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Compressed Air System Design for an Ocean Going Tug Boat in the Tropical Region

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ABSTRACT: The starting (Compressed) air system is primarily used for starting Diesel engines (that is main engines and auxiliary engines). It is also used for general service to operate pneumatic devices on board the vessel, to control air during maneuvering of the main engine, for air instruments to monitor condition of systems in the engine room in particular and the vessel in general and used for horns, releasing of hooks etc. The system consist of the tanks (storage), pumps, compressor, strainers, coolers, piping, valves, and fittings, purifier, sub system and condition monitoring devices amongst others. The starting air system of a tug boat whose transmitting power is about 955KW was calculated mathematically to obtain the capacity of air receivers from the formula given by Germanischer Lloyd. Modeled equations were employed to obtain the capacity of the air compressor and the power output of the compressor. Keeping in mind the piping systems and safety of the overall air system. The plotted graph gives a clear indication that the said design process met the international standard for the design of the starting air system of a tug boat. All designs were done in accordance to the Lloyd's specification rules and regulations for a sea going tug boat.

Keywords: Tug boat, Compressed air, Valves, Piping, Fittings and Condition Monitoring Device

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I. INTRODUCTION

The compressed air is a very good form of energy; it is safe and free from hazard such as, fire, electric or high pressure hazards. Most importantly it is very surplus all over the earth atmosphere and around us. It only demands the necessary work to be done on it. The compressed air on motor ships can be used for the followings: for starting Diesel engines (that is main engines and auxiliary engines), use for general service to operate pneumatic devices on board the vessel, use to control air during maneuvering of the main engine, use for air instruments to monitor condition of systems in the engine room in particular and the vessel in general and use of horns, releasing of hooks etc. The compressed air is obtained from a machine called the compressor, which collects the atmospheric air and does work on it to increase the pressure and remove the moisture in it. This compressed air is later stored in a bottle or reservoir, whose capacity is designed such that it is sufficient to provide not less than twelve consecutive starts of each main engine for the reversible type and not less than six consecutive start for the non-reversible type. The compressor capacity ranges in driving motor output from 50 horse powers up to 100 horse powers. Similarly, it is important to know that for starting engines this depends on the size of the vessel and the output power of the engine [1].

There are two basic ways compressed air could be used to start an engine either by a mechanical Pneumatic operated valves or using the air starter unit. From the former the valve which is located in each cylinder head is timed to open and close when the respective crank is in such a position that the starting air acts upon the piston attached to it and rotates the crankshaft in the desires direction. This is sufficient to set the engine in motion and compress the air in another cylinder to a temperature high enough to ignite the fuel when injected. The starting system of the main engine is made up of a relay valve, a pilot valve and a distributor. The pilot valve is operates by the engine control level or wheel, and when opened allows, air to flow to the piston-operated relay valve. Opening of the relay valve permits starting air to pass to the starting valve of each engine cylinder and the distributor controls the admission and cut-off of the starting air to the cylinder [2].

On the other hand, the air starting unit is attached to the flywheel of the main engine such that the starting air unit gear teeth has contact with that of the flywheel. Similarly, the unit has some sets of gear arrange in it so that when air is allowed into the unit through the inlet hole, due to the pressure of the incoming air, it sets the gear arrangement into motion and at the long run rotates the gear teeth of the starting air unit which in turn rotates the flywheel and start the engine. This is a resent development in the field of marine engineering. The compressed air in the tug boat could be used for various purposes at various pressures. For the starting of the main auxiliary and fire engines the pressure is always at 30bar but for other application such as for operating the horn, releasing of towing hooks etc which uses 7 bar the reduction is done by a reducing unit.

