The Bahamas Maritime Authority

Marine Safety Investigation Report

into an engine room fire onboard Pride of Hull on 20 October 2020

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1. Summary

What happened

On 20 October 2020, the ro-ro passenger ferry Pride of Hull was outbound in the Humber Estuary, UK, when a fire was detected in the vicinity of the thermal oil circulation pumps, part of the vessel's heat reclamation and transfer system. Shortly afterwards, the vessel lost electrical power and propulsion but used remaining headway to anchor safely.

The vessel's Hi-Fog fire suppression system activated automatically but did not operate as anticipated and could not control the fire, which was extinguished using the vessel's fixed CO_2 system. The vessel returned to port, under its own power, the next day.

No one was hurt, damage was limited and there was no pollution.

Why it happened

Examination of the thermal oil circulation pump identified that progressive bearing failures resulted in extreme frictional heating, generating temperatures in the order of 1,200°C, far in excess of the auto-ignition temperature of the thermal oil used in the system.

Assessment of the fire suppression system identified that the system's effectiveness was compromised by pump output when multiple zones were activated and its dependence on a domestic fresh water pump to maintain supply for longer than two minutes. Additionally, the system's pumps were not connected to the emergency switchboard and therefore stopped when the vessel lost electrical power. These limitations were compliant with requirements but were not reflected in emergency response guidance.

What can we learn

Frequent failure of equipment generally indicates a weakness in the system. Detection of causal factors can identify multiple ways to address particular weakness: it is important to assess the impact of an engineering change before execution to ensure the best approach.

Operators and crews should check that the design of their fire suppression systems meet their operational requirements and ensure contingency plans reflect any limitations of the system.

2. Factual Information

Pride of Hull

Vessel Type	Passenger / ro-ro ferry	**Flag**	Bahamas[1]
Owner	P&O Ferries Pride of Hull Limited	**Manager**	P&O Ferries Holdings Ltd
Classification Society	Lloyd's Register	**Gross/Net Tonnage**	59,925 / 26,868
Built	Fincantieri, Italy, 2001	**Propulsion**	Four engines driving two controllable pitch propellers through reduction gears.

IMO No.	Callsign	Length overall	Breadth	Draught
9208629	C6ZQ4	215.45m	31.88m	6.2m

Last BMA Inspection	Last PSC Inspection
Hull, 27 February 2020. No deficiencies.	Rotterdam, 03 March 2020. No deficiencies.

Pride of Hull (Source: P&O Ferries)

[1] Originally flagged in the United Kingdom, reflagged to Bahamas in 2011

Rank/Role on board	Master	Chief Officer	Chief Engineer	Second Engineer
Qualification	Master II/2	Master II/2	Chief Engineer III/2	Chief Engineer III/2
Certification Authority	Netherlands	UK	UK	Latvia
Nationality	Dutch	British	British	Latvian
Time in rank	4 years	4 years	8 years	4 years
Time with Company	20 years	14 years	13 years	13 years

Both the master and chief officer held pilotage exemption certificates for the Humber.

Environmental Conditions

Wind Direction	Wind Force	Wave Height	Tidal stream	Precipitation / Sky	Visibility Range	Light Conditions
SSE	3	<0.5m	Flood, 2.5 knots	Clear	Good	Night

Voyage Details

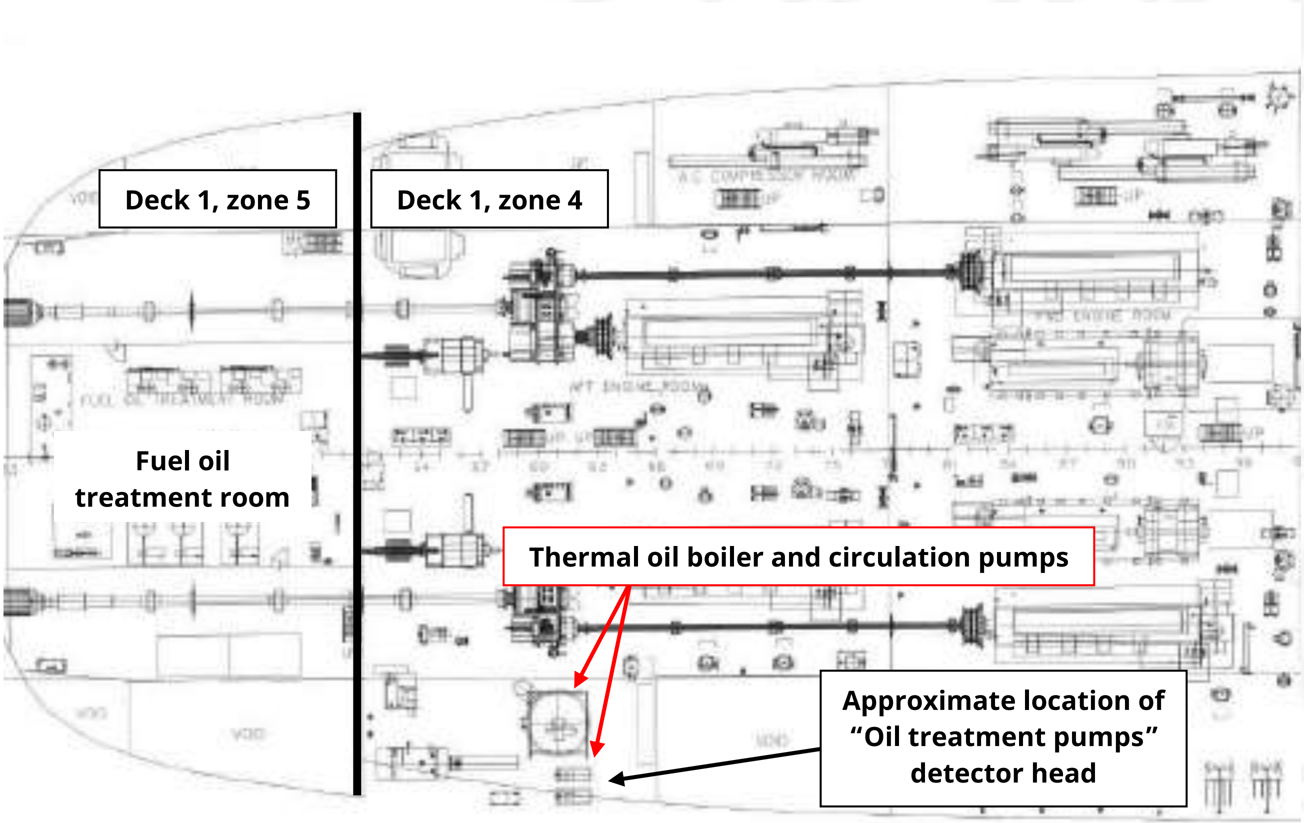
Departure Port	Hull, UK	Arrival Port	Rotterdam, Netherlands
Time of departure	20:01, 20 October 2020	Estimated time of arrival	08:00, 21 October 2020
Voyage duration	12 hours	Voyage distance	Approximately 200 nm
Cargo	Ro-ro cargo, 154 passengers	POB	264
Stage of passage	Pilotage area, outbound	Traffic density	Light

