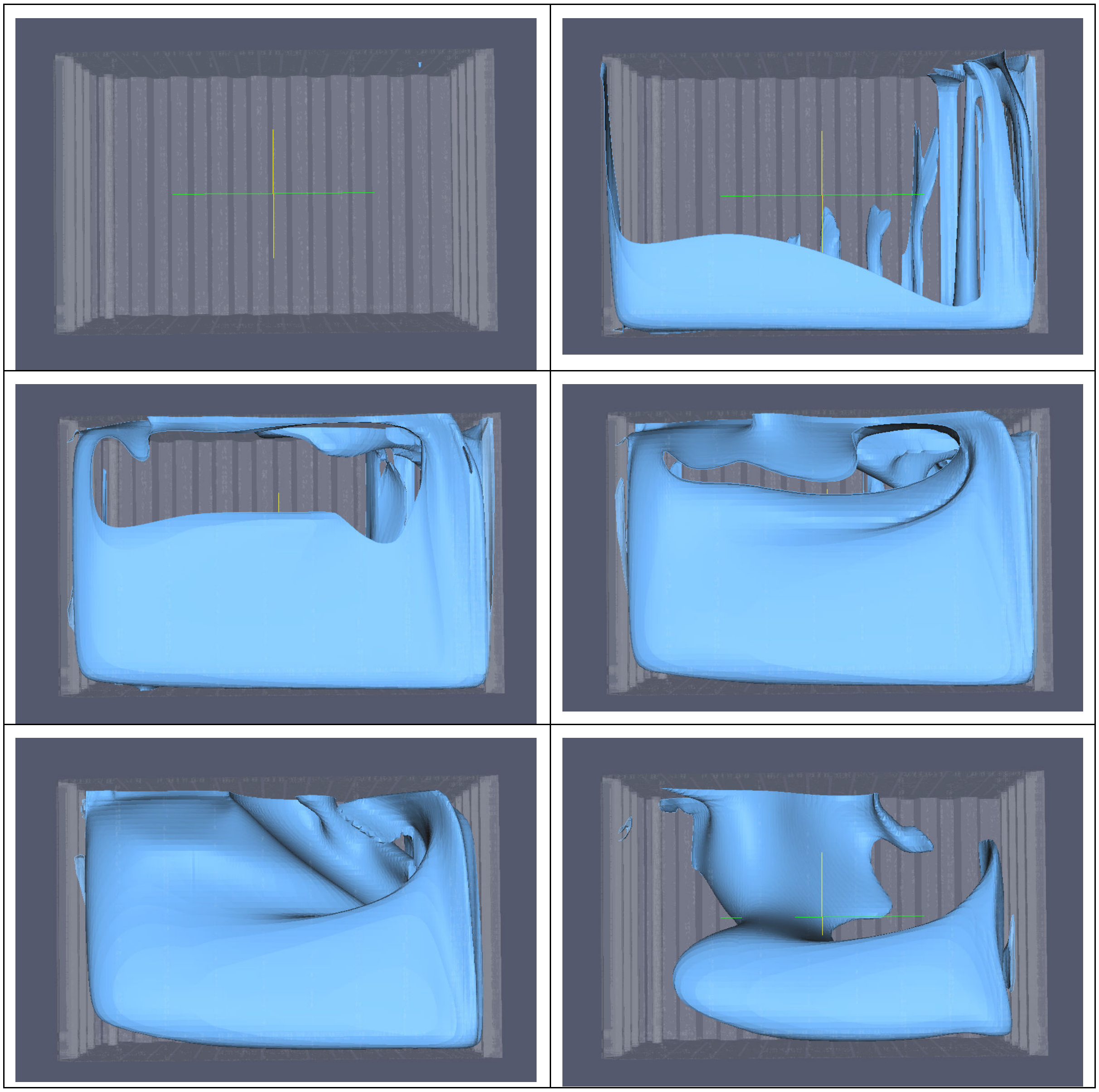


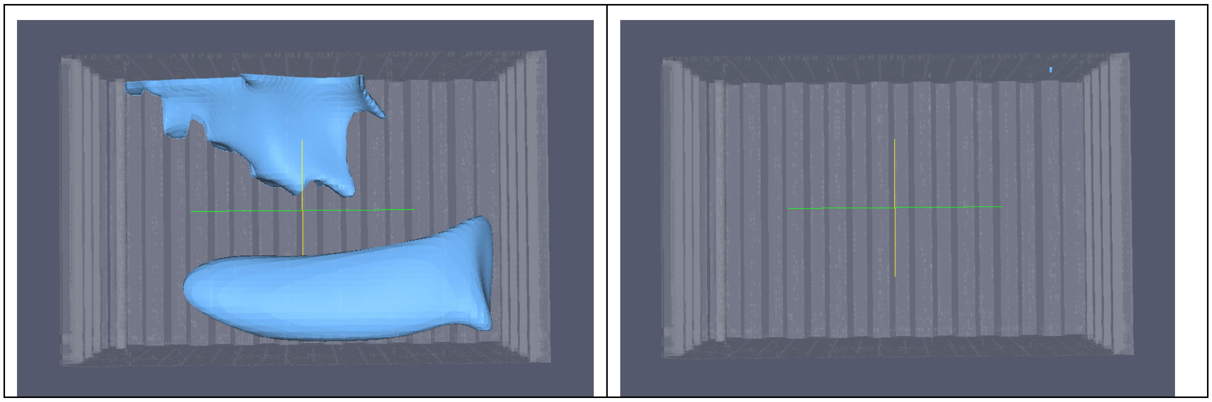
Kuva 28. Keskikokoisella verkolla ja RSM (Reynold’s stress model) turbulens-simallilla laskettu virtauskenttä.



