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Effectiveness of Crankcase-Oil Mist Detectors

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Abstract

Oil mist detection system is one of commonly used safety aids to monitor and detect engine's critical conditions in early stages, to protect engines from serious damages and to prevent catastrophic consequences like crankcase explosions. Therefore, this research attempt to assess the effectiveness of this system to measure if it is serving the aim that it is designed for or not and to assess the effect of the different measuring techniques used on the performance. Moreover, this research investigates whether the effectiveness is positively affecting the market share among other systems, and if the action taken by the system to protect the engines posing no other risks on the ship.

A questionnaire based study to investigate the research question is conducted, where a sample of 126 ships had participated, the sample included mix of different types of ships with different types of engine sizes and different oil mist detector makers using different measuring technique. Collected data from the sample are analyzed according to quantitative data analysis approaches. The main findings shows that oil mist detector is an effective aid in alerting engine operators about abnormal conditions and therefore it is used on 94% of the sample, it is also found that performance of the devices is affected by the measuring technique.

The research concluded that scatter light technique significantly improved the performance of oil mist detectors. But, linking the system to the engine shutdown system pose another risk to the ship operation, therefore, the study proposed a future research on dynamic system for inerting engine crankcase to overcome this risk.

Keywords: Oil mist, oil mist detector, protection of diesel engines, diesel engine's safety, engine crankcase inerting, risk of uncontrolled engine stop

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Introduction

Since 1920, the merchant ships gradually shifted from steamships to diesel engines, currently the diesel engines are widely used as a source of power about 80% of the world fleet (Marcus, H. S., 2003) because of its relatively low cost power and high efficiency (Globalisation, transport and the environment, 2010). Furthermore, in this very competitive shipping world, vessel's owners and operators are looking for every chance for savings to keep competitive advantages. The saving plans are currently applied for every small portion in the industry, including a philosophy to overcome the huge cost of the preventive maintenance of the marine diesel engines that based on the operational hours, where the maintenance and repair cost vary between 9 to 10 percent of the annual operating cost of the ships (Pedersen, F. 2013). Now the condition based maintenance programs replaced the traditional maintenance philosophies to limit the maintenance to the actual engine needs.

However, this philosophy requires highly efficient with rapidly effective response systems to monitoring the condition of the engine parts. These systems are not only to be used for tracking critical conditions, but also to provide suitable measures through a series of actions to protect the engines from serious damages. Nevertheless, apart from possible fatalities and the insurance costs, such damages to ship engines could cost the owner millions of dollars for the downtime and repairs.

Presence of oil mist in the engine crankcase is very serious if not taken with care. High levels of oil mist can result in serious damages to the engine due to overheating or explosions in worst-case scenario, posing a significant risk to the crew, engine, or the whole ship. Therefore, it is very important to monitor the oil mist levels in the internal environment of the engine through a fast response aid that can alert the engine operators as soon as possible if the normal levels exceeded. The oil mist detector (OMD) is a vital aid to serve this task. Thus, it is fitted on most of the ships.

Due to the importance and sensitivity of the task that this system is serving, it was important to investigate how effective this system is, and to assess if it is serving the aim that it is designed for. Makers of these systems are using different measuring techniques, so, to understand if the performance of these systems is affected by measuring technique is also beneficial. The study will also investigate if the actions taken by the system to protect the engine posing no other risks to the ship.

Assessment of effectiveness of the oil mist detection system and its performance based on the measuring technique could be very beneficial for ship owners or shipyards in their selection process of the oil mist detector among other safety monitoring systems, or even in selection of the system based on its measuring technique.

Literature Review

History of Crankcase Explosions

Crankcase explosions whenever occur puts engine crew on risk of life loss, in addition to serious damages to the engine itself, where such extensive damages to the engine could extend to have it been scrapped. Moreover, in many cases there have been such casualties where the engine room has had serious fires afterwards.

"REINA DEL PACIFICO" was a British passenger ship been lunched on 1930. In 1947, during sailing in the Irish Sea, one of the four main engines reported overheating in the no. 2 cylinder, and the engines stopped and restarted later after 5 minutes. After restarting the engine, 2 to 3 minutes later an explosion occurred due to ignition of the oil mist present in the crankcase by the overheated surface of cylinder no. 2 (GB Board of Trade, 1948).

The first explosion followed by other explosions in the crankcases of the other three engines of the ship. It was not clear how the crankcases of the other three engines has been ignited, but it is concluded that the high pressure produced from the first explosion in the engine-room pushed the crankcase doors of the other engines inwards. Then the oil mist inside the crankcases ignited when blown-off crankcase doors of the first engine formed a source of ignition for the whole engine-room gases (Pounder et al, 2004). These series of explosions caused 28 fatality cases mainly from the engine crew in addition to 23 injuries.

This incident highlighted the danger of explosions of engines onboard ships and encouraged to set regulatory actions to overcome this risk. It is also encouraged to technical developments to improve the design of the engines. Later Lloyds Register introduced in 1951 a set of regulations for the crankcase safety to improve design of the relief doors and crankcase vents by installing non-return valves to avoid crankcase air-ingress after the first explosion, which likely will result in a secondary explosion.

An analysis conducted by Lloyds Register on their classed fleet between 1990 and 2001 shows that 143-reported incident of crankcase explosions due to some failure in the engine (Pounder, 2004). Considering that Lloyds Register shares 11% of the IACS market (Lloyd's List, 2014), while IACS shares about 63% of the world fleet (Equasis, 2014). The number of reported explosions from the world fleet will be about 1300 incidents in 11 years, which means that over 100 engine explosions happen every year. These figures are for the reported incidents only where the damages resulted major loses, however, non-major loses incidents that not reported would be much more. A statistical study presented by the Swedish Club shows that total machinery insurance claims from 1998 to 2004 costed about 165 million USD, varied between 294,000 and 271,000 USD per ship, the explosions represented about 8 percent of these figures (Pedersen, F. 2013).

History of Oil Mist Detection

After the disaster of "REINA DEL PACIFICO" in 1947 when 28 persons dead, several stakeholders in the maritime industry like classification societies, engines manufacturers, and flag administrations started to look for measures to reduce these catastrophic incidents. In 1955 and 1956, number of published researches discussed the characteristics of the oil mist as an explosive substance and the possibility of measuring the concentration of this substance by the light absorbing principle. These studies resulted in development of the first oil mist detector made by Graviner UK early 1960. They relayed on the concept of light absorption when collide with oil mist as a substance. This light absorption (light loss) can be sensed by sensors sensitive to light fitted at the end of a light beam produced by a light source.

However, the significant developments of the oil mist detectors started in the seventies, when major manufacturers of powerful marine diesel engines become more interested in engine protection by early detection of the critical conditions that may cause explosion as an advantage to their products (MACSEA, 2012).

Crosshead slow-speed engines were the most engines used then, so, a suction pipe mainly withdrew the sample of the crankcase atmosphere from the crankcase area between the main bearings, while a dividing wall used to support the bearings separated the crankcase. The mixture of the extracted samples then fed by sequence using a valve system to the optical sensor in a sensing chamber. However, because the oil mist samples from all sampling ports were mixed in a mixing manifold before being measured, the concentration of a sample extracted from specific area was not exactly measured. It rather increase the average of the oil mist concentration of the mixed samples, which will be sensed by the optical system and trigger the alarm. This cycle was takes around one minute, and it was good time since the generation of oil mist is relatively slow in large crankcase volumes.

