ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1133890
DOI: 10.5604/12314005.1133890

A PROPOSAL FOR MARINE FUEL OIL SYSTEM ARRANGED TO BURN HEAVY FUEL OIL AND LOW SULPHUR DISTILLATE GRADE

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Abstract

The following paper introduces a retrofit proposal for marine fuel oil system arranged to burn heavy fuel oil and low-sulphur distillate grade. In the face of tighter requirements regarding sulphur content in fuel, which are obligatory both inside Emission Control Areas and among international waters, it is necessary to provide safe and efficient ship operation. Conventional methods for fuel change-over between heavy fuel oil and distillate grade are saddled with necessity of constant process control and compulsory engine load reduction during the realization of procedure. It ensures that maximum fuel temperature gradient amounts 2 °C/min, which protects injection system against thermal shock. The solution proposed by MAN Diesel & Turbo in cooperation with LEMAG Lehman & Michels turns mentioned procedure into unusual until now level thanks to guaranteed safety, control, smoothness and degree of automation. So-called Diesel Switch constitutes automatic fuel change-over system, which implements the process free from engine load factor. A built-in programmable logic controller and specially designed non-proportional valve enable to achieve smooth and linear characteristic of change. Furthermore, device controls other fuel oil system elements and also registers procedure run. The second element in retrofitted system concerns the way of distillate fuel cooling. Sulphur in the chemical bonds with other fuel components reveals lubricating properties. Reduction of its amount simultaneously with usage of low-viscosity distillate fuel creates a risk of damage to plunger and barrel assemblies. A guarantee of proper hydrodynamic lubrication film in injection system involves maintaining a minimal fuel viscosity of 2 cSt at engine inlet. Commonly used central cooling system on ships has a significant limitation. Water from low temperature cooling circuit, which provides a coolant cannot decrease fuel temperature below 40 °C. Applied solution proposed by Novenco is concerned with chilled water system assembly, which can cool down fuel even below 0 °C through vapour compression or an absorption cycle. As a result, low-sulphur fuel viscosity can be increased at any load independently of seawater temperature.

Keywords: *automatic fuel change-over, chiller, Diesel Switch, Emission Control Areas, low-sulphur fuel*

1. Introduction

Regulations of sulphur content in the marine fuel oil are defined by Annex VI rules, which are connected with MARPOL 73/78 convention and based on current ISO 8217 fuel standard. On the strength of amendment to convention i.e. "1997 Protocol," the Sulphur Emission Control Areas were created, which have extorted usage of low-sulphur fuel oil since 2005. At first, the maximum sulphur content was set to 1.5% in SECA and 4.5% in international waters. From January 2015 the permissible limit in Emission Control Areas, (they also contain restrictions of nitrogen oxides and particulate matter emission) will be reduced to 0.1%. However, the value required on international waters will be decreased to 0.5% not faster than in 2020. At present, there are four regions concerned as ECA. Moreover, there are special areas in which more demanding emission regulations were implemented e.g. European Union with European Economic Area or state of California in USA [1].

Residual fuels are the most common energy source of modern low- and medium-speed engines. On account of low price, which compensates the operational difficulties and high pollution emissions, they are basic fuel in sea transport. However, usage of low-sulphur heavy fuel oil is prohibited in some special areas. What is more, restriction of sulphur content will be tighter soon. Certain forecasts predict a switch over to low-sulphur marine gas oil. It is caused by purely uneconomical production of low-sulphur HFO. The process is relatively expensive and requires heavy processing, essentially high pressure and high temperature hydro-treatment and the use of expensive catalysts. Usually, it is most cost-effective to process residues to low-viscosity and low-sulphur distillates. Such fuels hit the wider market and are more attractive proposal. The usage of low-sulphur distillates, which are currently obligatory in state of California and forced in UE inland waters as well as in its seaports, will probably spread through all ECAs. From an operational point of view, fuel change-over from residue to low-sulphur distillate creates a potential risk for engine life, if it is not carried out properly. As an example, from the beginning of amendment to sulphur regulations in state of California there was over 100% increase in loss of propulsion incidents reported during period from 2009 to 2011. Half of the was caused by fuel change-over difficulties connected with incompatibility of periodically mixed fuels, cylinder oil lubricity and its total base number, manual change-over and above all viscosity and temperature. A facilitation or even necessity in relation to last three properties is application of automatic fuel change-over system and chilled water system aka chiller [2, 3].

