PRESENT AND FUTURE OF RENEWABLE ENERGY SOURCES ONBOARD SHIPS. CASE STUDY: SOLAR – THERMAL SYSTEMS

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Abstract: *In recent years, sustainability in a climate and an environmental perspective has become an issue of highest priority. This is an agenda that cannot and should not be ignored. The financial crisis has revealed a vulnerable global society. Fortunately, the latest developments have shown signs of recovery thanks to deliberate and well-coordinated global political actions which have created new confidence among companies and consumers. This political commitment can be seen as recognition that global production and trade create wealth for all of us, with shipping and associated maritime industries as the primary enablers. In order to keep focus on the important agenda of sustainable and green shipping attention must turn towards innovation and efficient regulation. Nowadays, shipping industry is dependent on fossil fuels. As oil price is constantly increasing, solutions must be found in order to ensure industry sustainability. Developing and implementing energy efficient and environmentally friendly technologies for energy production and propulsion of the ship will conduct to a valid non – fossil future. In this context, present paper makes a review of alternative sources of energy used in shipping and also reveals concepts of future ships. The novelty is represented by authors vision regarding implementing solar thermal systems onboard, in order to comply with thermal need of the ship.*
Keywords*: shipping industry, renewable energy, solar thermal*

INTRODUCTION

Approximately 80% of world trade by volume is carried by sea [1]. In 2007 international shipping was responsible for approximately 870 million tones of CO_2 emissions, or 2.7% of global anthropogenic CO_2 emissions [2]. Domestic shipping and fishing activity bring these totals to 1050 million tones of CO_2, or 3.3% of global anthropogenic CO_2 emissions. Despite the undoubted CO_2 efficiency of shipping in terms of grams of CO_2 emitted per tone-km, it is recognized within the maritime sector that reductions in these totals must be made. Shipping is responsible for a greater percentage share of NOx (37%) and SOx (28%) emissions [3] and recent legislation is aimed at reducing these emissions through the introduction of emission control areas and requirements on newly built marine diesel engines [4]. The base scenarios regarding CO_2 emissions from shipping from 2007 to 2050, modeled by International Maritime Organization (IMO), indicate annual increases of CO_2 emissions in the range 1.9–2.7% with the extreme scenarios predicting changes of 5.2% and - 0.8%, respectively. If global emissions of CO_2 are to be stabilized at a level consistent with a 2°C rise in global average temperature by 2050 it is clear that the shipping sector must find ways to stabilize, or reduce, its emissions - or these projected values will account for 12–18% of all total permissible CO_2 emissions.

The European Union (EU), in the strategy described in [5], marks a turning point in the protection policy against atmospheric pollution from vessels. 42% of the EU's domestic shipping and 90% of its trade with non-European countries is transported by sea. The energy consumption and CO_2 emissions per ton and mile traveled by ship is approximately 25% of fuel consumption by road. Therefore, the EU has established as a fundamental strategic objective the reduction of polluting and greenhouse gas emissions by transferring the transport of goods by road to motorways of the sea. Despite these measures, it is estimated that, by 2020, vessel emissions of sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM2.5) in EU waters will increase by 40%, 50% and 55%, respectively, compared with 2000 levels.

Studies made by the International Council on Clean Transportation [6] and IMO [2] concur on the range of technological and operational strategies available to the current global fleet [7]. In 2010, IMO introduced "Technical measures", "Operational measures" and "Economic instruments" as instruments for reducing CO_2 emissions. IMO also introduced the Energy Efficiency Design Index (EEDI), as the index for evaluating the technical measures [8]. It is expressed in grams of CO_2 per ship's capacity mile, and a smaller EEDI value indicates a more energy - efficient ship design. The far more complex EEDI formula itself may be roughly simplified as: EEDI = CO_2 Emission/Transport Work; broadly then, EEDI may be thought of as a ship's carbon dioxide output divided by its cargo-carrying capacity. From the EEDI equation, it appears that the main categories of EEDI reduction technologies and opportunities include the following:

- Policy issues on shipping logistic;
- Modified hull form (reduction in propulsion resistance);
- Modified propeller (enhanced propulsion efficiency);
- Energy-saving appendages on hull;
- Increase in deadweight capacity by increasing the hull size;
- Use of energy from exhaust heat recovery;
- Use of renewable energy (wind, solar, etc.).