It is known that several field other than marine engineering uses compressed air for the purpose or the other which may include; Rotating or retraction of soot-blower is powered by air motor, used for starting, reversing and shutting down engines, safe guarding and monitoring of condition through air monitoring devices. It is also used in driving motors for lifting, dragging and transporting equipments, in air motors to maneuvering machines, hatch-covers, soot blowers, operating trim valves and ballast valve, for purpose of inspection of area with risk of explosion, compressed air power turbo lamps are used, compressed air driven pumps and for instrumentation purpose and others [3]

The important part of the compressor to do the various works satisfactorily and all reliably is to remove from the operating air all moisture, oil and solid particles. Moisture present in the air will cause rusting (in operating cylinder) and freezing (up of valves). The presence of oil is ever more dangerous, which can be in three forms, droplets, vapour or gaseous forms. In the gaseous form it results from the cracking of the oil in the cylinder under high pressure and temperature operating. In droplet form, it can cause problem, in nozzles, orifice, measuring and control equipment. The layer of reservoir oil which can build up in parts of the system can seriously affect the response time of the controls. The presence of solid particular certainly have rapid effects on the smooth operation of control equipment, as well as causing blockage of orifice, damage of diaphragms and “O” rings. This can be avoided by using air compressor howling piston rings which does not require lubrication, thus ensuring that the air is 100% free of oil [4].

In this work I looked at the bilge and ballast systems of some vessels with respect to the sizes of the vessel with special interest on the tug boat. Highlights of some classification rules for the system are considered and various mathematical models were used to design the inner and outer diameter of the suction and discharge pipes of the system and a general discussion were done with the results obtained.

II. STARTING (COMPRESSED) AIR SYSTEM

Diesel engines are started by supplying compressed air into the cylinders in the appropriate sequence for the required direction. A supply of compressed air is stored in air reservoirs or ‘bottle’ ready for immediate use. Up to 12 starts are possible with the stored quantity of compressed air. The starting air system usually has interlocks to prevent starting if everything is not in order. A starting air system is shown in figure 1. Compressed air is supplied by air compressors to the air receivers. The compressed air is then supplied by a large bore pipe to a remote operating non-return or automatic valve and then to the cylinder air start valve. Opening the cylinder air start valve will admit compressed air into the cylinder. The opening of the cylinder valve and the remote operating valve is controlled by a pilot air system. The pilot air is drawn from the large pipe and passes to the pilot air control valve which is operated by the engine air start lever [5].

When the air start lever is operated, a supply of pilot air enables the remote valve to open. Pilot air for the appropriate direction of operation is also supplied to an air distributor. This device is usually driven by the engine camshaft and supplies pilot air to the control cylinders of the cylinder air start valves. The pilot air is then supplied in the appropriate sequence for the direction of operation required. The cylinder air start valve are held closed by springs when not in use and opened by the pilot air enabling the compressed air direct from the receivers to enter the engine cylinder. An interlock is shown in the remote operating valve opening when the engine turning gear is engaged. The remote operating valve prevents the return of air which has been further compressed by the engine into the system. Lubricating oil from the compressor will under normal operation passes along the air line and deposit on them.

In the event of a cylinder air starting valve leaking hot gases would pass into the air pipes and ignite the lubricating oil. If starting air is supplied to the engine this would further feed the fire and could lead to an explosion in the pipelines. In order to prevent such an occurrence, cylinder starting valve should be properly maintained and the pipelines regularly drained. Also oil discharge from compressors should be kept to a minimum, by careful maintenance. In an attempt to reduce the effects of an explosion, flame traps, relief valves and bursting caps or disc are fitted to the pipelines. In addition an isolating non-return valve (the automatic valve) is fitted to the system. The loss cooling water from an air compressor could lead to an overheated air discharge and possibly an explosion in the pipelines leading to the air reservoir. A high-temperature alarm or a fusible plug which will melt is used to guard against this possibility [6].