2. Challenges met by engine manufacturers – viscosity and temperature of distillate fuel

Fuel viscosity varies depending on its grade and temperature during operation. HFO is characterized by high viscosity; therefore, it is heated averagely to 120 or even 150°C, to fit the range of 10-20 cST at engine inlet. Modern engine fuel systems are designed to maintain high temperature for better operation on this kind of fuel. However, it makes difficulty with maintaining as low temperature as possible, which is equivalent to the highest viscosity during operation on distillate. Range of its kinematic viscosity in 40°C amounts to 2-11 cSt and crossing the bottom limit involves loss of hydrodynamic lubrication ability in precise pairs of injection equipment. Consequently, oil film thickness is decreased or even broken causing metallic contact, which creates a risk of wear, sticking or seizure. In addition, sulphur in the chemical bond with other fuel components reveals lubricating properties. Reduction of its amount simultaneously with usage of low-viscosity fuel contributes to damage the precise pairs. Moreover, too low viscosity causes an increased internal leakage in fuel pump. Despite the fact that internal leak is a part of design and is used in part to lubricate the pumping elements, its excessive amount leads to smaller than optimal injection pressures. As a result, an excessive injection lag occurs, which brings change of its angle. Next the ignition lag and decrease of peak firing pressure occur, which cause engine power drop and difficulties during start, reverse and low load operation. Distillate fuel cannot be heated and is even recommended cooling it. Minimum value of distillate viscosity measured at the engine inlet amounts at least 2 cSt, so the proper hydrodynamic oil film in injection equipment can be maintained. Above requirement determines safety margin decreasing risk of fuel pump seizure and it requires fuel cooler assembly. For tropical conditions, it should be equipped with chiller unit that will keep the fuel temperature below 40°C. For some MGO grades, required viscosity may be reached at temperatures above 35°C. As the fuel temperature increases during operation, it is impossible to maintain this low temperature at the engine inlet without a MDO/MGO cooler. In addition, at start and stop of engines with older fuel pump, the viscosity is recommended to be over 3 cSt, because the fuel will be by-pass the plunger. According to ISO 8217:2010 fuel standard, distillate grades DMX, DMA and DMB can be sold with a viscosity down to 1.4 or 2 cSt at 40°C. This will especially be the case if the <2 cSt DMX or DMA provided origins from automotive gas oil. The latest distillate introduced in ISO 8217 is DMZ with 3 cSt at 40 °C, which gives some margin. Relationship between distillate grades viscosity and temperature is shown in Fig. 1. The horizontal axis shows the bunkered fuel viscosity in cSt, which should be informed in the bunker analysis report. The black thick line shows the viscosity at reference condition (40°C) according to ISO 8217:2010 for marine distillates DMX, DMA, DMB and DMZ. For example, MGO with viscosity of 4 cSt at 40°C must have a temperature below 55°C at engine inlet, to provide a viscosity above 3 cSt. Distillate with parameters of 5 cSt/40°C reaches engine at 50°C. The green curves show that the fuel enters the engine at app. 4 cSt. Whereas, fuel with parameters of 2 cSt/40°C needs cooling to 18°C to reach 3 cSt/40°C [3, 4].

