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Sustainable shipping through alternate fuels and renewable technology.

Transporte marítimo sostenible a través de combustibles alternativos y tecnología renovable.

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ABSTRACT

The present use of fossil fuels for maritime applications is environmentally disastrous, and calls for decarbonization processes. A shift from existing energy technologies is essential since they prove to be an inefficient methodology toward carbon free environment. This necessitates the need of alternate ideology for achieving the same. Maritime authorities such as International Maritime Organization (IMO) in conjunction with classification societies like Det Norske Veritas (DNV GL), American Bureau of Shipping (ABS), Bureau Veritas (BV), Lloyd's Register (LR) etc. work on various techniques to bring out efficient strategies to create a possible outlook. The 75th session of the Marine Environment Protection Committee (MEPC) of IMO stipulatesa 50% reduction of GHGs, to be achieved by 2050 through sustainable shipping compared to 2008. The latest mandate by regulatory agencies is the stepping stone towards sustainable shipping across the globe. The focus has now deviated to renewable energy alternatives such as solar energy, wind energy, zero emission fuels etc, with the ultimate goal of developing a ship into a sustainable entity, which would not only comply with the new environmental regulations but would also result in least possible carbon emissions. India's first solar ferry Aditya, wind propelled ship developed by Wallenium Marine etc are the leading milestones in sustainable shipping. Along with alternate fuels, efficient design alternatives like cross bow, hull vane, flettner rotor etc contribute to energy efficient operation. Various researches are in progress around the globe to develop more and more efficient technologies to accomplish the targets.

Keywords: Sustainable shipping; Greenhouse gases; Zero emission fuels; Technology

RESUMEN

El uso actual de combustibles fósiles para aplicaciones marítimas es ambientalmente desastroso y requiere procesos de descarbonización. Un cambio de las tecnologías energéticas existentes es esencial, ya que demuestran ser una metodología ineficiente hacia un medio ambiente libre de carbono. Esto requiere la necesidad de una ideología alternativa para lograr lo mismo. Las autoridades marítimas como la Organización Marítima Internacional (OMI) junto con sociedades de clasificación como Det Norske Veritas (DNV GL), American Bureau of Shipping (ABS), Bureau Veritas (BV), Lloyd's Register (LR), etc., trabajan en diversas técnicas para sacar a la luz estrategias eficientes para crear una perspectiva posible. La 75a sesión del Comité de Protección del Medio Marino (MEPC) de la OMI estipula una reducción del 50% de los gases de efecto invernadero, que se logrará para 2050 mediante el transporte marítimo sostenible en comparación con 2008. El último mandato de las agencias reguladoras es el trampolín hacia el transporte marítimo sostenible en todo el mundo. El enfoque ahora se ha desviado hacia alternativas de energía renovable como la energía solar, energía eólica, combustibles de emisión cero, etc., con el objetivo final de convertir un barco en una entidad sostenible, que no solo cumpliría con las nuevas regulaciones ambientales, sino que también resultaría en las menores emisiones de carbono posibles. El primer ferry solar de la India, Aditya, un barco propulsado por viento desarrollado por Wallenium Marine, etc., son los hitos principales en el transporte marítimo sostenible. Junto con los combustibles alternativos, las alternativas de diseño eficientes como el arco transversal, la paleta del casco, el rotor flettner, etc., contribuyen a una operación energéticamente eficiente. Se están realizando varias investigaciones en todo el mundo para desarrollar tecnologías cada vez más eficientes para lograr los objetivos.

Keywords: Transporte marítimo sostenible; Gases de invernadero; Combustibles de emisión cero; Tecnología

