Fuel and Emission Reduction in Shipping Industry Based on Low Carbon Economy using Flexible Solar panels and Rotor Sails

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ABSTRACT

The idea is to substitute half the fuel required to run a ship using rotor sails to get energy from the wind and solar panels fit for marine environment to get energy from the sun. The use of rotor sails along with flexible solar panels onboard merchant vessels will help curb the carbon emissions. The temperatures are generally high around 43-45 degrees in a well-ventilated engine room from around 100 degrees of actual temperature. The rest of the heat generated is channelled to the surrounding through the exhausts; instead of dumping this heat to the atmosphere we can reduce the pollution from it by channelizing it for steam formation, to aid in the working of boilers onboard vessels. Installing energy efficient cycles onboard ships for crew to paddle and generate energy and from the mechanical work done and further storing that energy in batteries can aid in the internal lighting systems on the ship.

KEYWORDS: Greenhouse gases (GHGs); Wind Energy groups (WEGs); Energy Efficiency Design Index (EEDI); Deadweight Tonnage (DWT)

INTRODUCTION

Sustainable shipping is recognized as one of biggest challenges of 21st century. It is accepted that whilst shipping is relatively safe and clean, compared with other transport modes, the industry does have a significant impact on the environment. It meets the needs of the present without compromising the ability of the future generations to meet their own needs. It also focuses on lost sustainability, stabilization and subsequent reduction of CO_2 emissions whilst allowing maritime trade to thrive, which currently is only one of the greatest challenges facing the industry.

It consists of three emerging key areas, which are identified by the pillars of sustainability. It is mostly similar to green shipping initiatives. As shipping is a global industry, responsible for the transportation of approximately 90% of world trade, the impacts of increasing pollution and illegal discharges are felt worldwide. Shipping is the key to the world economy for the future populations and economic growth projected by the governing authorities. Nevertheless, shipping is expected to bear its share of the burden and contribute to overall Carbon emission Reduction. This concept may not be palatable to many but it's something the industry needs to be aware of and prepare for. The shipping industry, like all industries faces the challenge of what to do and how to ensure any solution to be effective for maritime trade to flourish. However, shipping is subject to less stringent environmental demands than those placed on land-based transportation businesses even though the sector continues to be responsible for producing large amounts of greenhouse gasses like CO_2. Marine pollution has been the leading issue with the shipping industry since a decade. The International Maritime Organization (IMO) estimates that carbon dioxide emissions from shipping were equal to 2.2% of the global human-made emissions in 2012 and expects them to rise from 50 to 250 percent by 2050 if no actions are taken. The Energy Efficiency Design Index (EEDI) was made mandatory for all new built ships and Ships Energy Efficiency Management Plan (SEEMP) for all existing ships, under the amendments made to MARPOL Annex VI, CHAPTER 4 [I]. As a result of this modern-day shipping faces an enormous challenge, to reduce its fuel Consumption and the Emission of CO_2 to meet the prescribed MARPOL targets.

