Developing A Method for Design and Application of Automatic Sprinkler System in Marine Power Plant

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Abstract - *The Ship's power plant is one of the most important sections in a ship and also a place where fire outbreak is likely to occur. Therefore, there is need for protection against such occurrence to save lives and properties onboard. In this study, the report of developing the design method for application of automatic sprinkler system in marine power plant is presented. The purpose of this study is to design a system that fights fire automatically in Ship's engine room. This will involve designing a suitable system configuration for an automatic fire fighting system to reduce human effort in firefighting and damage due to fire outbreak. This report provides a novel solution to a self-controlled smart fire sprinkler system, which can be assembled with multiple sensors and actuators, operated by micro-controller unit (MCU). Within the report, a method to determine the coverage area of the sprinkler system is also presented. Calculations on fluid flow rate, cross sectional area of the pipes, fluid pressure are determined to ensure effectiveness of the system. Results showing the flow rate, velocity and area are presented to ensure that the system is efficient. The automatic sprinkler system will have the capability to detect fire at its early stage and also fight the fire automatically without human effort*

Key Words*: *Design Method, Sprinkler System, Firefighting Marine Power Plant, Engine Room

1. INTRODUCTION

An automatic fire sprinkler is a standalone system that is capable of providing an automated response solution in the event of a fire outbreak or detection of abnormally higher temperatures that can cause an explosion. The fire alarm system usually consists of: Fire detectors (which can be smoke detector, heat, or Infra-Red detectors), control unit, and alarm system. Studies [1] defined a marine power plant as that part of a ship (vessel) or a system responsible for the generation of tough and thrust for propulsion. Several types of marine power plants exist and these can include: diesel engines, steam turbine, gas turbine, solar propulsion system, nuclear propulsion system and hybrid system which is a combination of any of the system mentioned. In this respect, there are different types of firefighting system onboard various marine power plants. Ship's engine rooms are the usual sources of shipboard fires; either from a fire in the engine room, or an engine internal fire or explosion causing a subsequent fire. This study aims to bridge the gap by contributing to the knowledge of developing a design method for application of automatic sprinkler system in marine power plant. A fire sprinkler is the part that discharge water when the effect of a fire or predetermined temperature has been detected or reached. Automatic fire sprinklers operate at a predetermined temperature, utilizing a fusible link [14], a portion of which melts, or a frangible glass bulb containing liquid which breaks [2]. This allows the plug in the orifice to be pushed out of the orifice by the water pressure in the fire sprinkler piping system, resulting in water flow from the orifice. The water stream impacts the deflector which produces a specific spray pattern designed in support of the goal of the sprinkler type (i.e. control or suspension) [3].

A concern of businesses looking into installing sprinkler systems is the fear that they will discharge accidentally, causing unnecessary water damage. However, accidental discharge rarely occurs due to the effectiveness of their design. Sprinkler systems that accidentally discharge have typically been exposed to extreme heat or have been damaged [2]. The automatic sprinkler system is a self-controlled fire-fighting device that has a system of sensors, pipes and valves from the storage tanks to the sprinkler heads controlled by a circuit. This system fights fire automatically when the sensors sense smoke and temperature above the maximum engine room temperature. They operate by sprinkling water and sounding the alarm signaling the crew of a possible fire outbreak. This helps in controlling the situation to fight the fire and ensure lives and properties are saved. Several investigations regarding automatic means of fighting fire using the automatic sprinkler system has been done by scientist and engineers [3][4]. Although, theses researches have been focused more on fire fighting in homes, schools, workshops and industries. However, firefighting technology has greatly improved from time to time but the researches for ships especially the engine room (power plant) where fire is likely to occur has been somewhat neglected.