INTRODUCTION

International Maritime Organization (IMO), a statutory body under United Nations, regulates commercial shipping across the oceans through mandatory rules and regulations for maritime safety and environmental protection. IMO was established in 1948 and became a mandatory body in 1959. Various regulations are formulated periodically in conventions that are important in improving the maritime world creating milestones in the economic development of the nations. The marine environment is highly polluted, which requires improved safety and protection norms. The major problem faced by the maritime sector at present is its contribution of 2.6% of global carbon dioxide emission (which is around 971 million tonnes annually). In 2018 IMO set a goal of achieving a minimum of40% reduction of Carbon Dioxide (CO_2) by 2030 and a 70% reduction by 2050, contributing to the overall reduction of GHG emission by a minimum of 50% [1][2]. The goals cannot be reached with the existing maritime technologies, which necessitates the introduction of Green Shipping. The advanced technologies that are capable of achieving decarbonization, including low or zero-emission fuel, renewable energy techniques etc. are important. Numerous researches are going on in different parts of the globe to achieve IMO's 2050 goal. The requirements for the reduction of emissions from ships and energy efficiency of the ship come under the Annex VI of "The International Convention for the Prevention of Pollution from Ships (MARPOL)". Annex VI was amended in 2011 which mandates the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) from 2013. These initiatives have a major focus on the energy efficiency of the ships which requires a minimum of 10% efficiency from 2015, 20% from 2020 and 30% by 2025 [1]. The 75th session of IMO's Marine Environment Protection Committee (MEPC) concludes for the increased energy efficiency specific type and size of vessels. The Energy Efficiency Design Index (EEDI) expresses the CO_2 emitted per tonnes miles of cargo transportations, which is calculated using the equation framed which gives the value of EEDI in grams of CO2 per tonnes mile. Smaller the EEDI value more efficient the ship. It is verified by the flag administrations at three different stages of production and the vessels satisfying the criteria are certified with International Energy Efficiency Certificate (IEEC). Similarly, vessels of gross tonnage greater than 400 should keep SEEMP on board. SEEMP is not a set of rules for operation instead it evolves in terms of better energy efficient mitigations. The improvisation of SEEMP depends on the various parties related to shipping like port operator, shipyard, seafarers, ship owners etc. This includes the documents regarding the regular maintenance of the machinery, voyage plan and schedule, investments in clean ship and energy efficiency technologies etc. SEEMP is a four-stage approach as follows, PLAN> DO > CHECK > ACT. Even though some measures to reach IMO's 2050 goals are attained, there exist some significant barriers still to be addressed such as NO_x and SO_x emissions. The various technologies like alternate fuels (low or zero-emission fuels) such as Ammonia, Hydrogen, Methanol, LNG, LPG, biofuels etc, along with the renewable technologies such as wind-assisted sail, solar, Flettner rotor etc with a few efficient design methods are analysed in this paper.

COMMON FUELS

Conventionally used bunker fuels are lower grades of fossil fuels obtained from petroleum distillation. These fuels are divided into six types, namely, MGO (Marine Gas Oil), MDO (Marine Diesel Oil), IFO (Intermediate Fuel Oil), HFO (Heavy Fuel Oil), NSFO (Navy Special Fuel Oil), and MFO (Marine Fuel Oil). MGO belongs to Grade 2 of fuel oil out of six grades which contain lighter particles only. With less production of sulphur, they are mainly used in ship's auxiliary units. MDO is a jumble of MGO and HFO with more content of gas oil and low viscosity. It belongs to Grade 3 of fuel oil. IFO, corresponding to Grade 4 of fuel oil, is also a mixture of MGO and HFO with low gas oil. Both MDO and IFO share similar properties like high density and are used in smaller mediumto high-speed marine engines and auxiliary units. HFO belongs to Grade 5 and Grade 6 of fuel oil, which purely contains heavier particles with high viscosity and density. Based on the amount of sulphur content, HFO is categorized into three, namely, High Sulphur Fuel Oil (3.5%), Low Sulphur Fuel Oil(1%), and Ultra Low Sulphur Fuel Oil(0.5%) [1][3]. The cost of the fuel oil decreases with an increase in the grade of the fuel oil. Hence, the cheapest fuel HFO is most widely used bunker fuel. But, the burning of these fuels emits Carbondioxide (CO_2), Sulphur Oxide (SO_X), Nitrogen Oxide (NO_X) and other organic compounds that are harmful to the environment and ecosystem. The CO_2 emissions from ships contribute to 2.5% of planetary CO_2 emissions which will lead to climate change as well as air pollution by depleting the ozone layer. On that account, IMO adopted few regulations to control GHGs and SO_X emissions which nurture the use of alternate renewable energy sources like solar, wind, etc...