Therefore, our ideas like wind propulsion could be a popular green initiative throughout the 21st century, particularly at the time of high bunker prices. The potential benefits are obvious; with the promise of reducing the fuel consumption of a ship, the possibility of improved profit margins, a reduced freight rate and reduction in greenhouse emissions. We have considered a Gearless capesize bulk carrier vessel for installation of Rotor Sails and Flexible Solar Panels. Generally, its capacity is between 100,000 and 200,000 Dead Weight Tonnage (DWT). It usually contains 9 holds. Such ships are often described as Capesize, since if they are travelling from Asia to Europe but do not intend to use the Suez Canal, they'll sail around South Africa's Cape of Good Hope. These large Bulk Carriers are gearless, they have no derricks or cranes and depend entirely upon onshore appliances for loading and discharging. This is because in most places where such cargo is handled the terminals have very advanced machinery designed for the quickest possible loading or discharging. Its power requirement is 25-26kW. Therefore, we plan to install Rotor sails on the open deck area of gearless capesize bulk carrier. Rotor Sails are a form of wind energy harnessing system that utilizes the Magnus Effect's phenomenon exhibited by a spinning body in a fluid flow incident upon it. It is this effect that is responsible for the curving flight path of a ball in many sports or the deviations of a spinning artillery shell in a crosswind. It typically comprises a cylinder with an end plate affixed to the top, mounted vertically to the deck of the shop through the action of a motor, the cylinder rotates in the air stream and a lift force is generated that can contribute to the propulsion needs of the ship. It can curtail the fuel consumption by 10-20 % of a running vessel. It reduces the fuel consumption by 8% per Rotor. These are completely independent, almost maintenance free and programmed to work without manual adjusting or any intervention from the crew members. The key advantages are "the plug and play installation", fully automated use, significant savings in Bunker costs and thus relatively short payback period. Therefore, even the older ships can benefit from their use.

Also, Solar Energy is one of the ancient means of renewable energy that has been looked for as a source of power since 1839. The vital role that the sun plays in life on earth has been recognized by nearly every culture of mankind. The Earth receives 174 petawatts (PW) of incoming solar radiation at the upper atmosphere approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. Harnessing this energy can prove to be a vital weapon in tackling the current needs of the world in fighting pollution and cutting down the greenhouse emissions.

The traditional solar panels that are used for shore requirements prove to fail when used onboard due to lack of strength to withstand strong winds and to work in high moisture content levels at sea. Flexible solar panels come into the picture to fix this problem. The use of lightweight polymer films instead of traditional glass covers up the problems faced by the use of crystalline silicon cells. The careful choice of materials and their thickness creates the right balance between protection of thin photovoltaic cells and the creation of a flexible and light casing. We can innovate and deploy the zero-maintenance solar power system onboard a ship. It will be capable of generating 5.4 kW electricity and replacing the ship's traditional 4.4 kW emergency diesel alternators. The solar power generating system can be installed by customizing and installing razor-thin, flexible solar panels on canopy of Helicopter deck (Heli/Helo Deck), poop deck, side deck and upper deck. It'll be light-weight, extra-thin, flexible and unbreakable along with no-fume solid electrolyte batteries. The flexible panels are shade tolerant hence they can work in mostly any light condition. The system is 100% reliable as a power source that can also be used for communication equipment, general lighting onboard and battery charging round the clock with battery outputs during night. The low-cost system will slash a yearly Carbon Emission of 60,225 kg and save around 22,995 liters of diesel used to run the vessel's Emergency diesel Alternator. The cost of generation of electricity using flexible solar panels is Rs 12 per kV/hour. Hence, the estimated savings in 15 years of service life is approximately 1 crore as the existing diesel generator consumes one litre of diesel to generate 5 units. Therefore, it will be one of the most prominent and efficient techniques to curtail carbon emissions.

One of the important ideas of this paper is utilizing the heat generated by the propulsion engine as well as different machineries present in the engine room. The typical temperature in the engine room is around 25-45 degree Celsius, installing inlet and outlet ports at different positions along with forced blowers can help channelize this heat and feed air from the atmosphere to the engine room. We are planning to construct a vacuum chamber in which the channelled heated air would be stored and simultaneously the temperature would be increased by the installation of an air heater inside it. The temperature would be displayed by the heat sensors installed, which would help to control it. The temperature of the heated air will be around 100 degree Celsius which would then be directed towards the sprinkler fitted in a mixing chamber which would take suction from the seawater tank. The sprinkler would sprinkle 10 drops per second which will cause the generation of low-pressure steam. As seawater contains a lot of salt, the precipitate formed after the formation of low-pressure steam will increase and after some time the mixing chamber can be vacated of this precipitate by the ease movements of a single drain system so that the salt can be separated out from the mixing chamber from time to time. The low-pressure steam is then directed towards the condenser which would condense the steam and result in the formation of freshwater.

