Proceedings of MARTEC 2010
The International Conference on Marine Technology
11-12 December 2010, BUET, Dhaka, Bangladesh

AN ENVIRONMENT FRIENDLY METHOD OF DRIVING SHIPS WITH AIR JET PROPULSION

Mohammad Jiaur Rahman

Naval Architect and Marine Engineer
Email: jia011_buet@yahoo.com

ABSTRACT

This paper presents a new method of driving marine vessels with air jet propulsion and thereby reducing green house effect. Air jet can be produced using compressor, which can be passed through pipes or nozzles installed at stern of the ship. Theoretical relationship among the ship speed and other parameters such as compressor pressure, displacement of ship, air inlet velocity etc. has been established. The elastic collision between air particles and water particles doubles the ship speed which is not possible in case of water jet propulsion. The method is applied for calculating speed of a patrol boat and satisfactory result has been obtained. Moreover, CO_2 present in the air jet is dissolved into sea water and thereby reduced green house effect.

Key words: Green house gas, Air jet, ship propulsion, Elastic collision, Joule-Thomson effect.

NOMENCLATURE

A is the cross section area of each pipe or nozzle

d Diameter of pipe or nozzle

n Number of pipes use for passing air jet

h` Depth of pipes from free surface of water

h Distance of compressor centre from datum line

h_o Distance of the centre of pipes from datum line

g Acceleration due to gravity

P Pressure of the compressor

P` Pressure of gas in a compartment

P_o Water pressure (hρ`g) + atmospheric pressure

m Mass of air passing through one pipe per unit time

M is the mass of the ship = Displacement of the ship (Δ)

k Proportional constant

k` Another proportional constant

R_n Reynolds number

V Velocity of air drawn from the out side of the compressor or environment

V_o Air velocity at the end of pipe

V` Velocity of ship which created due to air thrust on ship body

V`` Resultant velocity of ship

$\frac{dv}{dy}$ Velocity gradient.

T Temperature of gas

ρ Density of air

ρ` Density of water

η Viscosity of gas

μ Viscosity of water

1. INTRODUCTION

At present United Nation, European Union and rest of the world try to keep environment free from air pollution. Because the temperature of the world is increasing day by day, due to increase of green house gas e.g. carbon di oxide (CO_2)[1]. Figure 1 & 2 express the increase of CO_2 in atmosphere. Many scientists have reported on global warming and suggested to reduce the use of CFC, carbon di oxide, carbon mono oxide etc [2].

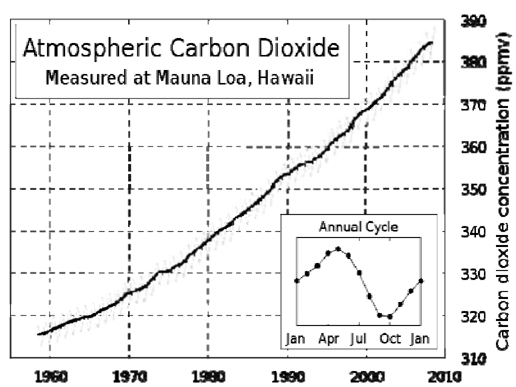

Figure 1: The Keeling Curve of atmospheric CO_2 concentrations measured at Mauna Loa Observatory. [3, 4]

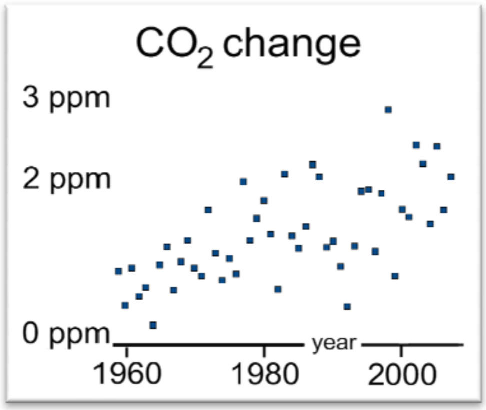

Figure 2: Yearly increase of atmospheric CO_2: In the 1960s, the average annual increase was 37% of the 2000-2007 average. [1]

