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International Journal of Naval Architecture and Ocean Engineering xx (2016) 1—10
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

Effective test of lacquer in marine diesel engines

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Received 18 May 2016; revised 29 September 2016; accepted 15 October 2016
Available online xxx

Abstract

We perform an experiment on lacquer formation with simple test device. The anti-lacquer is one of important issues to increase durability, and to improve performance in the engines because the lacquer formation cause sticking of fuel injection pump, scuffing of cylinder liners, and increase of lubricant oil consumption in the marine diesel engines. We suggest this simple test in order to save enormous experimental cost in marine diesel engines, and in order to have ease in performing the various tests. The influences of the Base Number (BN) of lubricant oils and the sulfur content of fuel oils in the formation of lacquer are investigated. In order to investigate physical and chemical properties of lacquer, we perform a variety of tests such as, visual inspection, EDS. In addition, we investigate adhesion of lacquer by pull-off test quantitatively, and perform dissolution test with dilute sulfuric acid.

Keywords: Lacquer; Simple test; Marine diesel engine; Cylinder liner; EDS; Base number; Sulfur content

1. Introduction

Environmental restrictions affect the composition of marine fuel oil and the designs of marine diesel engines. The reinforced environmental regulations such as International Maritime Organization (IMO) Tier 3 will have a significant effect on the sulfur content of fuel oil and emission limits.

Most marine engines use fuel oil with low sulfur content as a means of satisfying international environmental regulations. However, unexpected problems arise from the use of such fuel oils. One of these problems is the increased consumption of lubricant oil due to the generation of lacquer on the inner wall of the cylinder liner, as shown in Fig. 1(a). Moreover, the lacquer occurs in fuel injection pump, and causes sticking, as shown in Fig. 1(b) (Buhaug, 2003; Liaquat et al., 2014).

Lacquer forming in the cylinder liners of marine diesel engines has been a matter of concern for at least 20 years, but it is clear that there is little understanding of the phenomenon. Moreover, nothing is known of the precise chemical composition and structure of the lacquer, or how those characteristics are affected by engine operating conditions, engine design, lubricant formulations and fuel composition.

However, some researchers insist that liner lacquer has four main contributing factors, which are engine design, engine load pattern, fuel oils and lubricant oils. Operation with a lot of idle, part-load, or combined with full load operation condition seems to be the most lacquer-prone from the results of field tests (Bames et al., 2004). The characteristics of fuel oils, such as the boiling point and content of aromatics and paraffinics affect the formation of lacquer (Zhu, 2013; Chandel and Bala, 1986). Lacquer formation tends to be confined to situations in which the fuel final boiling point is the range 420°C—450 °C, compared to a typical of around 340 °C for non-lacquering fuel oils. A higher than normal final boiling point may indicate a higher than normal content of Polycyclic Aromatic Hydrocarbons (PAHs) in the fuel oils. Fuel oils with lacquering tendencies tend to be higher in aromatics and lower paraffinics (CEC Investigative Report, 2007). The Base

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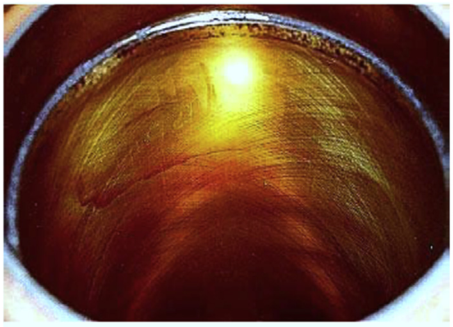
Peer review under responsibility of Society of Naval Architects of Korea.

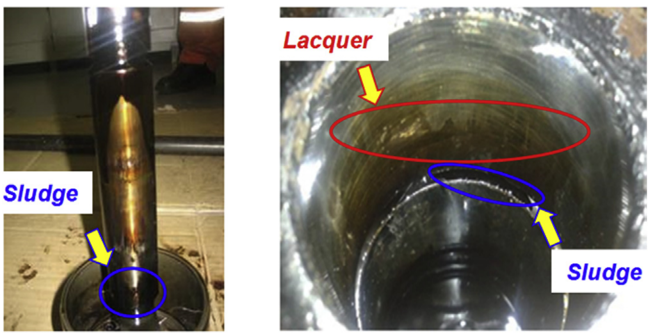
http://dx.doi.org/10.1016/j.ijnaoe.2016.10.002

Please cite this article in press as: Hong, S.-H., Ju, S.-H., Effective test of lacquer in marine diesel engines, International Journal of Naval Architecture and Ocean Engineering (2016), http://dx.doi.org/10.1016/j.ijnaoe.2016.10.002

+ MODEL



(a)



(b)

Fig. 1. Lacquer formation. (a) lacquer formation in cylinder liner (b) lacquer formation in fuel injection pump.