ALTERNATE FUELS

In the current scenario, reduced Green House Gases (GHGs) emissions become the primary goal for the maritime industry. The best method for emission reduction is replacing conventional fuels like heavy fuels with an abundance of carbon content. This leads the path for the introduction of a new term "Alternate Fuels" which is the fuel with minimal emissions. Alternate fuels include Ammonia, Liquified Petroleum Gas, Liquified Natural Gas, Hydrogen, Methanol, or Biofuels.

AMMONIA: Ammonia is a compound of hydrogen and nitrogen that exist in the form of colourless pungent odour gas with a boiling point around -33°C. It is in liquid form at moderate pressure and room temperature. Ammonia is generally used for manufacturing fertilizers and even used directly in some part of America. Due to the zero-carbon content, ammonia can have significant advantages as a marine fuel. The Haber-Bosch process is a widely used method for the production of ammonia. Based on the feed-stock, ammonia can be classified as Green, Blue and Brown [1]. Brown ammonia is produced from fossil sources such as natural gas and coal from which nitrogen and hydrogen gas are formed which are combined under high pressure and elevated temperature. The burning of fossil sources emits carbon dioxide and other gases which create a negative impact on the final product. Similar is the case of blue ammonia but this includes a carbon capture system that absorbs the carbon emission to a certain level. Green ammonia is produced from renewable electricity and is labelled as zero CO_2 emitting ammonia. It is less dense than air and is much easier to be stored than hydrogen, which is identical to propane (LPG).Ammonia being low energy content fuel, a large volume of storage is required compared to LPG and MGO provide the same power. However, the toxic nature of ammonia is its major drawback. Exposure to ammonia can cause serious health issues like damages to lunges or even death, so different organizations prescribe a certain amount of exposure to ammonia in case of accidents or leakage. Because of this drawback, special safety measures have to be implemented to prevent leakage of the gas and crews are to be trained for the same.Ammonia is reactive to various elements; it limits the materials that can be used in the construction of the tanks and has to follow the International Code of the Construction and Equipment of Ships carrying Liquified Gases in Bulks (IGC code) [1][2]. Technologies are needed to produce energy from ammonia. Research is in progress for developing spark-ignited engines and combustion ignited engines with ammonia as fuel. The lower flame speed and narrow flammability may lead to unburnt ammonia in the exhaust which is toxic, and measures like ammonia captures or SCR are to implement to remove unburned ammonia. Piolet fuels are required to improve the combustion in the engines and produce the required power output with minimal emission.

LIQUIFIED NATURAL GAS (LNG): LNG is mainly methane, the smallest hydrocarbon with a single carbon atom, and has the maximum potential for a reduced carbon footprint. LNG is widely used as marine fuel in the current scenario due to its reduced emissions and low price compared to heavy fuel oils and is known to be the cleanest burning fossil-based fuel currently available. The emission reduction depends on the technology of the engines used and varies based on the methane slip and NO_X. As a fuel, it also achieves reduced SO_X and CO_2 emissions and suggests an efficiency of about 20-24%. LNG alone cannot achieve the IMO's 2050 target, it requires additional technologies but has the potential to play a significant role. The majority of the LNG propelled vessels use Dual Fuel Diesel Engines (DFDE) for propulsion and power generation. Beyond all the advantages the storage of these fuels has to follow theIGC code with special types of tanks for storing them on board. The density of LNG is half the density of HFOs but the calorific value is 20% higher than conventional fuels. The storage tanks require roughly 1.8 times more volume for the same range of transport. Cryogenic tanks with thecapability to hold a temperature below -162°C (boiling point of LNG) and in the liquid state, its volume reduces by 1/600 than in the gaseous state [1]. The tanks, the fuel containment and fuel supply systems consume a large area on board which in turn reduces the space for cargo. So, an efficient general arrangement is essential for the proper enclosure of all the related elements. Major risks in carrying such fuels are their accidental leakages, high flammability in gaseous form and brittleness induced in the hull structure and its further weakening. Bunkering facilities are limited due to a lack of safe infrastructure facilities worldwide, and very few ports have the bunkering facility.