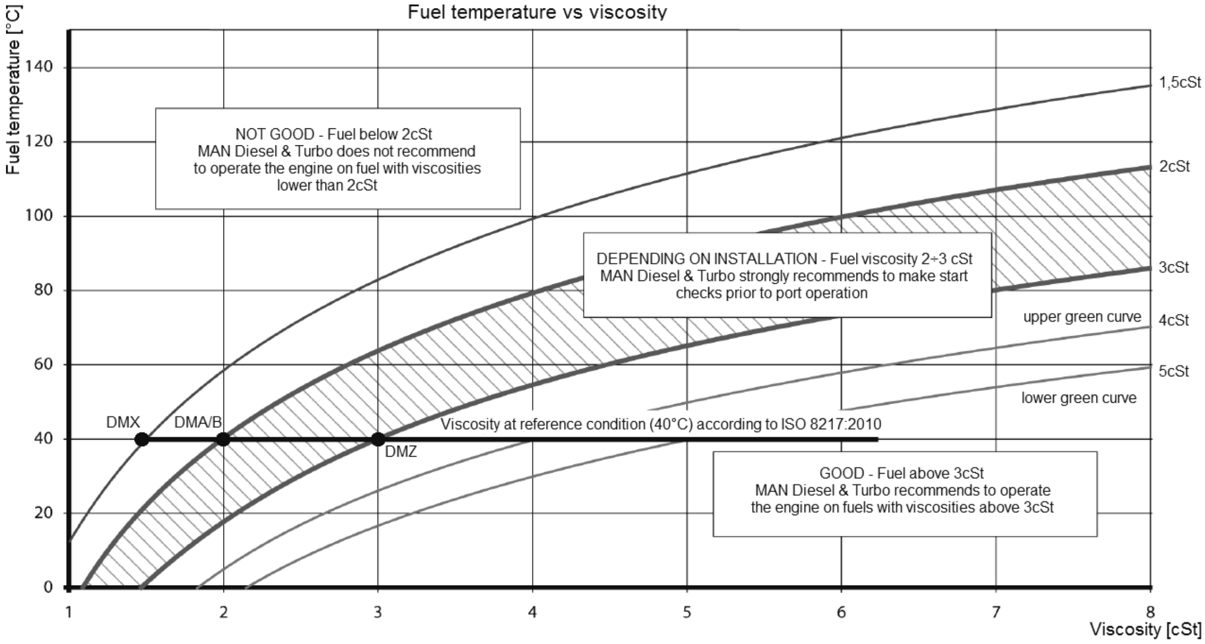

Fig. 1. Correlation between temperature and viscosity for different distillate fuel grades

Relationship between fuel viscosity and temperature has a significant influence on change-over process. Higher the temperature, lower the viscosity. Both residue overcooling as well as distillate overheating are not advisable, due to risk of fuel pumps overloading or fuel gassing-up in surge lines. During the proper operation, the temperature difference between these fuels can amount over 100 °C. Change-over procedure from HFO heated nearly 150°C to at least 40/50°C MGO/MDO and vice versa must be carried out with maximum rate of change equal 2°C/min. Rapid or uneven temperature changes may cause thermal shock damaging the injection equipment. If “cold” distillate, introduced at engine room ambient temperature, quickly reaches the circulation system at injection temperatures proper for HFO, then it causes precise pairs clearances decreasing. It is connected with uncontrolled thermal contraction of these elements. During the change-over process, a mixture of fuels with significantly different properties is circulated within the fuel system. For instance if the change-over to HFO is in progress, the fuel temperature would be increased at a steady rate. Simultaneously, HFO is slowly introduced into the fuel circulating system through a mixing valve. By mixing with distillate fuel in mixing tank, it gradually displaces distillate from the system. Throughout the process the appropriate fuel viscosity must be maintained adequately to fuel temperature rising. That being so, complete change-over procedure takes some time, even over 60 min for temperature adjustment only. Reduction of engine load (30-70% MCR – manoeuvring speed) can be useful in order to limit the fuel flow rate through the system. Solution, which makes independent from load factor and also simplifies the switching process refer to automatic fuel change-over system e.g. Diesel Switch produced by MAN Diesel & Turbo [3, 5].

