FUEL EFFICIENCY – CHALLENGES AND INNOVATIONS IN EMULSIFIED FUEL TECHNOLOGY

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Emulsified fuel technology has been developed since the early 1980's to the improve combustion efficiency of marine diesel engines by creating a secondary atomization effect after the initial fuel injection. The main challenge is to measure the improved sfoc of ships accurately and reliably. This paper presents a proposed method to measure the sfoc accurately and reliably to the order of 1%. Electronic governor also poses new challenge to measuring the sfoc of ships burning emulsified fuel. Meanwhile, fuel types supplied to ship owners are of increased varying properties although still complying to ISO8217 standard. This paper describes the innovations in emulsified fuel technology that were developed to meet these challenges.

INTRODUCTION

Emulsified fuel technology for marine diesel engine application has been developed since the early 1980's to the improve combustion efficiency by creating a secondary atomization effect after the initial fuel injection. The secondary atomization process produces a finer spray of smaller fuel droplets and thus, a better fuel-air mixture for more efficient combustion (Figure 1). Improved combustion efficiency has been measured in terms of improved heat release rate (HRR) as illustrated by Figure 2.

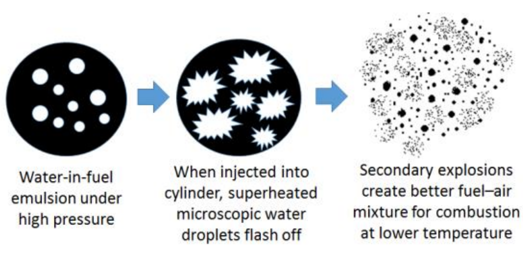

Fig 1: Illustration of secondary atomization

The ultimate challenge is to be able to measure accurately and reliably, any improved specific fuel consumptions, SFOC (gm/kW-hr) of the marine diesel engines of ships at sea when burning emulsified fuel compared to burning neat fuel. The main challenge in measuring the SFOC of ships is the random and constantly changing external factors such as the weather and sea conditions. This paper presents a proposed method to measure the SFOC at sea, accurately and reliably to the order of 1%. The basic concept is to measure relative SFOC rather than absolute SFOC and compare the SFOC when burning emulsified fuel to burning neat fuel within a short period so that the effects due to the random and constantly changing external factors such as weather and sea conditions, would cancel out. Results with at least 2% improvements in SFOC have been measured consistently with the proposed method.

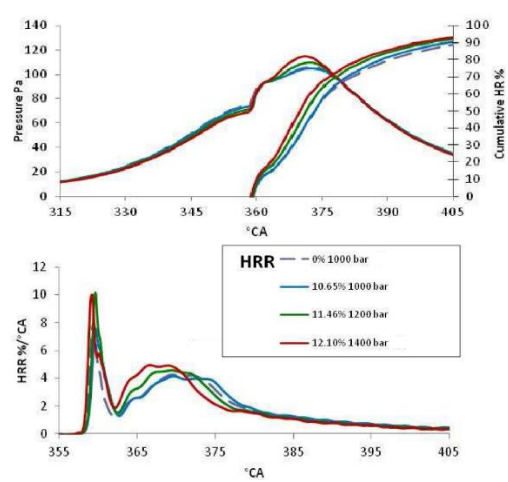

Fig 2: Measured increased HRR

Many ships today use electronic governor to control the main engine. When the main engine with an electronic governor operates with emulsified fuel, the fuel index limits which are meant to protect the engine from possible damages, can interfere with the engine performance in an unintended way, resulting in wrong adverse results. A proposed method to integrate the Emulsified Fuel System (EFS) controller to the electronic governor is described to obviate this problem.

Today, fuel types supplied to ship owners are of increased varying properties although still complying to ISO8217 standard. There are 380cSt, 500 cSt, 700cSt, LSFO, ULSFO, MDO, MGO etc of different paraffin and aromatic properties and not to mention the blended, ECA etc varieties. This paper describes the innovation which auto-tunes the % water content to optimize the efficiency performance in response to different fuel types.