Further on, there are presented some alternative sources of energy used in shipping industry, some innovative solutions identified by researchers and our vision regarding technical solution that is not yet taken into consideration in review literature. These efforts are made for reducing emissions from ships and, as ultimate goal, obtaining a zero emission vessel.

ALTERNATIVE SOURCES OF ENERGY IN SHIPPING

Several alternatives are proposed to reduce or to replace fossil fuels onboard a ship: sails, kites, receive electricity in ports, use of biodiesel, wind turbines, photovoltaic modules and hydrogen fuel cells. They can be used on their own or in conjunction with what are called hybrid systems for power generation onboard a ship. These are green energy generation systems that use renewable or clean energies.

Sails and Kites

The sole function of sails and kites will be to assist the propulsion of the vessel. Both systems, through the use of wind power, will provide savings in the fuel consumed by the ship's main engine.

In 1995, the Danish Department of Environment and Energy subsidized a study by the consultancy firm, Knud E. Hansen A/S, to look into sail propulsion for merchant vessels. As a result, the company between 1995 and 1999 developed a model tanker of 200 m length and 50,000 dwt designed to transport oil products, with sail-assisted propulsion in the form of wing sails. The feasibility studies for this project reached to the following conclusions

[18]: the vessel had an estimated cost increase of 10%; fuel savings varied between 20% and 27% for certain routes, depending on the average speed of the vessel; The ideal market segment for using sails on commercial vessels is long-distance bulk transportation. Fuel consumption is greatly reduced by lowering the vessel's speed.

Kites are a revolutionary system in the area of commercial vessel propulsion and have become more widespread recently. Their efficiency is based on the high altitude at which they operate, where wind speeds are much greater than on the sea surface. The advantages of kites over conventional sails can be summarize as follows: the system can readily generate propulsion power per square meter of sail five times greater than that generated by conventional sails; they can be installed easily and at low cost, in any type of vessel in service; the cost of acquisition, assembly and maintenance is notably lower than that of conventional sails; the effect on the heel of the ship caused by the force applied to the sail surface is minimized with kites, as this force is transmitted to the vessel towing point; they do not interfere with loading and unloading of the ship in port or when going under bridges. This innovation reduces fuel by 15%, reducing also dangerous gases emissions [17].

Biodiesel, wind turbines, photovoltaic solar modules and hydrogen fuel cells

The main function of this group of alternative sources will be to generate electrical power for auxiliary systems, although they will also be able to provide propulsion.

Biodiesel is a fuel derived from biomass for diesel engines. Taking into account that almost all propulsion and power generation systems for merchant ships now consist of diesel engines, it is clear that biodiesel can play a role in this sector. As advantages can be mentioned: significant reduction in the pollutants emitted into the air; it biodegrades in watery solutions, degrading between 85% and 88% in a 28-day period; it can be used in any conventional diesel engine and can be stored in the same tanks as diesel without any additional modifications or investment; the energy balance is positive, with a ratio of 1 (input)/2.5(output). Disadvantages consist in: high production costs, about twice that for diesel oil; market price is higher than that of conventional diesel for ships; it has harmful effects on the environment: destruction of forest and jungles for this type of crop and increased emissions of nitrogen oxides (NO_x); the refueling infrastructure for ships at port is still in the early stages of development; the current production of biodiesel is around 10% of the global market of diesel; problem of space: producing one tone of biodiesel requires three hectares of cropland.

In wind turbines energy from the wind acts on the blades, making a generator spin. This in turn converts rotational mechanical energy into electrical energy [10]. Their characteristics are: use of wind's clean and renewable energy, installation is made on the vessel's open deck and energy production is not continuous owing to the random existence of adequate wind conditions. Their most significant application in vessels is as part of a hybrid energy system, working in combination with hydrogen fuel cells. Thus, the electricity produced by wind turbines will be used to generate hydrogen through the electrolysis of water and this is used to charge the cells.

The most developed wind turbines are those of the Horizontal Axis Wind Turbines (HAWT) type, an excellent method of generating electrical energy. Their application on merchant ships is very attractive considering that the wind force is greater at sea than on land and, hence, a better performance is yielded. The technical feasibility of onboard installation can be analyzed based on their main dimensions: blade diameter, the axis rotation height, base diameter and weight.