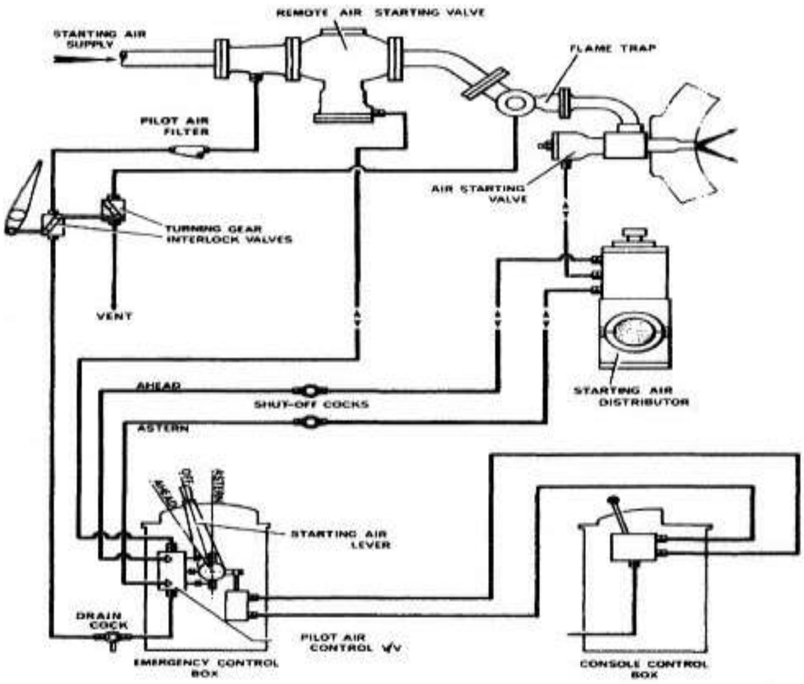

Figure 1: Starting air System (Source: Machinery Space) [7]

Starting Air System Precautions

Great care is to be exercised in the operation and maintenance of starting air systems. The hazard of compressed air and lubricating oil forming an explosive mixture must be avoided. Oil from any source must be excluded from the starting air system. Air compressor, starting air reservoir blow down drains are to be operated at regular intervals, and if automatic, their function verified. Periodic inspection of air starting system pipelines is to be carried out to ensure that no build up of oil is occurring. Highly flammable cleaning fluids must never be used in any part of the starting air system. Any residue of liquid or vapour could result in an explosion. Routine duties must include the manual checking of the main air starting valve pipes for any increase in temperature, which would indicate leakage of combustion gasses into the system. It is particularly relevant during maneuvering when the main air starting reservoirs are open to the system despite the existence of non-return valves and other devices.

It is absolutely essential that if an air starting valve is in any way suspect that immediate action is taken i.e. shutting the fuel off the unit in accordance with the manufacturer's instruction, "gagging" the valve shut, and replacing the valve at the first opportunity. Only in exceptional circumstances and according to the Master's authority is the main engine to be operated with leaking air starting system valve. Air starting systems usually incorporated two or more air reservoirs. According to experience with the main engine plant, the Chief Engineer is to issue standing instructions regarding the air reservoirs which are to be online during maneuvering. Following maneuvering and during full away passage conditions and dependent on the particular system i.e. connections with auxiliary engine air starting system etc., as many air reservoirs as possible are to be taken off line and their isolating and stop valves shut. The pressure in these reservoirs is to be maintained at the operating maximum [7].

III. RELEVANT REGULATION AND REQUIREMENT FOR STARTING AIR SYSTEM

3.1 The Starting Arrangement

Equipment for starting the main and auxiliary engines is to be provided so that the necessary initial charge of starting air or initial electric power can be developed on board ship without external aid. If for this purpose an emergency air compressor or electric generator is required, these units are to be power driven by hand starting oil engineer or steam engine, except in the case of small installations where a hand operated compressor of approved capacity may be accepted. Two or more starting and maneuvering air compressors are to be fitted of sufficient total capacity for the requirements of the main engine. The compressors are to be so designed that the temperature of the air discharge to the starting air receiver will not substantially exceed 93^{o}C in service. A small fusible plug or an alarm device operating at 120^{o}C is to be provided on each compressor to give warning of excessive air temperature. The emergency air compressor is expected from these requirements.