In seventies, as a development of engines power-to-weight ratio took place introducing the medium speed engines (Schaller Automation, 15) which generates more heat due to the compact design. The over-heating risk is also increased and consequently the importance of oil mist monitoring systems as an aid to alert operators about the critical conditions as early as possible not only before explosion. Schaller Automation has initiated experiment projects on large diesel engines in order monitor the behavior of the oil mist to improve the efficiency of the detection systems, some of the phenomenal effects on the oil mist have been discovered from this experiments such as oil sprays in the crankcase that generate diffusion of oil mist (washout effect). The concentration loss phenomena was also mentioned as one of the important phenomena that affecting the efficiency of the system. When the oil mist sample transferred from the crankcase compartment to the scanning device mounted some place on the engine crankcase, the properties of the sample may be changed in the suction pipe by the turbulence resulted by sudden change in the diameter or sharp bends or even the high speed of the suction flow (Çengel, & Cimbala, 2014). Therefore, concentration of oil mist in the sample that extracted by the suction system from the engine crankcase compartment, can be actually lower than the concentration of the oil mist if it is measured directly in the proximity of damaged location. Further losses can be resulted from the turbulent flow inside the engine crankcase that make the oil particles suspended in the air collide together and unite into comparatively large droplets not suspended in air due to its weight (Schaller Automation, 15).

However, these experiments lead to discover the effect of overheated parts inside engines crankcase due to some damage so-called hotspots on the generation of oil mist, which considered the most important. But researchers at that time failed to convince the manufacturers of engines to support further researches in this direction as these researches was based on tests that associated with financial risk on the engines. Therefore, the researchers simulated a hot spot damage by feeding oil mist generated from outside to the crankcase of running engines to test the effectiveness of the system. Only one maker "Motorenwerke Mannheim" deviated from the other makers' behavior. They provided the engine with slightly deformed piston for the testing purposes of piston seizure, which seized after 3 hours operation of the engine (Schaller Automation, 15). The oil mist detector responded when the oil mist concentration increased after 20 seconds of speed drop due to piston seizure. 60% of the light was lost corresponding to 12 mg/l of oil mist concentration that accumulated in 18 sec., further several experiments has been done by Schaller Automation (total of 11 experiments) from 1974 to 1989 for improving the opacity readings from the system.

As response to the repeated explosion incidents, the international regulatory bodies interested in the maritime safety like International Maritime Organization (IMO) and International Association of Classification Societies (IACS) issued many regulations to force proper measures in order to reduce these incidents.

SOLAS regulation II-1/47.2 issued by IMO required internal combustion engines that produce power of 2,250 kW or more, or having cylinders bore diameter of 300 mm or more, must be fitted with oil mist detectors or equivalent system (SOLAS, 2009). In the eighty-seventh session on May 2010, the IMO Maritime Safety Committee approved the OMD as a part of automatic shut-off arrangements as required by SOLAS regulation II-1/27.5 in case of emergency to stop the engines in case of medium and high-speed diesel engines and to slow down low speed diesel engines to prevent consequential serious damages (SOLAS regulation II-1/27.5: Machinery, 2009).

As a response from IACS to the SOLAS regulations concerning the measures set as for fire prevention, IACS adopted the M10 last reviewed on 4 July 2013, which defined the Low-Speed diesel Engines with rated speed of less than 300 rpm, and the Medium-Speed diesel engines with rated speed between 300 to 1400 rpm, and the High-Speed diesel engines with rated speed of 1400 rpm and above (IACS M10, 2013).

Safety Protection Systems

As well known, fire triangle consists of three elements, ignitable substance (fuel), source of ignition (heat), and oxidizing media or agent (oxygen) (Giesler, M. P. 2011). Fire is the inevitable result to the presence of these three elements. Therefore, fire-fighting systems are always working on elimination of one or more of these elements from the equation. Similarly, fire prevention systems are working on detecting or preventing presence of one or more of these elements. Prevention systems prevent production of this element from its source or at least reduce it to an ignorable level, while detection systems detect the presence of these elements to alert for the associated hazards. The idea of oil mist detector is understandable from its name “detection of oil mist”.

The oil mist defined in occupational safety dictionary publications as an aerosol generated by one of three ways, forced oil through a small hole or orifice, splashed oil into the atmosphere during normal operations, or condensed vapor in a relatively cooler atmosphere (Vincoli, J. W., 1999). Mist is tiny droplets suspended in the air, it is a physical state of formed dispersion when moist vapor meets sudden cooling. Similarly, the oil mist is arising in the internal combustion engines from either mechanical atomization or re-condensation of oil vapor. When the moving parts inside the crankcase dip into the lubricating oil surface of the oil pan, it spreads small particles called oil splash. The size of these oil droplets is relatively large, about 30 micron (Holness, M. H., & Smith, B. J., 2002), this oil splash can be ignored because of the droplets size. The mechanically generated oil mist from the lubricating oil film caused by friction between the moving parts can be also ignored as it is small amount compared to amount of oil mist generated from re-condensation of oil vapor. The other source of oil mist generated from condensation of vapor oil that has been vaporized from touching a hotspot surfaces at 200 to 600 °C and then re-condensed in the crankcase compartment atmosphere, which is approximately 80° to 100°C forming the oil mist (Holness, M. 1995). These very fine particles of oil droplets have size from 3 to 10 microns (Smith, B. J., 2001) spreads in the atmosphere of the crankcase.

Phenomena of oil mist was mentioned in the early invention of diesel engines by Rudolf Diesel (Crolla, D., 2009), as it usually present inside the engine crankcase during the normal operation and lubrication cycle of the engine parts inside the crankcase. However, the risk of fire becomes very critical only whenever concentration of the oil mist reaches the Lower Explosion Limit (LEL) of the oil, which is about 50 mg/l (BURGOYNE, J. 1963), where the oil mist can ignite at low temperatures.

The lubrication oil becomes flammable when it is in the mist state, even though it is comparatively nonvolatile liquid with flash point higher than the normal temperature. The high speared surface to the volume ratio of the oil droplets make it more flammable than the bulk liquid. Therefore, the oil mist is more sensitive to the heat input from any ignition source as more surface is subject to contact with oxygen in the crankcase environment. Smaller size of the mist droplet ignites at lower temperature (Holness, M. 1995). Ignition can happen at a low temperature as 150°C (Pounder, C. C., & Woodyard, D. F., 2004), same overheated hotspots that boiled the oil may act also as an ignition source to the oil mist (Pounder, 2004).

Above scenario leads to fire in the engine crankcase and consequently crankcase explosion in most cases when the pressure resulted by the fire exceeds certain limits (8 bars in dual-fuel engines), (MAN Diesel & Turbo, 2015). Therefore, MAN Diesel & Turbo decided since 1990 that their engines must be fitted with an Oil Mist Detector and optionally a Bearing Temperature Monitoring System as an aid of warning arrangements to prevent two-stroke engines from crankcase explosions (MAN B&W, 2014).

One of approved alternatives to the oil mist detection systems is “bearing temperature monitoring system” that use thermal sensors fixed on most of the engine bearings to measure the overheat generates oil mist and alert the operators through a wireless sensor gives pulse that is uniquely defined by the sensor temperature. When this signal is received by the main station antenna it gives alarm (Kongsberg Maritime, 2014). However, these systems are criticized because of the heat sink effect phenomenon which delay the response of the system to report the danger (Schaller Automation Oil Mist, 36).

Measurement Techniques of Oil Mist

When the oil touches a hotspot it boils and re-condenses inside the crankcase environment forming very fine particles, the weight of these particles allow it to remain suspended in the air inside the crankcase and not be affected by the gravity. When those colloidal fine particles suspended in the air inside the crankcase compartment it can be seen, therefore the measuring techniques depends on one of two techniques.