Vertical Axis Wind Turbines (VAWT) performs better than HAWTs with air turbulence, changes in wind direction and high-speed winds. Owing to their low altitude they also have less impact on the ship's stability, and this in turn makes their maintenance easier. However, they produce 50% less energy than HAWTs. This means that, to produce similar power, VAWTs are significantly larger than HAWTs and this fact makes them inferior to the latter.

Photovoltaic systems are renewable energy sources with various applications and their implementations in energy production and saving are verified. Installing those systems onto merchant marine vessels could prove to be an efficient way of minimizing fuel costs and simultaneously protecting the environment by reducing significant carbon dioxide emissions.

Feasibility of installing solar collectors onto vessels is considering the payback period from the adopted investment with respect to fuel oil savings. Thus, the two important parameters incorporated for a good parametric analysis are the solar radiation density and the fuel cost. For one square meter of the considered solar modules the peak output power is taken equal to 130W [12]. The payback period of the investment depends greatly on the fuel prices. For a reasonable fuel price annual increase at about 10–15% the estimated payback period varies from 16 to 27 years. The more the fuel oil increases, the methodology reveals that the payback period converges to a minimum of 10 years [11].

One good example of implementing solar modules onboard is PlanetSolar, the biggest solar ship in the world [19]. The 537 m^2 of photovoltaic modules and 6 blocks of lithium-ion battery, a technology that offers maximal power and energy density, enable a navigation time that is unmatched to date.

Another example is Nichioh Maru, a massive roll-on/roll-off coastal transporter ship, equipped with 281 photovoltaic solar modules mounted above deck. Producers, Nissan, state that the ship will lower its fuel bill by 1,400 tons of diesel per year, and lower carbon emissions by 4,200 tons [20].

Hydrogen fuel cells are electrochemical devices that can convert the chemical energy contained in hydrogen into electrical energy, yielding water as the only by-product. They are similar to batteries, except that they are designed to produce electricity continuously, provided that hydrogen and oxygen are supplied from an external source. Batteries, on the other hand, have a limited capacity [9].

Since the infrastructure needed in ports for ships to refuel hydrogen is not even in the design phase, ships carrying hydrogen fuel cells will need a short and medium term means of producing and storing hydrogen onboard. An interesting application on ships is by means of water electrolysis, a process in which electric current passing through water produces a disassociation of its molecules into hydrogen and oxygen. This is a clean hydrogen generation system. The electricity required can be provided using renewable energy, such as wind or solar power (power generation hybrid systems).

Some of advantages of hydrogen fuel cells onboard ship are: high yields result from the process of obtaining electricity (two to three times that of an internal combustion engine); hydrogen stocks are limitless; when operating the hydrogen fuel cell, water is the only waste (this is a zero emission, clean energy); low levels of noise are produced, less than a quarter of those produced by diesel generators; easy to use and maintain, working at low temperatures and having very few moving parts; versatile in that it can be part of hybrid systems in combination with other renewable energies, such as wind, solar or photovoltaic. As disadvantages it can be mentioned: the estimated investment cost to produce a hydrogen fuel cell system is about 6,000 Euros per kW; the technology has not undergone sufficient testing.

PROSPECTS FOR FUTURE

By considering the development of the technologies, we can imagine that future ships will produce less emission of pollutants into atmosphere. However, taking into account the large amount of energy used by a ship, it is obvious that only by design of hybrid systems based on alternative sources of energy there can be reduced environmental impact of shipping industry. Further, there are reviewed some innovative concepts that aim nearly zero emission ships by 2050.

One of these, the Aquarius MRE system will use array of rigid sails and solar modules to form a ship based renewable energy system. On large ships up to twenty rigid sails could be installed whereas on smaller vessels just one or two sails would be needed. The system is not intended to be a ship's primary source of propulsion [22]. Instead, the system is being designed to work alongside other technologies in order to reduce fuel consumption and harmful gas emissions for a variety of ships such as bulk carriers, oil tankers and cargo ships. Depending on the number, size, shape and configuration of the rigid sails it is estimated that the system will reduce vessels annual fuel consumption by up to 20%.

