ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2773-6202 (Online)
CODEN: JTIOCC

Journal of Technology & Innovation (JTIN)

DOI: http://doi.org/10.26480/jtin.01.2023.29.37

RESEARCH ARTICLE

DESIGN AND FABRICATION OF HEATING DEVICE FOR VEGETABLE OIL USED FOR DIESEL ENGINES

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ARTICLE DETAILS

Article History:

Received 18 January 2023
Revised 11 April 2023
Accepted 26 April 2023
Available online 15 May 2023

ABSTRACT

Countries worldwide are recently interested in economic efficiency in line with protecting environmental protection. Generally, optimization of cetane number, expanding fuel sources, and producing clean fuels with less pollution at the development trend in diesel fuel. Faced with that situation, global energy security is one of the top goals worldwide that can be ensured by diversifying energy resources parallel with minimizing fossil energy dependence. Among solutions, biofuel in internal combustion engines is a potential approach that receives great attention from global researchers. Among biofuel sources, vegetable oil or animal fat can be employed directly on compression-ignition internal combustion engines. This study presents a method to design and manufacture a system that utilizes exhaust heat with integrated electrical energy to heat vegetable oil for direct use in diesel engines.

KEYWORDS

Vegetable oil; Heating methods; Diesel engine; Waste heat recovery; Integrated energy

1. INTRODUCTION

Over the years, pollution of the ecosystem and excessive exploitation of natural resources are being concerned issues in all corners of the world. It is important to remark that air pollution is majorly caused by exhaust gas emitted from vehicles. The more developed technology and science, the more advanced means are invented to meet modern society. A question for researchers is how to mitigate emissions causing environmental pollution as little as possible and create renewable energy sources replacing fossil fuel that is more and more increasingly deplete. The products of burning fossil fuels include SO_2, SO_3, NOx, CO, CO2, hydrocarbons, and particulate matter; SOx causes corrosion in the machine, adversely influence human health, and is a reason for meteorological phenomena such as acid rain. Additionally, the incomplete combustion of fuel is the main cause of generating greenhouse gas. Components of hydrocarbon, such as aromatic compounds in the exhaust gas, are especially serious to humans, which is the reason for cancer. The exist of Particulate matter (PM) in emissions is difficult to recognize, which strongly pollutes the surrounding air and causes respiratory and cardiovascular diseases. Nations are currently interested in economic efficiency in line with protecting environmental protection. Generally, optimization of cetane number, reducing traffic, expanding fuel sources, and creating clean fuels with less pollution are the development trend in diesel fuel. Facing that situation, reducing emissions of environmental pollution ensures energy security. Diversification of energy resources and minimization of fossil energy dependence is one of the priority goals of the developed country. Using biofuels in internal combustion engines (ICE) is a critical solution and is attractive to countries.