Number (BN) level of lubricant oils and sulfur content of fuel oils are directly related to lacquer formation (Impact of fuel on lubrication, 2000). A higher BN and sulfated ash indicated a higher deposit risk (Buhaug, 2003). In addition, lacquer increases when either the liner temperatures or inlet air temperature are too low (Bames et al., 2004).

Some researchers have suggested its occurrence mechanism. In Shell's opinion, lacquer is believed to form when partially combusted and cracked fuel components condense on the cylinder liner surface. They undergo oxidation and polymerization and mix with calcium and zinc salts from the lubricant to form a layer. This layer becomes baked and forms a hard glaze from the heat of combustion, as shown in Fig. 2(a) (Bames et al., 2004; Hong, 2016). In Alberola's opinion, lubricant oils can be defined as low molecular weight liquid polymers; therefore the thermal and oxidative degradation of lubricant oils leading to deposit formation can be considered a thermosetting process of polymeric materials. In the thermosetting process, two macroscopic phase transformations occur during the chemical reactions, which convert the polymeric liquid to a solid – i.e. gelation and vitrification, as shown in Fig. 2(b) (Alberola et al., 1990; Chen and Wang, 2001; Hong, 2016). The two opinions about the generating mechanism of lacquer include oxidation process, and also include the process in which the residual layers are cured.

Cylinder liners are machined by plateau honing process leaving a surface topography with smoother plateaus and deep valleys for oil and debris retention, as shown in Fig. 3(a). But the build-up of lacquer on the cylinder will fill the honing grooves, as shown in Fig. 3(b). Moreover, the lacquer reduces the lubricant oil storing capability and impairing the lubrication. As a consequence, consumption of lubricant oil increases, as shown in Fig. 3(c) (Dimkovski et al., 2011).

In previous studies, the sulfur content of fuel oil, and base number (BN) and sulfated ash of the lubricant oil are stated as causes of lacquer but concrete assessment is inadequate. This research is focused on the formation of lacquer by simple test with various combinations of fuel oils and lubricant oils. The influences of the BN of the lubricant oil and the sulfur content of the fuel oil are investigated in the respect of lacquer formation. Moreover, the physical and chemical characteristics of the lacquer are evaluated through a visual inspection, a dissolution test with a dilute sulfuric acid, a pull-off test, and EDS (Energy Dispersive x-ray Spectroscopy) of residual layers.

2. Simple test of lacquer

Experimental tests related to lacquer are conducted on a rig test (Rossetti and Buhaug, 2001), a ship trial test (Bames et al., 2004; Rossetti and Buhaug, 2001), and an oxidation test or deposit test (Alberola et al., 1990; Chen and Wang, 2001; Xie et al., 1995a,b; Stipanivic et al., 1996; Devlin et al., 2009). The ship trial test focus on lacquer in the cylinder liners. Lubrication oil consumption, the mean surface roughness, and color were normally used to characterize the surface of the cylinder liners. A rig test or oxidation (deposit) test are usually performed because of convenience and cost saving compared to the ship trial test. The underlying principle in the tests is to oxidize a thin film of oil over a heated surface at high temperature (Chen and Wang, 2001; Hong, 2016). Moreover, the evaluation is normally performed by measuring time or temperature at which deposit is generated.

Simple test of lacquer is suggested, and characteristics of lacquer are investigated with various tests in this study. The method has the advantage that can be conducted an experiment at the same time for several oil samples. In addition, dissolution by acid, bonding strength of lacquer is newly evaluated in this method.

Fig. 4(a) is a schematic of the test apparatus. The experiments are performed on several mixtures of fuel oil and lubricant oil.

2.1. Experimental device and process

A tubular heater is installed on a sand base as a heating source and used to heat a plate. The temperature of the plate is maintained at a target value with temperature controller of a heater, and a thermocouple. The temperature controller of heater is controllable to within ±5 °C of the set temperature. The plate is divided into eight compartments so that experiments on eight mixtures of fuel oil and lubricant oil could be carried out at the same time, as shown in Fig. 4(b).

After mixing and stirring fuel oil and lubricant oil for a sufficient time, a variety of mixtures are prepared in advance,

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