Another concept is developed by Eco Marine Power [22] which is leading a project of an eco-friendly solar vessel specifically designed to operate as a commuter ferry in urban areas. The vessel design is known as Medaka and will be one of the first of a new class of green passenger ferries which will incorporate a range of technologies to minimize fuel consumption and emissions of noxious gases. In addition the ship will use a simplified hybrid electric marine propulsion system that will be easy to maintain and make the overall vessel a cost effective alternative to vessels powered by diesel engines alone. The solar modules mounted on the roof will use a concept which will allow them to be raised or lowered. In normal operation the modules are at a slight angle. It can also be configured to use a variety of power sources in addition to the solar modules such as an LNG or biofuel.

Solar Sailor, an Australian company specializing in renewable energy technologies, it will install its solar and wind power systems on a massive dry cargo ship that could be used to haul iron ore from Australia to China. The equipment is likely to be similar - but on a larger scale - to the zero-emission systems the company has installed on four dual-fuel passenger ferries operated by the Hong Kong Jockey Club. Solar Albatross is a 24 meter 100 passenger carrying catamaran ferry with its stow able SolarSails [23].

Finally, a concept that gathers all the renewable sources available on sea is E/S Orcelle produced by Wallenius Wilhelmsen. The E/S Orcelle will have an optimum cargo capacity of 85,000 m^2 of cargo deck stowage area, roughly equivalent to 14 football fields. This is up to 50% more space than today's modern car carriers, which are capable of transporting 6,500 vehicles. Primary energy sources include solar, wind and wave energy.

The main design considerations include [24]: a) Using the sun, wind and waves to employ multiple energy generators that include fuel cells; b) Optimizing cargo capacity and lowering energy consumption per transported unit; c) Taking into consideration other environmental challenges, such as completely eliminating the problems related to ballast water, thanks to the new hull design.

Solar energy will be utilized through photovoltaic modules located in the vessel's sails. When not in use for wind propulsion, the sails may be tilted, laid down or in other ways directed for maximum solar energy collection. The solar energy will then be transformed into electricity for immediate use, or for storage.

CASE STUDY: SOLAR THERMAL SYSTEM ONBOARD SHIP

As it can be seen from above, the solar thermal solution is not even mentioned as an option when consider alternative sources of energy in shipping. Reviewed literature reveal some concern related to usage of additional thermal energy onboard vessels, especially those which are involved in short maritime transportation [21]. Identified solutions rely mostly in storage of thermal energy produced onshore and transfer to ship before going on sea.

Thermal energy obtained through conversion of solar energy can be used onboard ships in domestic hot water and steam generation processes. In turn, steam is used in firefighting system, ship's heating plant, for heating marine heavy fuel and oil and for heating of fresh water required in starting procedures of main engine.

Research will focused upon reduction of fuel demand used for heating water, oil and marine heavy fuel oil by adapting solar thermal technologies for onboard operation. At this point, there are considered options like plane and vacuum tube collectors. Further is presented a CFD simulation [14] of a tube collector. The study has been carried with the ANSYS CFX using as input values of solar radiation from previous research [13].

The following section presents a study of a stationary solar – thermal collector, in order to assess it's main operational features before considering it's implementation onboard ships.

In order to assess the operational differences between the various exposure angles, there were developed two 3D models of a tube solar collector [25], corresponding to the two tilt angles of 0° and respectively 48°. Turbulent flow is simulated by solving the incompressible Reynolds-averaged Navier-Stokes equations (RANS), based on the finite volume method to build the spatial discretization of the transport equations. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass conservation constraint, or continuity equation, transformed into a pressure-equation. In the case of turbulent flows, additional transport equations for modeled variables are discretized and solved using the same principles. The gradients are computed with an approach based on Gauss's theorem.

Non-orthogonal correction is applied to ensure formal first order accuracy. Second order accurate result can be obtained on a nearly symmetric stencil. Inviscid flux is computed with a piecewise linear reconstruction associated with an upwinding stabilizing procedure which ensures a second order formal accuracy when flux limiter is not applied. Viscous flux is computed with a central difference scheme which guarantees a first order formal accuracy. We have to rely on mesh quality to obtain a second order discretization for the viscous term. Implicit scheme is applied for time discretization. Second order three-level time scheme is employed for time-accurate unsteady computation.

Several turbulence models, ranging from one-equation model to Reynolds stress transport model are implemented in Ansys CFX [16]. Most of the classical linear eddy-viscosity based closures like the Spalart-Allmaras one-equation model, the two-equation k-ω, SST model by Menter [15], for instance are implemented. Wall function is implemented for two-equation turbulence model.

