Economical and environmental advantages of using natural gas as a fuel for inland water transport

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Egypt currently deals with globalization, growth of international trade and the change of global sea trade pattern by updating its ports, in order to broaden the scope of its sea borne trade. However, for a sustainable sea borne trade it is also important to introduce an efficient, clean and cost effective transport network comprising Inland Water Transport (IWT). The aim of this study is to review the driving forces behind energy demand in Egypt, evaluating different solutions to offset the expected oil reserve and production decline. Alternative fuels, which can be used with relatively small changes in marine propulsion engines, were also compared. In addition, an environmental and economic assessment when using Natural Gas (NG) and gas oil up on varying speed, range, operating hour/day and fuel price was carried by constructing a mathematical model for 106 TEUs container barge. The comparison between fuels revealed that the NG could be considered the best alternative fuel for IWT due to its availability, adaptability, and compliance with local emission regulations. The mathematical model showed a reduction in slot cost by 5 % per trip when using NG compared to gas oil, also the operating hour/day is the most significant parameter on the calculated slot cost. Regarding the environmental assessment, emission of NO_x, CO_2, HC and PM was reduced by 80%, 30%, 50% and 70% respectively when using NG as a fuel.

تتعامل جمهورية مصر العربية حاليا مع التغير فى شكل التجارة الخارجية و الزيادة فى حجم تداولها وذلك بتعديل موانيها ومن أجل إستمرار زيادة التبادل التجارى الخارجى يجب توفير شبكة نقل رخيصة وصديقة للبيئة تشمل النقل المائى الداخلى. تهدف هذة الدراسة إلى مراجعة العناصر الدافعة لزيادة الطلب على الطاقة بمصر مع تحليل للحلول البديلة المختلفة لمعادلة الانحدار المتوقع فى الأحتياطى/ الأنتاج النفطى المستقبلى ولهذا تمت مقارنة لبدائل الوقود المختلفة التى يمكن إستخدامها بمحركات القوى البحرية حاليا بالأضافة الى أستنباط نموذج رياضى لتقييم الأثر الأقتصادى والبيئى عند إستخدام الغاز الطبيعى والسولار المعتاد لوحدة نقل حاويات نهرية سعة ١٠٦ TEU عند تغير (السرعة – مدى الابحار – عدد ساعات الابحار اليومية – سعر الوقود). أوضحت المقارنة بين بدائل الوقود أن الغاز الطبيعى يمكن أعتباره من أفضل البدائل للاستخدام بواسطة النقل المائى وذلك لوفرته - توافقه مع المحركات الحالية و قوانين الأنبعاثات المحلية. كما أوضح النموذج الرياضى أن سعر الوحدة انخفض بنسبة ٥% للرحلة الواحدة عند إستخدام الغاز الطبيعى عن السولار المعتاد وأن عدد ساعات الأبحار اليومية هى أكثر العناصر تاثيرا على خفض سعر الوحدة وكذلك أنخفضت نسبة الأنبعاثات المنفوسة عند استخدام الغاز الطبيعى لكلا من NO_x و CO_2 و HC وPM بنسبة ٨٠ % و٣٠ %و ٥٠ % و٧٠ % على التوالى.

Keywords: Containerization, Natural gas, And inland water transport

1. Introduction

Generally, population and economic growth are the major driving forces of growing global energy demand, because the increase in the population leads to a subsequent increase in the development of sea borne trade of the country.

In order to achieve a sustainable sea borne trade, it is important to ensure an efficient transport network comprising inland water-ways network and Mediterranean ports.

The inland waterway in this paper represents the first class waterway only, as described by River Transport Authority (RTA) navigation manual. Previous studies done on inland waterways transport came to a common conclusion is that Inland Water Transport (IWT) is not favorable in comparison to the road haulage [1]. Therefore, the RTA, are carrying out development plans for improvement /rehabilitation of inland waterways, in order to link the greater Cairo metropolitan with Mediterranean Sea ports due to its advantages over other alternative transportation networks[2]. In order to cope with such development, RTA introduced an advanced design concept of (4-rows, 2-tiers and 8-bay) coastal self propelled container pusher barge tided together with a dumb barge having a 106 TEUs total capacity, 920 ton displacement, 7.5m width, 90-100m length and 1.6m draft. Coping with the current trend of sea trade such barge is planned to be of wide distribution in the near future, and therefore, it was chosen to be employed in the economic and environmental assessment of the present study.