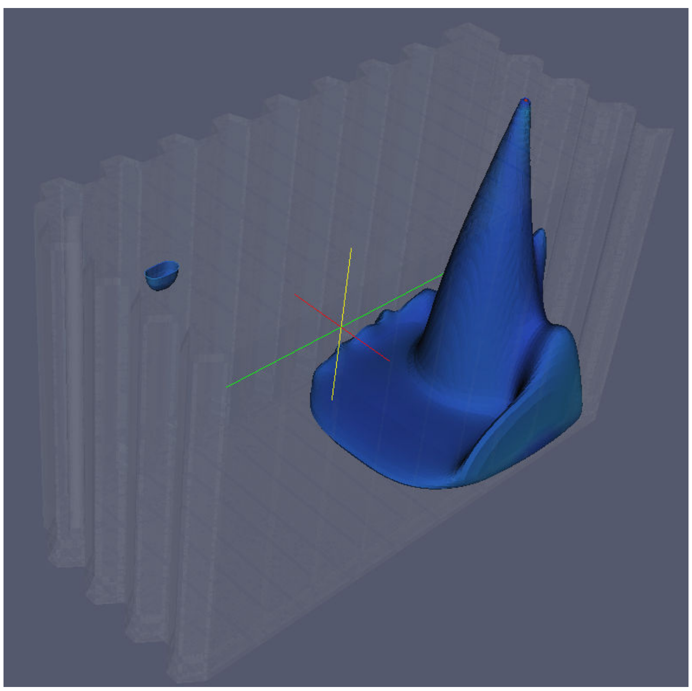


Kuva 28. Keskikokoisella verkolla ja RSM (Reynold’s stress model) turbulens-simallilla laskettu virtauskenttä. Eri ajanhetki kuin edellisessä kuvassa. Tämä osoittaa että virtaus on vähän heiluva, mutta ei merkittävästi.

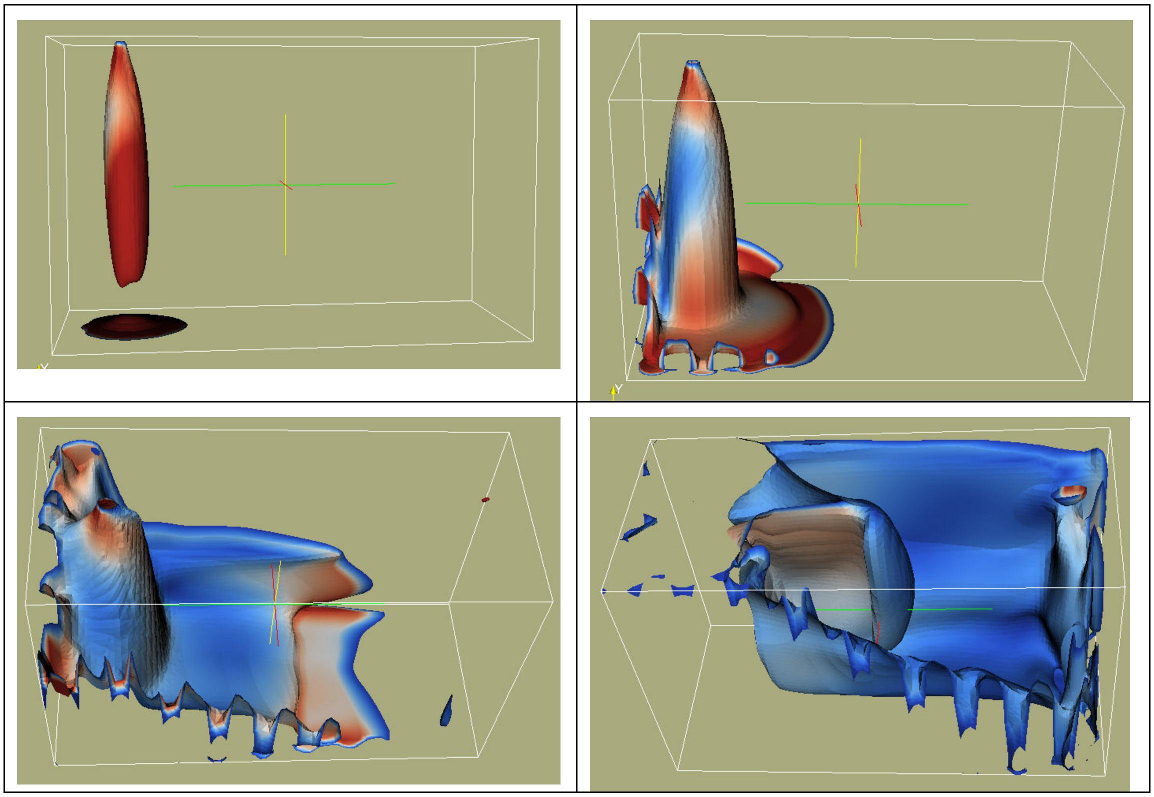




Kuva 29. Isoimmalla laskentaverkolla tehty kuvasarja kaasun sekoittumisesta, kuvattu isopinnoilla.



Kuva 30. Isoimmalla laskentaverkolla tehty kuva missä näkyy missä esiintyy voimakkainta turbulenssia realizable k-epsilon turbulenssimallilla.



Kuva 31. Keskikokoisella laskentaverkolla ja RSTM turbulenssimallilla laskettu kuvasarja joka näyttää miten kaasu leviää tankissa.