Narrative

All times used in this report are UTC + 1 unless otherwise stated.

At approximately 20:01 on 20 October 2020, Pride of Hull sailed from the river terminal in Hull, UK, on its scheduled service to Europoort (Rotterdam), Netherlands. The bridge team consisted of the master, chief officer and two ABs. The chief engineer was in the engine control room with the engineer officer of the watch (EOOW).

At 20:35 the vessel's fire detection system alarm sounded, with the bridge's fire panel indicating a fire on Deck 1, zone 4: Oil treatment pumps. The AB sent to check the fire panel then relayed this to the engine control room (and bridge team) as a fire detected in the "fuel treatment room". The EOOW went directly to the fuel treatment room to identify the cause of the alarm. 21 seconds later, the fire detection system started to identify further alarms in multiple locations in the engine rooms.



General arrangement plan with "oil treatment pumps" and fuel treatment room identified

Alerted by the additional alarms, the chief engineer left the engine control room and opened the watertight door to the aft engine room which was filling with thick black smoke; at approximately the same time, the vessel's Hi-Fog fire suppression system activated at the thermal oil circulation pumps. The engineer's call was activated, the bridge was informed and a "Code Bravo" (restricted incident) was announced on the public address system to direct crew to muster for firefighting and control.

At 20:39 Pride of Hull briefly lost electrical power but maintained propulsion. The bridge team reduced speed and shaped up to drop anchor, stemming the wind and tide. Humber VTS, Coastguard and local traffic were informed of the situation and a lifeboat and two tugs were tasked by Humber VTS to standby.

Propulsion was lost at 20:44 but emergency power was maintained and the vessel anchored approximately 10 minutes later.

Pride of Hull (ringed) anchor position (Source: Humber VTS)

The smell of burning plastic from the aft engine room and the loss of power lead the engineering team to believe the fire was electrical in nature. At 20:47 the first firefighting team[2] entered the aft engine room on breathing apparatus (BA) with two objectives: identify the source of the smoke and restore electrical power. Visibility was severely limited and no fire could be seen, the team proceeded with restoring power. In parallel, further teams were shutting down ventilation, isolating electrics and checking for hot spots.

Having attempted to reset breakers in the high voltage room, BA team 1 withdrew after a final visual check for flames, exiting the aft engine room at 21:11. BA team 2 then entered the aft engine room, identifying the fire in the vicinity of the thermal oil boiler six minutes later. The bridge was informed and preparations were made to release CO_2 in to the space.

With all crew and passengers mustered, quick closing valves and fire dampers closed, the chief engineer and chief officer made the final preparations for release of CO_2 into the aft engine room from the Deck 7 safety station. After a short delay waiting for the final ventilation emergency shutdown indicator, CO_2 was released at 21:23. Falling temperatures, monitored on all accessible sides of the space, confirmed the fire was extinguished and the lifeboat and one of the tugs were stood down at 23:33.

After the CO_2 was released, the engineering team continued their attempt to restore power and ensure the vessel could return to port under its own power. Two entries were made in to the forward engine room, on BA, to drain the economisers to enable starting an auxiliary generator. At 00:30 a BA team entered the CO_2 flooded aft engine room to reset breakers and put power on the switchboard. At around 03:30, when it was confirmed the vessel would remain at anchor, the auxiliary generator was stopped, eliminating the risk of damaging the empty economiser.