MEASURING IMPROVEMENTS IN FUEL EFFICIENCY

One of the biggest challenge of fuel efficiency system is to be able to measure fuel efficiency at sea to an order of accuracy and reliability of or better than the claimed improvement in fuel efficiency which is typically 2-5%.

The issues to the challenge are:

- ISO 3046 and ISO 15550 methods of measuring specific fuel oil consumption (sfoc) only provide accuracy and reliability to 3%
- Engine manufacturers only provide guarantee to sfoc as follows:
  - 50-64% load: 7% tolerance
  - 65-84% load: 6% tolerance
  - Above 85% load: 5% tolerance
- External factors such as the weather and sea conditions which can affect the sfoc never stay the same but change all the time

Figure 3 illustrates the typical plot of sfoc of a container vessel logged over a year. The variations of sfoc are typically of the order of about 10%.

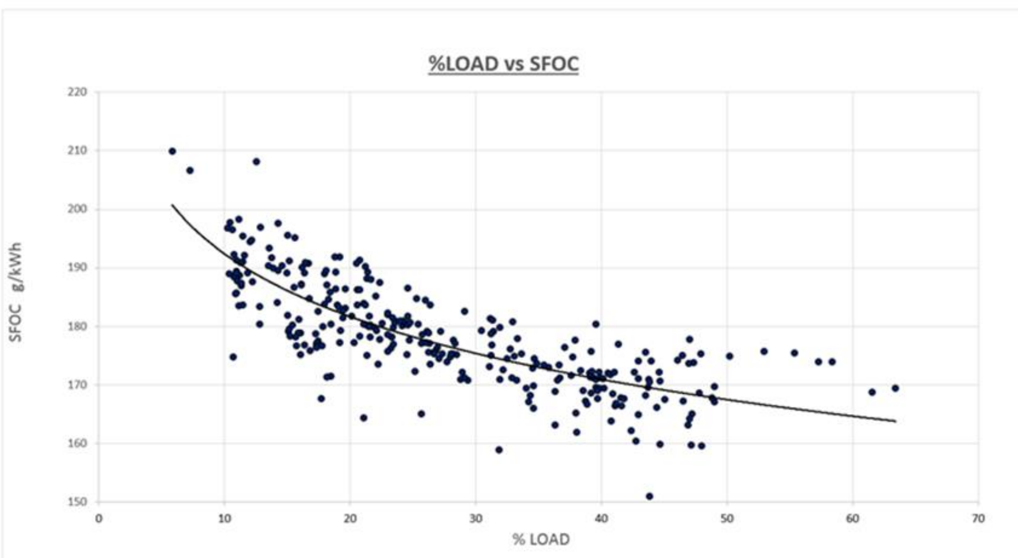

Fig 3: sfoc of a container vessel logged over a year.

It is obvious that it will be difficult to measure improvements in sfoc of 2-5% because the variations are of the order larger than the improvements to be measured. So for sfoc measurements taken over short voyages of a few days or weeks, the vessel may or may not be able to measure any improvements in fuel efficiency even if there were actual improvements. This does not provide high level of confidence to ship owners. In view of this challenge, the common practice is to take measurements over a long period (like a year) to try to prove a reliable and repeatable trend of improvement.

The major issue is that it is impossible to measure absolute sfoc to an order of accuracy better than that guaranteed by engine manufacturers (which is 5-7%), compounded by random and constantly varying external factors like the weather and sea conditions. Therefore, it is difficult if not impossible, to measure 2-5% improvements in the absolute sfoc of marine diesel engines.

This paper proposes a method of measuring the relative improvements of sfoc of marine diesel engines over a short period of relatively steady external factors like the weather and sea conditions. The concept is explained as follows. Assume that at a certain weather and sea conditions, the SFOC of a vessel has 2 components:

$$SFOC = sfoc_e + sfoc_{var} \quad \text{-----------------} \ (1)$$

where

- $sfoc_e$ is the sfoc of the engine
- $sfoc_{var}$ is the sfoc component due to external factors such as weather and sea conditions, and so on.