The first technique called Turbidimetry, also called obscuration technique or measurement of the loss of light, when a beam of light is obstructed by the fine particles of oil mist suspended in the beam straight direction that passing through between two LED in a sensing chamber. The light absorption due to these particles of oil mist reduces or obstructs the amount of light transmitted between the transmitter and the receiver. In this method the less light received by the receiver means more oil mist in the sample and if no oil mist in the sample, 100% of the light will be transmitted.

The second technique called Nephelometry, also called Scatter Light Technique. This technique use the opposite concept of the Turbidimetry technique. The concept of the scatter light is when light beam generated by the transmitter LED in a sensing chamber collide with oil mist particles it is deflected from its straight direction. The same like what we may notice when a dust particles are subjected to sunlight flecks that passes through a window, we can see the fine particles of dust that suspended in the air clearly (seeing the particles means that our eye received a light reflection form these particles). Similarly, when the light generated from the transmitter LED collide with oil mist particles, it is scattered or deflected to another direction where a receiver LED is fitted to receive this amount of scattered light. In this method the more light received means more oil mist in the sample and if no oil mist in the sample, 0% of the light will be received. The devices using this technique has less false alarms (Smith, B. J., 2001).

Using a complex program, models of oil mist detectors using Nephelometry Technique (Scatter Light Technique) obtains direct readings for the percentage of the oil mist in the air mixture inside the crankcase that should be monitored to be kept under the lower explosion level (Smith, B. J., 2001). But, the models of oil mist detectors that using the Turbidimetry Technique (light absorption) cannot measure the oil mist concentration, it only gives alarm signals when the base opacity is changed (Schaller Automation, 15).

However, these detection systems that using the technique of optical system for counting the particles are not detecting the vapor component of the emission. In addition to that, some of certain fraction of oil mist has a droplet size below the measurement capability range of said instruments (Wlaschitz, P., & Höflinger, W., 2007). Therefore, some other methods that can determine the concentrations of both oil mist and vapors manually using a gravimetric methods mainly used for calibrations (NIOSH, 1991). Such as American Method of The National Institute for Occupational Safety and Health (NIOSH) or the German BGIA Method, they use samplers contains filter with downstream adsorbent where the oil mist particles are collected onto this filter, and the passing vapor through the filter is collected by another absorbent next to the filter, and then measuring the mass of oil by a IR spectroscopy.

Quality of Measurement Techniques

Scatter light methodology (Nephelometry) uses a light receiver laterally positioned to the transmitter, this receiver is the main component used to measure the presence of the oil mist in the sensing chamber through the deflected light (scattered light). There is another receiver LED used to measure 50% contamination build up on the lenses to compensate the readings of oil mist. As long as this technique uses the proportionality relationship of the amount of received light and the amount of oil mist sensed, so the system can be calibrated at true zero where there is no oil mist (Smith, B. J., 2001).

On the other hand, the obscuration technique (Turbidimetry Technique) that use measures the loss of light when it is obstructed the oil mist particles during straight light passing through. Therefore, contaminated air from the comparator can lead to false alarm as the system can't differentiate between high oil mist concentration and contaminated LED. False alarms are one of the problems of this technique in addition to the relatively slow response (Smith, B. J., 2001). This technique don not draw a linear relation between the amounts of light absorbed as a result of presence of the oil mist to quantified measurement as mg/l. It is relying on deviations to trigger the alarm (Schaller Automation, 15). As long as this technique use an inverse relation between the amount of light received and the amount of oil mist sensed, so in order to set the zero value, the crankcase compartment is scanned to set the deviation values after comparing with clean air. Normally this clean air supply is not supplied from a calibrated supply, therefore, this contaminated air also affect cleanliness of the lenses (Smith, B. J., 2001).

There are very few studies investigating the quality of the measuring devices. Most of these studies are discussing the calibration procedures by makers or regulatory bodies. Wrong calibration of oil mist detectors and lack of maintenance may lead to presence of oil mist in the crankcase without effective sensing from the oil mist detectors, this has been mentioned in many studies as the main reason behind crankcase explosions (Cicek, K., & Celik, M, 2013).

Schaller Automation issued number of technical bulletins (No. TB-070408E – PART I and II) that discussing some of the problems that reported by the users. The most important problems reported by users was the late response or reaction of the oil mist detector between 30 to 50 seconds before the system start to take action to stop the engine as a preventive action. Such time is quite enough to damage the bearings or pistons in the engines. The other important reported problem was the false alarms (Schaller Automation, 2007).

In 2005, the International Association of Classification Societies issued a procedure for the type approval of the crankcase oil mist detectors and testing procedure, that includes equipment testing, functional testing, and the calibration method, which should be one of the gravimetric methods explained above, as well as the design and construction details. Lloyds Register and some other classes have enforced more restrict requirements to approve the oil mist detectors. This includes, failure and variation tests for the power supply, heat test, unit vibration test, insulation test, and static / dynamic inclinations tests, etc (Lloyd's Register Marine, 2015).

Currently there are about five major manufacturers for the oil mist detectors worldwide, Schaller Automation in Germany, Daihatsu Diesel in Japan, Graviner in UK, Quality Monitoring Instruments (QMI) in UK, SPECS in South Korea.

Potential Hotspots

In diesel engines, there are number of locations inside engine crankcase that have the potential to produce heat in case of abnormal conditions in case of damages. These locations are considered potential hotspots, which interact the lubricating oil in two ways or we may say two steps. The first step when the temperature of this hotspot reaches over 200 °C it starts to boil the oil film that touches its surface. When this film of lubricating boils it is transformed into vapor in the environment of the crankcase then re-condensed in the relatively lower temperature atmosphere inside the crankcase forming the oil mist. When this oil mist again touches the hotspot, which may be the same hotspot that boiled it, ignites causing fire in a closed media full of flammable gases leading to the crankcase explosion.

These hotspots could be the main crankshaft bearings of the engine, surfaces of the piston bearings, piston connecting rods, piston's cylinder liners, guideways of the cross-head, bearings and pins of the cross-head, guide blocks in cross-head engines, big-end bearings, camshaft and its cams and bearings, (Schaller Automation, 2007).

In addition to the hotspots that may ignite the oil mist, a spark generated by a damaged parts (holed or seized piston, damaged bearings, or a broken piston rod, etc.) may also act as a source of ignition for the oil mist.

According to CIMAC congress 2010, Lloyds Register reported that about 54,000 ships fitted with two and four stroke engines suffered from damages in the crank bearings in period of ten years (Schaller Automation, 35). Table 1 issued by MAN B&W summarize the causes of crankcase explosion cases over the years (MAN B&W Diesel A/S, 2003). As per the report issued by MAN B&W the below table is not exhaustive which means that these figures are only for the reported incidents, while the incidents have unknown or minor consequences that not reported should be more. Therefore, we can conclude that the crankcase explosion incidents are not rare.