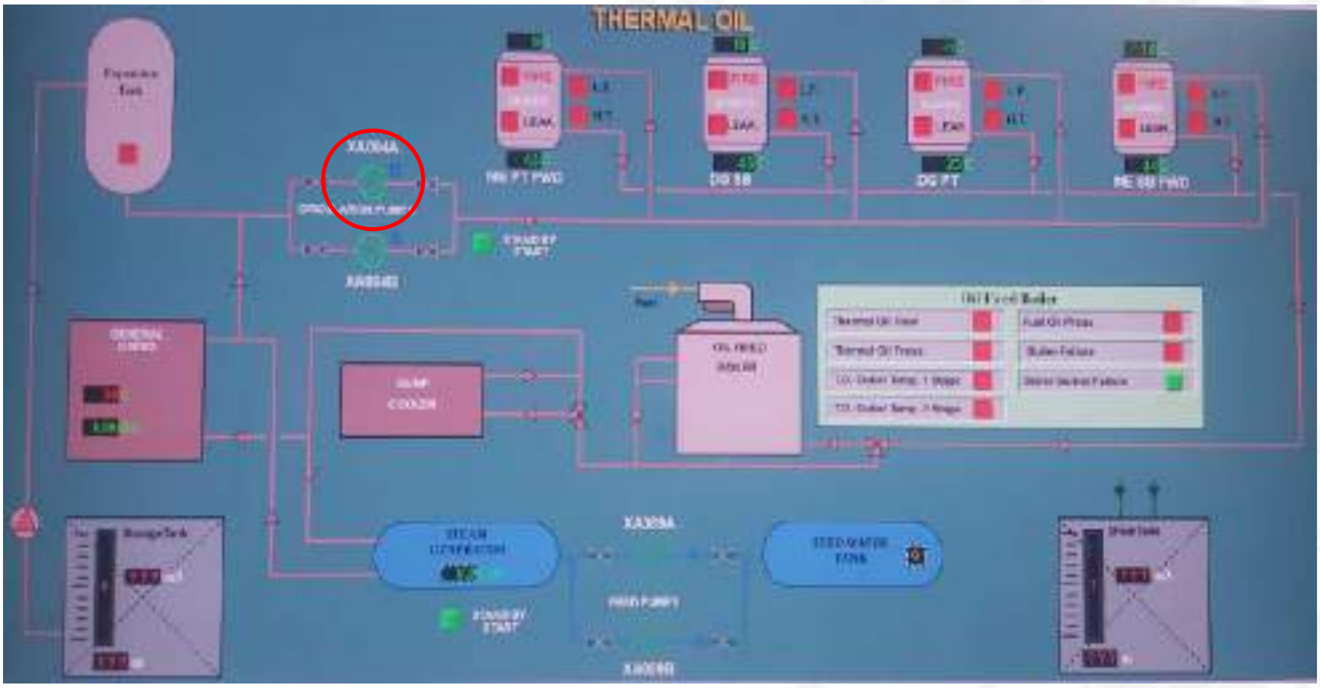
[2] Formally referred to as BA team 1

At 06:30 on 21 October 2020 the master and chief engineer agreed to ventilate the engine room and restore systems. After extended entries in BA, power was restored at 07:15 and propulsion was confirmed available at 10:00. The vessel re-berthed at the river terminal with tug assistance, but under its own power, at 22:30.

Post-fire scene examination identified that thermal oil circulation pump #1 was the seat of the fire.

Thermal oil system

Pride of Hull's thermal oil system was a low pressure[3] closed loop circuit, using Texatherm 32 to distribute heat energy from economisers on the main engines and diesel generators located in the forward engine room, or an oil fired boiler, located in the aft engine room, to the ultra-low sulphur fuel oil, domestic hot water system and other consumers. In winter, the system was operated with a set point temperature of 170°C.



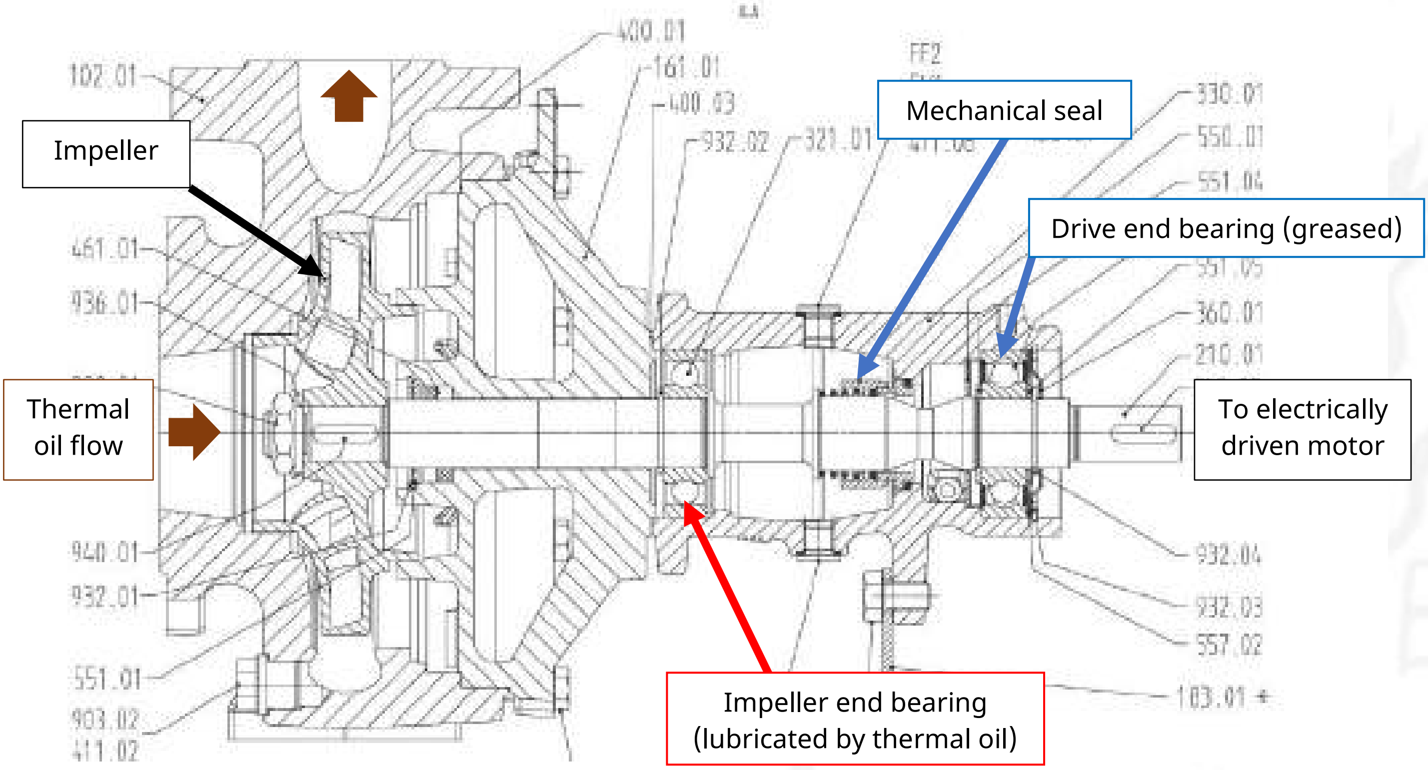
Thermal oil system overview. Circulation pump #1 ringed