Each compressor is to be fitted with a safety valve so proportionally and adjusted that the accumulation with the outlet valve closed will not exceed 10 percent of the maximum working pressure. Where the main engines are arranged for air starting, the total air receiver capacity is to be sufficient to provide (without replenishment) not less than twelve consecutive starts for main engine of reversible type and not less than six consecutive starts of the non-reversible type [8]

3.2 Starting (Compressed) Air Pipe Systems and Safety Fittings

In designing the compressor, air installation care is to be taken that the compressor air inlets will be located in an atmosphere reasonably free form oil vapour or alternatively an air duct from outside the machinery space is to be led to the compressor. The air discharge pipe form the compressor is to be led directly to the starting air receivers. Provision is to be made for intercepting and draining oil and water in the discharge for which purpose a separator or filter is to be fitted in the discharge pipe between compressors and receivers. The starting air system from the main and auxiliary engines is to be entirely separate from the compressor discharge pipe system. Stop valves on the receivers are to permit slow rises in the piping system. Valve chests and fittings in the piping system are to be of ductile materials [9]

Drain valves for removing accumulation of oil, and water are to be fitted on compressors, separators, filters and receivers. In case of any low-level pipe lines, drain valves are to be fitted to suitably located drain pots or separators. The starting air piping system is to be protected against the effects of explosion by the following arrangement. An isolating non-return valve or equivalent is to be provided at the starting air supply connection to each engine. In direct reversing engines bursting disc or flame arrestors are to be fitted at the starting valves on each cylinder. In non-reversing and auxiliary engines, at least one such device is to be fitted at the supply inlet to the starting air manifold on each engine. The fitting of bursting disc or flame arrester may be waived in engine where the cylinder bore does not exceed 230mm [10].

To enhance the working condition of the tug boat at full load and other sea conditions we must take a critical account of the stability of the vessel during any operation [11] and [12].

IV. MATERIALS AND METHODS

The Starting air system design calculations for equipment, component, piping and fittings for the Tug boat engines and generators.

The capacity of the engines onboard the vessel are given as follows

The Starboard side Main Engine	- 955KW and 1800 rpm
The Port side Main Engine	- 955KW and 1800 rpm
The Starboard side Aux-Engine	- 82KW and 1500 rpm
The Port side Aux-Engine	- 82KW and 1500 rpm
FI-FI pump set	- 133KW and 1800 rpm [13]

General Data for Diesel Fuel Oil (D.F.O)

Net Calorific value of D.F.O.	= 42700 KJ/kg
Mean overall heat transfer coefficient of fuel	= 760 KJ/M^2 deg hr
Specific gravity of .D.F.0.	= 900 kg/m^3
Specific heat of D.F.O.	= 1.82KJ/kg°C
Viscosity of diesel fuel oil	-5-15 cst at 20°C

Other parameters of the tug boat

Length of Boat	-	28m
Breadth of Boat	-	9m
Moulded depth of Boat	-	4.5m
Gross Tonnage	-	180
Net Tonnage	-	55

4.1 Total energy (Heat) input in Engine (Q_F)

The total energy input in main engine can be obtained from the relation

$$Q_F = \frac{SFC \ x \ LCV \ x \ MCR}{3600} \quad (1)$$

Where:-

SFC – Specific fuel consumption = 0.2 Kg/KWhr

LCV – Lower calorific value = 41,399
MCR – Maximum continuous rating = 1800 rpm
By simple substitution into equation 1

$$Q_F = 4140\ KW$$

4.2 Shaft Power Output (SPO)
The shaft power output could be obtained from the brake power and the gear efficiency

$$SPO = B_P\ x\ \eta_G \quad (2)$$

Where:-
SPO - Shaft Power Output
B_P – Brake Power output = 995 KW
η_G – Gear efficiency = 0.96 – 0.98
By Simple substitution into equation 2

$$SPO = 955\ KW$$

The calculation of the size of pipes are based on the classification regulation as in