Year	***Cause of Explosion***	***Cause of Failure***
1995	*Bearing in PTO gearbox*	
1996	*Inlet pipe for piston cooling oil falling off*	*Incorrect tightening*
1997	*Incorrect spring mounted in piston rod stuffing box*	*Unauthorized spare part*
1997	*Piston rod interference with cylinder frame*	
1999	*Weight on chain tightener falling off*	*Incorrect tightening*
1999	*Fire outside the engine*	
2000	*Main bearing*	
2000	*Camshaft bearing*	
2000	*Incorrect shaft in camshaft drive*	*Unauthorized spare part*
2001	*Crankshaft failure*	
2001	*Piston crown failure*	
2001	*Main bearing*	
2001	*Crankpin bearing*	
2002	*Inlet pipe for piston cooling oil falling off*	*Incorrect tightening*

Cases of explosions where the cause is known

Table 1

Uncontrolled Engine Shutdown

One of the limitations to the oil mist detection systems is that it only triggers an alert that a damage is starting, but it cannot prevent the damage arising. Therefore, the response time of the oil mist detection system or devices significantly affect the consequential damage magnitude (Schaller Automation, 15).

Engine slowdown in slow-speed diesel engines and shutdown in medium or high speed diesel engines is an action taken by the oil mist detector or the bearing temperature monitoring systems as a preventive action to protect the engine from serious damages after detection of the source of ignitable substance (oil mist) and the source of ignition (hotspots) Both systems are working on two of the three basic elements of the fire triangle, and due to the physical nature of the internal combustion engines, the only action can be taken to eliminate or reduce these two elements (oil mist or hotspots) is to stop or slow down the engine to avoid the risk of explosion.

However, during critical navigation, uncontrolled stop of engine could form a disaster to the ship. Many navigational situations can be considered as a critical navigation such as sailing in transit channels or shallow waters which called restricted navigation, berthing and un-berthing from quays, evacuations in case of emergency at the berth, maneuvering in high seas, or maneuvering beside other vessels, etc. Loss of ship's power in such situations can trigger very serious consequences like collision, grounding, pollution or fire.

A study by Journal of the Korean society of marine environment & safety in 2012, (Choi, B., & Kim, H., 2012), concluded that "*It is necessary to install the inert gas system (IGS) for preventing fire and explosion in LNGC main diesel engine crankcase besides oil mist detector (OMD)*". This study introduced the idea of working on the elimination of the third element in the fire triangle which is the oxidizing media or oxygen. It can be very useful if we aim to avoid the uncontrolled engine stop. However, the feasibility of installing such system with continued supply of inert gas to the engine crankcase chamber is criticized by the manufacturers as the presence of oil mist inside the crankcase is not a routine incident, it only happens whenever there is a defective or damaged part inside the engine crankcase, and this can be early detected by either the oil mist detectors or bearing temperature monitoring system. Therefore there is no need for the continuous supply of the inert gas into the engine crankcase chamber unless needed.

Research Methodology

The research methodology is the strategy set during the research to answer the research questions. While, when conducting the research, we use some specific activities and tools to collect and analyze the data such as questionnaire, interview, or observations, this what called research method, (Greener, S, 2008). This chapter will present the research strategy, research design, data collection, and data analysis.

Research Strategy

Research methodology or strategy could be one or both of two major approaches qualitative and quantitative (Bryman, A., & Bell, E., 2015). In order to select one of the two approaches that suit our research, we need to understand the relation between the research approaches and the research questions.

The quantitative strategy is normally used with a deductive approach to test an existing theory using numbers or facts, (Greener, S, 2008). In this strategy, researchers relies on data that takes numerical form and focus on quantification of data collection and analysis (Karami, A., 2012), it is normally transform the research problem into quantified data that can be statistically measures defined variables to formulate facts and draw patterns where the results may be generalized from the sample to the population setting some limitations. The data collection in quantitative strategy is more structured than it is in qualitative strategy, it takes forms of surveys or questionnaires, or interviews (Kumar, R., 2005). This strategy suites gaining knowledge as reductions to variables and use of measurements to test theories. In this strategy the variables defined in a way related to the research questions and determine the frequency and magnitude of its relationship (Bryman, A., & Bell, E., 2015).

On the other hand, the qualitative strategy normally used with an inductive approach to create theories using interpreting model that allow creating knowledge instead of finding it in reality, (Greener, S, 2008). Therefore, qualitative strategy focus on understanding of the process instead of analyzing quantification of data. Qualitative strategy is an exploratory research used to define and analyze reasons or opinions mainly used to get insights of a research problem and helps developing ideas or hypotheses of quantitative researches (Glaser, B. G., & Strauss, A. L., 2009). The data collection methods in the qualitative strategy uses either unstructured or semi-structured techniques. Common methods includes focus groups, individual interviews, and participations or observations (Goodwin, W. L., & Goodwin, L. D., 1996), and the sample size is normally small, (Klenke, K., 2008).

In order to select the suitable method to answer the research question which assess "Effectiveness of crankcase oil mist detector", five hypothesis were accordingly set to investigate each factor affecting the answer of the main question, the five hypothesis are mentioned below:

- Hypothesis no. 1

  Oil mist detectors proofed its effectiveness, so, ships' owners trust the oil mist detectors for the engine protection.

- Hypothesis no. 2

  Ship owners trust the oil mist detectors among the other alternatives.

- Hypothesis no. 3

  The Nephelometry Technique (Scatter Light) reduced the false alarms.

- Hypothesis no. 4

  Oil mist detectors take effective actions to prevent engine damages.

- Hypothesis no. 5

  Linking the oil mist detector to the engine shutdown system poses no risk to ships' operations.

As long as the oil mist detectors are widely used onboard ships, and there is already a set of rules regulates its operation, so the deductive approach would be feasible to test this existing theory of trustworthy by testing the above hypothesis using a quantified data of a sample of ships that fitted with oil mist detector or any other alternative. This approach is identical quantitative research approach.

Research Design

The methodological foundation explained above for the research strategy concludes the selection of the quantitative strategy in this research. So typical data collection methods of the quantitative strategy will be used, that takes forms of surveys or questionnaires (Kumar, R., 2005). Therefore, a questionnaire has been designed to collect the data of which will be used to test the hypothesis that form a core measure for the main research question.

Questionnaire Design

Questionnaires can be outlined by having a basic process contains a definition to the research aim, identification of sample represents the population, method of receiving replies, questionnaire design, running of pilot survey, conducting the main survey, and analyzing data collected, (Burgess, T. F., 2001).

In order to assess the practical effectiveness of the oil mist detectors, the end-users of the OMD have to be targeted segment. Therefore, a questionnaire were designed to collect data about the experiences of vessel's engine's crew with the OMD.

Defining the Research Aim

This research aims assessing the effectiveness of the oil mist detectors. Therefore it has to include the practical experiences of the end-users which can provide many details and information not included in scientific papers. The users of the oil mist detectors are the segment that use these devices to protect their engines from the risk of explosion due to fire in the crankcases of the diesel engines. The information required from the questionnaire can be summarized as follows; what is the percentage of the sample of ships using the OMD and how many OMDs fitted compared to another alternatives? Does the OMD fitted on the ships because it is one of the mandatory requirements or on a voluntary basis to protect engines? Does the OMD can take action to protect the engine? Does the engine department crew experiencing activations of false alarms? What is the most common reasons of activation either false or real alarms?

Identifying Sample and Population

The oil mist detector are required on all ships propelled with an internal combustion engine on unmanned mode, and the engine power of 2250 KW or more and cylinder bore diameter of 300 mm or more, and in case of emergency it is required to stop or to slow down the engines (SOLAS, 2009). Low-Speed diesel Engines are less than 300 rpm, Medium-Speed diesel engines between 300 to 1400 rpm, and the High-Speed are 1400 rpm and above (IACS, M10, 2013).

Engines with above specification are used on most of the merchant ships (bulk carriers, tankers, gas carriers, RO-RO vessels, container vessels, etc). Therefore, in order to ensure that the sample represents all merchant ships, it intended to contain all ship types to eliminate the limitation of installing the OMD or it is alternatives on the high standard ships that has comparatively higher level of safety due to the nature of the cargo (tankers and gas carriers).