The definition of biofuel is any fuel that is derived from biomass. They can be bioethanol, biodiesel, biogas, ethanol-blended fuels, dimethyl ethers, and vegetable oils. Bioethanol, biodiesel, and ethanol mixed gasoline are the main biofuels currently used in transportation. Bio-oil is a solution using biofuels comprised of either vegetable oil or animal fat that can be applied directly in compression-ignition internal combustion engines. Biofuels are produced from compounds of animal or plant origin. Fuel made from animal or vegetable oil (animal fats, coconut oil, waste vegetable, grains (wheat, corn, soybeans), agricultural wastes (straw, syngas, corn plants, orange), industrial waste products (sawdust, waste wood products, waste cooking oil), and algae (Soudagar et al., 2020; Sunnu et al., 2019; Dey and Ray, 2019; Gouran et al., 2021; Jannatkhah et al., 2019; Vellaiyan et al., 2018; Gavhane et al., 2020; Sivasaravanan et al., 2019; Singh et al., 2020; Sekar et al., 2021; Nayak et al., 2017; Yesilyurt, 2018; Dubey et al., 2020; Nair et al., 2020; Kalaimurugan et al., 2019). The usage of vegetable oils has been studied since the diesel engine was developed. From 1858 to 1913, the inventor of the diesel engine Rudolf Diesel applied peanut oil for his test. Until now, various vegetable oils have been studied to create alternative energy resources, such as jatropha oil, soybean oil, linseed oil, cottonseed oil, mahua oil, coconut oil, neem oil, castor oil (Kumar et al., 2019; Akram et al., 2021; Karakaya, 2020; Ganesan et al., 2020; Kumar et al., 2018; Narayanasamy et al., 2018; Nayak et al., 2017; Chandra Sekar et al., 2020; Pathmasiri et al., 2019). Most of the publications showed the good performance of vegetable oil as used in the diesel engine (Manchanda et al., 2018). However, their higher cost and some engine issues, especially direct-injection engines, are their drawbacks. The viscosity of vegetable oils is high that forms coking in the injectors causes poor atomization along with engine deposits. It is noted that when the preheating temperature increases, the viscosity will gradually decline. Additionally, due to the surface tension and viscosity being affected by temperature, heating fuel will decline its arithmetic diameter that minimizing the trouble in the injection process. Hence, the spray formation and combustion process improve. Transesterification, pyrolysis method, dilution with petroleum-based fuel, and emulsification are also solutions for reducing vegetable oil viscosity. This paper will discuss details on feedstock (vegetable oils), preheating method for biofuels.

2. CHARACTERISTICS OF BIOFUELS USED IN DIESEL ENGINES

Bio-based oil, normally comprised of either vegetable oil or animal fat, is

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refined fats and unmixed with other fuels to use as fuel for diesel engines. Bio-oil is symbolized as VO100 (the letter V specifies the vegetable oil name) or AF100 (the letter A specifies the animal fat name). The major component of bio-oil is long-chain fatty acids (**Figure 1**).

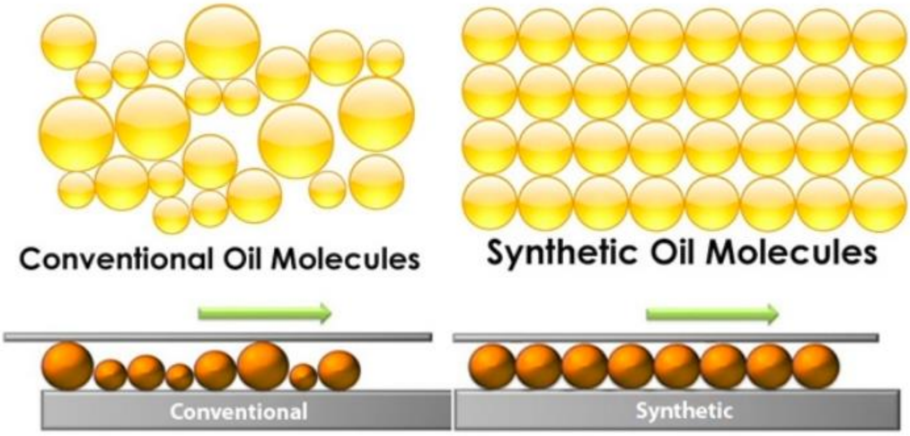

Figure 1: Molecular structure of the base bio-oil

Bio-based oils are triglyceride molecules and have three hydrocarbon chains attached to a glycerol base. As a result, high density and viscosity are its characteristics (Ranjit et al., 2020). The base bio-oil can be classified into edible and inedible vegetable oils. Sesame oil, soybean oil, or coconut oil are edible, while cottonseed oil, jatropha oil, and rubber seed oil are inedible vegetable oils. The main chemical composition of the base bio-oil is an ester of glycerol with saturated or unsaturated fatty acids. The common saturated fatty acids are palmitic (16: 0) and stearic (18: 0), while popular unsaturated fatty acids include oleic (18:1) and linoleic (18:2). Compared to fossil diesel fuels, the base biodiesel has a much larger molecular mass; the molecular formula of the base biodiesel has the form $C_{27-57}H_{54-104}O_6$ (Sheet, 2018). As can be seen in **Table 1**, the base biodiesel contains molecular oxygen, very little sulfur, and aromatic compounds, so the base biodiesel has a less negative effect on the environment.

