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A Comparative Study on Fuel Consumption between Actual and Optimal Propulsions of Inland Vessels of Bangladesh

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Abstract

This paper investigates the fuel consumption of some typical inland vessels of Bangladesh belonging to various categories. The optimum propeller was designed using the propulsive performance obtained from Holtrop and Mannen method and NSMB-B series. The fuel consumption of the optimum propulsion system of the vessels has been estimated using a standard curve for engine fuel consumption. The actual propellers fitted with the vessels were also measured and calculations were made to estimate the likely fuel consumption of the vessels fitted with optimal propellers. The comparisons show that the selected inland vessels are generally highly uneconomic in fuel consumption mainly because of the inappropriate RPM of the propeller and the use of improper propellers.

Introduction

The inland waterways of Bangladesh play a significant role in the transportation system of the country due to the existence of extensive network of rivers and canals which nature has bestowed on the land. Being the cheapest mode, water transport is always preferred to any other mode. Although the water transports are recognized to be the most fuel efficient transports, there had been hardly any study on the state of their fuel consumption in the past. The propulsive efficiency in the country boat sector were studied by Rahim et al. [10] which showed that because of use of inappropriate and faulty propellers, the country boats are a major source of wastage of fuel oil.

The design of the propulsion system can influence the performance of the engine in various ways. Overloading caused to engine due to poor propulsion design were shown by Rahim et. al. [11]. The state of maintenance of the engine also plays an important role in the fuel consumption but this not only confined to the water transport, rather it conforms to the national practice. This study aims at estimating the fuel consumption of some vessels operating in the inland waters of Bangladesh using locally available propellers and comparing the same with that of vessels with optimal propellers. The parameters of the actual propellers of the inland vessels studied were measured. The optimal propellers for the chosen vessels were determined. The power delivered to the propeller and the specific fuel consumption with the actual and optimal propulsion systems were estimated on the basis of EHP (effective horse power) characteristics, open water efficiency and wake factor at various speeds.

Methodology

The particulars of the vessels selected for the study has been shown in Table 1. The designed full load condition conforms to the Inland Freeboard Rules of Bangladesh [7]. The speed was estimated with the help of the ships' log, the distance of the ports called, and the time taken.

The resistance characteristics and speed-power relation of the vessels were determined using the method developed by Holtrop and Mannen [5]. The RPM of the propeller, the delivered power and the efficiency of the propeller for the speed range considered on the basis of the engine fitted, the reduction ratio employed, the wake factor and the actual propeller fitted have been estimated. Thrust deduction factors and relative rotative efficiency has been used. Among the well-known propeller series as developed by Schaffran [12], and others, the NSMB B-series propeller was used in the present study. The Bp-δ diagram [2] was used.

The same procedure was followed for evaluating the performance of the vessels using the same engine and RPM but fitted with the optimum propellers using the "optimum propeller" line of the Bp-δ chart. The blade area ratio was kept the same as that for the actual propeller.

Although lower RPM results in higher efficiency [8], but the limit to which the RPM can be reduced depends mainly upon the largest propeller [4] that can be accommodated in the hull considering the shape of the stern, the wake factor, clearance with the hull and other mechanical aspects including vibration. The complexity of the gearbox is also important if a large reduction ratio is to be employed.

Since all the vessels considered are single screwed, the wake at locations around the hub is the most important factor in deciding the size of the propeller. Although the flow of water into the propeller increases with an increase in diameter, but it also increases the variation in the wake in the various locations of the propeller. Due to non-uniformity of the wake field this contributes to increase in vibration [3]. The prediction of the performance of the propeller also becomes more difficult. However, a redesigning of the stern not only contributes to achieve uniformity of wake but also reduces the overall wake. It has also the effect of shifting the center of buoyancy of the vessel in the forward direction. This makes the loading arrangement of the vessels easier by avoiding trim by forward, a common problem with inland cargo vessels of Bangladesh. Considering all these factors, the evaluated optimal propeller for a vessel can be further optimized which will result in lowest fuel consumption within the limitations described. This ultimate optimum propeller for the highest RPM reduction has been used in this study and compared the performance with that of the actual ones. The engine RPM, power delivered and efficiency of this propeller were calculated for the speed range considered following the same procedure as in other cases.