How to Collect Replies

The data were collected by one of the following ways;

- After getting the vessel's captain permission, direct interview with the chief engineer on-board vessels, and after a brief short introduction to the aim of the research and the regulations related to engine size. The questions were asked one by one and answers were recorded directly to the questionnaire sheet.
- During a meeting with the vessel's captain, and after getting his permission, handing the questionnaire sheet to the chief engineer to fill it himself freely, and receive it back.
- By sending a blank questionnaire sheet to a fleet operator of vessels that the OMD or one of its alternatives is required to be fitted onboard. The operator company sent the

questionnaire for their fleet and reverted back with the replies either through the operator company office or directly from the ship.

- The questionnaire is posted on specialized online survey site for online responses and collected directly from the website. This step gave the option to chief engineers who are on their leave to be included in the sample of the responders as the rotation of the seafarers are comparatively of long periods which could be beyond the whole questionnaire collection period.

The above four ways for of data collection would ensure all levels of freedom to the responders to avoid effects on their response answers should they consider that the data required are sort of confidential data to their workplace.

Questionnaire Design

The questionnaire included 15 questions, five of them are informative in order to assist in the limitation and generalization of the research findings, and the other ten questions represents all required information to test the hypothesis. Some of the questions are divided into sub-questions depending on the main answer of the question as a consequence of an answer *yes* for example. The questions made clear and direct, structured according to the sequence of the information starting to check whether the oil mist detector is applicable to this ship or not and if the oil mist detector is fitted or not and then assessing the experiences of the engine crew about activation of oil mist detector either real or false alarms. The questions sequence and the aims are illustrated in table 2 (see also Appendix A);

Question	Aim
Does the ship certified as unattended engine room?	Data limitation
Propulsion system, Engine mechanical connected to the propeller or Diesel electric propulsion?	Data limitation
Engine power (kW):	Data limitation
Engine speed (rpm):	Data limitation
Cylinders bore diameter (mm):	Data limitation
Is the engine fitted with oil mist detector (OMD)?	Hypothesis no. 1 and Hypothesis no. 2
Is the engine fitted with bearing temperature-monitoring system?	Hypothesis no. 2
Is the engine fitted with equivalent devices other than the above?	Hypothesis no. 2
a. If the engine is fitted with OMD, Who is the maker of the system?	Hypothesis no. 3
b. If the ship's engine is slow-speed engine, does the OMD slow down the engine?	Hypothesis no. 4
c. If the ship's engine is medium or high-speed engine, does the OMD shut down the engine?	Hypothesis no. 4
Have you experienced incidents with OMD system activation?	Hypothesis no. 4
If so, what was the reason and what was the action taken?	Hypothesis no. 4 and Hypothesis no. 5

Table 2

As the inclusion of unnecessary headings is not preferred, (Burgess, T. F., 2001), therefore, no headers at all are included in the questionnaire. However, as a good practice the questionnaire had a title represents the questionnaire aim “Questionnaire for the effectiveness of Oil Mist Detector onboard vessels”. This had made it clear to the responders about the targeted segment required to respond for this questionnaire. Also an introductory statement about the applicability of the oil mist detectors was briefed and explained before starting any interview. In the third data collection method, the email and returning information of filled sheets are included directly after the header in a special version so to facilitate easy collection process and to avoid hassle of receiving the filled sheets by the operator company and re-sending accordingly. During the design of the questionnaire, two questions (IMO Number and Ship's Name) has been included for reference purposes which could be also helpful during the analysis stage should any important data found missing.

Pilot questionnaire

A testing questionnaire is recommended to evaluate the reliability and validity of the questions (Brace, I. 2004). Therefore, the first version of the questionnaire have been distributed to respondents who were available for another clarifications if the responses were not clear as a result of unclear questions. Seven questionnaires collected and after evaluation some of the questions were modified to be clearer for the respondents as they gave unwanted answers for these specific questions. Then the questionnaire were resubmitted for the same respondents within one week, and answers to the new questions were correctly submitted. Some of the questions have been made as "closed questions" to have specific consistent answers to facilitate receiving the proper answer. Also, a brief introduction and statement about the regulations of oil mist detectors was added overleaf to the questionnaire sheet in order to explain the applicability of the oil mist detectors onboard ships for clarification purpose.

Carry out the main questionnaire

After the testing period, the questionnaire was carried out in the four pre-described ways. Ship's IMO Number used to give the questionnaire sheet a unique identification. The questionnaire was distributed to the responders and collected in 60 days.

Data analyses

Before start to analyze the collected data, we need first to identify the type of the collected data by identifying the level of measurement has obtained from these data. There are four types of data depending on the level of measurement as follows;

Nominal data – is a basic data that has no logical form or rank, mostly expressed by zero or one, yes or no, male or female, so there is no grade or order associated with the answer yes or no, the nominal data are normally represented by a category without inherent order or rank. For example, collecting the number of males and females in a sample of people, the gender here will be a nominal variable, which means that being male, makes no advantage or disadvantage among being female.

Ordinal data – is a data that has a logical order, but without standardized distance between the values, when expressed in happiness for example when a person is sad or okay, or happy, the distance between sad and okay is not equal or even related to the distance between okay and happy.

Interval data – is a ranked data with equal or standard distance in a logical order, but without the zero value, for example the Fahrenheit temperature scale could be expressed as interval variable as the difference between 45 degrees and 46 degrees is same as the difference between 90 and 9 I degrees. But temperature of 90 degree is not twice the 45 degree.

Ratio data – is a continuous data logically ordered with standardized distance. It can have zero value, for example: the length, can be zero and can be expressed in a way of ranking as if we say that 10 inches length is twice 5 inches length. However, the ratio data cannot have a negative value (Grosshans, W., & Chelimsky, E., 1992).

All questions of the questionnaire are intentionally designed as direct questions, which can be answered by either *yes* or *no* in order to make it easy to answer so to increase the number of respondents. In light of the above and identification of data by the level of measurement that previously described, we can see that the data we have collected are nominal data.

After we have identified levels of measurement of the data collected, and in order to use some of the quantitative data analysis procedures that suits the nominal data, we can first tabulate the data to have comprehensive picture on how the data looks like and to identify patterns of variables, (Grosshans, W., 1992). Nominal data can be analyzed by different methods, such as Table of frequencies, Bar charts, Pie charts, or Percentages (Reynolds, H. T., 1984).

Validation of Data

In order to ensure the completeness and consistency of collected data before start the analysis, we need to apply a validation process to remove the incomplete or inconsistent answers that may affect the results of the analysis in wrong direction because of its incompleteness or inconsistency (Patrick, C. J., Curtin, J. J., & Tellegen, A, 2002).

The questionnaire was carefully designed to have the questions to be direct and clear, so no wrong interpretations from the participants might affect the quality of the answer. However, due to lack of knowledge from some participants about the difference between real and false alarms, wrong classification of some answers has been discovered and corrected.

Nevertheless, due to the significant sensitivity of the classification associated with answers of question number 15 to test the hypothesis no. 3, a dependent question was intentionally linked to describe the reason of the alarm for the sake of data validation.

The description provided of the alarm reason were clear enough to classify three of the answers correctly that were wrongly classified by the participants.

Ethical Considerations

All participating personnel that have been interviewed for filling the questionnaire have been informed before conducting the meeting about intention of the data usage and the basis of the voluntary and involvement was communicated to all participants. The option to withdraw from participation was offered either before start or even during the interview. The content of the questionnaire were explained clearly at every interview before start filling the sheet and some of the questions that contain sensitive data such as ship identifications offered to be removed should it be against the company policy.