The main focus of this study is protecting the engine room of a ships using diesel engine against fire outbreak. As long as men go to sea in ships there has been a fear of fire aboard. Major fires occurring on modern ships account for a large number of lives lost, especially on cruise ships and ferries. The main portable means of firefighting equipment are the different types of handheld extinguishers. These are located throughout the engine room at different levels, along with hoses and hydrants supplied by the seawater pumps [5]. Fire in the engine internal spaces can be attacked and extinguished using inert gas such as CO_2, foam, or water mist sprays [5]. In section 2 a review of related work and basics of fire detection and sprinkler alarm system is presented. Types of sprinkler system and the firefighting equipment used in today's modern engine rooms are discussed. Section 3 deal with the design method of automatic sprinkler system together with materials selection and processing. In Sub-section 3.3 and 3.4 modeling of the sprinkler system and sample design calculation for the sprinkler system are presented. The results are presented in Section 4 and concluding remarks are presented in Section 5.

2. Related Literature

2.1 Related work

The issues of forest fires suffered and mainly occurring in peat land area in Indonesia was considered a serious international issue due to haze and CO2 emission. Studies [6] suggests that one strategy to detect and monitor peat-forest fires in Central Kalimantan, Indonesia is to use a Wireless Sensor Networks (WSNs). This system containing miniature sensor nodes is used to collect environmental data such as temperature, relative humidity, light and barometric pressure, and to transmit more accurate information to fire-fighter and remote monitor [6]. An effective utilization of energy resources has been implemented with the help of Passive Infrared (PIR) sensor, temperature sensor, and humidity sensor [4] [7]. The design and deployment of wireless sensor network is used to provide fire alarm system and for monitoring in rooms and restricted areas of facilities to ensure security against intruders [7]. Study [8] stated that addressable systems have more versatility and features compared to the conventional systems. They utilize a Signaling Line Circuit (SLC) to communicate with detectors, modules and auxiliary devices to complete the system. Due to the additional circuit boards and modules in the addressable systems, they can be expanded to perform more remote relay functions, dry contact monitoring, remote power control, releasing service and conventional zone monitoring. .[8][9]. The control unit contains the microcontroller which is capable of receiving inputs from the receiver, temperature sensor, smoke sensor, and low battery sensor [9]. Study [10] show that the control unit is the heart of the system and the operation is such that signal is transmitted from fire location to the firefighting center where a fire sensor connected to the microcontroller is interfaced to the local server to transmit the status of the location continuously to the central sever in the firefighting center. It is capable of outputting the appropriate signals and bits to the tone generator and transmitter. fire detector indicates the location of fire and produces alarm in the fire location and the center of fire. By using fire detecting system, it is possible to study and develop systems that can sense the occurrence of fire in different locations such as factories, houses and engine rooms of ships.

2. 2 Basics of Fire Detection and Sprinkler Alarm System

Smoke detection has become a fundamental component of the active fire protection strategy of most modern buildings, particularly residential occupancies. Smoke sensors provides a resource to detect smoke and to serve as an early fire warning system. The basic types of smoke detector in use include: ionization smoke detectors, optical detectors, and heat detectors or Temperature Sensor [11]. An ionization smoke detector uses a radioscope, and are more sensitive to the flaming stage of fire. Optical detectors, are more sensitive to fires in the early smoldering stage [11]. Temperature Sensor or Heat detectors are the oldest type of automatic fire detection device [12]. They began development of automatic sprinklers in the 1860s and have continued to the present with proliferation of various types of devices [12]. A heat detector is best positioned for fire detection in a small confined space where rapidly building high-output fires are expected. This includes areas where ambient conditions would not allow the use of other fire detection devices. Generally, heat detectors are designed to operate when heat causes a prescribed change in a physical or electrical property of a material or gas. They are generally positioned on or near the ceiling and respond to the convected thermal energy of a fire. They respond either when the detecting element reaches a predetermined fixed temperature or to a specified rate of temperature change [11, 12]. Heat detectors that only initiate an alarm and have no extinguishing function are still in use. Although they have the lowest false alarm rate of all automatic fire detector devices, they also are the slowest in fire detecting [12].