2. Driving forces behind Egypt energy demand

According to the world population prospective by U.N. [3], the average annual growth rate was 1.9% for the period 2000-2005, a gradual decline year by year to about 0.7% for the period 2045-2050.

The current total population is distributed in Lower, Middle, Upper Egypt and frontiers by 62.15%, 20.2%, 16.3% and 1.4% respectively. Fig. 1 shows the average Egypt population over the next decades.

Most of the overseas trade cargoes of Egypt are passing through five principle ports, namely "Alexandria including Dekheila port – Damitta- Port said- Suez - Safaga". The total percentage volume of cargo handled excluding transient shipment from the above mentioned ports at year 2003 were 52%, 20, 5%, 13.8%, 8.3%, 4.9% respectively. Alexandria port is the largest port in the volume of cargo handled followed by Damietta, the volume of the cargo

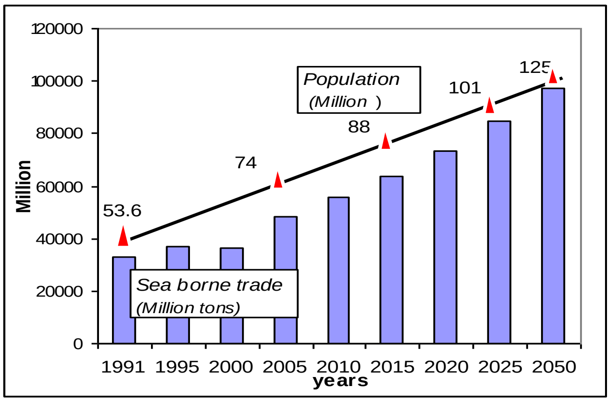

Fig. 1. Prospective of Egypt population and sea borne trade [4, 3].

handled by the two ports accounted for over 76% in 2004 [4]. Both Alexandria port and Damietta port have a barge basins connected with cannels having accesses to the river Nile. However, barge transported by inland waterway from/to Damietta port, has not been operated since the opening of the port in the 80s. Fig. 1 shows the expected sea borne trade during the next decades by assumingan annual growth rate 3%. This expected increase in sea borne trade will lead to increase in the total energy consumption and congestion in inland transportation network. Such increase in the energy consumption is considered to be a real problem due to the fact of the progressive decline in oil reserve and production. Therefore, reliable solutions for that problem are needed.

3. Solutions to offset the expected oil problems

Started by the Marion king Hubbert [5], in 1956 several models were proposed to estimate oil decline pattern following the peak (when about half of the original resource has been extracted). Also, John L. Hallock Jr in 2004 [5], summarized the different scenarios and predicted the year of peak or decline point to be within 15-30 years.

Therefore the oil analysts proposed some solutions to offset such decline in the oil energy as follows [6, 7]:

1. Improvements in oil recovery factors due to the use of tertiary recovery methods ('enhanced recovery oil).
2. Use of non conventional fuels (natural gas liquids NGLs), heavy oils, tar sands and shale oils, bio-fuels,... etc;
3. Expand the share of renewable energies as (solar, wind, bio-mass, ...etc).
4. Use alternative fuels as NG to substitute oil for transportation and industrial purposes.
5. Improvement in the end use efficiency (facing the problem from demand not from supply).

Owing to the fact that marine propulsion engines are different from the land base ones due to their difference in size and horsepower so at present, only certain alternative fuels can be used on board ships. Such alternatives are analyzed as follows.