Texatherm 32, produced by Chevron, is a mixture of highly refined mineral oils and has a typical flash point[4] temperature of 220°C and an auto-ignition temperature[5] of 320°C at manufacture. Thermal oil can degrade through use and a build-up of lighter components within the oil can lower its flash point (and auto-ignition) temperature. To monitor this, along with the condition of other oils and lubricants onboard, samples were routinely sent to Chevron's fluid analysis service and trending (FAST).

The thermal oil was circulated by one of two electrically driven centrifugal pumps. The circulation pumps, both 55kW Allweiler NTT 80-200's, had a capacity of 189m^3 an hour, operating at 3565 rpm, creating localised pressure of around 7 bar. One was used as the primary pump with the other in automatic stand-by mode, in case of failure of the primary. At the time of the fire, pump #1 was primary with pump #2 stand-by.

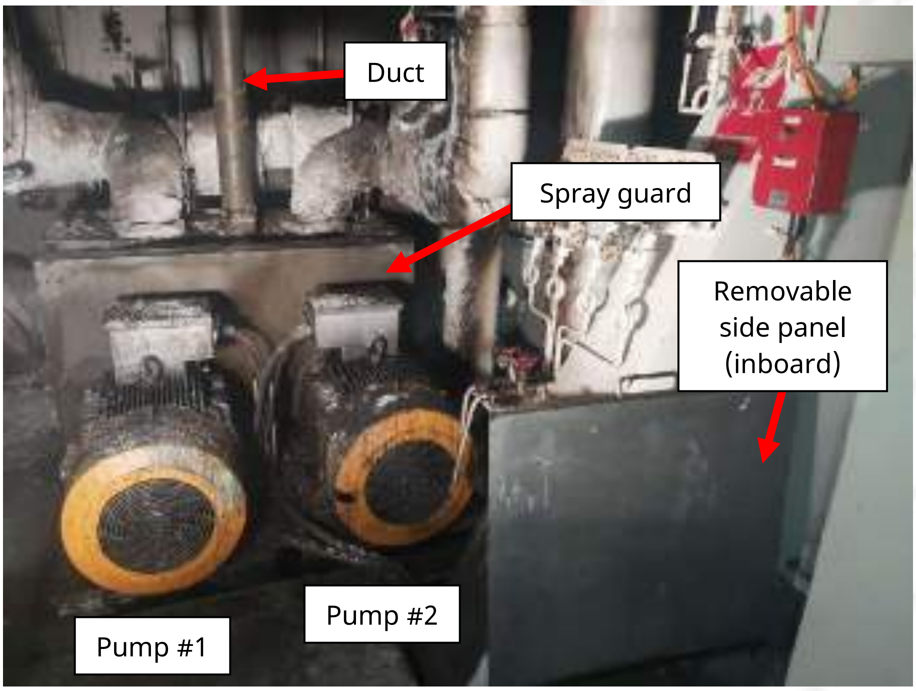
[3] Approximately 2 bar
[4] ASTM D92 Cleveland Open Cup test
[5] ASTM E659 test standard

The pumps had a single stage centrifugal impeller fitted to a shaft, rotating on two bearings: a grease packed single row ball bearing design at the electric motor (drive) end, and a thermal oil lubricated single row ball bearing design at the impeller end.



Circulation pump cross-section

The thermal oil circulation pumps had a spray guard fitted to retain oil in the event of a seal failure. The original spray guard was manufactured onboard and installed by the engineering team in 2001. Removable side panels were added in 2017 and a duct, connected to the engine room ventilation system, was added in July 2018. At the time of the fire, the side panels were not in position.



Thermal oil circulation pumps with spray guard arrangement, seen from aft (post fire)

Fire detection, suppression and fighting systems

Pride of Hull was fitted with a Consilium fire detection system, Marioff Hi-Fog fire suppression system and CO_2 fixed firefighting system. In addition, CCTV provided a live feed[6] covering the machinery spaces to enable remote visual checks.

The Hi-Fog system was designed to provide localised fire suppression whilst preparations were made for the discharge of the CO_2 firefighting system in the machinery spaces[7]. The Hi-Fog system was linked to the fire detection system so that it would activate, after a timer delay, when detector heads were triggered. Coverage was split in to seven sections:

- Section M1 Port forward (main engine) & diesel generator
- Section M2 Starboard forward (main engine) & diesel generator
- Section M3 Port aft (main engine)
- Section M4 Starboard aft (main engine)
- Section M5 Thermal oil boiler
- Section M6 Fuel treatment room
- Section M7 Thermal oil circulation pumps

Due to the Hi-Fog's localised design parameters, the system's pump capacity was dimensioned to cover the single most demanding section in terms of maintaining minimum pressure at each spray head – 195 litres per minute. As such, activation of additional sections impacted the performance of any other activated sections. Water was drawn from a dedicated "break" tank with a 426 litre capacity that was topped up from the vessel's domestic fresh water supply using a domestic water pump with a capacity of 200 litres per minute. The system was fitted with a sea water inlet but this was plugged during build and never connected.

The arrangement, as a whole, was determined to be in compliance with regulations and approved by the vessel's Flag State on the basis that the conditions of the Certificate of Fire Approval[8], issued by Lloyds Register, were adhered to.