3. Chilled water unit – chiller

In direct cooling, heat dissipation is introduced in straight line between fuel and coolant. If the vessel has a seawater cooling system, double walled coolers with titanium plates are required, which are quite expensive. Sweater-Freshwater heat exchanger protects against leakages. Freshwater it is cooling fuel through Freshwater-Fuel Oil cooler. A direct Seawater-Fuel Oil connection is not allowed due to possible leak of fuel to seawater. In case of central cooling system, freshwater can be a coolant. Heat dissipation capacity is sufficient to fulfil the ISO 8217 fuel oil specification, temperature can be controlled automatically and there is no need for additional pump and separate cooling medium. Unfortunately, in both cases coolant can cool the fuel to 40°C. Another solution is cooling by refrigerating compressors of direct expansion connected by a cooler. It is relatively simple and no so expensive, but it is difficult to control accurately the cooling temperature of refrigerant inside the cooler. An unfortunate turn of events may result in cooling of distillate below its pour point (paraffin will be produced) and consequently blocking of the cooler. In addition, there is a limit of operation on low load (below 25%) and the risk of fuel contamination with refrigerant. In 2010 Danish company Novenco introduced chilled water unit with fuel oil cooler designed for low-viscosity MGO/MDO. Novenco Hi-Pres® MGO Cooling System or Cooling Marine Chiller – QCM cools the low-sulphur fuel to rise its viscosity independently of seawater temperature. Solution contains indirect cooling, in which the heat dissipation is as follows: water from low temperature cooling circuit LT (25-36°C) is a coolant for refrigerant (tetrafluoroethane R134a or zeotropic mixtures R404a and R407c), which cools the chilled water (low-temperature water in aqueous solution with ethylene or propylene glycol due to inconvenient coagulability in 0°C) in closed circuit. While chilled water receive heat from fuel oil. In chilled water system, heat is removed through vapour compression or an absorption refrigeration cycle, which is shown in Fig. 2. System allows stable running conditions at practically any load and ensures precise control of surface temperature in coolers. Risk of fuel contamination with chilled water was eliminated thanks to chilled water pressure decrease from 6-10 to below 2 bar (whereas fuel pressure in cooler amounts app. 6-8 bar), what guarantees system leak tightness from the water side. Furthermore, system can cool the fuel below 0°C if necessary [6-8].