4.3 Capacity of Air Receivers
The capacity of the starting (compressed) air receiver for the air system may be calculated from the formula given by the GERMANISCHER LLOYD

$$J = \frac{a}{(D+s)}\ x\ \frac{V_s}{(p-a)}\ x\ 3\sqrt{z}\ x\ a\ x\ c\ x\ d \quad (3)$$

Where:

J	=	Total capacity of starting air receivers
a	=	$\frac{4300}{D}$ + 5000 for two-stroke engine
a	=	$\frac{3500}{D}$ + 2500 for four-stroke engine
V_s	=	Piston displacement (swept volume of one cylinder)
D_c	=	Cylinder diameter, cm
s	=	Piston stroke, cm
p	=	Maximum pressure in receiver assume 30 bar
z	=	Number of cylinders
b	=	coefficient
	=	1.0 for two-stroke engine and P_e < bar
	=	$\frac{Pe}{5.3}$ - 0.3

For supercharged two stroke engine P_e > 7 – 10bar stroke

	=	1.0 for four-stroke engine, $P_e \leq$ 10 bar
	=	$\frac{Pe}{5.6}$ - 0.8

For supercharged two stroke engine P_e > 10– 15bar stroke

In all the cases when the mean effective pressure P_e = 10 bar for two stroke engines and P_e > 15 bar for four-stroke engines b = 1.0

CP	=	Coefficient depending on propulsion system.
Cps	=	1 for single propeller and one main engine (direct or indirect drive)
Cps	=	2 for single propeller and two geared main engine without disconnecting Clutches.
Cps	=	1.5 for two propeller and two main engine (direct or indirect drives)
Cps	=	1.5 for single propeller and two geared main engine with disconnecting Clutches.
d	=	Coefficient depending on maximum pressure of starting air
d	=	1 when Pmax ≤ 30 bar
d	=	Pmax when Pmas > 30 bar

For diesel – electric drive the coefficient “Cps” depends on the number of main diesel-electric sets “n”.