4. Alternative fuels

Any new fuel to be introduced should be evaluated from the aspects of availability, re-newability, safety, cost, adaptability to the existing engine, performance and finally compliance with the emission regulations. The alternatives fuels can be used in maritime transportations are analyzed in the following weight matrix, table 1. Details for each fuel with respect to the above aspects were given in a previous study by the authors [8]. Comparison of different alternative fuels reveled that NG collectively could be considered the best alternative despite of it is drawback of being non-renewable compared to the hydrogen and bio-diesel, which come in the next grade after NG. However, the geologists say that, since they have not been looking for gas, there would be a lot more to find once effort are put in.

Ibrahim [9] estimated the oil and natural gas reserves in Egypt and expected that the crude oil would last for about 24 years and NG will last for 150 years with the present production rate. However, the introduction of natural gas for IWT introduces a lot of questions regarding fuel consumption, cost saving, emission benefits to comply with the current local regulations, gas storage, weight and volume onboard will be considered in the following economical analysis.

5. Economic analysis

Based on machinery specific weight, fuel consumption, storage capacity, acquisition and fuel cost, two extremities of engine specifications were given; a model was proposed on 106 TEUs container barge to figure if there is any incentive for using natural gas over gas oil as alternative fuel for IWT. Any change in specific weight and volume is compared to gas oil (base fuel) lead to a change in the cargo capacity, which is directly proportional to the revenue potential of the 106 TEUs container barge.

5.1. Model layout

1. Specific fuel consumption, cost, machinery and fuel weight, were calculated to estimate the propulsion cost for both types of engines (diesel and gas engine), having efficiency of 44% and 42 % respectively. Any change in specific weight is represented by increasing or decreasing of the augmented number of designed TEUs (revenue capacity), which can be calculated from the following equation.

$$Rc = \frac{\Delta \sum W_{Total}}{W_{TEU}} . \quad (1)$$

2. Non-propulsion related cost was calculated for diesel engine as (base fuel) by estimating the slot cost for diesel engine propulsion and assumed to be equal for both engines.

$$NPc = Pc - Sc. \quad (2)$$

3. The propulsion fraction of slot cost per trip is calculated by dividing the propulsion cost over augmented no of slot cost.
4. The difference in slot cost between diesel oil and natural gas propulsion is determined from the following equation.

Table 1
Comparison between alternative fuels for marine use

	Coal	Bio-diesel	F-T diesel	Alcohol	H_2	N.G
Availability	++	++	+	++	+++	++
Re-newability	-	++	+	++	+++	-
Safety	+++	++	++	--	-	++
Cost	+++	+	-	+	--	++
Adaptability	++	+++	+++	++	+	+++
Performance	+	++	+++	+	+	+++
Emission compliance with IMO	--	++	++	++	+++	++

*Sign indicates that: +slightly better, ++better, +++best and – slightly worse, -- worse.

$$\Delta Sc = \frac{Pca + NPca}{D * \sum TEUs} - SC_d \, . \qquad (3)$$

By taking the engine horsepower, efficiency, fuel cost, number of working hours/day and depreciation rate, the change in slot cost can be calculated as follows:

$$\Delta Sc = \frac{3.6 * Bhp}{\Delta \sum TEUs} \left(\frac{h * \Delta Fc}{\eta * \Delta C.V} + \Delta Ac * K \right) . \qquad (4)$$

Where, k is a constant depends on the life span and interest rate.

The economic analysis reveals that although, weight and acquisition cost for gas engine is higher than diesel engine, the slot cost has been reduced by 5 % per trip when using Compressed Natural Gas (CNG) in best extremity and remains as the diesel engine for worst extremity, this is due to the high calorific value of NG and low NG price comparison to gas oil. The augmented number of TEUs was reduced by 2-3 TEU, when using CNG. The storage capacity for CNG was calculated to be 39 m^3/TEU at specific density of 0.143 t/m^3 and pressure 200 bar. The influence of changing range, speed, operating hours/day and fuel price on the difference of slot cost between the two alternatives was calculated, by taking reference values of (300 mile, 7Knot, 400LE/ton, 8 working hours /day)respectively, as shown in figure 2, from which one can directly determine the difference of slot cost in percent upon varying the percentage of the mentioned parameters. Fig. 2 also shows that the most effective parameter on the difference of slot cost is speed, followed by operating hours, range and finally fuel prices. However, the significant effect of speed is case of IWT is negligible due to the limited allowable maximum speed, but the difference of the slot cost can be increased by increasing the operating hours/day followed by increasing the navigational range.

