



High pressure oxygen system flash-fire on board *Searoad Mersey*

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At about 1540¹ on 22 September 2006, the trainee engineer on board *Searoad Mersey* was preparing the fixed oxy-acetylene system for a small hot-work job in the engine room. He had opened the oxygen cylinder valve and, as he was reaching up to the pressure regulator, two of the system's high pressure hoses and the oxygen regulator exploded in a flash fire. The trainee engineer was hit in the head by the regulator and he received burns to his face, head and arms.

Searoad Mersey

Searoad Mersey (Figure 1) is a roll-on roll-off general cargo ship that operates a scheduled service between Devonport in northern Tasmania and Melbourne in Victoria. The ship also calls at King Island once each week.

Searoad Mersey was built in 1990 by the Singapore Slipway and Engineering Company and then lengthened in 1996. The ship has an overall length of 118.8 m, a moulded breadth of 18.50 m and a moulded depth of 13.60 m.

It has a deadweight of 4824 tonnes at its summer draught of 5.512 m.

At the time of the incident, *Searoad Mersey* was registered in Australia, classed with Det Norske Veritas (DNV) and managed by Patrick Shipping, Melbourne.

Searoad Mersey is fitted with two four-stroke, single-acting, Wartsila 8R32E main engines each with a maximum continuous rating of 3280 kW at 750 rpm. The engines are clutched into individual reduction gearboxes which in turn drive a pair of contra-rotating controllable pitch propellers to give the ship a service speed of 15 knots².

The accommodation superstructure is located at the forward end of the ship and the main cargo deck is located aft of it. The main vehicle deck is located under the cargo deck and accommodation with access for roll-on cargo via a stern door. The engine room is located under the vehicle deck at the aft end of the ship.

Figure 1: *Searoad Mersey*



1 All times referred to in this report are local time, Coordinated Universal Time (UTC) + 10 hours.

2 One knot, or one nautical mile per hour, equals 1.852 kilometres per hour.

At the time of the incident, *Searoad Mersey* had a crew of 13 Australian nationals.

Searoad Mersey's master held an Australian master class one certificate of competency. He had 36 years seagoing experience and had been master of the ship for the previous five and a half years.

The chief engineer had been at sea for 25 years and held an Australian class one certificate of competency. He had been chief engineer on board *Searoad Mersey* for the previous five years.

The first engineer had 18 years seagoing experience and held a class one certificate of competency. He had sailed on board *Searoad Mersey* for the past two and a half years and rejoined the ship the day before the incident.

The trainee engineer had trained as a diesel fitter with the Royal Australian Navy and, after leaving the navy, worked as a fitter for about three years before starting his training as a marine engineer. He had been at sea as a trainee since October 2005 and, because there was no second engineer on board the ship at the time of the incident, he was acting as an uncertificated second engineer.

The hose assembler, who supplied the failed oxygen hoses, purchased the Enzed 'hose doctor' franchise for northwest Tasmania in 1998. After buying the franchise and a fully equipped service truck, the hose assembler attended a two week 'hose doctor' franchisee training course at the company's training centre. The hose assembler originally trained as a fitter in the Royal Australian Navy and had since worked in a variety of technical roles.

Fixed oxy-acetylene system

Searoad Mersey is fitted with a fixed oxy-acetylene system which has the gas cylinders located outside the engine room to reduce the risk of a fire in the engine room when the welding gases are not in use.

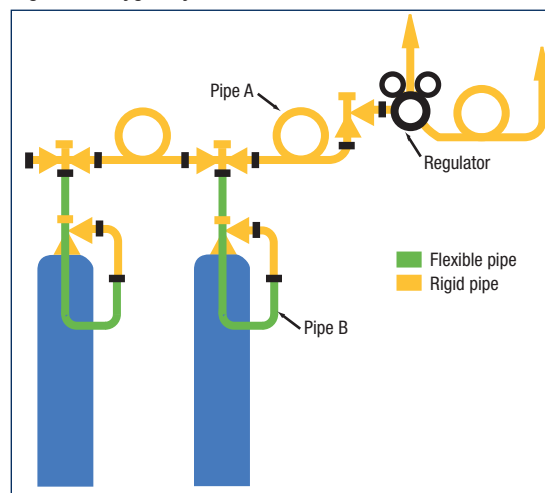
The system was originally installed on board *Searoad Mersey* by the shipbuilder using components supplied by Unitor, an international supplier of gas welding equipment, when the ship was built. At the time of installation, the system met with DNV approval, the AMSA requirements for gas welding and cutting

equipment³ and the appropriate international standards for welding gas installations.