Equation (1) is simply interpreted as:

TOTAL FUEL CONSUMPTION = (fuel consumed for propulsion) + (fuel consumed due to external factors)

The aim of this paper is to measure the improvement in sfoc when emulsified fuel is burnt. So we are interested to measure the relative improvement of sfoc of the marine engine when emulsified fuel is burnt compared to when neat fuel oil is burnt.

From equation (1), the SFOC when the engine is consuming neat fuel is

$$SFOC_{FO} = sfoc_{fo} + sfoc_{var1} \quad \text{----------------} \ (2)$$

and when emulsified fuel is burnt is

$$SFOC_{EMUL} = sfoc_{emul} + sfoc_{var2} \quad \text{----------} \ (3)$$

The measurements of SFOC represented by equations (2) & (3) are taken over 15 min. Care must be taken that the engine and fuel oil system have stabilized before the measurements are taken whenever the fuel was changed from neat fuel to emulsified fuel or vice versa. The typical stabilisation time is less than 2 hrs. Therefore, the typical time interval between measuring $SFOC_{FO}$ and $SFOC_{EMUL}$ is less than 2 ½ hrs. We can reasonably assume that within 2 ½ hrs that external factors like weather and sea conditions etc $\approx$ constant

$$\text{i.e.} \ sfoc_{var1} \approx sfoc_{var2} \quad \text{----------------------} \ (4)$$

Therefore, the measured relative change in SFOC of the engine during the 2 ½ period is

$$\Delta SFOC = SFOC_{FO} - SFOC_{EMUL}$$

$$\Delta SFOC = sfoc_{fo} - sfoc_{emul} \quad \text{--------------} \ (5)$$

The significance of equation (5) is that the sfoc components due to random and constantly varying external factors such as weather and sea conditions cancelled out. Therefore, equation (5) above is interpreted as *the relative improvement in fuel efficiency ΔSFOC is not affected by the external factors like the weather and sea conditions,* $sfoc_{var}$ *if the measurement period is relatively short.*

The practical implementation of equation (5) is to measure $SFOC_{FO}$ for 15 mins, then switch on the emulsified fuel system and wait for the engine and fuel oil system to be stabilized in about less than 2 hrs and then measure $SFOC_{EMUL}$ for 15 mins. The cycle can be repeated as many times as possible. Figure 4 illustrates the results obtained using the proposed method of measuring the relative improvements in sfoc. It showed that an accuracy of the order of 1% was obtained reliably. The significance of this method is that the improvements in fuel efficiency can now be measured accurately and reliably in a relatively short period of days and weeks instead of months or years.