70% portion of the world is covered by water and therefore, water ways vehicle play very important role on transportation. All these vessels are moved by hydrocarbon (oil, gas etc) which produce carbon di oxide, carbon mono oxide, etc as well as help to increase temperature of the world. The chemical reaction of hydrocarbon is

$$C_x H_y + (x+\frac{y}{4}) O_2 = x CO_2 + \frac{y}{2} H_2O$$

Here, $C_x H_y$ is Hydrocarbon or fuel.

CO_2 is carbon di oxide.

H_2O is Water.

From the above equation it is seen that large quantity of CO_2 is produced from hydrocarbon. Fuel consumption of high speed vessel is relatively higher than low or medium speed vessel. On the other hand high speed vessel has low efficiency due to slip, cavity etc as well as shaft losses occur at time of propeller revolution. All these losses increase fuel consumption i.e. green house gas. But air jet propulsion is free from these losses. If high speed vessel can be run by air jet propulsion, then fuel can be saved. Therefore it helps to decrease green house gas. Now a days many ship designer try to reduce green house gas by design optimization such as hull form optimization to reduce frictional resistance, changing the shape of bridge deck, funnel, wheel house to reduce wind resistance by making aerofoil section and so on [5]. But this optimization is not sufficient to reduce green house gas. From this research it is shown that CO_2 absorption is accelerated by air jet propulsion in sea water.

Sea water absorbs CO_2 and produces carbonic acid with bi carbonate and carbonate ions [6]. This absorption occurs naturally but this absorption increase by air jet propulsion. In this method, air jet is incident on water by compressor pressure and sometimes it is convert into turbulent flow which depends on Reynolds number and Reynolds number define as defined by

$$R_n = \frac{\rho` V_o d}{\mu}$$

Turbulent flow is suitable for mixing any gas (here gas is CO_2) with sea water. This incident of air helps to mix CO_2 with ocean water easily than natural process. In this process CO_2 absorption will be accelerated than natural process. Therefore air jet propulsion help to reduce CO_2 i.e. green house gas from surrounding.

2. MATHEMATICAL ANALYSIS OF AIR JET

In Figure 3 let a compressor or a series of compressor is used to supply air through the n number of pipes installed at the stern of the ship. The cross section area at the end of the pipe is A and pressure P_o [which is atmospheric pressure +h'Þ'g (water pressure)]

The works of the

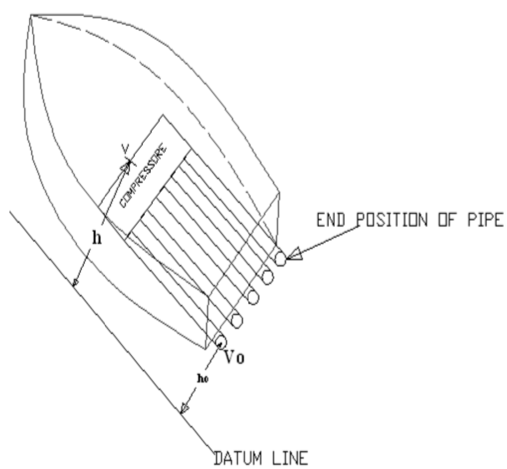

Figure 3: Schematic diagram of a ship and piping system with compressor or series of compressor or a device which can perform according to the proposal of this theory.

Compressor is drawn air from the environment and drive out through the pipes or nozzles with a great velocity V_o. Let the inside pressure of the compressor is P and drawn velocity of air to the compressor from environment is V. The distance of the compressor and the end of the pipe from a datum line are h and h_o respectively. So the mass of the air passes through the each pipe per unit time is $m=\rho AV_o$

The whole mass of the air passes through the n number of pipes is $nm = n\rho AV_o$……… (1).