The physical properties of the base bio-oil affect the quality of combustion greatly and are characterized by important parameters like density, viscosity as well as surface tension **(Table 2**). These parameters affected the magnitude of the van der Waals intermolecular forces. The improvement of the molecular weight can be made by increasing the carbon chain length, which leads to the enhancement of the magnitude of the Van der Waals forces; hence, the viscosity is increased (Acharya et al., 2014). Moreover, the atomization quality of the fuel was determined strongly by these properties that are proved to be an inverse relationship with the temperature (Satyanarayana et al., 2012). It is necessary to improve the above parameters within the allowable range and close to the value of traditional diesel fuel when using bio-based oil directly in diesel engines (Ozsezen, 2012). Base biodiesel's flashpoint, cloud point, and pour point are higher than base biodiesel and conventional diesel fuel. For this reason, bio-based oils are almost incapable of working at low temperatures due to the loss of fluidity of the liquid fuel.

The heat value of the base bio-oil depends on the saponification index (SV) and the Iodine index (IV), an increase of SV and IV means an increase in the number of double bonds (-C = C-), thereby reducing the heat. Cetane numbers determine how fast the ignition of the liquid fuel in the cylinder is after the engine's ignition is forced (Dai et al., 2021). The cetane number of biodiesels is usually smaller than the base biodiesel and traditional diesel fuel (**Table 3**). Studies have shown that the cetane number of the base biological oils containing linear chain saturated hydrocarbon is a generally higher or branched chain containing benzene ring (Acharya et al., 2010).

Table 1: Chemical Composition of Base Bio-Oil, Base Biodiesel, and D2 Diesel Fuel

No.	Chemical composition	Vegetable oils	Biodiesel	D2 Diesel fuel
1	Carbon content, %kl	73-77.6	75-77	83.5-87
2	Hydrogen content, %kl	11.6-12.3	11.6-12.5	11.5-14
3	Oxygen content, %kl	10.8-12.5	10.75-11.82	0
4	Sulfur content, %kl	0.006-0.02	0.006-0.02	0.02-0.05
5	Nitrogen content, %kl	0.002-0.007	0.002-0.007	0.0001-0.0003
6	Content of aromatic compounds, %tt	0	0	28-38
7	Iodine Index	70-157	65-156	0
8	Ash content, %	0.002-0.03	0.002-0.036	0.006-0.01

Table 2: Viscosity, Density, Surface Tension, the Flashpoint of Base Biodiesel, Base Biodiesel, and D2 Diesel at 40⁰C

No.	Fuel	Kinematic viscosity at 40°C, cSt	Density, kg/m ^{3}	Surface tension, mN/m	Flashpoint, °C
1	Biodiesel	3.5-5	870-885	27.8-29	110-180
2	Vegetable oil	24-48	903-924	31-35	195-270
3	Diesel fuel D2	2.7-3	822-837	24	73

Table 3: Heat Value, Cetane Number, Cloud Point, and Pour Point of Base Bio-Oil, Base Biodiesel, and D2 Diesel Fuel

No.	Fuel	Heat value, MJ/kg	Cetane number	Cloud point, °C	Freezing point, °C
1	Base Biodiesel	38-40	50-70	1-12	-15÷ -7
2	Base bio-oil	37-39.5	28-42	3-15	-6÷ -2
3	Diesel fuel D2	43	48	-14	-30