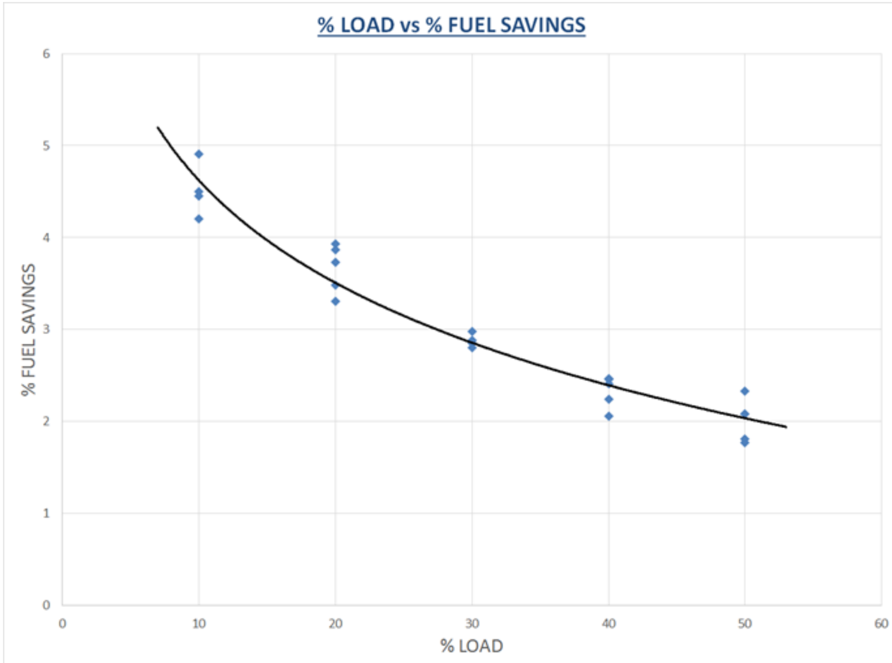

Figure 4: Measured % Load vs % Fuel Savings using proposed method

INTEGRATION TO ELECTRONIC GOVERNOR

More ships are using electronic governor to control the main engine. The electronic governor uses limiters to protect the engine from possible damages that may be caused by:

- over torque / load
- over RPM
- over fuel injection

An example of a RPM-Load Limiter envelope provided by engine manufacture is illustrated by Figure 5.

To protect the engine from possible damages, the electronic governor monitors the fuel index to ensure that the fuel index does not exceeds the envelopes of the RPM-Fuel index and P_{scav}-Fuel index charts provided by the engine manufacturer. When the limits of the envelopes are exceeded, the electronic governor will reduced the fuel pump command to protect the engine and fuel pumps from possible damages.

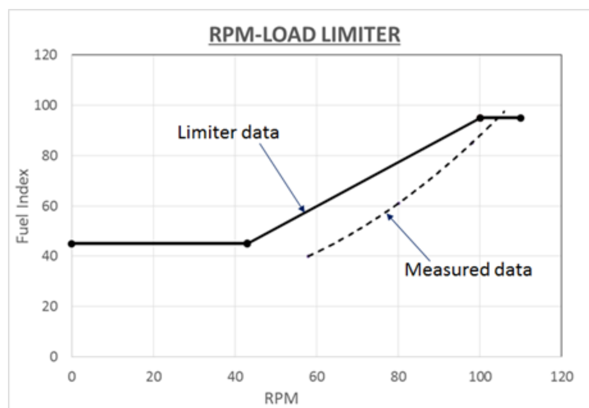

Fig 5: RPM-LOAD Limiter plot

When the engine burns emulsified fuel, the fuel index will increase by an amount

$$\Delta\text{Fuel index} = \%\text{water content} - \%\text{fuel saving} \quad \text{-- (6)}$$

The fuel index increases because more liquid is injected into the engine cylinders due to the additional water content. With the increased fuel index, it is possible that the fuel index may exceeds the limit provided by the engine manufacturer, at the operating RPM. Figure 6 illustrates the measured effects on the main engine when the fuel index exceeds the RPM-Load limit due to emulsified fuel.