Applying the equation of continuity at the end of each pipe, then it becomes

$AV_o = k$ ……. (2)

According to Newton`s third law of motion, when air jet is coming out from the stern of ship, it will move forward.

Let the speed and mass (displacement in tonne) of the ship are V` and M respectively. Therefore it can be written from the conservation of momentum

$M V` = nmV_o$

Or, $MV` = \rho AnV_o^2$ [Substituting the value of nm from equation (1)]

Or, $V` = \rho An\, V_o^2/M$ …………………… (3)

In Equation (3) n, ρ, A & M are constants. So the ship speed is directly proportional to the squared of air velocity V_o^2;

i.e. , $V` = k'\, V_o^2$ [where, k' is another constant]

Or $V` \alpha\, V_o^2$

For supplying air jet, there is a need continuous flow of air through compressor and the end of the pipe. So applying the Bernoulli equation [15]

$$\frac{P}{\rho g} + h + \frac{V^2}{2g} = \frac{P_O}{\rho g} + h_o + \frac{V_O 2}{2g}$$

$$V_o = \sqrt{[\frac{2(P - P_O)}{\rho} + 2g(h - h_o) + V^2]} \text{ ……….. (4)}$$

Combining Equations (3) & (4)

$$V` = \frac{n\rho A}{M}[\frac{2(P - P_O)}{\rho} + 2g(h - h_o) + V^2] \text{……. (5)}$$

But Po = atmospheric pressure + h`ρ`g.

This is the air jet velocity which is protruded from end of pipe or end of nozzles. But the collisions between air & water particles are almost elastic collision. Since the mass of water particles are very large than air particles. The density of air and water are respectively 1.293 kg/m³ and 1000 kg/m³ at normal temperature and pressure.

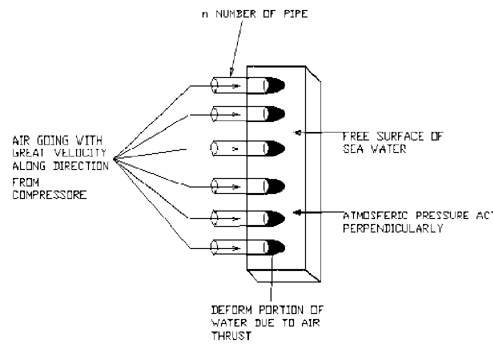

Figure 4: Schematic diagram of air jet when produce thrust in the water.

That means the density of water approximately 800 times greater than air. The air consists of so many gases particles such as nitrogen, oxygen, inert gases etc and according to gas kinetic theory these particles are always moving. Since the air consists of different gas particles, adhesive force is act among them. Again the range of adhesive force of gas particles is very small and approximately 1EXP-10m. But according to gas kinetic theory, a small distance always exist among the gas particles. For these reasons adhesive force of gas particles is very small. But the cohesive force of water particle is very much larger than adhesive force of air particles. From gas law we know that temperature and pressure of gas are related proportionally (P` α T) when volume and number of moles of gas are constant.

In the compressor gas temperature is high due to high pressure but in Figure-5 the temperature of portion 1 is normal, because in this region pressure energy of gases must be dropped and converted into velocity energy according to Bernoulli equation. Here gas density is very much lower than compressor gas density. Therefore the gas particles posses a distance among them in this region 1 and this kinetic energy gain by absorbing gas temperature and pressure (According to Joule-Thomson effect.). Again these pipes are always kept in the water or cold region compared with compressor gas temperature. For those reasons the temperature of this region remains normal. At normal temperature, viscosity of gases is low.

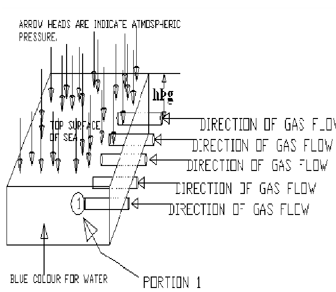

Figure 5: The atmospheric pressure act on sea surface which increase inertia of water.