2.3 Types of Sprinkler System

There are currently four types of sprinkler systems and these include: Wet pipe sprinkler system; Dry pipe sprinkler system; Deluge sprinkler system and Pre-action sprinkler system. The main portable means of firefighting equipment are the fire water hydrant, the sprinkler systems, and different types of handheld extinguishers such as: Soda acid portable fire extinguisher, Foam type portable fire extinguisher, Dry powder fire extinguisher and CO2 portable fire extinguisher. These types of extinguishers require human effort in fighting fire. Wet Pipe System consists sprinkler pipes that are always filled with water under pressure and it is used in normal ambient conditions. With wet pipe system, each individual sprinkler can react to heat from a fire, operating to distribute water over the source of that heat [13]. The heat from the fire is capable of breaking a glass bulb, fusible link, or chemical pellet that is under pressure, releasing a spring which allows water to dispense out of the sprinkler [14]. Experience with sprinklers [5] mentioned that in 2007, 89% of reported fires involved only one or two sprinklers when wet pipe sprinklers operated. The wet pipe sprinklers system is heat sensitive and will only activate after reaching a designated temperature. In addition, dry pipe systems are commonly found in colder environments where there is the possibility of the wet pipe system freezing. Hence, it uses heat sensitive sprinklers. This system is filled with air under pressure rather than being filled with water like the wet pipe system. Air is released when the heat sensitive sprinkler activates and water flows to the open sprinkler where it is dispersed [5]. Clarification on the similarity of dry pipe systems to the wet pipe system have been given [13, 14], such that only the sprinkler that reaches the designated temperature will discharge water. The water is held back in piping at a climate-controlled environment to prevent freezing. The Study [5] stated that in 2007 when dry pipe sprinklers operated, 74% reported fires involved only one or two sprinklers. Furthermore, deluge system is similar to the dry pipe sprinkler system, but is equipped with open sprinklers and a deluge valve. Water disperses when the system is triggered and activated by an alarm system [13] Sprinkler systems are designed in such a way that accidental discharge rarely occurs. Sprinkler systems that accidentally discharge have typically been exposed to extreme heat or have been damaged [14]. Finally, pre-action systems are found in critical areas such as museums, spaces containing computer or communication equipment, and other facilities where inadvertent water leakage or accidental discharges of water from system piping is of major concern [15]. A pre-action system is classified as a type of dry system that employs a deluge-type valve, fire detection devices, and closed sprinklers [15]. The operation is such that once the detection system signals the pre-action system, water will be discharged into the piping system like a wet pipe sprinkler system. This imply that the system only discharges water into the piping in response to a signal from the detection system. Hence, the system will not disperse water onto the fire until each Sprinkler head is activated.