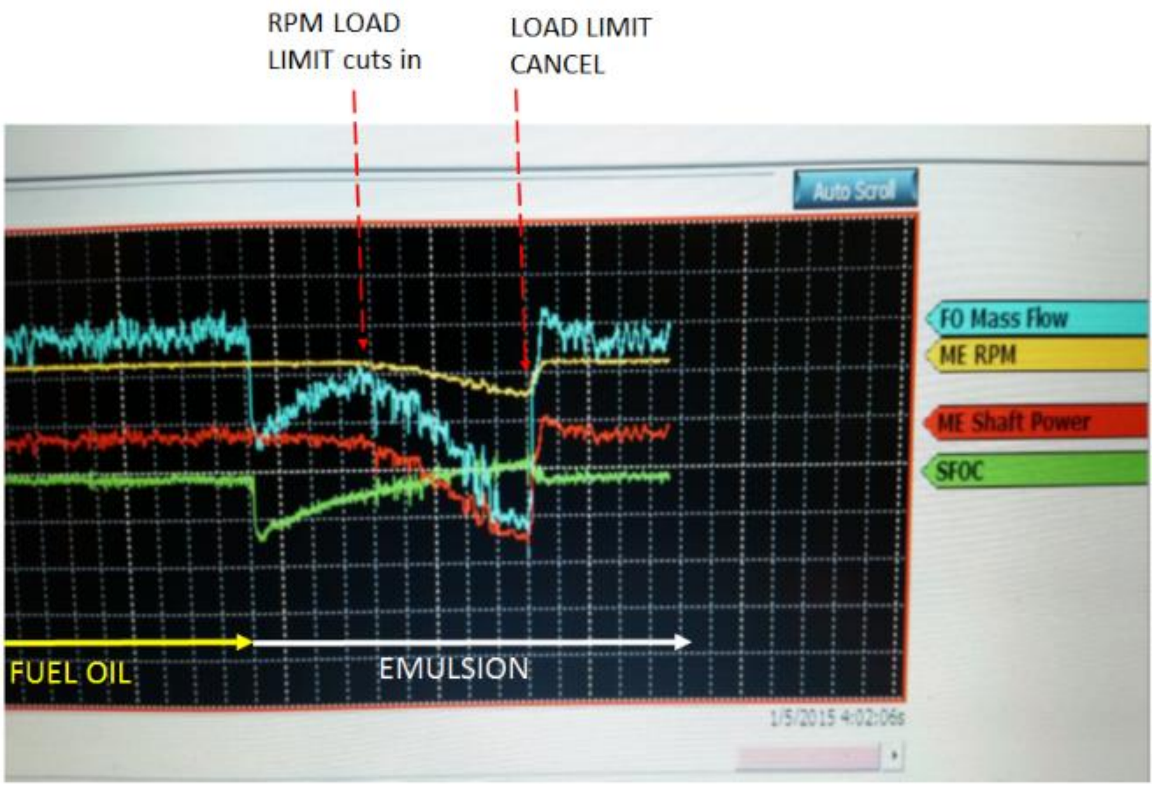

Fig 6: Effects on main engine when RPM-Load limit is exceeded.

As shown in Figure 6, when the fuel index exceeds the limit, the RPM-Load Limiter cuts in and the electronic governor will reduce the power and speed of the engine to protect the engine from possible damages. Referring to Figure 5, this is equivalent to the current RPM-LOAD point sliding backwards along the boundary of the Limiter envelope. The delivered actual power and speed will then become less than the ordered power and speed unless the Limiter is cancelled manually. The sfoc of the engine will also be affected adversely as shown in Figure 6. Therefore, if sfoc measurements are taken without cancelling the Limiter, the results will show an adverse increase in sfoc instead of fuel savings.

Generally, it is not advisable to cancel the Limiters as it will expose the engine to possible damages. Therefore, the below solution as illustrated by Figure 7 is proposed to address the issue of increased fuel index exceeding the limits, due to emulsified fuel.

The proposed solution is described as follows. When emulsified fuel is burned, the emulsified fuel system (EFS) controller sends the CANCEL LIMITS signal to the electronic governor and takes over the monitoring of the limits from the electronic governor.

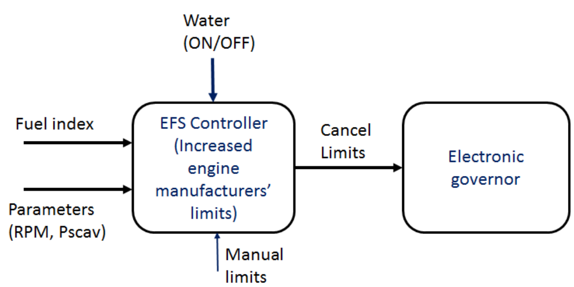

Fig 7: Integration of EFS Controller to Electronic Governor

Additionally, the EFS controller will also increase the limits by an amount which corresponds to the increased fuel index due to burning emulsified fuel (Refer to equation (6)).

At the same time, the EFS controller will also monitor the fuel index to ensure that it does not exceed the manually set upper and lower manual limits of the fuel pump index. The upper and lower manual limits are "soft" limits which correspond to the upper and lower physical positions of the fuel pumps. The upper and lower manual limits should not be exceeded because if exceeded, it may cause the fuel pump actuator to exert excessive forces on the fuel pumps and cause possible damages to the fuel pumps.