This freshwater generated would serve as a replacement for the uses of the freshwater generator onboard vessels. It can also be utilized as a feed for boiler water for generation of high-pressure steam. The generated low-pressure steam can also be utilized as accommodation heating during cold climate condition.

The installation of energy efficient cycles onboard merchant vessels to curtail some of the power required for internal lighting of the superstructure of the vessel is the last sub-idea of this paper. A typical machine of such make will generate 0.11kW energy per hour. A general crew allotment of a ship is of around 20 people. An hour of using the machine by each crew member simultaneously would generate 2200 Watts of power. Assuming the internal lighting system to consist of 4 CFL bulbs of 5-Watt rating would consume a total power of 2400 Watts. The energy produced would be stored in batteries and will be utilized in emergency blackout situations as well as for other lighting requirements of the ship.

These are some revolutionary ideas which will help in curtailing the carbon emissions up to maximum extent as per the upcoming regulations of IMO by 2020.

We have incorporated 4 sustainable ideas to help the shipping industry tackle the ongoing rate of Sox emissions. These ideas will not help in completely reducing the pollution caused by the shipping industry, but they surely can contribute a significant effect on the environment and help the maritime fraternity move towards a greener shipping era. The following are the ideas presented by us in this paper:

1. Rotor Sails
2. Flexible Solar Panels
3. Utilization of heat from engine room machineries
4. Energy Efficient Cycles

Flettner rotors

Flettner rotors (FR's) are a form of a wind-based propulsion system that utilizes the Magnus effect shown by a spinning body in a fluid flow incident upon it. A Flettner rotor is a smooth cylinder with disc end plates which is spun along its long axis and as air passes at right angles across it, the magnus effect causes an aerodynamic force to be generated in 3rd dimension. A Flettner Rotor typically comprises of a cylinder with an end plate affixed to it on the top. The rotating cylinder in an airstream generates a lift and a drag force that contributes to the propulsive need of the ship. The rotation to the Flettner Rotor is generally given by an electric motor.

Principle

The principle on which the Flettner Rotor works is that of Magnus Effect. Magnus effect is defined as the generation of a sidewise force on a spinning cylindrical or spherical solid immersed in a fluid (liquid or gas) when there is relative motion between the spinning body and the fluid.

A spinning object moving through a fluid departs from its straight path because of pressure differences that develop in the fluid as a result of velocity changes induced by the spinning body. The Magnus effect is a manifestation of Bernoulli's theorem: fluid pressure decreases at points where the speed of the fluid increases. In the case of a ball spinning through the air, the turning ball drags some of the air around with it. Viewed from the position of the ball, the air is rushing by on all sides. The drag of the side of the ball turning into the air (into the direction the ball is traveling) retards the airflow, whereas on the other side the drag speeds up the airflow. Greater pressure on the side where the airflow is slowed down forces the ball in the direction of the low-pressure region on the opposite side, where a relative increase in airflow occurs.

The force of the Magnus effect can be calculated with the following equation:

$$F_m = S\,(w \times v)$$

Where:

Fm =the Magnus force vector

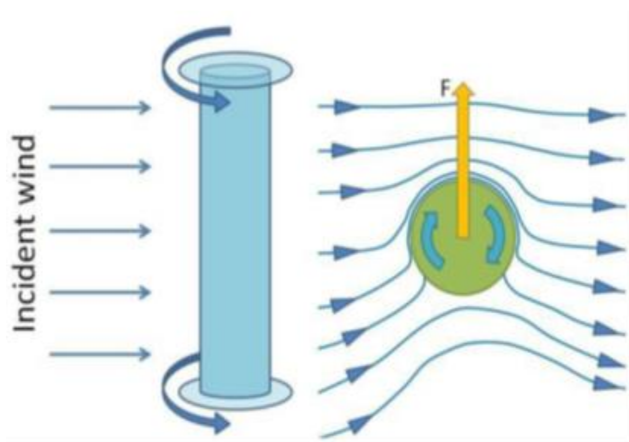
w= angular velocity vector of the object

v=Velocity of the fluid (or velocity of object, depends on perspective)

S= air resistance coefficient across the surface of the object

Once Fm is found we can use the basic kinematic equations to predict the characteristics of spinning objects in flight.