During collection of data, the four principles that have been set as ethical commitment were taken into account (Diener, E., & Crandell, R., 1978). No physical or career harm to the participants have been recorded. Authorizations from ship's master in all interviews was taken before starting the questionnaire with engine crew.

The questionnaire title explained to the participants the objective of data collection and the targeted segment. Also a brief of related information and application was written for the participants overleaf. Before conducting the questionnaire, all participants were given brief information as needed to take their decision freely whether they wish to participate or not.

Ship unique information will not be mentioned in any analysis as explained for the participants and will not be disclosed. It has been only used for identification of sheets and to facilitate completing missing data in case needed. One of the responders had requested to not mention the ship IMO in the sheet and his request has been positively attended.

No deception involvement has been conducted during the data collection, all participants have been informed that they were going through a questionnaire for collecting data about their practical experiences with OMDs and that these data will be analyzed and used for the research purposes.

Findings

In this chapter, the findings will be presented in accordance to the hypothesis created before to answer the research questions taking into consideration the literature review. However, the findings will be discussed in the discussion chapter.

The respondents to the questionnaire were 126 in total, majority was 71 responses from the questionnaires handed to chief engineers by hand representing 56% of the total respondents. The questionnaires filled during interviews were 27 questionnaires representing 22%, and 26 questionnaires (about 20%) received by emails from fleet operators, while online responders to the questionnaires were only 2 participants (almost 2%).

Out of total ships participated, it was found 119 ships were fitted with oil mist detector, 52 ships were fitted with the oil mist detectors only without another aid for protection of the main engine, 68 ships were fitted with OMD along with another alternative, typically *"bearing temperature monitoring system – BTMS"*. Only three ships had used *"bearing temperature monitoring system"* only without oil mist detector.

Effectiveness of Crankcase-Oil Mist Detectors

Below table of frequency (Table 3) illustrates the collected data from the questionnaires.

		OMD	OMD ONLY	BEARING	BEARING ONLY	OTHER
TOTAL INCLUDING NOT APPLICABLE	FITTED	119	52	71	3	0
APPLICABLE ONLY	FITTED	106	41	67	3	0
	NOT FITTED	3		41		0

Table 3

This table was used to test many of the hypothesis that set to answer the research questions which will be elaborated later in the discussion chapter.

From table 3, the below pie-chart (figure 1) was created to illustrate the percentage of the ships fitted with OMD compared to the ships not fitted with the OMD on the sample.

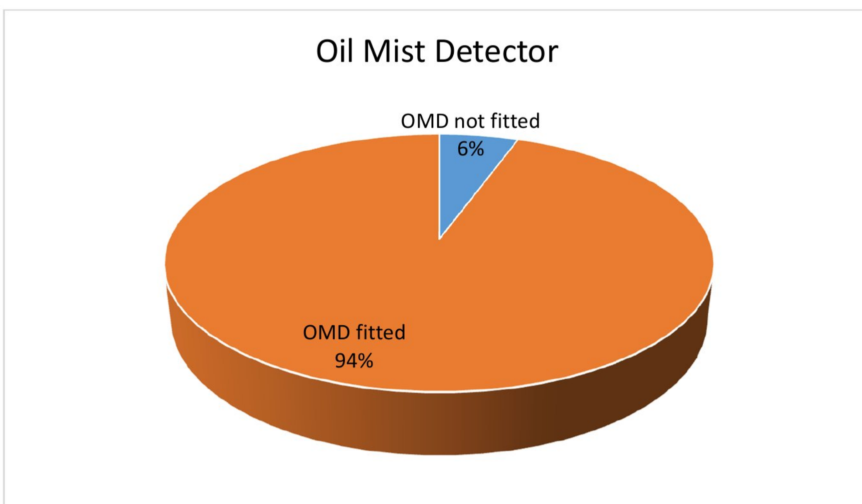


Figure 1

From the same table 3 above, it was created below pie chart (figure 2) to illustrate the percentage of the ships fitted with OMD compared to the ships fitted with another systems.

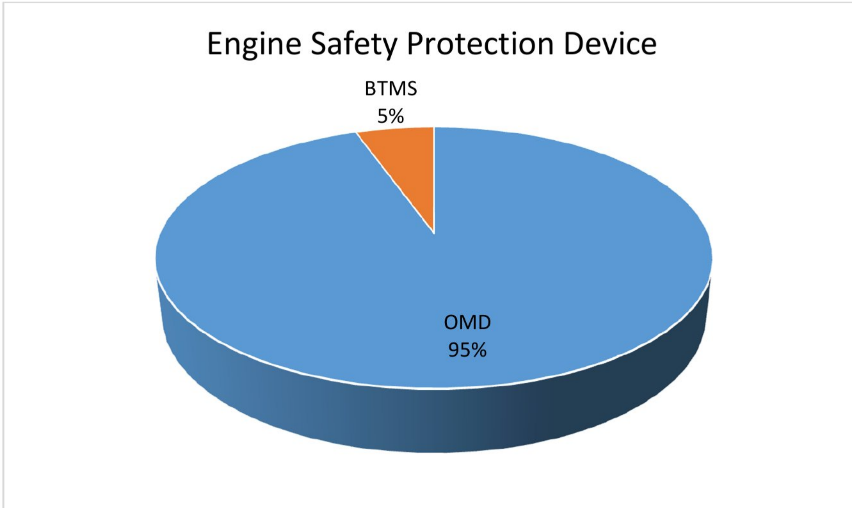


Figure 2

For the sake of data reliability, before we investigate the hypothesis no.3, we need first to test if there is a relation between the number of false alarms and the measuring techniques, to ensure that indeed we are measuring what we want to measure (Bignami-Van Assche, S, 2003). Therefore, using SPSS, Statistical Analysis Software, a Chi-Square test have been made to test the relationship between the measuring technique and the number of false alarms.

OMD activation * Measuring Technique Cross tabulation

			Measuring Technique		
			Obscuration	Scattered Light	Total
OMD activation	NO	Count	67	40	107
		% within OMD system activation experienced?	62.6%	37.4%	100.0%
		% within Technique	85.9%	97.6%	89.9%
		% of Total	56.3%	33.6%	89.9%
	YES	Count	11	1	12
		% within OMD system activation experienced?	91.7%	8.3%	100.0%
		% within Technique	14.1%	2.4%	10.1%
		% of Total	9.2%	0.8%	10.1%
Total		Count	78	41	119
		% within OMD system activation experienced?	65.5%	34.5%	100.0%
		% within Technique	100.0%	100.0%	100.0%
		% of Total	65.5%	34.5%	100.0%

Table 4

Chi-Square Tests

	Value	DF	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.032[a]	1	.045		
Continuity Correction[b]	2.848	1	.091		
Likelihood Ratio	4.942	1	.026		
Fisher's Exact Test				.056	.038
N of Valid Cases	119				

Table 5

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.13.

b. Computed only for a 2x2 table

The chi-square statistic is 4.032. The p-value is .044645. This result is significant at $p < .05$.

We can see that P-value (0.045) is less than the significance level (0.05), so, we cannot accept the null hypothesis.

Therefore from the chi-square test we can conclude that there is a relationship between the measuring technique and the number of false alarms. So the hypothesis no. 3 can be tested using this relation.