2.4. Engine Room Fire Fighting Equipment

In this section the relevant engine room firefighting equipment such as Aqueous Film Forming Foam, Engine room sprinkler system, Fire Hydrants and Hoses, and Engine room Fire Extinguishers are discussed. Aqueous Film Forming Foam also known as AFFF and (pronounced A triple F) was developed in the sixties and is a great innovation to firefighting not only in ships engine rooms, but on oil and gas platforms worldwide [16]. AFFF is operated by pressurized seawater and it is supplied in its own containers and added to an AFFF storage tank. The seawater mixes with the specialist liquid and exits the $1^{1/2"}$ rubber hose through a brass nozzle as a pressurized film of thick, viscous foam. This is directed to the base of the fire, quickly smothering the flames, dissipating the heat, smoke and fumes. Engine room sprinkler systems can be operated automatically by sensors or manually by the engineer. It is a modern type of water nozzles that actually supply a very fine mist, rather than a flow of water. It is important to emphasize that water is not normally used on oil fires. Nevertheless, since fine mist is injected into the area it not only starves the fire of oxygen, but also dissipates the smoke [17]. These systems cover different areas of the engine room, but not the switchboard or the electrical generating component of the power generators. In addition, Fire Hydrants and Hoses are often positioned throughout the engine room. To ensure effective operation the hydrant valves should be opened; hoses run out and discharged to the bilges at regular intervals. A fire axe is sometimes positioned alongside the fire hoses. Engine room fire extinguishers are operated by removing the protective pin, before pulling the trigger smartly. Fire extinguishers are usually stored in a container and the containers are positioned at different levels in the engine room at high fire risk locations. There are four main types of fire extinguishers with a different colored band around the top of the body, denoting the type of medium it contains. They include: Dry Powder Fire Extinguisher. This has a black band around the body and is used for extinguishing electrical and liquid fires. Secondly, the CO_2 Fire Extinguisher, also has a black band around the body and is also used to extinguish electrical and liquid fires. It is significant to note that only the Dry Powder and CO_2 extinguishers should be used on electrical fires. Thirdly, is the Foam Fire Extinguisher. This differentiated with a yellow band around the body and is used for extinguishing oil fires. The fourth type is the Water Fire Extinguisher, this has a red band contained between two thin white bands around the body. It is used to extinguish paper, wood and cloth. The procedure that can be adopted on board in an event of fire outbreak to give a very first response to fire was suggested by [16]. The report recommended that, on the discovery of a fire or unexpected strange smoke, a crew member being aware of the possible danger, and If he cannot find the flames or the source of the smoke, he should first attempt to locate the fire, and then alert the whole ship by raising the alarm. An attempt is made to fight the fire and finally report the situation to the officer of watch.

3. Design Method

3.1 Design of Automatic Sprinkler System

The design standard published in the National Fire Protection Association [18]. illustrates all aspects of the sprinkler system starting from the preliminary state to the finished design state. In this respect, the design process of the sprinkler system is rather arbitrary in that the specific application in the system to determine most of the key design parameters, and recommended design practices are also published in the National Fire Protection Association

[19]. These documents are an invaluable tool published in order to provide guideline for the design of the automatic sprinkler system across all industries. They do not only provide recommendation for
design but also entails the manufacturing considerations, performance requirements and standard for the illustration of the automatic sprinkler system.

3.2 Materials Selection and Processing

The material for automatic water sprinkler system is expected to be of high quality and capable to withstand pressure, ship vibration, corrosion, and heat from the engine room. The choice of materials used for engineering components depends deeply on it chemical and mechanical property. The first criteria applied in the material selection is consideration of the mechanical property of the material. However, corrosion prevention is of utmost importance in water sprinkler construction but it may not be the only property to be considered in material selection. In Table 1: the materials used for the components are presented.

Table 1: Materials used for the components (Askeland, 1992)

Materials	Components
Plain carbon steel	Pump shaft
Rubber	Pipes
Iron	Support
Stainless steel	Pump impeller
Mild steel	Water storage tank
Cast iron	Sprinkler head
Stainless steel	Valves
Cast iron	Pump casting

Figure 1: Sprinkler Head

The material must be able to resist corrosion since the system will be operating with salt water. Thus, depending on the specific application of the automatic sprinkler system the necessary material property and treatment of the material is determined as it may be required. The additional treatment that may be required is the hardening of the material which may not be limited to carbonization, nitration, and induction flame hardening. However, most equipment used in the construction of sprinkler system are designed and fabricated to meet the requirement of pressure vessel and piping codes.