Due to low viscosity of gas particles, air jet or air particles can impinges on water with high velocity. The viscous force of water particle is very much larger than air particle since

Viscosity of water at 20°C is 1EXP-3 Ns/m²

Viscosity of air at 20°C is1.8EXP-5 Ns/m²

Again atmospheric pressure and water pressure (h`ρ`g) act opposite to the direction of gas flow on the end of nozzles and these features increase the elasticity of water.

Finally following features of water and air can be considered:

1. Mass of water particles are very large than air particles.
2. Cohesive force of water particles are greater than adhesive force of air particles.
3. Viscosity of water also greater than air.
4. Atmospheric pressure and water pressure (h'Þ'g) help water to increase inertia.
5. Mass of air particles is very much smaller than that of water particles.
6. Adhesive force of gas particles is small.
7. Viscosity of air is smaller than that of water.

From the above decisions it can be said that the collision between air particle and water particle must be elastic collision. Therefore reaction thrust of water gives equal velocity (V`) to air jet .

Therefore the resultant ship speed becomes

V``=V`- (-V`)………….. (6)

Because water behaves like a movable wall which always exist against air jet flow.

Or, V`` =2V`………………. (6a)

Substituting the value of V` from equation (5) in equation (6a) then it becomes

$$V``=\frac{2n\rho A}{M}\left[\frac{2(P-P_o)}{\rho}+2g(h-h_o)+V^2\right] \ldots\ldots (7)$$

But M is equat to ship displacement and substitute by Δ, then equation (7) becomes

$$V``=\frac{2n\rho A}{\Delta}\left[\frac{2(P-P_o)}{\rho}+2g(h-h_o)+V^2\right] \ldots\ldots (8)$$

Estimation for a patrol boat in case of ideal fluid:

Let for a patrol boat moving through ideal fluid

n=100 , Þ=1.293 kg/m³ , M=140000 kg Or,140tonnes , P=250atm , h-ho=3m V=5m/s , A=πr²

If r=1cm, A=0.000314 m²

Put this value in the equation (5) then velocity become V`=11.169m/s

From the equation (6a) the resultant velocity of the ship is V``=2*11.169=22.34m/s = 80.424 km/h V``= 43.47 knots without resistance.

3. RESULTS AND DISCUSSION

Figure 6 shows the variation of ship velocity (V``) with nozzle or pipe number (n). This figure is constructed from equation (8) and others parameters of this equation are considered as a constant. This figure produce a straight line y = mx whereas x is an independent variable, y is a depended variable and m is slope. Figure 6 shows that the line passes through origin. That means when nozzle number zero (n=0) then ship velocity is zero (V``=0). But ship velocity linearly increases with increase of nozzle numbers. Therefore designer should provide more nozzles to increase ship speed. But complexity will come to install large number nozzle since it needs more air supply, more compressor pressure and so on. Therefore designers have to be chosen optimum number of nozzles and ship speed.

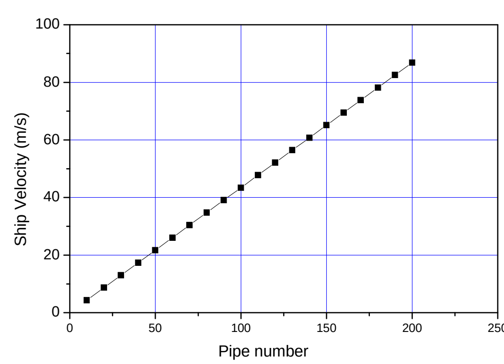

Figure 6: Variation of ship speed (V``) with different number of pipes (n).

Figure 7 shows the variation of ship velocity (V``) with nozzle diameter (d). From equation (8) it shows that ship velocity is squarely proportional to nozzle diameter. Therefore this figure is slightly exponential. Others parameters of equation (8) are also considered as a constant. From the equation of continuity it is clear that velocity of air jet and area of nozzle are vice versa. Since equation of continuity represent a reverse relation between cross section area and velocity of flow (AV_o=k). If cross section area increases then same jet velocity can be maintained by increasing supply of air. However designer can easily set any parameter from working formula (Equation-8) to maintain compressor pressure with large diameter.