The high pressure oxygen and acetylene cylinders were located in separate lockers on the upper deck, adjacent to the funnel casing. From here, the welding gases were piped to the engine room workshop at a lower pressure. Each locker contained gas cylinders, high pressure manifold pipes, valves and a regulator to reduce the gas pressure.

In the engine room, an outlet station in the welding bay contained isolating valves, flame arrestors and service regulators for both gases. An oxy-acetylene cutting or welding torch was connected to the low pressure side of the service regulators when hot work was being undertaken.

Figure 2: Oxygen system



The oxygen locker contained three oxygen gas cylinders, two of which were connected to the manifold (Figure 2) with the third stored as a spare. The oxygen regulator reduced the gas pressure from the cylinder pressure of about 200 bar⁴ to the system pressure of about 7 bar. The low pressure side of the regulator was fitted with a relief valve that vented to the atmosphere.

The system valves were designed for use with high pressure oxygen and were of a 'slow opening' type. These valves reduce the rate of pressure rise within the system so that the associated temperature rise can be tolerated

³ Marine Orders Part 12, Appendix 4, Section 11.

⁴ 1 bar = 100 KPa (approximately one atmosphere).

by correctly specified system components. The manifold consisted of isolating valves separated by loops of stainless steel pipe.

The cylinders were originally connected to the manifold by high pressure hoses that had been supplied by Unitor.

Fixed oxygen system history

On 18 May 2006, the pipe loop between the manifold valve and the regulator isolating valve was found to be leaking (Pipe A in Figure 2). When requested to by one of the ship's engineers, the Enzed hose assembler supplied and fitted a hose into the system to replace the leaking pipe. However, this hose subsequently failed so the hose assembler supplied and fitted a new hose with a higher pressure rating.

On 20 June, two spare hoses were ordered from the hose assembler for the high pressure oxygen system and were delivered to the ship.

In early August, the first engineer inspected the oxygen system and found that two hoses in the oxygen locker were leaking; one of the original hoses from a cylinder to the manifold was cracked (Pipe B in Figure 2) and the new hose that had been fitted between the manifold and regulator was leaking from where the hose was joined onto the end fitting (Pipe A in Figure 2).

On 18 August, the first engineer replaced the leaking hoses with the two spares. He then pressurised the system and checked it for leaks.

The system was used, without incident, several times between 18 August and 22 September, the day of the fire.

Apart from the hose replacements and the regular exchange of cylinders and seal washers, no periodic routine maintenance or inspection work was undertaken on the high pressure oxygen system.

The incident

On 22 September, *Searoad Mersey* was berthed at number two Webb Dock, Melbourne. The trainee engineer had planned to do a small hot-work job in the engine room workshop.

At about 1540, he went to the oxygen and acetylene lockers on the upper deck to turn

on the gas. He opened the oxygen locker and then opened the oxygen cylinder valve. As he reached up to check the regulator valve, a small flash-fire erupted and the regulator exploded, knocking him to the deck.

When he picked himself up, the fire had self-extinguished except for a small flame that was still burning in the regulator. He shut off the oxygen cylinder to stop the flow of gas from the ruptured hoses and then hurried to the accommodation to get help.

The first engineer was working in the ship's office when the trainee engineer ran in shouting that there had been a fire in the oxygen locker. When he saw how badly burnt the trainee engineer was, he told him to get into a shower to cool his burns. The first engineer then went to the oxygen locker to ensure that all of the cylinders were isolated and that the fire had been extinguished.

The chief integrated rating heard the commotion and notified the master of the incident. The master instructed the terminal manager to call an ambulance before he went to assist the trainee engineer. The ambulance arrived at 1600 and the trainee engineer was taken to hospital for treatment at 1610.