If any of the limits (after adjustments due to emulsified fuel) are exceeded, the EFS controller will shut down the EFS and cancel the CANCEL LIMITS signal to the electronic governor and returns the monitoring and control back to the electronic governor. Figure 8 illustrates the implementation of Figure 7 which integrates the EFS Controller to the Electronic Governor to address the issue of increased fuel index due to emulsified fuel. The proposed solution was able to cater to the increased fuel index due to emulsified fuel and also, protects the engine and fuel pumps from possible damages. It has been successfully implemented on vessels at sea.

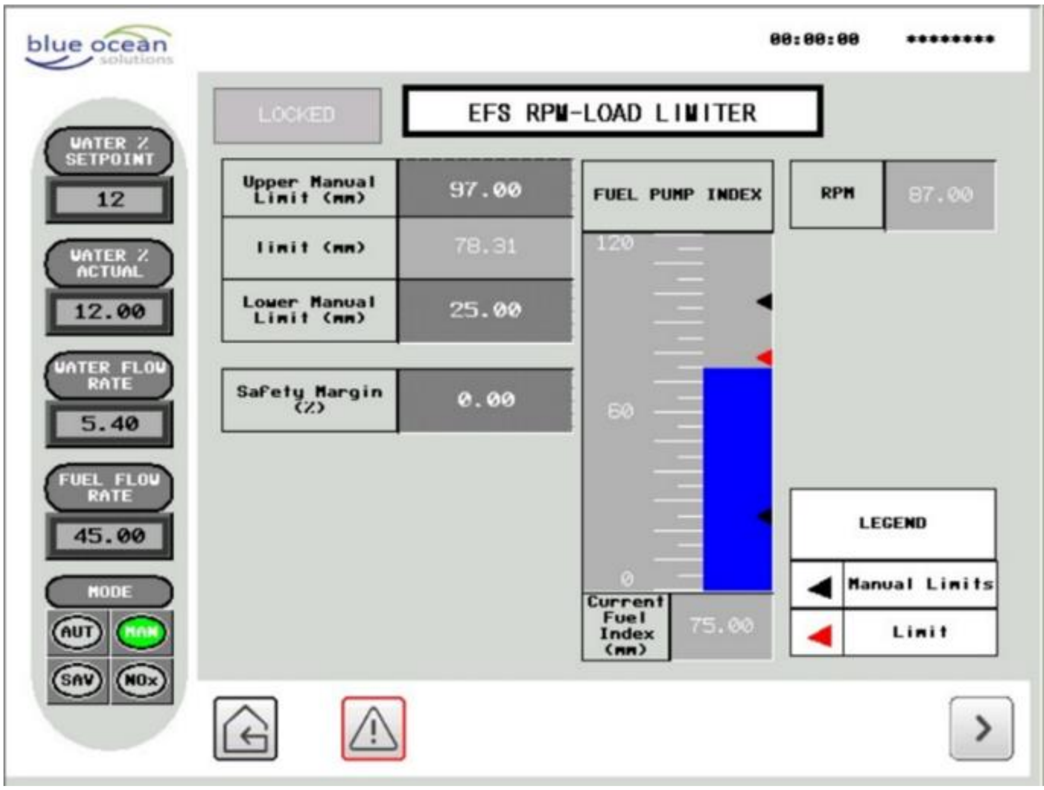

Fig 8: Implementation of EFS Controller-Electronic Governor integration

OPTIMISING THE % WATER CONTENT FOR DIFFERENT FUELS

Today, the fuel types supplied to ship owners are of increased varying properties although still complying to ISO8217 standard. There are 380cSt, 500 cSt, 700cSt, LSFO, ULSFO, MDO, MGO etc of different paraffin and aromatic properties and not to mention the blended, ECA etc varieties. Each fuel types are required to be heated to different temperatures to meet the engine manufacturers' recommended viscosity of 12 cSt to 18 cSt.