Regulations and Guidance

Extracts from relevant instruments:
MSC/Circ.913 (1999) Guidelines for the approval of fixed water-based local application fire-fighting systems for use in category A machinery spaces. **Principal requirements for the system**:
3.5 The system should be available for immediate use and capable of continuously supplying water-based medium for at least 20 minutes in order to suppress or extinguish the fire and to prepare for the discharge of the main fixed fire-extinguishing system within that period of time.
3.9 The electrical components of the pressure source for the system should have a minimum rating of IP54. Systems requiring an external power source need only be supplied by the main power source.

MSC.1/Circ.1387 (2010) Revised guidelines for the approval of fixed water-based local application fire-fighting systems for use in category A machinery spaces and supersedes MSC/Circ.913:
3.1 System operation
.5 Where automatically operated fire-fighting systems are installed:

[6] CCTV was live footage only: after the feed was lost, due to fire damage, there was no ability to review.
[7] The system also covered the galley ranges, operated manually
[8] Certificate of Fire Approval for the fixed local application fire-fighting system Hi-Fog for Machinery Spaces of Category A, to standard IMO Maritime Safety Committee (MSC)/Circular 913, Certificate number SAS F000501 issued by Lloyds Register on 15/08/2000

.2 the detection system should ensure rapid operation while consideration should also be given to preventing accidental release. The area of coverage of the detection system sections should correspond to the area of coverage of the extinguishing system sections. The following arrangements are acceptable:
.1 set-up of two approved flame detectors; or
.2 set-up of one approved flame detector and one approved smoke detector.
Other arrangements can be accepted by the Administration. However, use of heat detectors should in general be avoided for these systems;
.3 the discharge of water should be controlled by the detection system. The detection system should provide an alarm upon activation of any single detector and discharge if two or more detectors activate. The Administration may accept other arrangements; and
.4 visual and audible indication of the activated section should be provided in the engine control room and the navigation bridge or continuously manned central control station. Audible alarms may use a single tone.

3.3 System components
.1 The system should be available for immediate use and capable of continuously supplying water-based medium for at least 20 min in order to suppress or extinguish the fire and to prepare for the discharge of the main fixed fire-extinguishing system within that period of time.
*.4 The electrical components of the pressure source for the system should have a minimum rating of IPX4** if located in the protected space. Systems requiring an external power source need only be supplied by the main power source.*

3. Analysis

The purpose of the analysis is to determine the contributory causes and circumstances of the casualty as a basis for making recommendations to prevent similar casualties occurring in the future.

Seat, fuel and cause of the fire

Fire damage patterns indicated that thermal oil circulation pump #1 was the seat of the fire and thermal oil was the fuel.

Prior to the fire, samples of thermal oil had been sent to Chevron FAST on a quarterly basis. Test results from September 2018 highlighted that the oil's flash point was above the safety limit but required attention.

> Product given as : TEXATHERM 32
>
> (ATTENTION) FLASH POINT ABOVE 140°C (SAFETY LIMIT) BUT BELOW 190°C. REGULAR SAFE VENTING AND BOILING OUT OF SYSTEM IS ADVISED TO REMOVE LIGHT MATERIAL.

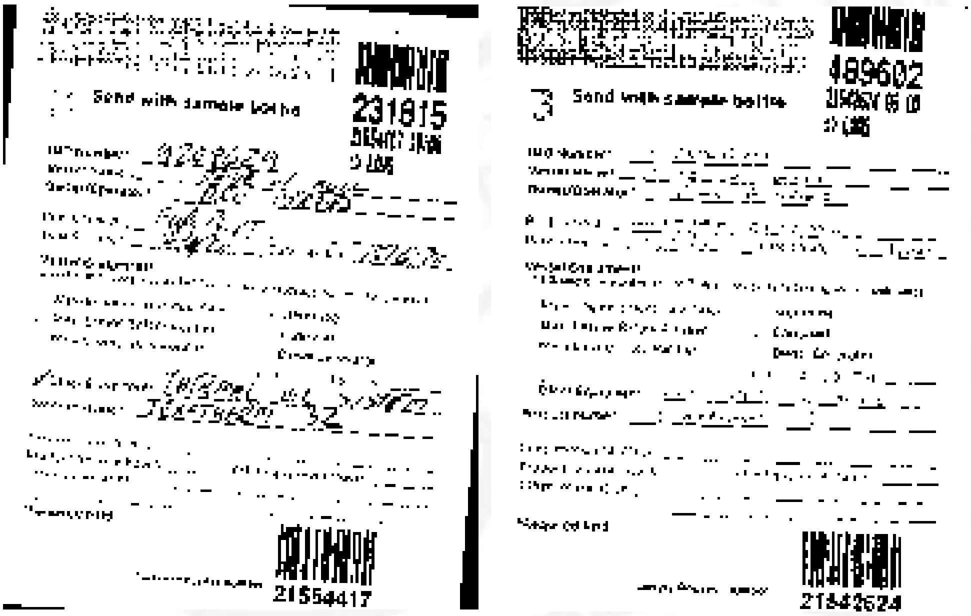
Analysis[9] of the sample drawn on 14 June 2020 identified the sample to be close to the flashpoint safety limit of 140°C:

> (ATTENTION) FLASH POINT ABOVE 140°C (SAFETY LIMIT) BUT BELOW 190°C. REGULAR SAFE VENTING AND BOILING OUT OF SYSTEM IS ADVISED TO REMOVE LIGHT MATERIAL.
>
> AD-HOC COMMENTS HAVE BEEN ADDED FOR THIS SAMPLE.
>
> borderline 140°C

The most recent sample of Texatherm 32 was drawn on 20 September 2020 and tested on 05 October 2020. Tests identified a flash point of 135.5°C. The test results report did not identify a safety limit or highlight that the flash point was lower than the safety limit.

Chevron attributed the absence of safety advice on the test report to the sample label not identifying the equipment it had been drawn from. Texatherm 32 was not used in any other equipment / system onboard Pride of Hull.