The Melbourne Fire Brigade (MFB) arrived at 1610 in response to the report of a fire on board the ship. They inspected the oxygen cylinder locker accompanied by the ship's manager, the master and the chief engineer.

At 1620, the master informed the harbour master of the incident and told him that the ship would not sail at 1630 as scheduled.

At 1735, an AMSA surveyor attended the ship and examined the incident site.

The MFB was unable to determine the cause of the fire and requested that a specialist fire investigator attend the ship. The fire investigator arrived at 1755, examined the scene and removed the damaged oxygen system components and debris for further examination. The damaged system components were subsequently sent to the ATSB for a detailed examination.

The AMSA and MFB investigations were completed by 1845 and a notice was issued by AMSA prohibiting any further use of the

fixed oxy-acetylene system until the cause of the fire was established and the system was permanently repaired.

Searoad Mersey sailed from Melbourne at 1918, bound for Devonport.

The fixed oxy-acetylene system was subsequently repaired by Unitor to its original specifications and the prohibition notice was lifted by AMSA.

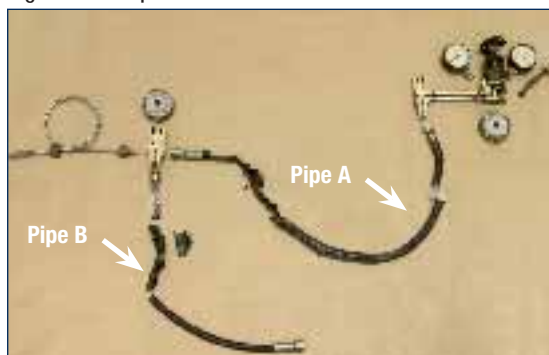
Analysis

On 22 September, a flash fire occurred in the high pressure oxygen system on board *Searoad Mersey*. The trainee engineer received minor head injuries when he was struck by flying components from the regulator when it failed in the fire. He also received burns to his arms from the flash-fire and from molten hose material landing on his skin when the hoses ruptured. He was wearing overalls at the time but the sleeves were rolled up. Consequently, his arms were exposed to the burning hose debris.

The fire

Three elements; oxygen, fuel, and heat are required to initiate and sustain a fire. Fires in open air can be prevented, or extinguished, by removing any one of the elements, but the elements are more difficult to separate in a high pressure oxygen system because both fuel and an abundant supply of oxygen are contained within the system.

Figure 3: Components sectioned for examination



If any combustible component in an oxygen system is heated beyond its auto-ignition temperature⁵, it will burn. The ignition source

⁵ The lowest temperature at which the material will ignite due to heat alone, without the introduction of a flame.

may come from within the system and, in this instance, the two possible primary ignition sources were near-adiabatic compression⁶ and particle impact.

An analysis of the system components was performed by the ATSB. When the hose between the manifold and the regulator (Pipe A in Figures 2 and 3) was sectioned, it was revealed that the entire inner core had been burnt in the fire. The damage to the hose liner was greatest near the pressure regulator shut-off valve and the damage decreased back towards the mid-stage manifold valve. The burning of the hose liner adjacent to the regulator valve, followed by a rapid advance of the flame back along the lining of the hose, suggests that near-adiabatic compression was the most likely ignition source.

When the trainee engineer opened the oxygen cylinder valve quickly, the oxygen from the cylinder flowed into the manifold and compressed the oxygen that was already in the system until the pressures had equalised. The compression was near-adiabatic and it heated the hose liner to above its auto-ignition temperature, causing it to ignite in the pure oxygen environment.

The combustion products increased the system pressure. The over pressurisation within the system caused the regulator to fail and caused the other hose, also heat damaged by the fire, to rupture.

Other oxygen fires

Oxygen system fires are not common but a number of them have been documented.

In 1997, a Bell helicopter was destroyed following an oxygen system fire. In this case, either particle impact or near-adiabatic compression ignited the inner lining of a polyester lined, flexible hose that had been fitted to the system and was 'designated by the manufacturer as being oxygen compatible'.⁷

In the USA, between 1995 and 2000, there were 40 reported fires in portable medical

⁶ When the oxygen within a system is compressed rapidly, with little heat loss to the surrounding material, it can cause a rapid temperature rise in the gas.