Fig.: Magnus effect applied on Flettner Rotor



Results & discussions

The Flettner rotor is an old technique that consist of one or more number of rotors that will be driven by electrical motor drives. In this study one Flettner rotor of 12.5 m height (*h*) and 2.1 m diameter (*d*) with aspect ratio (ratio of height of rotor to the diameter of rotor) of 6 is used for analysis.

Parameters	Assumed values
Co-efficient of lift *CL*	12.5 [13-15]
Co-efficient of drag *CD*	0.2 [13-15]
Density of air	1.225 Kg/m3
Dynamic viscosity of air	1.789 × 10-5 N-m/s2
Efficiency of ship propulsion	0.75 [12]
Drift angle	Neglected
Bearing friction	Neglected
skin friction coefficient (*cf*)	[17]

FLOW-CHART OF THE POWER-ANALYSIS

1. Input : Wind Parameters Vr (True Wind Speed) and Geometric and Kinetic Parameters Vs (Ship Speed)
2. Determine : Apparent Wind Velocity Va and Direction β
3. Assume Lift Coefficient CL, Drag Coefficient Cd and Coeff. Of rotation, Crot
4. Determine Rotational speed Urot using Crot
5. Determine Lift and drag forces L and D.
6. Determine : Effective Force in Ship Direction Fx
7. Determine : Avg. Skin friction Coefficient Cf
8. Power Consumed by Motors to rotate Flettner Rotor
9. Net Power Output (Pnet) By Flettner Rotors

SYSTEM CONFIGURATION AND FORMULATION OF PROBLEM

The apparent wind speed *Va* depends on the true wind speed *Vt* and the ship speed *Vs* which are known. The calculations have been made for very small drift angle , so *Vs'* coincides *Vs.*

The apparent wind speed *Va* is given by eq.

$V = (V_X{}^2 + V_Y{}^2 - 2V_X V_Y \cos\gamma)$ ^ (1/2)

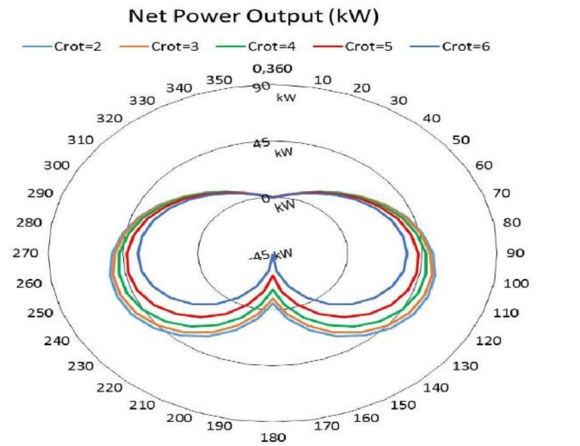
$L_1.I = \rho\ .A\ .V.a..\Gamma$

Where ī is circulation, ī =2ʌȦr^2

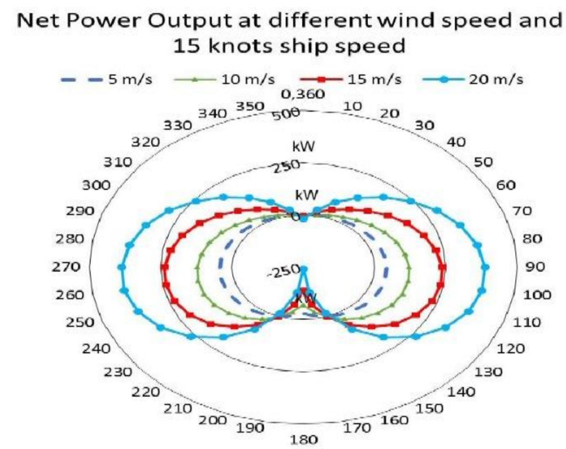
is the angular velocity *r* is the radius of the rotor

The coefficient C_{rot} is introduced as the relationship between rotational speed of rotor U_{rot} and the apparent wind speed V_a.