[9] Included an additional mini flash test



Thermal oil sample labels, June and September 2021

Post-fire testing of residual thermal oil from the system identified an auto-ignition temperature of 347°C.

At the time of the initial fire alarm, thermal oil circulation pump #1 was in operation. Shortly afterwards, the system automatically changed over to the stand-by pump due to a ‘low flow’ alarm on pump #1. To confirm the seat and cause of the fire, the driving motor and both pumps were examined.

The motor of thermal oil circulation pump #1 was examined by an independent repair and service company. It was identified to have sustained damage from an external heat source: melted aluminium from the rotor was present only at the bottom of the motor, indicating that the motor was not running at the time the rotor melted. Therefore, the motor is not considered the cause of ignition.

Metallurgical examination identified that the damage to the pumps was consistent with a bearing failure and fire originating at pump #1. The pattern of damage to pump #1 indicates that the impeller end bearing failed first and the drive end bearing collapsed shortly afterward. This collapse led to the drive end bearing’s outer race rotating in the bracket housing, which resulted in extreme frictional heating, generating temperatures in the order of 1,200°C - well in excess of the thermal oil’s autoignition temperature. Due to the failure of the mechanical seals and circlips, there was a path for the thermal oil to reach the hot spot internally as well as spray to make contact externally.

Thermal oil pump #1's bearing housing, split longitudinally. Arrows show the drive end bearing's outer race fused to the housing (left) and heat affected longitudinal band (right).

The metallurgical examination of the pumps did not conclusively identify the reason for the initial bearing failure. Both the bearings were Allweiler parts, of correct design for application and had failed after a relatively short period of operation. However, it was identified that the surface of the bracket housing in which the impeller end bearing sits was pitted and "possibly slightly" worn. This may have affected the fit of the bearing and potentially led to premature failure.

Spray guard

The thermal pumps' spray guard was fitted in response to thermal oil circulation pump seal failures experienced onboard the Pride of Hull and its sister ship, the Pride of Rotterdam, shortly after entering service[10]. Both vessels fitted spray guards of a similar design: providing protection forward, above and aft of the circulation pumps. The design differed in their exact placement: on the Pride of Hull the guard's aft end incorporated the drive end bearing whilst on the Pride of Rotterdam's the drive end was covered by a separate, smaller guard.

Spray guard position in relation to drive end bearing
Pride of Hull (left) and Pride of Rotterdam

After a bearing failure resulting in pressurised oil release and activation of the Hi-Fog in 2017, the spray guards on both vessels were adapted to "box in" the pumps on all sides. On Pride of Hull, this resulted in the pumps overheating. In response, the engineering team added ducting to provide air from the ventilation system. The forced air did not resolve the overheating and the side panels were subsequently removed.

Considering the identified cause of ignition, the open sides and ventilation duct are not considered to have had an impact on the cause of the fire but may have limited the effectiveness of the spray guard in terms of containment.

Tests have not been conducted on the specific arrangement but Marioff have stated that the presence of the spray guard would not impact the performance of Hi-Fog: the fire would have been (at least) suppressed by the spray heads mounted above the circulation pumps if they had been provided with sufficient water at the designed pressure.

[10] Seal failures was attributed to debris in the thermal oil pipework, from build

Pump Maintenance

In the 15 years prior to the fire, thermal oil circulation pump #1 was overhauled 12 times due to bearing or mechanical seal related issues. In the same period, pump #2 had three bearing / seal issues. In February 2017 the planned maintenance schedule for pump bearing overhaul was reduced from 18 months to 12 months.

The thermal oil transfer pumps were operated with one pump as primary and the other in automatic stand-by mode. Pumps were scheduled to be switched between primary and stand-by on a monthly basis however this was not always the case, resulting in significantly higher running hours for pump #1.

In the weeks before the fire, the pump use imbalance was identified and, to avoid imbalance of use in the future, the maintenance schedule was set to 6000 running hours on 14 October 2020.

Prior to the fire, thermal oil circulation pump #1 was last overhauled by ship's staff on 3 October 2020 as part of the planned maintenance schedule. The pump's bearings and mechanical seals were renewed and the coupling assembly inspected. On completion of the overhaul, the pump was tested for any abnormal vibrations or variation in running loads. All tests were found satisfactory and the pump was put in service. The pump had operated for 432 hours between the overhaul and the fire.

Fire detection, alarms and fire suppression

The naming of the fire detector section that incorporated the thermal oil circulation pumps as "Oil treatment pumps" created confusion and resulted in a delay in confirming the existence of the fire and its location.

The bridge team briefly saw that the Hi-Fog operating on the CCTV system before the live feed was lost due to fire damage but there was no indicator or alarm on the bridge to identify the status of Hi-Fog or where it had been activated. In contrast, the engineer's call, activated from the engine control room, could not be silenced on the bridge and created an additional complication to bridge communications and stress levels throughout the casualty.

The fire detectors used in the machinery spaces were predominantly smoke detectors. After the initial triggering of the fire detector at the thermal oil circulation pumps, the smoke continued to spread, triggering fire detectors throughout the aft engine room - 20 alarms over the next 5 minutes, 45 alarms over the course of the casualty.

The programming between the Consilium system and the Hi-Fog control system meant that Hi-Fog Section M7 (thermal oil circulation pumps) would activate, after a set time delay, if the single detector above the pumps was triggered and not reset. As such, the Hi-Fog system activated 121 seconds after first detection. However, the spread of smoke resulted in the automatic release of Hi-Fog in Sections M3, M4, & M5 within two minutes. Fire detectors were also activated in the forward engine room 34 minutes later.

Activation of the Hi-Fog in these additional sections meant that the pump could not provide sufficient pressure to create mist at any of the sections. Other than manually resetting both the Hi-Fog and Consilium systems and isolating individual fire detectors, there was no facility to stop a section once activated.