Owing to the economic benefit when using natural gas, further investigation was done to study the effect of changing range and speed on the calculated slot cost for different gas engine horsepower. As shown fig. 3, the influence of gas engine horsepower is pronounced on the calculated slot cost, which is directly proportional to speed and inversely proportional to the navigational range. Therefore the selection of the gas engine should be based on the optimum horsepower rather than efficiency.

6. Environmental analysis

Since the Nile River is the principle water source in Egypt, almost the entire population (90%), agriculture, commercial and industrial developments are located in the vicinity of inland water transport area also the great archeological treasures of the ancient civilization are centered along the Nile valley.

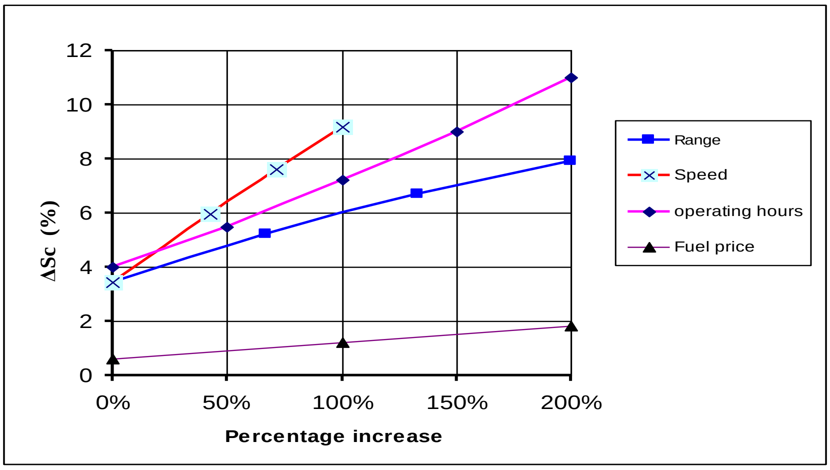

Fig. 2. The influence of different parametric changes on the difference of slot cost.

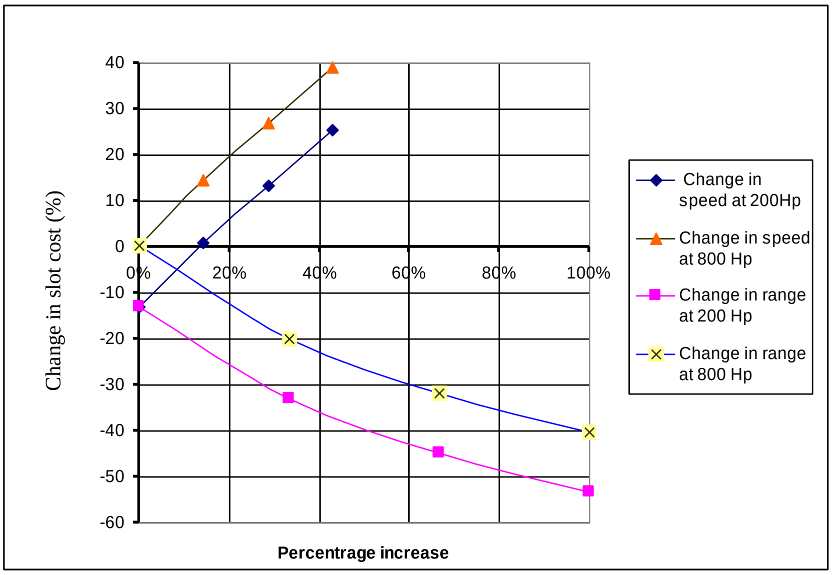

Fig. 3. The effect of changing range –speed on calculated slot cost for different horsepower.