⁷ Bureau of Air Safety Investigation (BASl), Report 9701421, Page 22. BASl was incorporated into the ATSB on 1 July 1999.

oxygen systems where near-adiabatic compression or particle impacts were suspected to have caused the ignition of aluminium regulators or polymer valve seals in the systems.

The United Kingdom Health and Safety Executive recorded 167 oxygen related incidents involving hot-work between 1990 and 2002⁸. The causes of these incidents included opening valves too quickly resulting in near-adiabatic compression.

Flexible hoses

Flexible hoses are used in high pressure oxygen systems to allow easier connection of the gas cylinders. Correctly manufactured hoses should not increase the hazards associated with these systems.

At the time of the incident, there was no Australian Standard for high pressure oxygen hoses. The originally installed hoses met the requirements of the international standard, ISO 14113⁹. The replacement hoses did not meet this standard and, therefore, were not safe for use in a high pressure oxygen system.

ISO 14113 states that the auto-ignition temperature of the hose lining shall not be less than 400° C and that the complete assembly shall be tested for non-ignition. ISO 14113 also states that the complete assembly shall be pressure tested, leak tested and cleaned ready for service with oxygen. Once complete, the hose assembly must be marked with its sizes, pressure rating and the name of the gas that it is suitable for.

The original Unitor hoses had a Teflon liner, which has an auto-ignition temperature of 434°C, with stainless steel braiding and a protective outer sheath. They had also been cleaned and tagged as suitable for oxygen.

Two different hoses were installed on board *Searoad Mersey* on 18 August although they appeared to be very similar. One hose (Pipe A in Figure 3) was marked as a 'Parker 580N'

series hose and the other (Pipe B in Figure 3) as a 'Gates 4C8S' hose. The fittings used on both hose assemblies were similar and the ferrules were stamped with the same markings (SN8-4). The fittings on both hoses appeared to have been swaged using a similar machine.

Both hoses had a pressure rating of 5000 psi¹⁰ and had similar physical characteristics. Both hoses had an inner tube made from polymeric nylon. Nylon is chemically compatible with oxygen but has an auto-ignition temperature of 178° C¹¹, making it vulnerable to near-adiabatic compression ignition in a high pressure oxygen system.

The replacement hoses supplied by the Enzed hose assembler were fabricated using the equipment fitted on board his service truck. The working areas of the truck, including the hose cutter and the swaging machine, were probably contaminated with oil when the oxygen hoses were assembled.

The presence of oil within a high pressure oxygen system can increase the system's vulnerability to compression ignition. The replacement hoses were not cleaned to remove any oil contamination, pressure tested, or tagged before they were delivered to the ship.

The replacement hoses did not comply with ISO 14113. The hoses had liners that were made from a material with a relatively low auto-ignition temperature, were manufactured in an oily environment, were not cleaned after assembly and were not tagged as suitable for use with high pressure oxygen. The hoses were not fit for their intended purpose.

The hose assembler

The hose assembler received his franchisee training at the Parker/Enzed training centre in 1998. The training included an introduction to the company's range of products, techniques for repairing and replacing hydraulic and other industrial hoses, business development and administration. However, it did not cover specialised hose types such as high pressure oxygen and did not include safety information

8 Health and Safety Executive, reports TD5/015 and CD5/056.

9 ISO 14113 - 1997, 'Gas welding equipment - rubber and plastic hoses assembled for compressed or liquefied gases up to a maximum design pressure of 450 bar'.

10 A unit of pressure, pounds per square inch. One atmosphere is approximately 14.7 psi.

11 Ed. Beeson, H., Stewart, W., Woods, S. (2000): Safe Use of Oxygen and Oxygen Systems, ASTM, p 60.

relating to high pressure oxygen systems or the standards relating to their manufacture.