Effect of Wind Speed variation on power output at 15 knots ship speed when other parameters are kept constant



Effect of Coeffient of Rotation(Crot) on Net Power Output(Pnet):



Outcome on Adoption of Rotor Sails

- At ship speed of 15 knots, net power output of the Flettner rotor system increases as the true wind speed increases. The maximum values of net power output are 42.2 kW, 124 kW, 239.9 kW and 386.7 kW at 5 m/s, 10 m/s, 15 m/s, 20 m/s wind speed respectively.
- For increased value of ship speeds, it gives further higher power. At ship speed of 20 knots, the maximum values of net power are 68.2 kW, 189.5 kW, 358.8 kW and 575.2 kW at 5 m/s, 10 m/s, 15 m/s, and 20 m/s wind speed respectively.
- Net power output of Flettner rotor decreases as coefficient of rotation increases because the power consumed by rotor increases with the increase in the coefficient of rotation.
- Maximum power consumed is 2.3 kW, 7.44 kW, 17.0 kW, 32.29 kW and 54.49 kW corresponding to the coefficient of rotation values of 2, 3, 4, 5 and 6 respectively. Maximum values of net power

generated are 54.62 kW, 52.39 kW, 48.81 kW, 43.23 kW, and 35.96 kW corresponding to the coefficient of rotation values of 2, 3, 4, 5 and 6 respectively.

Net power

The power consumption of a Flettner Rotor was taken to be the sum of the motor power required to overcome the aerodynamic resistance and the resistance from the bearings. Aerodynamic power is calculated by treating the endplate and cylinder as separate entities and summing the required powers. The relevant equation for each is given below:

$$P_{disk} = Cm_{disk} \cdot \rho_{air} \cdot N^3 \cdot R_{disk}^5$$

$$P_{cyl} = \frac{1}{2} \cdot Cm_{cyl} \cdot \pi \cdot \rho_{air} \cdot N^3 \cdot R_{cyl}^4 \cdot L_{cyl}$$

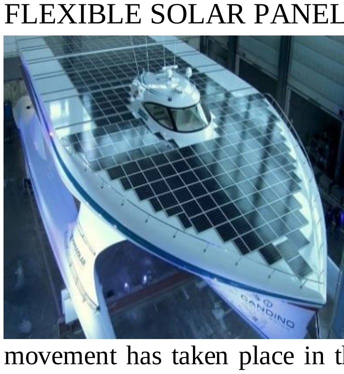
$$P_{bearing} = \frac{k_{bearing} \cdot F_{bearing} \cdot D_{bearing} \cdot N}{2}$$

Conclusion

It can be thus concluded from that Flettner rotors are an alternative supportive propulsion system which are possible to be integrated on existing vessels. It works on the principle of Magnus Effect and taps in the power of wind energy to propel the ship in the desired direction. It consists of rotating cylinders, these cylinders mainly generate forces in the horizontal plane, forward plane and sideway forces. To make sure the seagoing properties of the vessel remains good, it must be prepared and planned because the healing movement influences the stability and the strait of the cylinder foot must be properly supported as it is subjected to high stress. The vessel needs to have a sufficient free deck surface. At the same time no objects should block the accessibility of free wind and operational height limitations must be taken into account. The German wind turbine manufacturer "Enercon" has constructed a new ship the E-Ship 1, which incorporates four large FRs as auxiliary propulsion and has operated successfully at sea in 2013, yet a lot of changes and advancements need to be done.