Table 2: The main components of the sprinkler system

S/N	Component	Description
1	Sprinkler head	This is the nozzle which sprays water over the defined area
2.	Control circuit	This is an electric circuit made up of a step-down transformer, smoke detector, diode, 12volt relay, electrolytic capacity, Darlington amplifier and main supply.
3.	Stop valve	This is used to isolate the water supply coming into the sprinkler system
4.	Valve monitor	This is used to monitor the open and close state of the stop valve.
5.	Alarm valve	This is used to control the flow of water into the sprinkler system
6.	Alarm test valve	This is a small valve normally secured in the close position. The alarm test valve is fitted between the sprinkler system side of the alarm valve and the drain. The purpose of the alarm valve is to stimulate the flow of water in the system when opened
7.	Motorized alarm bell or gong	The motorized alarm bell or gong is a mechanical device which operates by the flow of water oscillating a hammer that strikes a gong causing an audible alarm signal.
8.	Pressure switch	This is an electro-mechanical device that monitors the sprinkler system for a fall in water pressure after the alarm valve. The purpose of monitoring a fall in pressure is to activate a switch that is monitored by a fire alarm panel signaling an alarm to the control room.
9.	Flow switch	This is an electro-mechanical device that monitors the flow of water through a section of pipe within an automatic fire sprinkler system.

A wide variety of iron and nickel-based materials are used for pressure tank, vessels, piping and other major equipment in the sprinkler industries. On the other hand, the material processing refers to the heat treatment in which the components are subjected to. The heat treatment depends on the material used for various components of the sprinkler system. The components of this system are often made up of alloy of carbon and steel. The main components of the sprinkler system are highlighted and described in Table 2.

3.3 Modeling of the Sprinkler System

The flow parameters of the system were designed and analyzed by examination of specific details such as the storage capacity, area of the pipe, velocity and flow rate. These are essential elements to determine the flow from the operating sprinkler orifice. Thus, considering the storage capacity given the Length (L)=5m, Height (H)=9m, and Breadth (B)=5m. Volume of the tank=L × B× H=225m. Also, given that diameter of the pipe(d)=5m, the area of the pipe is calculated using the formula:

$$\text{Cross Sectional Area of Pipe (A)} = \frac{\pi d^2}{4} = \frac{3.142 \times (5)^2}{4} = 19.64\text{m}^2 \quad (1)$$

Therefore, the Area of pipe used between tank and the pump is 19.64m^2. The area of the pipe must be known in order to determine the flow rate of the fluid. This is the velocity of water from tank to pump calculated by using Bernoulli's equation given by the formula:

$$P_1 + \rho g h_1 + \frac{1}{2}\rho V_1{}^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho V_2{}^2 \quad (2)$$

Point 1 is the atmosphere pressure same as point 2; Given that: $V_1 = 0$; $h_1 = 40$m; $h_2 = 0$. Substituting these values, we obtain:

$$\rho g h_1 = \frac{1}{2}\rho V_2{}^2 \quad (3)$$

Multiplying through by 2 and rearranging the equation we have the velocity of the fluid flow calculated using the formula:

$$V_2 = \sqrt{2gh} \quad (4)$$

Where: V_2: = the velocity at the outlet
g: = acceleration due to gravity
h: = height
Thus, substituting value of g: and h: into the equation we have V_2:=28m/s. In addition, the flow rate (Q) is calculated using the formula:

$$Q = \frac{\text{Volume of Fluid (V)}}{\text{Time Taken (t)}} = (\text{m}^2/\text{sec}) \quad (5)$$

Alternatively, (Q)= A.V, where Q= flow rate; A= cross sectional area, and V= velocity. By substituting values, into the formula we obtain:

$$Q = A.V = \frac{\pi d^2}{4}.V = \frac{3.142 \times (5)^2}{4} \times 28 = = 19.64 \times 28 = 549.92\text{m/s} \quad (6)$$

In addition, the flow from the operating sprinkler orifice is calculated using the formula:

$$Q = K\sqrt{P} \quad (7)$$

Where: Q=Flow Rate; P=Operating Pressure at the sprinkler orifice, and K=the constant sprinkler coefficient. However, the Volumetric flow rate is calculated using the formula:

$$\tilde{V} = \pi r^2.v \quad (8)$$

Where: r=radius of the pipe=2m; V=Mean velocity flowing through the pipe=2.171. By substituting values, into the formula we obtain: $\tilde{V}$ == 27.29m³/s. In addition, the frictional losses in pipes is calculated using the formula:

$$S = \frac{\Delta P}{L} \quad (9)$$

Where S=Frictional losses, ΔP=Change in Pressure; L=Length of the pipe. The Head loss is calculated using the formula:

$$H_L = F\left(\frac{L}{d}\right) \times \frac{v^2}{2g} \quad (10)$$

Where: H_L=head loss (m)
F=friction factor
L=length of pipe work (m)
d=inner diameter of pipe work (m)
v= velocity of fluid (m/s)
g= acceleration due to gravity (m/s²)