Two long-term programs targeting air quality monitoring in Egypt are applied, one of them concerning the whole country and the other for the greater Cairo are Environmental Information and Monitoring Program (EIMP) and Cairo Air Improvement Project (CAIP) Respectively. One of the major component of the CAIP is the reduction of emission from land base transport through the expansion of the use CNG. At present, Egypt ongoing for widening of natural gas distribution, road and industrial applications in order to comply with local quality standard for the ambient air [10]. The great benefit of the natural gas is the lack of sulphur, therefore there is no SO_x emissions. NO_x and CO_2 emissions were calculated for diesel and gas engines at 85 % MCR, based on emission factors 12g_{Nox}/Kwh, 630g_{CO2}/Kwh for Marine gas oil (MGO) and 2g_{Nox}/Kwh, 450g_{CO2}/Kwh for N.G. as shown in fig. 4.

Also the relative emission was reduced when shifting to N.G of nitrogen oxides (NO_x), Particulate Matter (PM), carbon dioxide CO_2, and hydrocarbon (HC) by 80 %, 70 %, 30 % and 50 % respectively. Other environmental benefit of natural gas is elimination of potential soil and water contamination by spilled or leaking fuel.

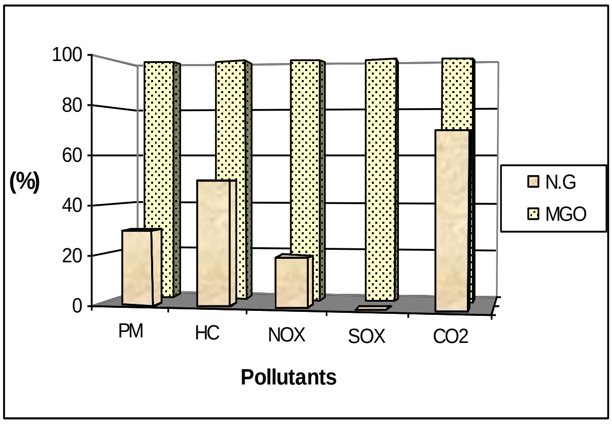

Fig. 4. Relative pollutants emission for NG and gas oil.

7. Conclusions and recommendations

1. The demand on energy production will increase by increasing the population and sea borne trade.
2. The use of other alternative fuels should start over to replace diesel oil for IWT. Natural gas is considered a good candidate for such replacement
3. To pull the river transport system out of its recession, it is important to improve the infrastructures, operation and management systems, also its navigational and physical obstacles.

4. Using CNG is preferable due its wide local distribution companies and a successful application in road transportation in Egypt, the issue of volume is not effective due to the small size of the vessel and limited navigational ranges.
5. Expanding the local use of Egypt's natural gas resources will reduce the need for imports of liquid fuels.
6. The economic benefit of using natural gas over gas oil for 106TEU container barge is 5 % reduction in slot cost.
7. Operating hours/day and changing in range are the most significant parameters on the difference in slot cost between natural gas and gas oil, ignoring the speed due to its limitation in IWT
8. Pollutants emission of NOx, CO_2, HC and PM was reduced by 80%, 30%, 50% and 70% respectively when using NG as a fuel.
9. The selection of the gas engine should be based on the optimum horsepower rather than efficiency.

Nomenclatures

Ac	is the acquisition cost,
Bhp	is the engine brake horsepower,
ΔCV	is the difference in fuel calorific values,
D	is the number of days/trip,
ΔFc	is the difference in fuel cost/ton,
h	is the number of Working hours /day,
K	is the constant,
NP_C	is the non-propulsion cost,
Pc	is the propulsion cost,
Rc	is the revenue capacity in TEU,
Sc	is the slot cost,
ΔSc	is the difference in slot cost between two alternatives,
W_{TEU}	is the homogeneous containers weight, and
W_{total}	is the total weights of engine, fuel and containers.

Subscript

a is the alternative option, and
d is the diesel option.

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