The range of cost of Flettner Rotor is quite high but with further technological and material science advancements, the Flettner rotor can eradicate the problem of pollution, provide fuel savings and ensure reduction potential from 3-15% on main engine fuel consumption depending on vessel size, segment, operation profile and trading areas.

FLEXIBLE SOLAR PANELS



Introduction

Solar energy is one of the most looked for energy as a source of sustainable unlimited power. The use of silicon based solar panels has increased in the past few years as the nations throughout the world realize the importance of a pollution free environment. The same green movement has taken place in the shipping industry as well. The International Maritime Organization (IMO) has taken the initiative to curb the SOx emissions onboard ships to help limit pollution caused by the diesel engines of merchant vessels. As per the rules laid down by IMO outside an Emission Control Areas (ECA) established to limit the SOx and particulate matter emissions, the fuel oil standard (0.50% m/m) shall become effective on 1 January 2020 and inside an ECA established to limit the SOx and particulate matter emissions, the fuel oil standard (0.10% m/m) has become effective on and after 1 January 2015.

Flexible solar panels

The marine environment makes normal glass made crystalline solar panels of no use due to the high moisture content in air at sea. To counter this flexible solar panels can be used instead of the traditional rigid one's onboard merchant vessels to generate electricity from solar energy. The factors that would influence the working of these flexible solar panels are length, height, weight and thickness. These would influence the power produced by these panels. The construction of panels would be of thin material of monocrystalline cells. Polymers of high strength would be used to make the panels resulting in better durability of the panels. Making the solar panels flexible will provide it resistance to weather and degrading agents such as thermal shock, fog and salt water and hence prove to be a better alternative than traditional glass solar panels

Net energy

The global formula to estimate the electricity generated in output of a photovoltaic system is:

E=A*r*H*PR

E =Energy(kWh)
A =Total solar panel Area (m2)
r = solar panel yield or efficiency (%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

Conclusion

The flexible solar panels provide to be an alternative source of energy for the 2 stroke diesel engines used in a merchant vessel for propulsion. It's an overall low-cost system as only the cost of installation is high after which the panels run with no trouble throughout their lifetime with little to no interference required from the crew members. The low-cost system will slash a yearly Carbon Emission of 60,225 kg and save around 22,995 liters of diesel used to run the vessel's Emergency diesel Alternator. The cost of generation of electricity using flexible solar panels is only Rs 12 per kV/hour, hence the estimated savings by using these instead of the diesel engines all the time are significant in number. It will help curtail the carbon emissions and help merchant vessels to abide by the new rules of Carbon and Sulphur emissions laid down by the International Maritime Organization.

UTILIZATION OF HEAT GENERATED BY DIFFERENT MARINE MACHINERIES PRESENT IN ENGINE ROOM

The heat generated by the propulsion engine as well as the different machineries present in the engine room can be utilized for various steam involved processes. The typical temperatures in the engine room is around 25-45 degree Celsius, installing inlet and outlet ports at different positions and using forced blowers can help channelize this heat and feed air from the atmosphere to the engine room. We are planning to construct a vacuum chamber in which the channeled heated air would be stored and simultaneously the temperature would be increased by the installation of an air heater inside it. The temperature of vacuum chamber would be displayed by the heat sensors installed on the upper region which would help to monitor it. The temperature of heated air will be around 100 degree Celsius which would then be directed towards the sprinkler fitted in a mixing chamber which would take suction from the seawater tank. The sprinkler would sprinkle 10 drops per second which causes the generation of low pressure steam. As seawater contains a lot of salt, the precipitate formed after the formation of low pressure steam will increase and after some time the mixing chamber can be vacated of this precipitate by the ease movements of a single drain system so that salt can be drained out from the mixing chamber from time to time. This drain system will have connection with seawater suction and a regulating valve at starting point of inlet which can be opened from time to time anyone can open the port as per requirement of removal of salt. This will cause again dissolution of accumulated salt in mixing chamber and can be easily drained off. The low-pressure steam is then directed towards the condenser which would condense the steam and result in the formation of freshwater. Furthermore, water released from condenser can be treated through chlorine and required elements to get 100% purity.