3.4. Sample Design Calculation for the Sprinkler System

In designing the automatic sprinkler system certain elements of the basic components were initially, analyzed in order to determine the efficiency of the system. These basic elements which include the storage capacity, area of pipe used between tank and the pump, the velocity of water from tank to pump, Volumetric flow rate, were examined as discussed in the preceding section. In addition, an example for determining the flow rate of the fluid and the velocity and flow rate from pump to sprinkler heads is presented in the following section.

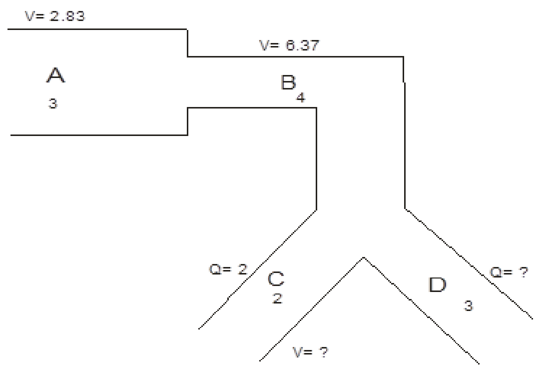

Figure 1: Schematic of the designed Sprinkler System

4. Results and Discussion

Table 3 the velocity and flow rate from tank to pump

Area (m^2)	Velocity (m/s)	Flow rate (m^3/s)
20	28	559
22	30	660
24	32	768
26	34	884
28	36	1008
30	38	1140
32	40	1280
34	42	1428

Table 4 Shows the flow rate and pressure from the pump to sprinkler heads

Pressure (N/m^2)	Velocity (m/s)	Area (m^2)	Flow rate (m^3/s)
2634	0.16	28	4.48
2636	0.15	30	4.5
2638	0.14	32	4.48
2640	0.13	34	4.42
2642	0.12	36	4.32
2644	0.11	38	4.18
2646	0.10	40	4.0
2648	0.09	42	3.78
2650	0.08	44	3.52
2652	0.07	46	3.22

Table 5 Flow rate at the pipe orifice

Pressure = p (N/m^2)	$\sqrt{P}$ (N/m^2)	Q =5.6$\sqrt{P}$ (m^2/s)
2633.79	51.32	287.39
2638.79	51.37	287.67
2643.79	51.42	287.95
2648.79	51.47	288.21
2653.79	51.51	288.48
2658.79	51.56	288.76
2663.79	51.61	289.03
2668.79	51.66	289.30
2673.79	51.71	289.57
2678.79	51.76	289.84

5. Conclusions and Recommendation

There is often the need to save lives of crew members and machineries onboard the vessel. This is by providing a fast reliable and automatic method of fighting fire outbreak onboard a ship power plant. This study contributes to knowledge of helping to reduce human effort in fighting fire outbreak. The system is designed to protect the engine room (Power Plant) from fire outbreak onboard, the system uses smoke detector, sensors and a circuit which triggers the sprinkler by breaking the mercury glass bulb to spray water to extinguish the fire immediately when the sensors senses a temperature above 600C-700C. This firefighting system is capable supporting real-time monitoring of every point of the ships engine room at all time and early detection of the fire threats. The Automatic sprinkler system is one of the most important firefighting equipment not only for the power plant (engine room) in every sea going vessels but to all other sections such as; Cabins, Cargo space. Therefore, the regulatory authorities should make the system a necessity for every sea going vessels in the maritime industry.

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