The advantages of biodiesel as an alternative fuel are its fluidity, regeneration ability, low sulfur, and aromatic content, availability, and biodegradability (Yan and Song, 2019). There are no standards for bio-based oils as engine fuels, but to use them, it is necessary to rely on several standards for diesel fuel. Nevertheless, the major drawback of biodiesel base is that its viscosity is 10 to 17 times higher than traditional fuel (Pourabdollah et al., 2013); with the density and surface tension, large possibility evaporates less, and reaction unsaturated hydrocarbon chains should easily degrade the oil. Several results were obtained from the base biodiesel usage on diesel (Ademodi et al., 2015). See it on the injector cup, adhesive cement serge, and denatured lubricant. **Figure 2** shows several advantages and disadvantages of the base biodiesel fuel compared with traditional diesel fuel. Base biodiesel understood according to QCVN 1:2009/BKHCN, is a fuel obtained through the esterification process with alkanols from biological materials (vegetable oil, animal fat, or other products), with ingredients are mono-alkyl esters (usually methyl esters or ethyl esters) of long-chain fatty acids, unmixed with different fuels to employ as fuel in diesel engines, symbol B100.

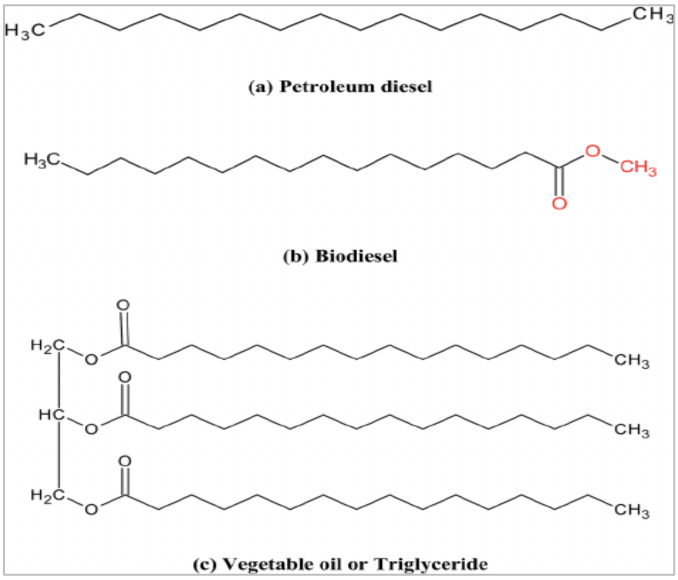

Figure 2: Molecular structure of the original biodiesel

Differences in structure and molecular composition affect the properties of the base biodiesel. The base biodiesel properties are viscosity, density, surface tension, cetane number, freezing point, flash point, calorific value and elemental composition, ash content, and ash content. Sulfur, carbon deposits, acidity. Chemical analysis shows that the molecular formula of the original biodiesel has the form $C_{15-25}H_{28-48}O_2$. Hence, the original biodiesel component contains oxygen, which makes the original biodiesel burn cleaner than diesel fuel. However, the original biodiesel contains large acid nitrogen content greater than diesel fuel, which increases emissions of NO_x and causes corrosion. Viscosity, density, and surface tension are the most important properties of base biodiesel due to their effects on the injector's performance, especially at low temperatures where viscosity, mass specificity, and high surface tension affect the fluidity of the fuel (M.R. et al., 2021). When the viscosity, density, and surface tension are high, that leads to reductant of fuel atomization and poor injection. Reducing these parameters will easily facilitate atomization (Xiang et al., 2011). Compared with the base biodiesel, the base biodiesel has a molecular weight of only one-third. The density is reduced by about 4%, the viscosity is reduced by about eight times, and the surface tension is reduced by about 15%. Biodiesel derived from animal fats has a higher viscosity, density, and surface tension than those derived from vegetable oils. It is noted that the ignition quality of the fuel is characterized by the cetane number (CN). The obtained data from references indicated that the CN of fossil fuel is normally lower than that of the base biodiesel. The CN of animal fat-derived biodiesel is higher than that of vegetable oils-derived biodiesel (Demirbas, 2009). Besides, cloud point (CP) and pour point (PP) are necessary parameters when investigating the use of base biodiesel at low-temperature conditions. The CP and PP of base biodiesel are higher than fossil diesel. Meanwhile, improvement of the combustion process is related to the oxygen content; thus, the combustion efficiency of the base biodiesel is higher than conventional fuel. The calorific value of the base biodiesel is relatively high, about 37 - 41 MJ/kg. Thus, the benefits of biodiesel usage are availability, regeneration, low sulfur, and aromatic compounds, better combustion efficiency (Liu et al., 2017), high cetane number, and high availability. Biodegradability, high flash point, and good lubricating properties (Chung et al., 2011). However, the original biodiesel also has some disadvantages compared to diesel fuel, such as being easily decomposed by bacteria because it is derived from vegetable oils and animal fats, high cost, and damaging high-quality components. Rubber in the fuel system (some studies have found FKM- GBL-S and FKM- GF-S synthetic rubbers to replace conventional rubber parts), and there is a possibility that it reacts with some metallic materials due to the small number of free acids in the composition (Balat, 2008; Bagci, 2006). Currently, QCVN 1:2009/BKHCN or ASTM D6751 have set standards for biodiesel for direct use in diesel engines (**Table 4**).