This freshwater generated would serve as a replacement for the uses of the freshwater generator onboard vessels. It can also be utilized as a feed for boiler water for generation high pressure steam. The generated low-pressure steam can also be utilized as accommodation heating during the cold times. The high-pressure steam from the boiler then can be used to rotate the turbine and hence provide energy to help propel the ship forward.

ENERGY EFFICIENT CYCLES

The world needs every possible way to substitute the energy from the fossil fuels with a greener form of power generation. The use of energy efficient cycles onboard could help us provide enough energy to at least sustain the internal lighting of the cabins of the crew members for a few hours every day. The usefulness of this apparatus may not seem much but taking off

few hours of fuel requirement for lighting systems every day creates a compounding effect whose results show overall pollution and cost reduction in the long haul. The cycles would work on the basic principle of conversion of mechanical work done to electricity. The basic model of which can be demonstrated by the use of a belt and two pulleys connected to a generator which further is connected to an inverter and a battery. Tweaking certain aspects of this apparatus can help us increase the overall efficiency of these cycles. A typical machine of such make will generate 0.11kW energy per hour. A general crew allotment of a ship is of around 20 people. An hour of using the machine by each crew member simultaneously would generate 2200 Watts of power. Assuming the internal lighting system to consist of 4 CFL bulbs of 5-Watt rating would consume a total power of 2400 Watts. This can help us to substitute the power source of internal lightings of the ship during the day time and hence prove to play a part in the overall pollution reduction by the vessel up to a certain extent.

UPSHOT OF STUDY

The maritime fraternity is in dire need of a green makeover considering the impact the shipping industry has on pollution. Our paper aims to curtail the Carbon and Sulphur emissions onboard merchant vessels in order to make them compatible with the future rules of International Maritime Organization regarding the levels of emission of these gasses. The ideas presented in this paper if implemented can have a positive impact on cutting down SOx and Carbon emissions, clean energy as well as reduce the overall coinage of the shipping companies.

This will help bring on a new era of green ships that are environment friendly as well as being equally efficient in transporting cargo which can result in preservation of marine life and hence build a greener earth. Our goal is to start a green trend in the shipping sector in this world of decreasing fossil fuel resources to make the world a greener and pollution free home to our future generations. Therefore, we emphasize that promotion of green shipping offers a powerful tool to provide opportunities and incentive schemes for policy makers to put a GREEN BEACON at the horizon of 21st century shipping! This paper outlines our current thoughts on policies, technological and operational measures to control carbon emission from ships. This paper also discusses about the Reduction in fuel consumption for marine propulsion and about their prime drivers.

RESULTS AND FINDINGS

We introspected in detail about all the four sustainable ideas that we thought of in our paper. All the four ideas separately may not be able to provide a significant reduction in the Sox emissions but all of them combined and utilized in one green ship can surely make a difference. The rotor sails and flexible solar panels can be used together so that if one fails the other can sustain at least some power to help run the engine of the ship. The energy efficient cycles cannot be used all the time to provide for the lighting onboard, but they can be used as a backup in situations like blackout where there is no power. Energy from the machineries in the engine room can help aid the boiler and hence in freshwater generation helping us cut down the requirement for a separate freshwater generating plant and help us cut costs. Some of the ideas mentioned in this paper area already being thought up by different shipping companies throughout the world in order to tackle the rules laid down by IMO. All the ideas mentioned are practical and can be implemented in helping us save the marine environment, we do agree that some of the ideas in this paper may require a high installation cost, but the overall expenditure of the company will decrease in the long run.

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