METHANOL: It is an abundantly available chemical of composition CH_3OH which are widely used in chemical industrial applications. Methanol is also known as methyl alcohol (or pure alcohol) and is a colourless and tasteless liquid at ambient temperature and pressure. It can be produced from various feedstocks such as natural gas, biomass, and renewable energy sources and the rate of emission depends purely on the source. Reduced CO_2, NO_X emissions and zero sulphur content of methanol pave the way for its application as a marine fuel. The highest hydrogen-to-carbon relation of any liquid potentially reduces CO_2 emission from combustion, compared to other fuels. It can be stored in normal fuel tanks with slight modification in the materials since methanol is corrosive to different elements. The energy density and specific density of the methanol is significantly lower compared to conventional fuels which demand a higher volume of fuel storage tanks, roughly 1.5 times higher volume than required for LNG. Since methanol is a low flash point fuel, certain engine technologies like high-pressure injection, pilot fuel in dual fuel dieselengines etc and has to satisfy the International Code of Safety for Ships using Gas or other Low -Flashpoint fuels (IGF code) for its use as a marine fuel [2]. There are certain limitations for its application in the maritime sector such as the lack of experience with the characteristics and properties of the methanol which necessitates proper crewing to ensure safety on board. The toxic nature of methanol demands enhanced personal safety standards on board in case of accidents. Exposure to methanol beyond a limit can cause loss of life. Methanol, though flammable does not vaporize like liquified gases and is denser than air. So, leakages will result in the accumulation of fuel in the bilge area, and proper ventilation is to be made available to avoid causalities. The dissolving nature of methanol in water avoids the risk during the spillage and threats to marine life. Hence methanol plays a major role in attaining the 2050 IMO target.

HYDROGEN: It is an abundantly available element in the form of some compounds that need to be separated for its use as fuel. The separated hydrogen is mixed with oxygen in a fuel cell to produce energy. A large percentage of hydrogen is produced from fossil fuels such as natural gas, oil etc. It leads to increased emission during the life cycle even though hydrogen is a clean fuel. Hydrogen the cleanest marine fuel in the sense of its combusted output of NO_X, SO_X and particulate matters, but this can be achieved if hydrogen is produced from renewable sources. There are several methods for the production of hydrogen with nearly zero carbon footprint such as electrolysis power by renewable energy (e.g.: photovoltaic cells), high-temperature water splitting, photobiological water splitting, photoelectrochemical water splitting etc. The barriers in adopting hydrogen as a marine fuel are high initial cost, storage, lack of experience, safety both onshore and offshore, transportation, large scale production etc. Hydrogen is stored as a compressed liquid or gas. Its storage in a liquid state requires less volume of the tank and should withstand cryogenic temperature (-253°C). Leakage in enclosed spaces can cause asphyxiation, so tanks must have the ability to withstand these negatives and hydrogen in contact with structure causes brittleness in steel. Storage of gaseous hydrogen needs much higher volume (roughly 4.1 times) with high-pressure tanks, and the low density makes the storage facility larger and heavier and difficult to accommodate the related arrangements [1]. Power generation from hydrogen can be obtained either by combustion engines or gas turbines or can directly be used as fuel for fuel cells. The bunkering and transportation of hydrogen are risky as the storage due to its leaky nature because of the smallest molecular structure and flammability. It also has an explosive nature. This necessitates the importance of general awareness about the risk of hydrogen as a marine fuel. If these obstacles overcome, hydrogen can be tagged as an emission-free marine fuel, which can contribute a large part in achieving IMO's 2050 goal.

GREEN SHIP TECHNOLOGIES

HULL VANE: Hull Vane is a hydrofoil shaped retrofit positioned astern below the waterline to optimise the propulsive efficiency of a ship by about 26%. It is a patented design that has proven its ability of improved fuel efficiency for ships with a transitional speed range (Froude Number = 0.2 - 0.8). There are four working principles by which hull vane operates they are,

Forward Thrust – produced by the lift force generated due to angled upward flow at the stern (i.e., flow at the stern is not horizontal).

Reduced wave making – the low-pressure region at the top side of the hull vane pulls down the waves thus minimising the stern waves.

Reduced running trim – the vertical component of the lift generated keeps the ship almost in even keel reducing the dynamic trim at various speeds.

Reduced motion in waves – the added resistance generated due to the motion of the ship in waves is deduced by around 30% with reduced pitch, roll, heave, and yaw motions because of the pumping effect (Forward Thrust) [4][5].