Engine efficiency: the case of ship propulsion

The fuel consumption of the engine is measured as "Specific Fuel Consumption (SFC)" expressed in kg./bhp/hr. indicating how much fuel is burned by the engine per hour for each BHP produced. The fuel consumption of the engine depends on two factors; (i) the RPM and (ii) the load. The variation in the fuel consumption takes place due to the fact that with the fuel injection system employed in ordinary diesel engines; individual pump system with constant beginning of injection; there is very little control available to control the injection characteristics and thus the combustion process. It is possible only to control the quantity of fuel injected. As a result, the highest temperatures can not always be obtained during combustion. Since efficiency of such engines depends on the temperature of fuel combustion burning of fuel particles late in the stroke contributes to the reduction in the efficiency.

A typical curve [6] describing contours of constant SFC on RPM-Load relationship is used in this study to determine the fuel consumption. It appears that depending upon the RPM and load, the fuel consumption per HP of power produced can vary significantly and the minimum SFC is for about 70% of the RPM and 80% of the power. These characteristics, however, vary significantly with design of the combustion chamber. However, application of microchip based combustion is changing the simple relationships.

In case of ship propulsion, the load is the power demanded by the propeller for producing the required thrust. As the ship starts, the RPM is increased to increase the speed of the ship. The increased RPM enables the engine to produce more power and the propeller produces more thrust. This increased thrust accelerates the vessel and the speed of the vessel increases. While the characteristic of power generation is a function of the engine itself, the propeller demand is the function of a hull-propeller combination. The present work deals with the fuel consumption in the propulsion of the vessels. The power requirement of the propeller increases at a much faster rate compared to the maximum power that can be delivered by the engine. Consequently, beyond a certain stage, the power required by the propeller exceeds the power that can be generated by the engine and this condition represents the maximum speed attainable by the vessel fitted with this propeller. The scenario will change if either the engine or the propeller is changed with the hull remaining the same. As far as the fuel consumption is concerned, this is dependent on how much power the engine is producing and at what RPM. However, it is seen [6] that the SFC, has an optimum value close to the highest RPM. Fuel consumption suffers both at light load and at high loading. Thus SFC obviously varies considerably as the speed of the vessel is changed and this change is not generally monotonous.

Results and discussions

In order to determine the fuel consumption of the vessel fitted with the actual propeller, the propellers of the vessels were measured. Table 1 shows the RPM, size (diameter and pitch), and the open water efficiency of the propellers fitted with the vessels.

Table 1: Propulsive parameters of the actual propellers of different vessels

Vessel Type	Displacement (tons)	Speed (knots)	Propeller RPM	Propeller Size		Open Water Efficiency (%)
				Diameter (m)	Pitch (m)	
Oil Tanker	1422.00	10.1	585	1.321	0.878	43.43
Passenger Vessel	112.00	7.50	800	0.610	0.567	41.06
Cargo Vessel	1110.00	8.52	853	0.813	0.813	30.28

As mentioned earlier, it was suspected that the propellers fitted with the vessels are not the optimum ones. Thus, the optimum propellers for the vessels and the respective design speeds were determined. The results are presented in Table 2.

Table 2: Propulsive parameters of the optimum propellers of different vessels

Vessel Type	Displacement (tons)	Speed (knots)	Propeller RPM	Propeller Size		Open Water Efficiency (%)
				Diameter (m)	Pitch (m)	
Oil Tanker	1422.00	10.1	327	1.746	1.257	51.79
Passenger Vessel	112.00	7.50	518	0.818	0.622	50.86
Cargo Vessel	1110.00	8.52	405	1.392	1.058	46.48

The curves representing ship speed versus power delivered are shown in Fig. 1 to 3. It is seen from Fig. 1 that at the design speed of 10.1 knots of the 1422 tons oil tanker, the power required by the actual propeller is 605 hp whereas the optimum propeller is 500 hp. It is also seen that the power required changes very rapidly at speeds. Fig. 2 show the power required by the passenger vessel (112 tons) at the design speed of 7.50 knots is 51 hp by the optimum propeller and 63 hp by the actual one. Within the vessel speed range of 8.0 and 9.0 knots, power required by both actual and optimum propellers changes abruptly. For the cargo vessel (1110 tons) the power required (Fig. 3) are 452 hp and 305 hp at the design speed of 8.52 knots and the rate changes very high over 8.0 knots. Therefore, the results show that in almost all cases, the ships require considerable higher power in the actual case compared to the optimum propulsion design.