Table 1: Values of C_L and n

n	1	2	3	4	5	6	7	8
C_L	0.3	0.6	0.84	1.06	1.26	1.38	1.44	1.50

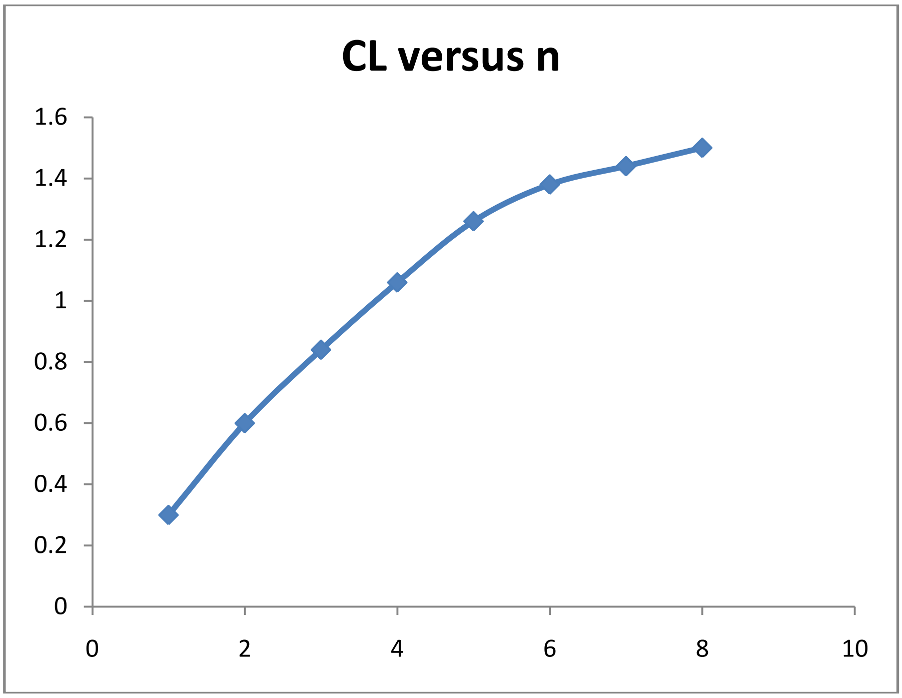

Figure 2: Graph of C_L verses n

NOTE: The required capacity of compressed air receivers and air bottles may also be evaluated from

$$V = (2.5\ to\ 3)\frac{\pi D^2}{4}\ x\ S\ xL\ x\ n\ x\frac{P_b}{P_{max} - P_{min}}\ (m^3) \quad (4)$$

Where:

V = Total capacity air receiver (m^3)
D_c = Cylinder diameter, m
s = Piston stroke, m
i = number of cylinders
n = number of starting operations
P_b = barometric pressure
P_{max} = Maximum pressure in air receiver
P_{min} = Minimum pressure in air receiver

Obtained values

P_b = 1 bar
P_{max} = 30 bar
P_{min} = 10 bar
D_c = 168mm = 0.168m
S = 200mm = 0.200m
i = 16
n = 16

By substitution into equation 4

V = $0.1703m^3$
= 170.3 liters

Therefore chosen capacity of air receiver is 200 liters each bottle

$\therefore V_T = 400$ liter = $0.400m^3$

From the manual / emergency air compressor the capacity of the air should be for one starting operation

$$V_E = \frac{V}{16} \quad (5)$$

By substitution into equation 5

$$V_E = 25\ liters$$

4.4 Capacity of Air Compressors

The capacity of air compressor may be calculated from the formula

$$Q = \frac{V}{t}\ x\ \frac{P_{max} - P_{min}}{P_b} \quad (6)$$

Where:

Q = Total required capacity of air compressors (m^3/hr)

V = Total capacity of air receiver calculated

L = time (filling recharging)

Obtained Values

Q = ?

V = 400 liters = $0.4m^3$

t = ¼ hrs = 15min. = 900 sec.

P_{max} = 30 bar

P_{max} = 10 bar

P_h = 1 bar

By substitution into equation 6

Q = $32m^3$/hr

Chosen total required capacity of air compressor is $35m^3$/hr for each compressor.

4.5 Power output of Compressor

The formula for the power output of a compressor is given by

$$P = n\left(\frac{K-1}{K}\right) P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} - 1\right] \quad (7)$$

Where:

P = power output

n = number of compression stages (2 stages)

K = Adiabatic index (K = 1.4 for air)

P_1 = Initial gas pressure = 1 bar

P_2 = discharge gas pressure = 3 bar

V_1 = volume flow rate

V_1 = $\frac{35\ x\ 2}{3600}\ m^3/s$

= $0.019m^3$/S

By simple substitution into equation 7

P = 19668.584 W = 19.7KW

V. RESULTS AND DISCUSSION

The starting air system is designed for starting Diesel engines (that is main engines and auxiliary engines). It is used to operate pneumatic devices, control air during maneuvering, monitor condition of systems onboard the vessel and other auxiliary purposes. The system consist of the tanks (storage), pumps, compressor, strainers, coolers, piping, valves, and fittings, purifier, sub system and condition monitoring devices amongst others. The starting air system receiver capacity of a tug boat whose transmitting power of 955KW is calculated to 200 liters for each bottle and the emergency air receiver bottle is estimated at 25 liters from the formula given by Germanischer Lloyd. The compressor capacity for this size of tug boat is calculated to be $35m^3/hr$ for each compressor and the Power output of the compressor is estimated to be about 20KW. Keeping in mind the piping systems and safety of the overall air system. The trend of the graph in figure 2 gives a clear indication that the said design process met the international standard for the design of the starting air system of a tug boat.