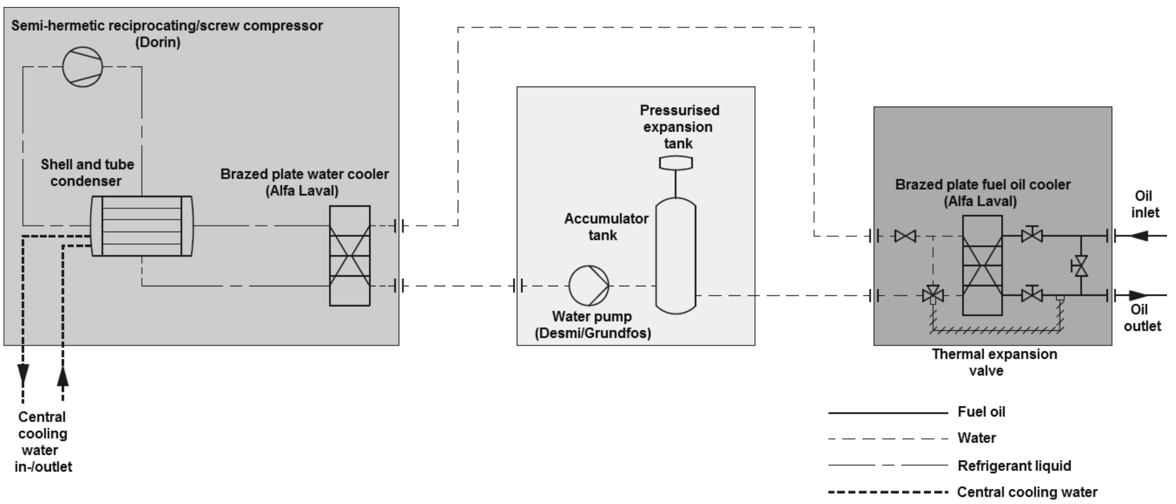

Fig. 2. Working principle of Novenco's QCM chiller unit with single condenser

Cooling capacity of units with single condenser range is from 30 to 210 kW. Whereas, range of units with twin condensers is doubled; and amounts adequately to 60-400 kW. The performance of the cooling plants depends on how the actual system parameters compare to the system design parameters. Applied PLC control system Siemens Climatix with electronic expansion valve guarantee a very precise fuel temperature control within 2 °C at all conditions. In addition, the unit output is accurately controlled with range specified for individual compressors. At the same time, it can control of up to four independent chilled water consumers. However, the heat load given by the fuel to the chiller must be enough, when running at minimum load to keep the compressor running. Normally, applied compressor can only unload to 25% of its full capacity. The unit automatically stops when the output demand drops below that point. It restarts after a preset delay time when the output demand again rises above the minimum compressor capacity. The compressor can only start/stop a specific number of times per hour to prevent the motor from overheating. Accurate temperature control at low load is problematic if not considered carefully. One of technical solutions to counter this problem is hot gas bypass control, which allows reducing the cooling capacity even further [8, 9].

With reference to fuel oil cooler with chiller assembly in fuel oil system, Novenco suggest three possible solutions. First one, so called in-line cooling intends to assembly the unit after the circulating pumps and fuel oil heater but before the viscometer. Characteristic of this solution contains fast load adjustment reaction time and minimum power consumption. Although, there is on/off regulation when load <15% of design capacity. Another idea is a proposal for the installation of a distillate service tank-cooling module. This approach allows the chiller to work with a larger energy mass, as it cools all the fuel in the service tank rather than just cooling the fuel circulated by the booster pump. This gives the chiller a much better working characteristic as the service tank acts as a buffer tank. As a result, chillier is allowed to work for longer periods of time when the engine load (fuel consumption) is at minimum. The advantages of this solution are as follows: low operating cost and stable running conditions at low capacity. However, the distillate service tank requires insulating. The last variant is a symbiosis of both mentioned solutions. "Unit start" temperature measuring point is set at the engine fuel inlet and “Unit stop” temperature measuring point is set at the outlet line from fuel oil cooler to the service tank. Besides the requirement of service tank insulation, the advantages of connecting in-line cooling with tank cooling are as follows: fast load adjustment, optimal running conditions at all capacity levels (0-100%) and 15% system redundancy. From an operational point of view, it is recommended to install the cooler after the circulating pumps and before the viscometer, thus it is possible to optimise the viscosity regulation at engine inlet. This location guarantees the fastest reaction time of the fuel temperature control. What is more, cooling system becomes independent form the heat cumulated in the heater or in case of its working or lack of bypass. Possible decrease of fuel viscosity below 2 cSt at the supply and circulating pumps should be considered as a matter of technical issue with fuel pumps designed for operation on low-sulphur fuel [8].

4. Automatic fuel change-over system – Diesel Switch

Solution offered by MAN Diesel & Turbo i.e. Diesel Switch is a retrofitted device formerly used for a fuel change-over from marine diesel oil to liquefied natural gas. Shown in Fig. 3, it is characterized by high degree of automation and control, at the same time guarantees necessary flexibility and safety of carrying procedure. Product carries out change-over from HFO to MDO/MGO and vice versa with keeping up proper temperature gradient and it monitors a periodic operation on mixed fuel. Thanks to that, risk of damaging the engine injection equipment decreases, thus avoiding loss of power or even loss of propulsion. Interesting retrofit was introduced by German company LEMAG Lehmann & Michels. Produced under license from MAN, LEMAG CONTROLmag realizes the fuel change-over process based on both temperature gradient as well as medium flow. Also shown in Fig. 3, DIESEL switch 1 is completed system delivered on a foundation containing following elements: automatic change-over valve, integrated static mixing tube, electronic cabinet with advanced software, two non-return valves and two automatic shut off valves. Necessity of applying static mixer is caused by need for periodic mixing of both fuels in arbitrary proportion, with increased participation of fuel, upon which the fuel system is switched.

It takes place before feeding the supply pump suction with fuel. What is more, mixer is connected with automatic temperature stabilization system. If the difference in supply pressure of both fuels is too large, it is necessary to install the DIESEL switch 2, which consists of an additional MDO/MGO pump module to adjust the pressure accordingly [10].