During the simulation were especially observed the radiative heat transfer process, described for a particle of known dimensions d_p, with uniform temperature T_p and emissivity ε_p, by applying the following equation:

$$Q_R = \varepsilon_p \cdot \pi \cdot d_p^2 \cdot (I - \sigma \cdot n^2 \cdot T_p^4) \quad (1)$$

where I is the radiation intensity on the particle surface at the location of the particle, n is the refractive Index of the fluid, and σ is the Stefan-Boltzmann constant. An equivalent amount of heat can be removed from the radiation field.

The solar collector geometry

For developing the 3D geometry used in the simulations, there were chosen an existing solar collector type, with a 1,5 m2 absorbing area, consisting in 30 tubes of 1500 mm long and 47 mm in diameter, disposed at a distance of 20 mm. The storage tank has a volume of 230 liters (figure 1) [26].

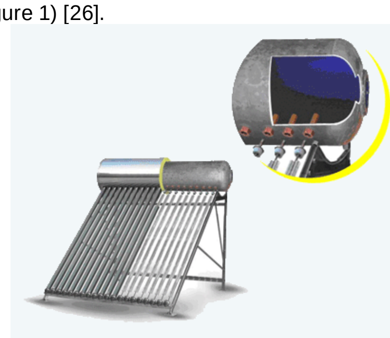
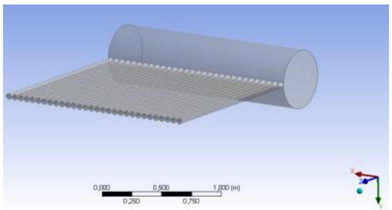
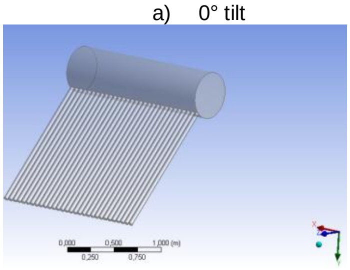


Fig. 1. The arrangement of the tube solar collector [26]



a) 0° tilt

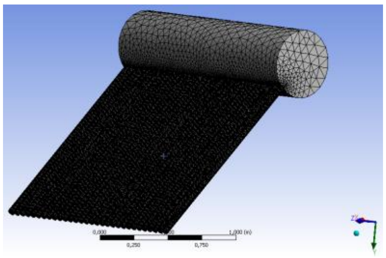


b) 48° tilt

Fig. 2. The 3D models used for the study

Simulation settings

Initially, for developing the simulation, it was developed an unstructured mesh, with 307369 nodes and 1404607 elements (figure 3).



a)

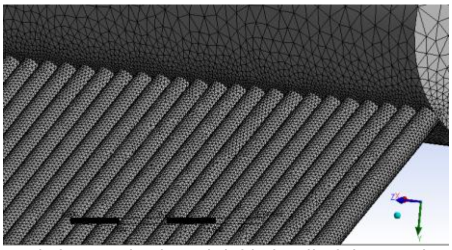


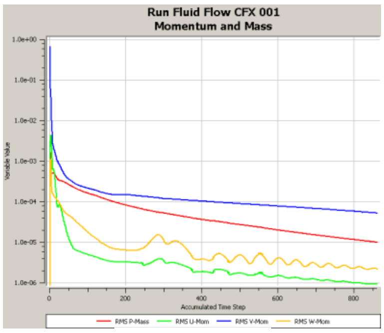
Fig. 3. a) the meshed model; b) detail of the mesh at the intersection between the tubes and the tank

The initial conditions were determined for two tilt angles of 0 and 48 deg. The energy flux used at the boundary conditions is of 156 W/m^2, which corresponds to the radiation value determined as an average for 27th of October, between 10.00 and 13.00 hours [13]. The physics used in the simulation are described in table 1.