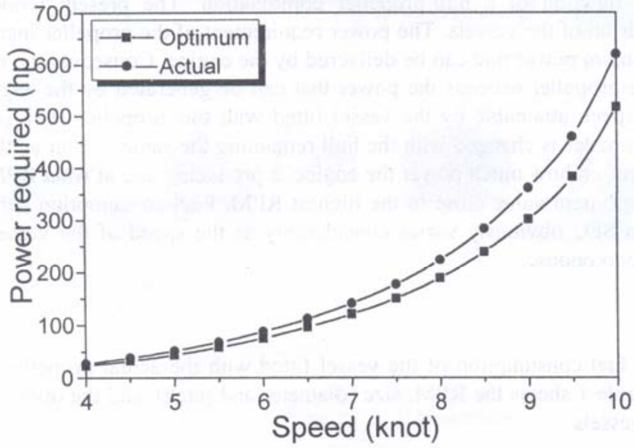

Fig. 1. Power required versus vessel speed of 1422 tons oil tanker

The estimated fuel consumption at progressing speed of the vessels fitted with the actual propeller and the optimal propeller are plotted in Fig. 4 - 6.

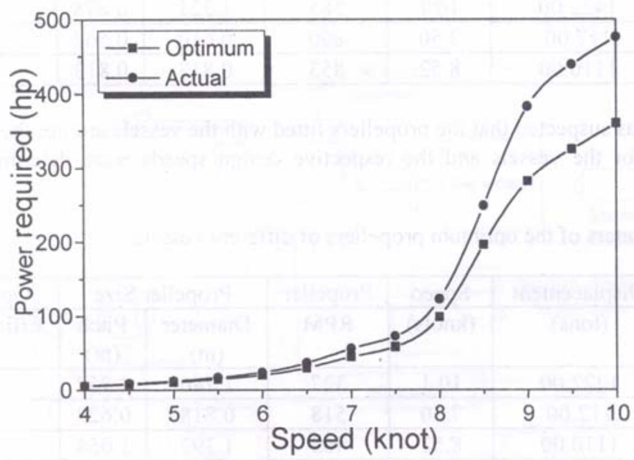

Fig. 2. Power required versus vessel speed of 112 tons passenger vessel

Fig. 4 for the 1422 tons oil tanker shows that at speeds above 9 knots, the fuel consumption in the actual case is considerably higher than that of the optimal one. However, below 9 knots, the difference is minimal. This indicates that the actual propeller and propulsion system in this case is very close to the optimum one. The increase at the later stage has been found to be due to the engine overloading as supported by the Fig. 1 showing the predicted performance of the propeller itself. However, when the engine gets overloaded, a slight increase in power generation results in very high increase in the SFC. This is also the case of under-load conditions where a slight decrease causes the SFC to rise sharply.

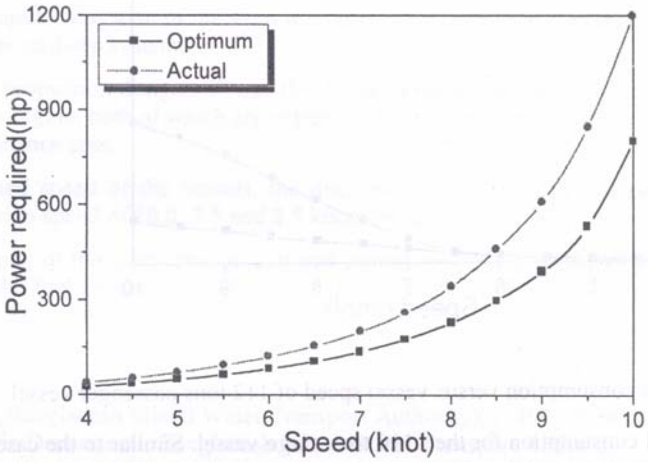

Fig. 3. Power required versus vessel speed of 1110 tons cargo vessel

Fig. 5 shows the predicted performance of the 112 tons passenger vessel. The difference between the actual and optimal cases are negligible upto 6.5 knots and thereafter the fuel consumption with the actual propeller increases very rapidly. This is also apparently due to the engine overloading since Fig. 2 shows that the power required by the propeller does not increase very much either in the actual or in the optimum case up to 8 knots. It is only the overloading of the engine at speeds exceeding 6.5 knots that results in very high fuel consumption. It may also be noted that the rate of increase reduces significantly when the speed increases over 9 knots. This is apparently due to the hump-hollow characteristics of the vessel resistance and does not have anything with the characteristics of the propeller except for second degree effects of water spin velocity in the propeller race.