Fig. 3. Products Diesel Switch (L) and DIESEL switch 1(R) manufactured by MAN Diesel & Turbo and LEMAG Lehmann & Michels

Fuel change-over carried out with typical three-way ball valves does not guarantee a safe process realization. They are usually controlled only in reference to different inlet temperature of the different fuels. As a result, they are controlled to work in steps to allow the fuel system to compensate the temperature changing steps. In case of different tank levels, they have to be adjusted sensitive, what is not so simple. Range of their movement amounts 90°C, but researches carried out by LEMAG discovered that only 4-8% movement of a lever could cause 90% change-over, as shown in Fig. 4. However, fuel on the tank on the higher filling level was the dominant fuel passing the valve. It is caused by presence of significant fuel pressure differences induced by different level in the fuel service tanks. This can be almost be compared to a distillate on/off switch, which puts the engine under great risk of a thermal shock.

Thanks to the PLC controller and especially designed non-proportional valve with orifice equipped with exchangeable inserts, it is possible to reach linear change-over process. It is important, because the clearance between fuel pump precise pairs is often below 15 μm and the tolerance is often only 1 μm. Reaching a proportional characteristic minimizes a risk of damaging these elements. Mentioned inserts have special opening surfaces inducing turbulent flow, which compensate pressure differences up to 2.5 bar. System can handle with different tank levels up to 25 m, without necessity of additional MDO/MGO pump module installation. In this way, product can be assembled to any kind of fuel system, both on new buildings and existing vessels. Moreover, non-proportional change-over valve is hermetically sealed by magnetic coupling to avoid any leakages. Previously, engine manufacturers advised to reduce the engine load to 30-70% before carrying out a change-over procedure. Diesel Switch becomes independent from that factor, due to the constant checking temperature versus time. If the fuel temperature at the engine inlet exceed 2°C/min or rate of change is too rapid, the system will then freeze the process in current position. Thus, it avoids injection equipment damage from a thermal shock and at the same time generates an alarm. For safety, the system has a manual override; and can be stopped at any time. In addition, there is an integrated emergency start function, which flushes the fuel system with pure HFO, in case of overheating the distillate, to ensure that the engine can be started [10].