The catalogue used by the hose assembler to select the hose for the high pressure oxygen system on board *Searoad Mersey* stated that the hose that he selected was rated to 5000 psi and had a polymeric, flexible nylon liner. A chemical compatibility table in the same catalogue indicated that the compatibility of the nylon lining with gaseous oxygen was:

‘Good to excellent. Little or no swelling, tensile or surface changes. Preferred choice.’

With this information at hand, the hose assembler believed that his hoses would be suitable for the high pressure oxygen system.

There was no specific information in the catalogue about high pressure oxygen hoses and Parker/Enzed had not provided a help-line or web site to provide technical advice on high pressure oxygen hoses.

The hose assembler had not been given any information by Parker/Enzed regarding the dangers associated with high pressure oxygen, despite the fact that the information was available within the company. Parker Instrumentation had issued an engineering performance report¹² that explained the dangers associated with oxygen systems with respect to fires, material selection, and cleanliness. However, this engineering performance report had not been distributed to hose assemblers.

The hose assembler fabricated a hose for use with oxygen at high pressure based on the information that he had available. He had not been trained or informed about the dangers associated with high pressure oxygen systems, was unaware of the standards associated with these systems and did not have clear and unambiguous guidance in his catalogues.

Shipboard procedures

The ship's engineers had a basic understanding of high pressure oxygen systems and understood that oil and grease should never be used in these systems due to the increased risk of fire and explosion. However, they were not aware, and had never been informed, of

the dangers associated with compression ignition in a high pressure oxygen system or of the standards relating to high pressure oxygen systems.

The AMSA requirement for gas welding and cutting equipment, Marine Orders Part 12, Appendix 4, states that the cylinders must comply with Australian Standard AS 2030. The marine order also states that:

All the equipment and fittings required by this Appendix must be installed, serviced and maintained so that they remain safe to operate and do not endanger the safety of the ship and the persons on board¹³.

Neither the marine order nor the DNV rules specify any standard, such as ISO 14113, for the hoses or fittings used in a high pressure oxygen system.

The ship operator's safety management system did not contain any procedures for the maintenance of the high pressure oxygen system that could have provided guidance for the ship's engineers.

The ship's operator did not have any procedures or guidelines for procuring equipment, from suppliers other than the original equipment manufacturer, with respect to specifying standards for the equipment.

When the pipe loop failed in May 2006, one of the ship's engineers asked the hose assembler to replace it with a flexible hose.

The engineer was not aware of all of the hazards associated with the system and did not inform the hose assembler of them.

The chief engineer ordered the spare hoses from the hose assembler because he expected delays if he tried to procure the parts from Unitor. The chief engineer's purchase order for the spare hoses was to 'Supply 2 off high pressure hoses for fixed oxygen installation'. The purchase order did not specify an appropriate standard.

When the ship's engineers ordered the replacement oxygen hoses, they did not understand all of the hazards associated with the high pressure oxygen system and did

¹² EPR 4103-2 - revision, 'Cleaning for Oxygen Service', Parker Instrumentation.

¹³ Marine Orders Part 12, Appendix 4, Section 11.9.

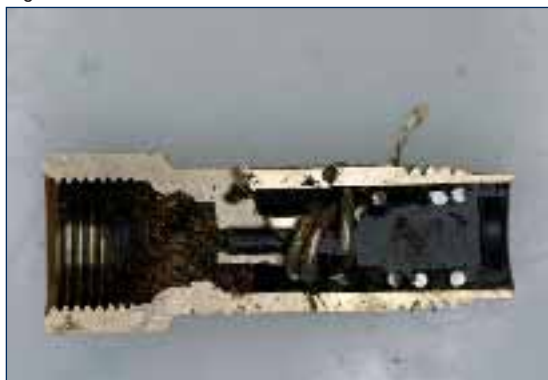
not specify an appropriate standard for the manufacture of the hoses.

Maintenance practices

The fixed oxy-acetylene oxygen system was not included in the maintenance management system. No routine preventative maintenance was performed on the system and, therefore, the hoses, pipes, fittings and the regulator were not inspected on a regular basis.

The pressure relief valve on the regulator was designed to protect the low pressure system. The condition of the relief valve, which had become corroded and blocked (Figure 4), was indicative of the lack of maintenance on the oxy-acetylene system.