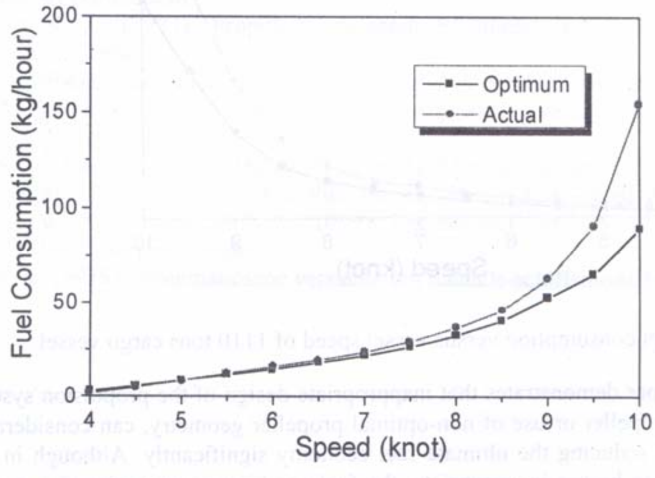

Fig. 4. Fuel consumption versus vessel speed of 1422 tons oil tanker

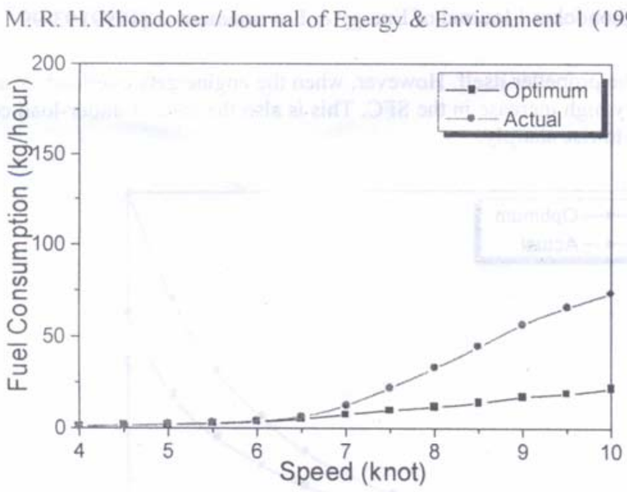

Fig. 5. Fuel consumption versus vessel speed of 112 tons passenger vessel

Fig. 6 shows the estimated fuel consumption for the 1110 tons cargo vessel. Similar to the case of the passenger vessel, the fuel consumption increases rapidly with speeds in excess of 8 knots. This figure should be compared with that of the propeller power consumption (Fig. 3). This figure shows that the power required by the propeller in case of the actual one indeed increases rather rapidly in speeds in excess of 8.5 knots. Thus the excessive increase of the power required coupled with the apparent engine overloading has resulted in the dramatic increase in the fuel consumption both in the actual and the optimum cases.

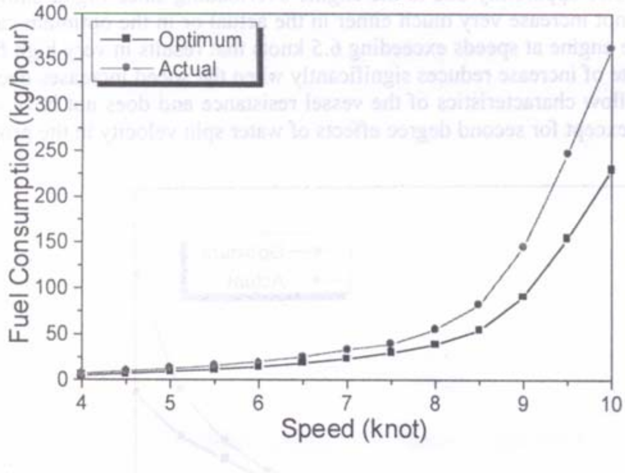

Fig. 6. Fuel consumption versus vessel speed of 1110 tons cargo vessel

results presented in the paper demonstrates that inappropriate design of the propulsion system, be it due to on-optimal RPM of the propeller or use of non-optimal propeller geometry, can considerably increase the :onsumption of the vessel reducing the ultimate fuel economy significantly. Although in some cases, the ller used may not appear to be too inappropriate, the fuel can become excessive due to the engine over-ıg.

Conclusions

The results of the study presented in this paper reveal some characteristic factors of propulsion performance of three typical inland vessels of Bangladesh, which are as follows;

- The actual propulsive system of the vessels requires substantially higher amount of fuel compared to that of the optimum propulsion system.
- An improved propulsion design will pay the dividend mainly by avoiding either overload or serious under-loading of the engine, both of which are extremely harmful in terms of the specific fuel consumption and the engine maintenance cost.
- At the designed speed of the vessels, the decrease in fuel consumption could be 42.14%, 55.47% and 33.08% at design speed of 10.0, 7.5 and 8.5 knots for oil tanker, passenger and cargo vessels.
- Proper designing of the stern arrangement and propulsive system of the inland vessels can help significant reduction of the fuel consumption as well as the engine maintenance cost greatly improving the operating economics of the vessels.

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