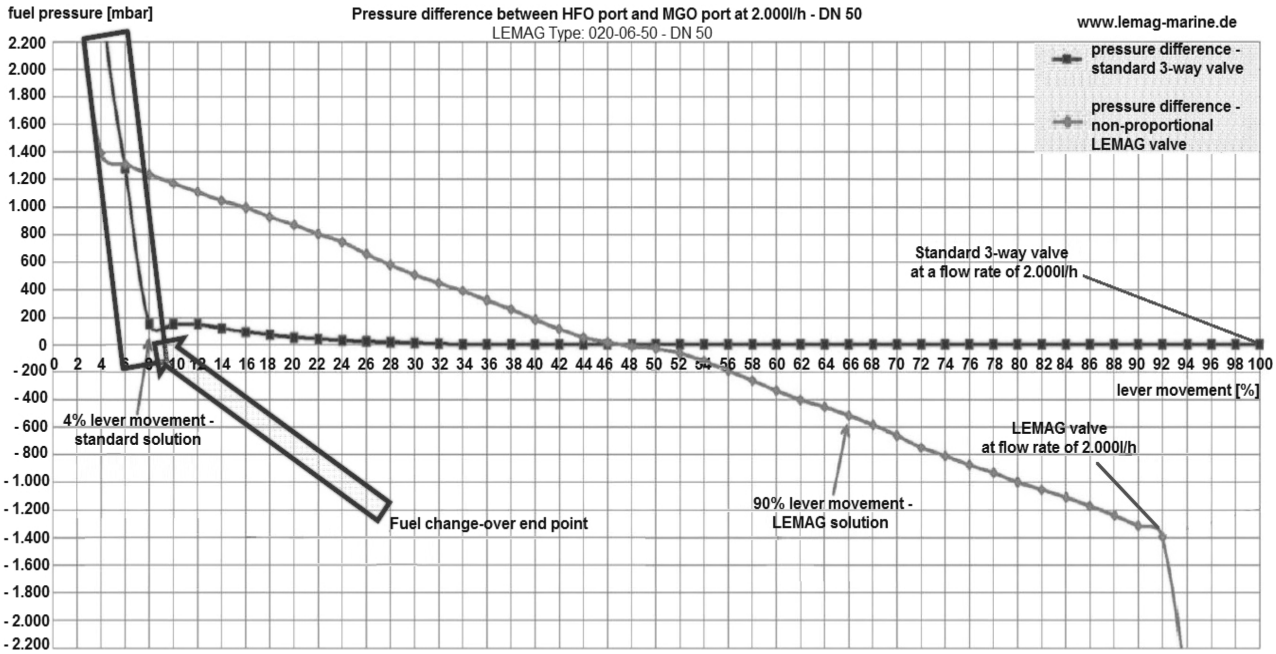

Fig. 4. Linear change-over process with LEMAG valve compared to the same operation with standard valve

To avoid improper operation and especially fuel viscosity decreasing, LEMAG CONTROL-mag® controls the fuel oil cooler operation and bypassing valve using a PID controller. Adequate synchronization is vital as after a certain amount of time the change-over process from residue fuel to distillate will no longer reduce the fuel temperature due to the rest heat energy in the booster circuit (i.e. fuel heater, strainers). What is more, fuel pumps create a lot of heat energy, especially during low load operation, which heats the MDO/MGO. In many cases, the fuel temperature will therefore not be reduced by just adding new fuel. For this reason, system therefore always runs and controls the cooler during the MDO/MGO mode to increase safety and protect the fuel system. Diesel Switch also rises an alarm if the distillate temperature is too high. To date, these situations were always created by non-closed trace heating systems. In addition, there is a risk of excessive temperature drop. If the cooler is operated manually and started too early, the temperature drop can be more than 12°C/min, which can severely damage the engine. If the cooler is not operated correctly and at the wrong time, the fuel flow through the cooler can easily be blocked by cooling down HFO. System also controls fuel pipes trace heating and the steam heating valve [10, 11].

System is intuitive to use and all the user has to do is as follows: choose period for change over, choose change-over direction start the process. Touch-screen control panel enables hardware control, constantly displaying status of change-over, current temperature change rate before engine inlet and remaining change-over time. In addition, it allows controlling MDO/MGO cooler and adjustment of fuel temperature. A tamperproof data-logger gathers information, in case of possible use as official documentation for port authorities if required. It can be proved that was used in regulated areas for the correct fuel. It is worth noticing that in some regions such recording is obligatory and regulated by law. The data is based on integrated sensors indication, i.e. the one for detecting current and end positions. Furthermore, they concern alarm history log and also course of operation like change-over start time, moment when HFO or MFO/MGO pipes were completely closed and period after which the remaining HFO in the booster circuit is fully consumed. The last value is establish based on engine load factor. Optionally, the system can correlate the tome with the GPS position. To avoid unnecessary distillate fuel consumption, LEMAG's product automatically calculates the exact fuel change-over start point, to ensure the booster circuit is fully flushed of HFO just before entering an ECA [10].

Summary

A proposed system fully complies with requirements for the design of marine fuel oil system arranged to burn heavy fuel oil and low-sulphur grade. It enables a smooth and controlled fuel change-over from residual grade to distillate and vice versa. Ultimately, a proper distillate fuel is DMZ grade, which was formed with the idea of safe engine operation, which can interchangeably burn also heavy fuel oil. A proposed automatic fuel change-over system Diesel Switch and fuel oil cooler with chiller allows using DMA or DMB grades either. Any fluctuations on a viscosity-temperature line is registered immediately and cooling system enables fuel temperature decrease even below 0 °C. Thanks to the fact, navigation both on international waters as well as in ECA or other special areas with more demanding local regulations proceeds smoothly, with a considerable safety margin.

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