VI. CONCLUSION

The compressed air is a form of energy that is safe and free from hazard like fire, electric or high pressure hazards. Air is surplus all over the earth atmosphere and around us, when a little work is done on it, serves a lot of purposes onboard the vessel. The compressed air on motor ships can be used for starting Diesel engines, for general service to operate pneumatic devices on board the vessel, use to control air during maneuvering of the main engine, use for air instruments to monitor condition of systems in the engine room in particular and the vessel in general and use of horns, releasing of hooks etc. Hence the design of compressed air system is very important. The compressed air is stored in a bottle or reservoir, whose capacity is designed to be 200 liters each, which is sufficient to provide not less than twelve consecutive starts of each main engine for the reversible type and not less than six consecutive start for the non-reversible type. The compressor capacity ranges in driving motor output is about 20KW. It is important to know that for starting engines this depends on the size of the vessel and the output power of the engine.

REFERENCES

[1]. Urbanski P, Nierojewski K and Douglas I.E. (1983), Methodology for Determining the Main Characteristics of Auxiliary Machines in Marine Diesel Power Plant. Department of Marine Engineering, Rivers State University of Science and Technology Port Harcourt.

[2]. Nitonye, Samson (2017), Design Calculations for equipment and components specification for Lubricating oil System of a Tug Boat. International Journal of Advances in Engineering and Technology, Vol. 10, No 3, 449-462. http:/ doi.10.7323/ijaet/V10_iss3/ www.ijaet.org

[3]. International Maritime Organization |Maritime Environment (2014). Retrieved from International Maritime Organization website: http://www.imo.org/OurWork/ Environment [Accessed 20 January, 2014].

[4]. Caterpillar Engine Division (1990), Caterpillar Marine Engines Application and Installation Guide, Printed in USA

[5]. Detroit Engine Division (1990), Detroit Diesel Engines Manuel (Series 149), Printed in Holland

[6]. General Cargo ship (2016), Ballast Water Retrofitting - Impartial Resources & Advice, Available online http://generalcargoship.com/bilge-systems-layout.html (20th June 2017)

[7]. Machinery Spaces (2015), Starting Air System For Diesel Engine – How It Work available online http://www.machineryspaces.com/cooling.html 20th June 2017

[8]. Lloyd's Register of shipping (1976), Lloyd's Rules and Regulations for the Construction and Classification of Steel Ships. Lloyds' Publisher

[9]. Roy L. Harrington, (1976), Marine Engineering. The Society of Naval Architect and Marine Engineering

[10]. Ogbonnaya, E.A., Orji, J.C., Ugwu, H.U., Poku R., and Samson, N. (2014). Condition Monitoring and Fault Diagnosis of a Steam Boiler Feed Pump. International research journal in Engineering, Science and Technology,(IREJEST) Nigeria 11 (1), 13-21 (http://www.irejest.org)

[11]. Nitonye Samson, (2015). Stress and Resistance Analysis for the Design of a Work Barge, International Journal of Scientific and Engineering Research, (IJSER) India Vol.6 No: 5, (pn-1064974) (http://www.ijser.org)

[12]. Nitonye Samson**.**, Ogbonnaya, E. A., & Ejabefio, K. (2013). Stability analysis for the design of 5000-tonnes Offshore Work Barge. International Journal of Engineering and Technology, 3 (9), 849-857. (http://www.ijet.journal.org)

[13]. Nitonye, Samson (2017), Numerical Analysis for the Design of the Fuel System of a Sea Going Tug Boat in the Niger Delta. World Journal of Engineering Research and Technology, Vol. 3, No 1, 161-177. http:// www.wjert.org.

Samson Nitonye. "Compressed Air System Design for an Ocean Going Tug Boat in the Tropical Region." International Journal of Research in Engineering and Science (IJRES), vol. 05, no. 12, 2017, pp. 14–22.