The Hi-Fog's pumps were not connected to the emergency switchboard. Consequently, the pumps stopped when the vessel lost electrical power and restarted when power was restored. This arrangement complies with the requirements of IMO MSC Circ.913 for local protection but was not captured in shipboard contingency plans.

Notwithstanding the lost electrical power's effect on the Hi-Fog's pumps, the break tank's 426 litre capacity meant that, for continuous operation, the domestic fresh water pump refilling the tank had to remain in operation. After a blackout, this pump was required to be reset and restarted locally. When this pump was not reset, the break tank was emptied within two minutes of Hi-Fog restarting.

The Hi-Fog's Certificate of Fire Approval stated that to ensure the system was capable of 20 minutes' operation, the system was to incorporate a sea water inlet via remotely operated valve, allowing for automatic change-over upon loss of fresh water, unless alternative arrangements were agreed at the design stage. During design and approval, the domestic water supply was considered to be an adequate fresh water supply to meet these alternative arrangements, so whilst there was a sea inlet, it was plugged and no automatic change-over valve was provided.

In total, due to these constraints, the Hi-Fog system was active for under six minutes and working as designed for a significantly shorter period.

Managing the navigation situation

After it was confirmed that there was smoke in the engine room, the bridge team reduced engine speed and identified an appropriate anchorage position in anticipation of a loss of power and/or propulsion. With a flood tide and a head wind, they identified that the vessel's momentum could be managed without engines and, on a call with the engine room prior to the vessel losing all power, it was confirmed that the navigational situation was relatively safe and the vessel would soon be able to anchor.

The vessel's ground speed reduced to zero and the port anchor was let go at the edge of the channel, the vessel was brought up with approximately three shackles of cable and remained in position. This was completed without power, the only complication being the anchor had to be let go from its housed position and a lack of effective lighting on the forecastle.

Firefighting

The vessel's "Technical emergency situation check card" (TESCC 1) for a fire in the aft engine room contained guidance to deal with fires that could occur within the space. Additional guidance on use of Hi-Fog System was contained in TESCC 28.

For a fire in the thermal oil system, TESCC 1 identified Hi-Fog as the initial means to fight the fire along with use of CCTV to investigate (as well as further guidance related to isolating the system and maintaining power). Flooding of the space with CO_2 (and the steps to take) was identified as an option if the fire was deemed out of control.

The initial delay caused by the naming of the fire detector section, combined with the loss of CCTV feed due to fire damage, meant that the cause of the fire alarm could not be investigated without entry by a fire team. However, due to the thick smoke, the fire could not be seen on entry and the team was not equipped with the ship's thermal imaging camera.

Based on what they could smell, the engineering team had a shared mental model that the smoke and resultant alarms were the result of an electrical fire or related issue. The fire team's secondary objective, restoring power, was to enable ventilation and thus identify the source of the smoke so that the appropriate next steps could be taken.

The complications in achieving this meant it was over 40 minutes between the initial alarm and confirmation of a fire but once confirmed, the decision to release CO_2 into the aft engine room was taken quickly. Preparations were completed following the emergency checklist (including double checking a full muster) and the CO_2 was released according to the instructions. An entry to the CO_2 room (using breathing apparatus) confirmed that the correct number of cylinders[11] had emptied and monitoring of hot spots and bulkhead temperatures, using the ship's thermal imaging camera on all accessible sides of the space, confirmed the fire was extinguished.

Whilst neither TESCC, nor the checklists available on the bridge, identified the limitations of Hi-Fog when installed as a fire suppression system or the effects of a blackout on its operation, they were in all other respects detailed and ship-specific.

Restoring power

With the aft engine room flooded with CO_2 and the thermal oil system compromised, the only way to restore electrical power and propulsion was to run a generator or main engine in the forward engine room - with its economiser drained and vented. It was decided to drain the economisers on both forward main engines and forward starboard diesel generator.

Draining the economisers required entry to the forward engine room. As the space was adjacent to the CO_2 flooded aft engine room, this was done with a two-person team using BA. To complete the task, electric inlet and outlet valves had to be closed manually before the vent and drain valves were opened. Due to workload and resultant breathing air consumed this required two entries.

After the economisers were drained, it was realised that before the generator could be started, a selector switch in the high voltage room had to be set to automatic. This required entry to the CO_2 flooded aft engine room. It was identified that entry brought with it the risk of re-introducing oxygen to the scene of the fire but it was assessed that this could be mitigated by entering the space via the emergency escape and keeping a closed door between the aft engine room and the outside environment. A two-person BA team made the entry approximately three hours after CO_2 release, set the switch and made an initial assessment of the condition of the aft engine room before exiting without incident.

Identifying a further risk of the generator starting automatically when the selector was changed and a need to manage the re-powering process, a three-person BA team entered the engine control room[12] in parallel. The generator was started in a controlled manner and power restored. Shortly after power was restored, a second entry was made to the aft engine room to assess cause and extent of damage and create a plan for restoring systems.

Electrical load was minimised to reduce exhaust temperatures and therefore the risk of damaging the drained economiser but, once it was confirmed that the vessel was to stay at anchor, the generator was stopped to eliminate this risk.

After a discussion between the master and chief engineer, the engineering team re-convened at 06:30 and set about ventilating the aft engine and restoring power and systems whilst wearing BA. Once full power was restored, ventilation was reconfigured to also force ventilate the engine control room.

[11] Individual cylinders can be introduced to multiple areas depending on release set-up but brackets are colour coded by space (forward engine room, aft engine room, fuel oil treatment room, cargo hold) to assist identification and counting

[12] Engine control room was adjacent to, but separate from, the aft engine room

There was no available means to measure CO_2 but, aware of a limited supply of replacement BA bottles, it was decided that BA was no longer needed in the engine control room – this was based on the strength and duration of the forced ventilation and oxygen readings from two portable oxygen meters. Breathability was demonstrated, whilst ventilation continued, by one member of the team removing BA with another in a support role, ready to intervene if required. This was executed without incident.