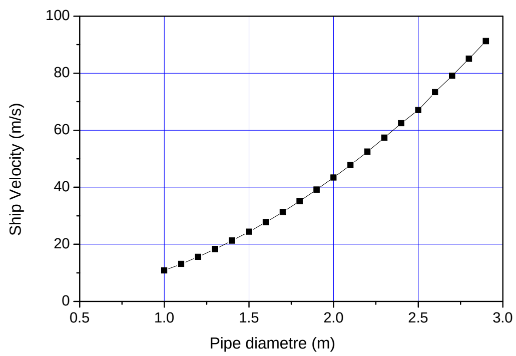

Figure 7: Variation of ship speed (V``) with different nozzle or pipe diameter (d).

Figure 8 shows the variation of ship velocity with displacement. Rests of the parameters of equation (8) are fixed. It shows that ship velocity decrease with increasing displacement. Initially ship velocity is decreased at a higher rate with increasing displacement but latter decrease at a lower rate. Therefore the process is comparatively suitable for large displacement. But displacement related with resistance, inertia of ship and these parameters are related with propulsion power. Therefore large displacement need large propulsion power and propulsion is depended on compressor pressure. The compressor pressure and others parameters have to be capable to gain these situations.

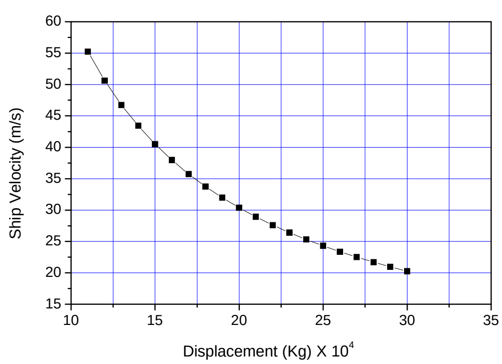

Figure 8: Variation of ship speed (V``) with different displacement (Δ).

Figure 9 shows the variation of ship velocity with respect to compressor pressure. Ship velocity is increasing with increase of compressor pressure. Here compressor pressure change spontaneously and others parameters are fixed. But for zero compressor pressure there is a reverse velocity. This reverse velocity produces for water pressure and atmospheric pressure which is already been mentioned. Due to the velocity, water will go in pipe and compressor and other devices if they are situated below water line. To protect this problem designer should be given one way bulb in the end of nozzles or in suitable position of nozzles.

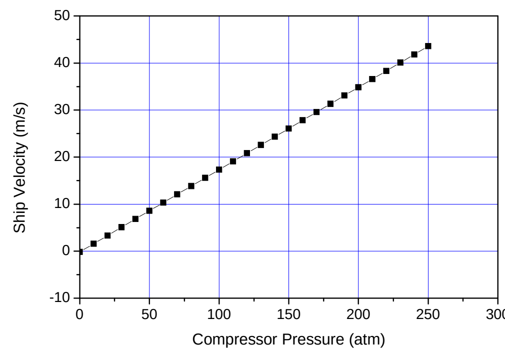

Figure 9: Variation of ship speed (V``) with different compressor pressure (P).