		OMD	REAL ALARMS	FALSE ALARMS	PERCENTAGE
Technique	Scattered Light	41	0	1	2.5%
	Obscuration	78	0	11	14%

Table 6

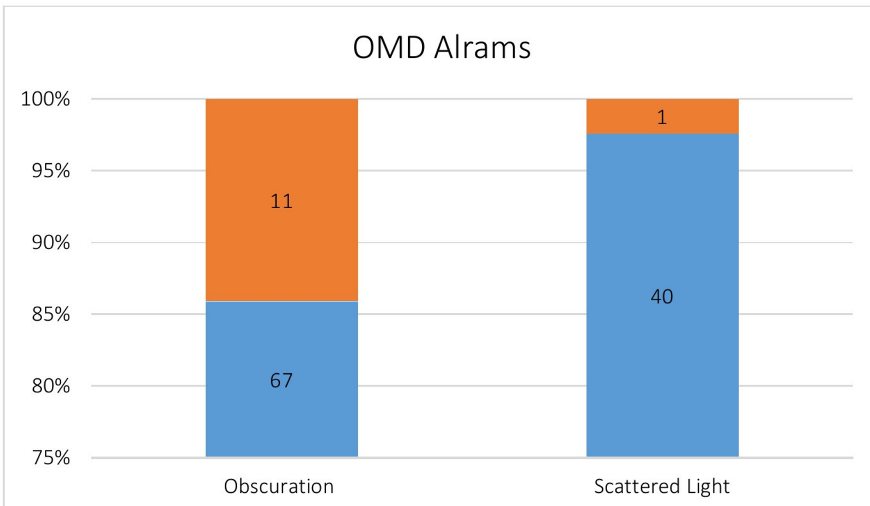


Figure 3

All participated ships fitted with oil mist detector have linked the OMD to the engine automatic control system which can slowdown or even shutdown the engine depending on the engine size and speed.

Using SPSS, a reliability of scale test is done to measure internal consistency for the questions set to measure the hypothesis no. 4 (as stipulated in table 2) by calculating coefficient of reliability that called Cronbach's Alpha.

Reliability Statistics

Cronbach's Alpha	N of Items
.750	3

Table 7

Table 7 extracted from the SPSS shows that the Cronbach's Alpha value is 0.75, so the questions measuring the hypothesis no. 4 has a relatively high internal consistency (Santos, J. R. A, 1999).

The hypothesis no. 5 will be discussed in the discussion chapter, however, in this chapter we will present only the results that have been concluded from the data analysis with regard to the questions associated with this hypothesis.

Among the whole sample participated in questionnaire, all the 119 ships' chief engineers has reported that no real alarm has been experienced during last 12 months of ship operation, this was quite surprising, however, 2 participants had reported 2 different incidents which is very important for the discussion.

The first incident, *"During servicing of OMD, the P.S. engine shutting off and we went 50% blackout (DP-system redundancy) during sub-sea operations, Schaller service engineer concluded that the unit was faulty, he said probably electronic."*

The second incident, *"One accidents happen to a sister ship owned by this company communicated to us during service as 3rd engineer on a bulk carrier 16 years back, the OMD gave real alarm due to oil mist in the crankcase, but the vessel were navigating in a critical turn in transit channel, so, the captain gave order to override the alarm to avoid grounding, after about 2 minutes the crankcase exploded and engine stopped, after that the ship ran aground".*

The most common false alarms of the devices working on the obstruction technique, as reported in the questionnaire, varied between "*faulty controller assembly, protecting glass, sensor dirty, low air flow, measuring head was malfunction, dirty lenses, wrong pressure adjustment, dirty sensors*".

Some of findings also has been noticed in the literatures, which will be briefed and highlighted in this chapter, as follows, in order to be discussed in the discussion chapter in light of the collected data from the questionnaire.

- *Sharp bends in the relatively long piping systems of sampling ports was one of the reported problems that cause pipe blockage and consequently series of false alarms such as low air-flow pressure and un-uniform suction from all pipes.*
- *Dirty lenses of the OMDs working by the obstruction technique was also one of the reported problems that cause many false alarms, especially in absence of makers issued information for the normal levels of oil mist in their engines during normal operations.*

Discussion

In this chapter, findings which have been concluded from the data analysis will be discussed to test if the hypothesis used answer the research questions could be accepted.

The hypothesis set in this research to assess the "Effectiveness of crankcase oil mist detector" were, *"1- Oil mist detectors proofed its effectiveness, so, ships' owners trust the oil mist detectors for the engine protection", "2- Ship owners trust the oil mist detectors among the other alternatives", "3- T The Nephelometry Technique (Scatter Light) reduced the false* *alarms", 4- Oil mist detectors take effective actions to prevent engine damages", and "5- Linking the oil mist detector to the engine shutdown system poses no risk to ships' operations".*

The results of the data analysis proofed that most of these hypothesis that were mainly based on the literature review, can be accepted, except hypothesis no. 5 that assumes the oil mist detector poses no risk to ship operations when linked to automatic shutdown system.

Accepting hypothesis no. 1, 2, 3, and 4, concludes that the oil mist detector is effective in alerting operators about abnormal conditions inside the engine crankcase in early stages in addition to that the scatter light technique indeed significantly reduced the false alarms. The oil mist detector can also protect the engines from consequential serious damages or explosions by shutting off or slowing down the engine.

Hypothesis no.1 can be accepted based on the results illustrated in Figure 1 in the findings that show 94% of the sample ships trust using oil mist detectors to protect their engines.

Figure 2 shows that 95% of the sample preferred to use the oil mist detectors as a single standalone system compared to only 5% that used another system. So, hypothesis no. 2 is also accepted.

Table 6 and figure 3 shows that number of false alarms associated with scattered light technique is significantly less compared to the obstruction technique which proof veracity of the hypothesis no. 3.

100% of the participated ships used the option of linking the oil mist detector system to the engine automatic control system which shutdown/slowdown the engine in case of abnormal conditions that may lead to serious damages. Therefore, the hypothesis no. 4 can be accepted.

Effectiveness of Crankcase-Oil Mist Detectors

The data collected from the questionnaire does not support hypothesis no. 5: *"Linking the oil mist detector to the engine shutdown system poses no risk to the ship operations"*, as there were two incidents reported in the data collected shows that linking the oil mist detectors to the automatic control of the engine poses some risk on the ship operations as the engine's automatic control system is designed to protect the engine, but not taking other risks may posed to the whole ship into consideration.

The first incident when the oil mist detector shutdown one of the two engines due an alarm triggered during servicing the device was about to result in a disaster for the divers conducting sub-sea operations. Losing ship's power in such critical situation (sub-sea operations) may cause disaster for the personnel using ship's power to control the diving chamber. Further to the causalities that may happen as a result of ship drifting due to high waves, strong currents, or high wind speed when the dynamic positioning system lost as a result of blackout.

The second incident also have a catastrophic scenario. The vessel was navigating in a restricted navigation area and due to a damage in some part in the crankcase, oil mist was generated and sensed by the oil mist detector that accordingly attempted to slowdown the engine speed, but because of the critical maneuvering situation, crew decided to override the alarm until they finish turning and be in a safe area. However, the situation went beyond their control when the concentration of the oil mist inside the engine crankcase reached the lower explosion limit and lead to explosion, however, the ship finally ran aground after losing ship's power. This incident support the limitation mentioned in the literatures, that the oil mist detectors cannot prevent the engine crankcase from explosions.

Therefore, every chance to prevent uncontrolled engine stop has to be dealt with care to avoid such sudden power loss in critical situations. Thinking from this prospective leads to the need of another measure that achieve the importance of preventing the engine crankcase explosions and at same time can keep the engine running for some time where the ship and crew can overcome the critical situation to avoid the dangerous consequences which equal to that risk of engine explosions, if not higher.