The decision and approach for restoring power was made with consultation within and between teams. As the plan progressed though, it steadily became more demanding and the risk associated with completing the original objective increased.

4. Conclusions

- The fire was caused by a series of mechanical failures in thermal oil circulation pump #1. A bearing failure created a hotspot of around 1,200°C, this also resulted in failure of the mechanical seals and circlips which created a route for the thermal oil to come into contact with the hotspot, well in excess of its autoignition temperature.

- The thermal oil circulation pump #1 had a history of bearing and mechanical seal failures.

- The vessel's fire detection system activated at the thermal oil circulation pumps but the fire zone naming protocol created confusion and led to a delay in the crew identifying the source of the alarm.

- Thick black smoke prevented the fire team locating the seat of the fire during the initial entry. A thermal imaging camera was available but was not used by the fire team.

- The vessel's Hi-Fog fixed fire suppression system activated as designed but its pumps were not fed from the emergency switchboard so stopped when the vessel lost electrical power, this was compliant with requirements but not captured in the vessel's contingency plans.

- Notwithstanding the above, the Hi-Fog output pressure was compromised by successive zone activation due a prevalence of smoke detector heads – activating Hi-Fog zones well way from the fire as the smoke spread.

- Notwithstanding the above, the entire Hi-Fog system was compromised by its dependence on a domestic fresh water pump whose operation was distinctly separate from the fire suppression system.

- The installation was determined to be in compliance with regulations and approved by the vessel's original flag State but its limitations were not reflected in emergency guidance or identified by the current flag State or the vessel's Classification society when responsibility for oversight changed.

- The vessel's CO_2 fixed firefighting system was released according to contingency plans and manufacturer's instructions. It was effective in fighting the fire.

- The early decision to anchor made the navigational situation relatively safe, helped the bridge team manage their mental workload and reduced the operational need for ship's systems to be restored.

- Once the vessel lost power, the engineering team focused on restoring power and worked tirelessly in difficult conditions for many hours.

5. Lessons to be learned

- Frequent failure of equipment generally indicates a weakness in the system. Identification of causal factors can facilitate a discussion with the equipment's manufacturers to identify effective remedial actions.

- Any engineering change or modification of equipment should be preceded by an impact of change assessment to ensure the modification does not have unwanted impact on the operation of the equipment or associated systems.

- Fire suppression systems installed in machinery spaces before 2010 may not be as effective as those installed later. Operators should check that the system design meets their requirements and ensure that contingency plans reflect any limitations of the system.

- Fire suppression systems that are not connected to the emergency power supply do not work when the vessel loses mains power. Water mist systems do not work if their water supply is compromised. If the system is dependent on separate feed pumps, these should be connected to the emergency switchboard and activate automatically.

- Thermal imaging cameras are an excellent tool for identifying the seat of a fire, especially in reduced visibility.

- Re-entry into a space after CO_2 flooding carries a risk. CO_2 has a limited cooling effect on temperatures at the seat of a fire and does not remove fuel. Entering the space too soon may allow entry of oxygen and can cause the fire to reignite.

6. Actions taken

P&O Ferries has:

- Reviewed CCTV requirements and is incorporating emergency power supply and engine room playback functionality where practicable within the fleet.
- Reviewed the operational effectiveness of Hi-Fog within the fleet and is implementing system change to ensure continuous operation in the event of a black out and incorporate direct fresh water feed with sea water backup where practicable.
- Ensured that fire zone names clearly align with actual location on all fire detection systems within the fleet.
- Adapted fire detection systems on its vessels with automatic Hi-Fog release to incorporate a mix of smoke and flame detectors.
- Replaced Pride of Hull's thermal oil pumps and reviewed the condition monitoring plan within the planned maintenance system.
- Provided fleetwide guidance on the principals of installation of spray guards.
- Worked with Chevron to ensure that incorrectly labelled oil samples are voided and new samples provided.
- Refreshed guidance on CO_2 release and supplemented shipboard decision support material.

7. Recommendations

The Bahamas Maritime Authority is recommended to:
Consider conducting a safety campaign to ensure all Bahamas registered vessels fitted with a fire suppression system installed under MSC.1/Circ.981 are aware of the findings of this report. Further, to verify that systems are operable as intended and any limitations understood by all persons involved and documented within relevant safety management system to ensure future learning.

The Bahamas should consider, together with other interested States, proposing to the International Maritime Organization an amendment to MSC.1/Circ.1387 requiring the provision of emergency power for local protection systems.

The Maritime and Coastguard Agency is recommended to:
Consider sharing the findings of this report with operators, managers and surveyors to assist in the verification of system operating parameters in accordance with the revised guidelines contained within MSC.1/Circ.1387.

8. Glossary and Definitions

AB	Able-bodied seafarer
Auto-ignition temperature	The lowest temperature at which a substance spontaneously ignites without a source of ignition
BA	Breathing Apparatus
bar	Unit of pressure: 1bar = 100,000 pascals
CCTV	Closed-circuit television
CO_2	Carbon dioxide
°C	Degrees Celsius
EOOW	Engineer officer of the watch
FAST	Chevron's service: fluid analysis service and trending
Fire suppression	A reduction in heat output from the fire, control of the fire to restrict its spread from its seat, a reduction in flame area.
Flash point temperature	The lowest temperature at which a substance will ignite, with a source of ignition.
Hi-Fog	Marioff's trade name for their water mist-based fire suppression system
m	Metre. Unit of measurement: 1 metre = 1000mm
Ro-ro	Roll-on/roll-off
Shackle	Unit of measurement applied to anchor cable: 1 shackle = 27.4m
VTS	Vessel traffic services