Figure 4: Corroded and blocked relief valve



The blockage in the pressure relief valve and associated piping had remained undetected because the system had not been inspected or maintained in accordance with Marine Orders Part 12.

Findings

From the evidence available, the following findings are made with respect to the oxygen system flash-fire that occurred on board *Searoad Mersey* on 22 September 2006 and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The replacement hoses used in the high pressure oxygen system did not conform to ISO 14113 and were not fit for purpose.
- The hose assembler was not aware of the hazards associated with high pressure oxygen systems or of any standards for the fabrication of high pressure oxygen hoses.
- The hose assembler did not have unambiguous guidance in his hose catalogues for manufacturing a hose for a high pressure oxygen system.
- The ship's engineers were not aware of all of the hazards associated with high pressure oxygen systems or the standards required for them.
- There were no shipboard procedures for maintaining the high pressure oxygen system in accordance with the requirements of Marine Orders Part 12.

Other safety factors

- Marine Orders Part 12 and DNV rules did not provide detailed guidance on the safety issues associated with high pressure oxygen systems or on the standards required for them.

Other key findings

- The ignition of the nylon hose liner was probably caused by near-adiabatic compression of the oxygen within the hoses.
- The burns received by the trainee engineer on his arms would have been less severe if his overall sleeves were not rolled up.

Safety action by Parker Hannifin

The ATSB has been advised that the following safety actions have been taken by Parker Hannifin as a result of the high pressure oxygen system flash fire on board *Searoad Mersey*.

- A thorough review of all of training procedures/practices has been undertaken to confirm that explicit guidance for the use of high pressure oxygen hoses is included in all training sessions for hose assembly.
- On 10 October 2006 Parker Hannifin re-issued a newsletter in order to reiterate to all of their ENZED franchisees and all other Parker Hannifin Fluid Connector distributors, the care that should be taken when making 'Hose Assemblies Used with Oxygen'.

ATSB recommendations

MR20070014

Suppliers of hoses and fittings for high pressure oxygen installations should ensure that the equipment they supply is fit for purpose and manufactured according to appropriate standards.

MR20070015

The Australian Maritime Safety Authority should consider reviewing Marine Orders Part 12, or issuing a Marine Notice, with the aim of highlighting the potential risks of high pressure oxygen systems.

MR20070016

Det Norske Veritas should consider reviewing its rules with the aim of providing more detailed guidance for high pressure oxygen systems.

MR20070017

Ship owners, managers and masters should ensure that equipment procured for fixed high pressure oxygen installations is fit for purpose in accordance with the appropriate standard and that the system is adequately maintained.

MR20070018

Parker Hannifin should review its Newsletter, 'Hose assemblies used with oxygen' and training procedures/practices in line with the international standard ISO 14113.

Media Release

Crew member burnt in oxygen system flash fire

The ATSB has found that a high pressure oxygen system fire on board the roll-on/roll-off cargo ship *Searoad Mersey*, on 22 September 2006, occurred when an unsuitable replacement hose fitted to the system ignited. The ship's trainee engineer was hit in the head by the gas regulator and received burns to his face, head and arms.

At about 1540 on 22 September 2006, the trainee engineer was preparing the fixed oxy-acetylene system for a small hot-work job when two of the oxygen system's high pressure hoses, and the oxygen regulator, exploded in a flash fire.

It is probable that, when the trainee engineer opened the cylinder's valve, the heat created by the compression of the oxygen in the line ignited the lining in one of a pair of replacement high pressure hoses that had been recently fitted to the system.

The replacement hoses were not designed for use in a high pressure oxygen system. The hose liners had a low ignition temperature, the hoses were probably assembled in an oily environment, and the hose material did not comply with the appropriate standards for high pressure oxygen hoses.

The ATSB report also found that the hose assembler who supplied the hoses was not aware of any special requirements for high pressure oxygen systems when he assembled the hoses. Similarly, the ship's engineers were not aware of all of the hazards associated with high pressure oxygen systems or of the standards required for them.

The ATSB has made several safety recommendations with the aim of preventing further incidents of this type.