When water is added to fuel oil to produce a homogeneous water-in-fuel emulsion to be burnt as fuel, the viscosity of the water-in-fuel emulsion increases. The temperature of the fuel must then be increased to maintain the engine manufacturers' recommended 12 cSt to 18 cSt viscosity. As a general rule, the fuel temperature should not exceed 150 deg C due to the max temperature specifications of electronic components and sensors which may be installed in the fuel oil system.

The secondary explosion effect of water-in-fuel emulsions when injected into the engine cylinder (Fig 1) is affected by the fuel temperature and water content. These in turn affect the fuel efficiency performance of the emulsion i.e. % fuel savings.

The ship's existing viscometer will automatically control the fuel temperature at the set viscosity of between 12 cSt to 18 cSt when water is added. However, the optimum % water content must be determined to provide the best fuel efficiency. The method to optimize the efficiency performance of emulsified fuel in response to different fuel types, is illustrated by Figure 9. The basic concept is to auto-scan the sfoc at different % water content in steps from 10% to 16% water content, to determine the optimum % water content which provides the best sfoc.

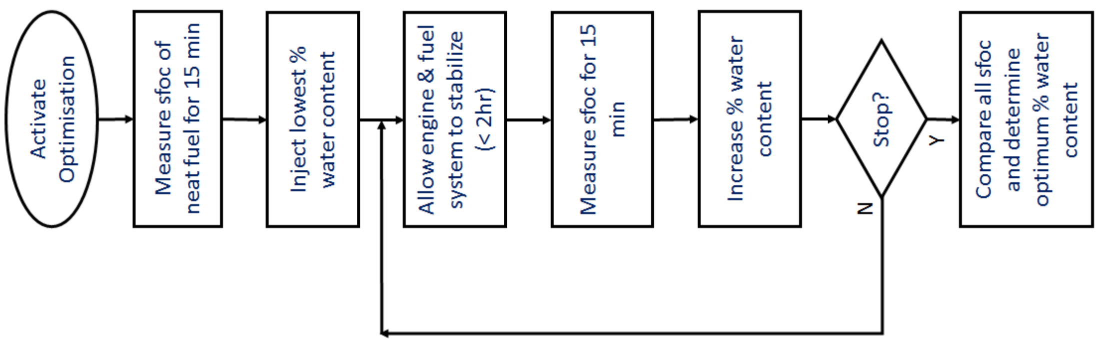

Fig 9: Method to optimize % water content for different fuels.

The auto-scanning steps of determining the optimum % water content is described as follows:

- Step 1: On activation of auto-tuning, the system will first measure the sfoc for neat fuel for 15 mins.
- Step 2: Then EFS is switched ON, starting with the lowest % water content eg 10% water
- Step 3: Wait for the engine and fuel system to stabilize (less than 2 hrs)
- Step 4: Measure the sfoc for the emulsion for 15 mins
- Step 5: Increase the % water content
- Step 6: Repeat step 3 to step 5 until %16 water is reached.
- Step 7: Compare the sfoc of each % water content and determine the optimum % water which gives the best fuel efficiency.

The entire auto-tuning optimization process should take less than about 10hrs. The proposed method allows the emulsified fuel system to achieve optimum fuel efficient performance for all types of fuel oil.

CONCLUSIONS

A method of measuring the relative improvements of fuel efficiency of the main engines of ships at sea was proposed and implemented. Results has showed that measurements of % fuel savings with accuracy and reliability of the order of 1% has been achieved in a relatively short period of a few days compared to the current practice of months or years. When burning emulsified fuel, the fuel efficiency of the main engine can also be adversely affected by the increased in fuel index due to emulsified fuel. The proposed integration of the EFS controller to the electronic governor of the main engine was able to address this problem and was tested successfully. Finally, the challenge of different fuel types which affect the fuel efficiency performance of emulsified fuel was addressed using auto-tuning method to optimize the % water content to provide the best sfoc.

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