The collected data supported the literatures that discussing the problem of false alarms of the systems using the obstruction technique. The most common false alarms were because of "*dirty lenses and low air flow because of pipe blockage*" (Smith, B. J, 2001).

Conclusion

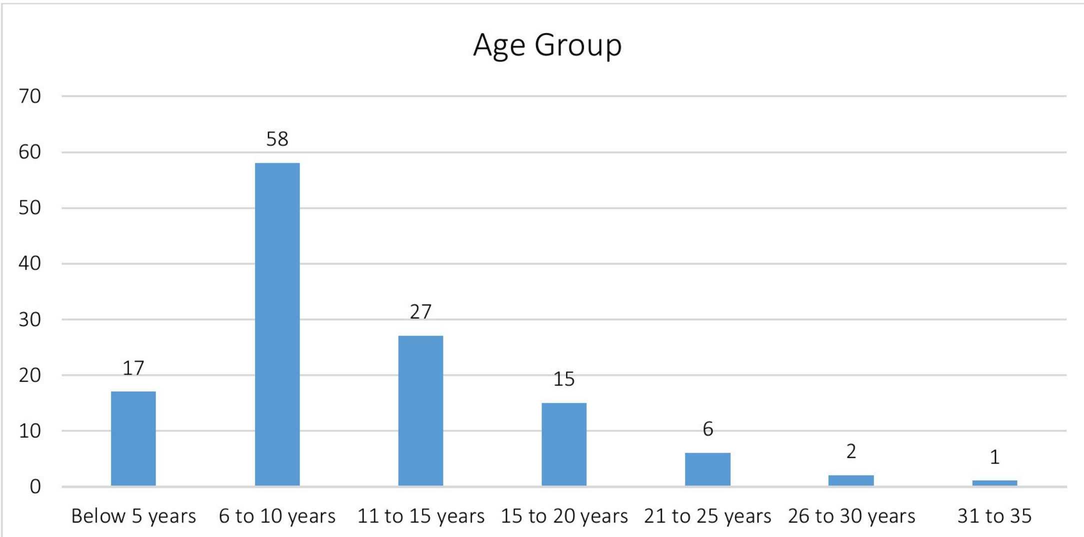
- Crankcase oil mist detector is effective in alerting engine operators with abnormal conditions inside the crankcase.
- Scatter light (Turbidimetry) technique overcome most of the false alarm problems of the obstruction (Turbidimetry) technique.
- Linking oil mist detector system to the engine shutdown system prevent the engines from serious damages, but at same time poses high risk to the ship operation in critical situations.
- Proper measures to be taken to prevent uncontrolled sudden engine stop.
- The findings of this research can be generalized to all ships. However the limitation of the data should be taken into consideration.

Data Limitation

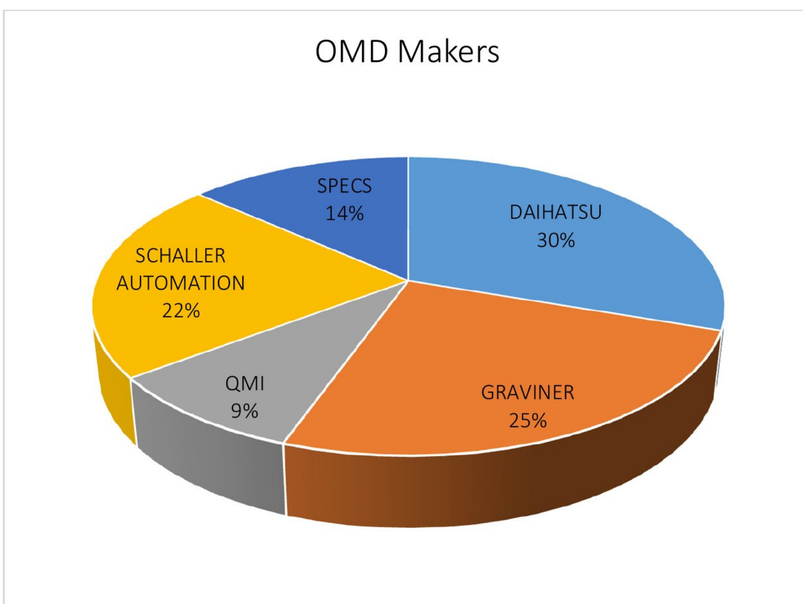
- 26 vessels (20%) responded to the questionnaire were from same company (BW), which may follow same philosophy in the OMD maker selection.

Effectiveness of Crankcase-Oil Mist Detectors

- Age of the vessels in below bar chart shows the age group of the sample, majority of the vessels participated in the questionnaire 46% between 6 to 10 years and 21% of the vessels from 11 to 15 years old.



- Oil mist detectors manufacturers limited to the five major companies, Schaller Automation, Daihatsu Diesel, Graviner, Quality Monitoring Instruments (QMI), and SPECS.



- Engines power, 56% of the participated vessels were having engine power between 5,000 to 10,000 KW, followed by 30% with power between 10,000 to 15,000 KW, 94% of the vessel were 2 stroke engines.
- 97% of participated vessels were classed under one of the IACS classes.

Proposal for Further Research

Referring to the (Choi, B., & Kim, H., 2012) study. Presence of the ignitable substance (oil mist) and the source of ignition (hotspots) inside the crankcase with absence of the oxygen posing no risk of fire or at least reduce it to very low levels. Nevertheless, no systems are working on elimination of the third element in the fire triangle which is the oxidizing media or oxygen. Therefore, it would be imperative to consider further researches on presentation of a system similar to the inerting system on tanker using the nitrogen or CO_2.

This system could be a dynamic system, which means that crankcase will not be under inert gas at all times. The system will rather be able to open the valves to flood the crankcase with inert gas through directed tubes on each section of the engine compartment whenever OMD or BTMS triggered the alarm alerting about abnormal conditions in the engine crankcase. This dynamic link between this proposed system and OMD or BTMS systems will facilitate using the system only whenever required if the ship in a critical situation and cannot survive if she lost the power. Prevention of uncontrolled engine stop keeping ship's power available for the crew for some time will give them the option to proceed to safe area or to overcome the critical situation and then to stop the engine to check the damage or the reason of the triggered alarm.

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Appendix A- Questionnaire Form

Questionnaire for the effectiveness of Oil Mist Detector onboard the vessels

Kindly forward completed questionnaires to mahmoud.abdul.hamied@student.hbv.no

1. Vessel name:	
2. IMO:	
3. Class:	
4. Year built:	
5. Unattended engine room?	
6. Propulsion system (Tick off): • Engine mechanical connected to the propeller • Diesel electric propulsion	
7. Engine maker/ type (2 stroke – 4 stroke):	
8. Engine power (kW):	
9. Engine speed (rpm):	
10. Cylinders bore diameter (mm):	
11. Is the engine fitted with oil mist detector (OMD)?	
12. Is the engine fitted with bearing temperature monitoring system?	
13. Is the engine fitted with equivalent devices other than the above?	
14. If the engine is fitted with OMD, • Who is the maker of the system? • If the ship's engine is slow-speed engine, does the OMD slow down the engine? • If the ship's engine is medium or high-speed engine, does the OMD shut down the engine?	
15. Have you experienced incidents with OMD system activation? 16. If so, what was the reason and what was the action taken? 17. Differ between real and false alarms. Use next page if necessary. Real alarm: False alarm:	