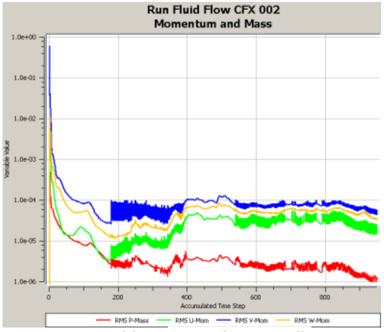
Table 1. Domain Physics

Domain - Default Domain	
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Buoyant
Buoyancy Reference Temperature	1.0000e+01 [C]
Gravity X Component	0.0000e+00 [m s^-2]
Gravity Y Component	9.8100e+00 [m s^-2]
Gravity Z Component	0.0000e+00 [m s^-2]
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Total Energy
Thermal Radiation Model	Rosseland
Spectral Model	Gray
Turbulence Model	SST
Turbulent Wall Functions	Automatic

The settled simulation is a transient study and it was carried for 3600 seconds with a time step of 2 seconds; the chosen time step proved to be a convenient one, since the residuals values were established around the value of 10^{-4} (figure 4).



a) RMS for 0° tilt



b) RMS for 48° tilt

Fig. 4. The residuals development during the simulation

where RMS P-Mass is root mean square of the calculated mass, RMS U-Moment is root mean square of the calculated moment on the Ox axis, RMS V-Moment is root mean square of the calculated moment on the Oy axis and RMS W-Moment is root mean square of the calculated moment on the Oz axis.

Simulation postprocessing

After achieving the results of the simulation, there was determined the peak values for temperatures and fluid velocities in the tubes and the tank for the two selected tilt angles (table 2).

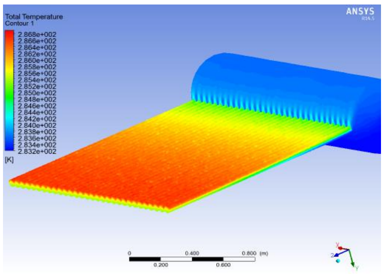
Table 2. Fluid temperatures and velocities by tilt angle

	0 deg	48 deg
Max temperature	2.857e+02 [K]	2.842e+02 [K]
Min temperature	2.833e+02 [K]	2.835e+02 [K]
Max pressure	8.328e-03 [Pa]	5.112e-01 [Pa]
Min pressure	-3.241e-03 [Pa]	-2.770e+00 [Pa]
Max Fluid Velocity	2.247e-03 [m/s]	7.697e-03[m/s]
Min Fluid Velocity	-5.990e-04[m/s]	-6.151e-03[m/s]
Min Fluid Entropy	-2.132e+02 [J/ kg x K]	-2.101e+02 [J/ kg x K]
Max Fluid Entropy	-1.791e+02 [J/ kg x K]	-1.999e+02 [J/ kg x K]

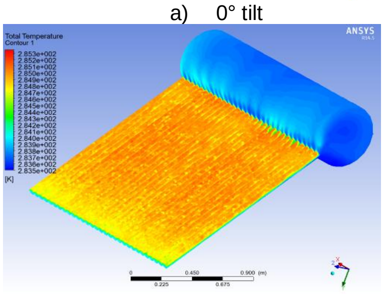
RESULTS AND DISCUSSIONS

By studying the values obtained for the two situations that the maximum temperature in the tank raises with 12,55K in the 0 degrees tilt angle situation and with 11,05K in the 48 degrees tilt angle situation.

When studying the temperature charts in the two situations, it may be seen that in the 0° tilt angle situation, the peak values for the temperature are established at the bottom of the tubes line (figure 5a), while in the 48° angle situation, the temperature fields are more uniform, with peaks established at the intersection between the tubes and the tank (figure 5b)



a) 0° tilt



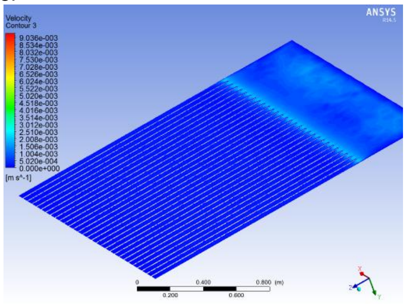
b) 48° tilt

Fig. 5. Temperatures chart for the two considered cases

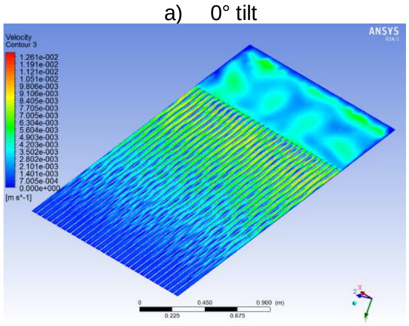
When speaking about the fluid velocities in the system, it can be seen that the natural flow has better qualitative and quantitative parameters for the tilt angle of 48° (figure 6).