4. CONCLUSION

This paper seek new type of propulsion system to enrich the ship propulsion as well as to reduce the green house gas. This propulsion system will be environment friendly with respect to other propulsion devices used presently. If the compressor can be designed according to expectation, then this propulsion can be implimented practically. Now a days some air cusion vheicles (ACV) have been developed and these air cusion is produced by compressor[10]. This propulsion absorbs CO_2 by the sea from environment but this CO_2 produce carbonic acid with bi carbonate and carbonate ions which have already been mentioned. Some of this CO_2 are minimized by photosynthesis of organism present in sea water. But most of the carbonic acid adversely attack to sea alkalinity and this effect seriously harm organism as well as decrease shell forming [2]. These problems of acidity can be removed by adding extra dilute alkali substance since acid-base reaction produce water and salt which neutralize the acid or base density (Ph) of a solution [11]. But a big challenge will come in this way to mix the alkali substance and it may be overcome by moving of ship. If alkali solution is passed at stern of ship, it will react with sea acidity. After that it will be easily mixed and neutralized by producing water and salt since most of the ship is run by propeller and propeller produce uniform flow with circulation which is very helpful to mix solution. But further research is needed to do this because there is may be come various problems and impact on sea environment. In spite of these difficulties, this method can be used to reduce green house gas to save our environment.

ACKNOWLEDGEMENT

Prof. Dr Mashud Karim, Head of department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering and Technology has been acknowledged for his valuable suggestion for the study.

REFERENCE

1. Pieter (2008) "Annual CO_2 mole fraction increase (ppm)" for 1959-2007 National Oceanic and Atmospheric Administration Earth System Research Laboratory, Global Monitoring Division (additional details).

2. Garrison, Tom (2004). *Oceanography: An Invitation to Marine Science*. Thomson Brooks. pp. 125. ISBN 0534408877

3. Mauna Loa CO_2 annual mean data from NOAA. "Trend" data was used. See also: Trends in Carbon Dioxide from NOAA.

4. "Annual Mean Growth Rate for Mauna Loa, Hawaii". *Trends in Atmospheric Carbon Dioxide*. NOAA Earth System Research Laboratory. http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_growth. Retrieved 28 April 2010.

5. Swedish research body (2008). Optimized hulls lower gas emission. International journal of the Royal institution of naval architects. www.rina.org.uk/tna.Vietnames shipbuilding/Norway`s marine industries CAD/CAM update/ Green ship technology/ January 2008. P-73.

6. Doney, Scott C.; Naomi M. Levine (2006-11-29). "How Long Can the Ocean Slow Global Warming?". Oceanus. http://www.whoi.edu/oceanus/viewArticle.do?id=17726. Retrieved 2007-11-21

7. A Ground Test Rocket Thrust Measurement System Mary Fran Desrochers, Gary W. Olsen, and M. K. Hudson Department of Applied Science and The Graduate Institute of Technology University of Arkansas at Little Rock, Little Rock, AR 72204 USA

8. "Climate and CO2 in the Atmosphere". http://earthguide.ucsd.edu/virtualmuseum/climatechange2/07_1.shtml. Retrieved 2007-10-10.

9. Martini, M. (1997). "CO_2 emissions in volcanic areas: case histories and hazaards". in Raschi, A.; Miglietta, F.; Tognetti, R.; van Gardingen, P.R. (Eds.). *Plant responses to elevated CO_2: Evidence from natural springs*. Cambridge: Cambridge University Press. pp. 69–86. ISBN 0521582032.

10. ACS Demonstrator, which features a ground-breaking energy-saving air cavity system integral to her hull. International journal of the Royal institution of naval architects. www.rina.org.uk/tna. / Green ship technology/ CAD/CAM update/ Vietnames shipbuilding/ Norway`s marine industries January 2009. P-26-31.

11. Miessler, L. M., Tar, D. A., (1991) "*Inorganic Chemistry*" 2^{nd} ed. Pearson Prentice-Hall p165.

12 . "Volcanic Gases and Their Effects". http://volcanoes.usgs.gov/Hazards/What/VolGas/volgas.html. Retrieved 2007-09-07

13. Climate Change 2007: Synthesis Report, IPCC

14. PMEL Ocean Acidification Home Page. http://www.pmel.noaa.gov/co2/OA/

15. Halliday, Resnick, Krane, Thrust on a Rocket, John Wiley & Sons, Physics, Volume1, Fifth edition. P-358. P 360-361.