Moreover, hull vane reduces the slamming in head sea condition and cause a small effect in turning circle manoeuvre but is acceptable. These are of different types namely, T, U, X type hull vanes.

Fig.1. Hull Vane [11]

CROSS BOW: It is a nature-inspired (water mammals) design mimicked to ships bow resulting in an efficient form than the conventional designs. The inverted or backward sloping bow design provides more displacement volume distribution from the waterline and sectional angle. The tapered fore ship creates a water piercing effect with uniform distribution of force across the surface [6]. The nature-inspired design improves the efficiency of the ship since it uses less fuel for the motion through waves. This has significant advantages on marine life and the environment because of its reduced noise and emissions, causing fewer threats to aquatic life and helps in achieving IMO's 2050 goals. Beyond these positives, the design reduces the pitch motion in rough sea ensuring the safety and comfort of the passengers and crews enabling their works to be carried out effectively with minimal distractions. Since this bow shape splits the water on entering after emergence imposes fewer vibrations on the hull structure assuring the safety of the vessel. Thus X-bow design proves to be more productive than any other bow shapes.

Fig. 2. Cross Bow[12]

AXE BOW: The axe bow is a type of wave-piercing bow where the stem is a vertical, narrow entity, resembling the shape of the axe. Because of the deep forefoot not raising above the waterline, there is less chance of slamming. The bow may need more rudder action to hold the vessel in course. The key feature of this bow is the weight distribution. Weight being focused in the aft, a huge moment arm is presented. With the thin bow, longer vessels are capable to withstand the wave slope way before the bulk of the vessel weight encounters the wave [6].

Damen Shipyard Group adopted and expanded this concept with a few more features of the axe bow. This Axe shaped bow suitable for small vessels and provide a linear as well as a predictable response to the wave and a reduction in the pitch acceleration.

Fig. 3. Axe Bow [13]

SOLAR ENERGY: One of the most abundantly available sources of renewable energy is solar energy. Generation of electricity from solar energy is based on the principle of the photoelectric effect by using solar panels or photovoltaic cells. A photovoltaic cell contains two different semiconductors with varying electric potential. When sunlight strikes on the surface of this cell, electrons flow between the semiconductors and feeds power to the load. Multiple photovoltaic cells together produce large quantities of power that can run large machinery. In the maritime sector, the solar power production system is generally used by yachts, recreational vessels, ferries etc. For ocean going ships, higher power requirements and lesser area for installation of solar panels are challenging for solar power production. A hybrid system by combining both solar energy and wind energy will be more satisfactory for large vessels [3].

Fig. 4. Solar Powered Boat [14]

WING SAIL: Sails were the primary source of propulsion for the ship for more than 2000 years. With the increasing use of fossil fuels and carbon emissions, use of the sail is to be again considered for reducing fossil fuels. During the 19th century, a clipper ship known as Cutty Sark could propel at a speed of 15 knots at favourable wind conditions. Onboard a vessel, by installing wing sails, the objective is to improve the aerodynamic efficiency of the vessel by reducing drag and creating lift forces to reduce resistance. The asymmetric (hydrofoil) design of the wings causes a difference in the speed of the air around it, resulting in a higher and lower pressure combination that causes lift. Here, drag is the force that acts against the ship movement. Lift is the force acting at right angles to the direction of the drag. Thrust is the force required to overcome the drag [7]. There are three different types of sails, soft sail, made of light materials that flexes due to wind force, rigid sail which is made of material that does not deform due to wind force and hybrid sail combining the properties of soft and rigid sail.

Fig. 5. Wing sail [5]

The calculation based on the amount of fuel saved varies greatly depending on factors such as the total surface area of the sail, type of sail and the state of the wind. Fuel efficiency is estimated to be about 8-10% in ship fitted with wing sail. This could lead to a reduction in CO_2 emissions of about 77 tonnes, which in turn would lead to a reduction in operational costs. It is pertinent to note that stability aspects require more in-depth research, but in some ships, it has shown some improvement. In the vessel named Usuki Pioneer, approximately 30 per cent of fuel savings were estimated.