It may be observed that the maximum temperature, reached after 1 hour it is higher for the 0° tilt angle is bigger than the temperature reached for the 48° tilt angle. In the same time, if we are looking at the temperatures in tank, it may be observed that the temperature distribution in the figure 5 covers more space, which indicates a better overall exchange system.

At this point it can be concluded that the free flow has a better development in the 48°, when also the flow velocities are higher and evenly spread than in the first case.



a) 0° tilt



b) 48° tilt

Fig. 6. The the velocity chart of the free flow

This situation shows that, at least for the submitted tilt angles, the second solution may be an alternative for increasing the free stream profile.

CONCLUSIONS

The idea of gradually substituting conventional fuels, used in propulsion and power generation for merchant vessels, with alternative solutions that use clean or renewable energies, is becoming a reality driven by two fundamental factors. First, there is an increase in international policy aimed at eliminating the use of polluting fuels in ships, efforts being made especially by IMO. Secondly, the price of these fuels is continuously rising, because of dwindling oil reserves. In search of a "green" ship, alternative solutions identified consists in use of kites, sails, biodiesel, wind turbines (with horizontal or vertical axis), photovoltaic solar modules, hydrogen fuel cells or combined systems.

However, ship-owners are skeptical regarding implementing renewable sources of energy onboard ships, due primarily to high costs associated with these technologies. Efforts must be made, generally by policies and special facilities and benefits, for encouraging development of "greener" ships.

REFERENCES

[1] UNCTAD, 2008. Review of maritime transport. In: Proceedings of the United Nations Conference on Trade and Development, Accra (Ghana).
[2] IMO, 2009. MEPC59 - Second IMO Green House Emission Study. International Maritime Organisation.
[3] AEA Energy & Environment, 2008. Greenhouse gas emissions from shipping: trends, projection and abatement potential. Didcot, Final Report ED43808, Issue 4.
[4] MARPOL, 2005. MARPOL 73/78 revised ANNEX VI, MEPC59. IMO.
[5] Communication from the Commission COM (2002) 595 final The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality
[6] International Council on Clean Transportation. Reducing greenhouse gas emissions from ships: cost effectiveness of available options. Washington: ICCT; 2011.
[7] Nuttall Peter, Newell Alison, Prasad Biman, Veitayaki Joeli, Holland Elisabeth, A review of sustainable sea-transport for Oceania: Providing context for renewable energy shipping for the Pacific, Marine Policy 43 (2014), 283–287
[8] International Maritime Organization, Marine Environment Protection Committee, Interim Guidelines on the voluntary verification of the Energy Efficiency Design Index for new ships, MEPC.1/Circ.682, 2009
[9] European Commission. EUR 20719 EN. Hydrogen Energy and Fuel Cells. A vision of our future. Luxembourg: Office for Official Publications of the European Communities. 2003 – 36 pp. ISBN 92- 894-5589-6.
[10] David A. Spera, editor. Wind turbine technology. Number 0-7918-1205-7. ASME, 1998.
[11] Glykas,A., Papaioannou, G., Perissakis, S. 2010,, Application and cost-benefit analysis of solar hybrid power installation on merchant marine vessels, Ocean Engineering 37, p. 592 -602
[12] Kagaraki, K., 2001. Photovoltaic Technology. Symmetria Publications, ISBN: 978-960-266-183-3, pp. 52–129
[13] Frouin, R., Gauttier, C., Katsaros, K.B., Lind, R.J., 1988, A comparison of satellite and empirical formula techniques for estimating insolation over the oceans, Journal of Applied Meteorology, volume 27, pp. 1016 - 1023
[14] Chung, T.J., 2002, Computational Fluid Dynamics, Cambridge University Press, ISBN 0-521-59416-2
[15] Menter F.R., 1994, Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications, AIAA Journal, Vol.32, pp. 1598-1605
[16] Ansys CFX User Manual
[17] http://www.skysails.info
[18] http://www.ibiblio.org
[19] http://www.planetsolar.org
[20] http://marineinsight.com
[21] ww.quasiturbine.com
[22] http://www.ecomarinepower.com
[23] http://www.sail-world.com
[24] http://www.2wglobal.com
[25] http://www.designworldonline.com
[26] http://www.wksolar.com