FLETTNER ROTOR: Flettner rotors are rotating cylinders that use the Magnus effect to produce lift when they are kept in a fluid stream. The idea was given by a German engineer who studied the efficiency of rotating cylinders as propulsion of a ship in the 1920s. When a spinning object is kept in a fluid stream, the flow accelerates on one side of the rotor and decelerates on the other side which would create a change in the speed of the wind flow resulting in apressure difference which in turn creates a lift force perpendicular to the fluid flow. There are certain factors to consider when setting up such enormous structures. The initial factors to be considered for installations of FRs are sufficient deck space, strong mounting points, clearance from adjacent structures etc.

Fig. 6. Rotor sail [16]

Yet another important aspect is to ensure that the FRs do not obstruct cargo loading and unloading due to their height. Wind speed and sea state must be considered because rotors are most effective between Beaufort conditions 3 to 8. The rotor suits best for vessels operating at a slower speed with an open deck. The most significant benefits of FRs are fuel savings and the reduction of greenhouse gas emissions. Nearly 10% fuel efficiency can be achieved by installing 2 large rotors. Maersk Pelican became the first tanker to be installed with wind-assisted technology [8][9].

MAGNETO HYDRODYNAMICS: MHD abbreviates "Magneto Hydro Dynamic" is an existing technique, but a new concept in the marine propulsion applications. The concept enables a propeller less propulsion by producing a Lorentz force (electric-magnetic force)to the conducting fluid in motion through the propulsion channel using the interaction of the applied magnetic and the electric fields. The produced force thrusts the vessel forward. MHD can be explained best as; a system that can move electricity conducting fluid without any moving parts. The ions that generally take part in the conduction are sodium and magnesium salts present in seawater. This system works by accelerating these ions on passing through the propulsion channel by imposing a thrust force on them, i.e., the acceleration of particles depends on the salinity of the water that varies from place to place on earth. When the conducting fluid gets charged with an electric load it becomes controllable by magnetism thus speed could be built up and be converted to pressure i.e., a pump action is created, reversing the matter creates electric current. MHD can be used in two different ways to propel the vessel either as main propulsion system or as secondary system supporting the main. Using MHD as main propulsion system requires large amount of power supply which may always not possible, but is efficient on its role of a supporting secondary system during long voyages. The propulsion speed depends on the power of magnetic force field and electric power running through the electrodes and the efficiency is directly proportional to speed. Due to the fact that ions are required to conduct, this system fails in fresh water since it contains less than 0.05% ions. The MHD system requires very limited space for setup increasing the cargo space and by reducing the weight of the vessel. MHD is also capable of contributing to IMO's 2050 target with reduced emission about an average of 30%. The major drawbacks of MHD are the higher initial setting up cost, lack of experience on the working and knowledge, and cannot be installed in existing ships[10].

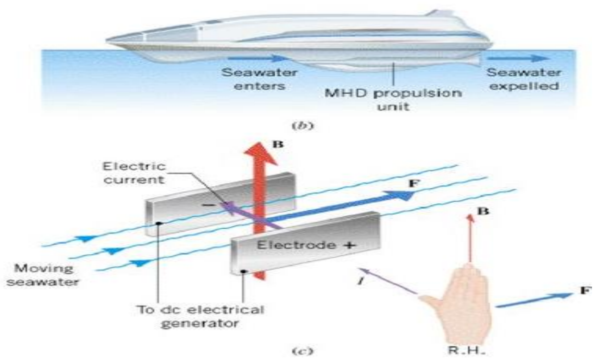

Fig. 7. MHD Propulsion System [17]

As conclusion, according to the reports of IMO's third Greenhouse gas study conducted from 2007-2012, the annual carbon dioxide emission from international shipping contributed around 2.6% to global emission, and is predicted to increase to 70% by 2030. This demands the reduction in the annual CO2 emission. The design of carbon free ships needed by 2030, demands technologies that go far beyond the current state of the art. Carbon-neutral or near-zero-carbon fuels, renewable energy, slow steaming and design optimization contribute greatly to the decarbonization of maritime industry. The operating profile of a vessel plays an important role in deciding the technologies to be implemented without compromising the intended function. Safety, time and cost limits the adoption of these technologies in sustainable shipping in the current scenario. Various researches are progressing around the globe to efficiently implement latest technologies to overcome its hindrance. Among the mentioned technologies solar energy and magneto hydrodynamics are unpatented, so they can be subjected to further researches and development.

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