Table 4: Standards for B100 Base Biodiesel

No.	Component	Test method	QCVN 01:2009	ASTM D6751
1	Flashpoint, °C, min	D93	-	130
2	Water and sediment content, % by the maximum volume	D2709	0.05	0.05
3	Kinematic viscosity at 40°C, mm ^{2}/s	D445	1.9-6.0	1.9-6.0
4	Sulfur content, % mass, maximum	D5453	0.05	0.05
5	Ash content, % mass, maximum	D482	0.02	0.01
6	Number of cetane, minimum	D613	47	47

3. Methods of Heating Biofuels Used In Diesel Engines

3.1 Steam Heating Method

Due to water and steam having high heat transfer efficiency and ease of control, their usage for heating oil is popular and the most efficient method (Guowie et al., 2019). However, water evaporates to become water vapor at boiling temperature to only work as a pressurization system. Additionally, they have a limitation of safety as operating. It is necessary to have a device known as a boiler that generates steam to heat fuel. The steam for heating fuel accounts for 60% to 80% of the total steam yield produced by the boiler. After that, the steam will condense into water and back to the boiler. A coiled tube is widely used in boilers. The steam will flow in the coil tubes through the main steam pipe is superheated steam. After transferring heat to the oil, the majority of the steam condenses into water, and then the condensed water will be backed to the bulb of the boiler (Zafar et al., 2021). The disadvantage of this method is that there is a possibility that the section of the pipe running in the oil chamber is flooded with condensed water. Oil leakage will happen when the joints (welded) have been broken or the pipes appear as holes (**Figure 3**).

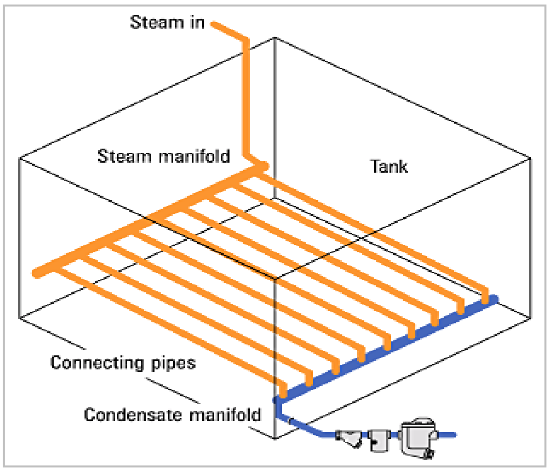

Figure 3: Steam Fuel Heating Diagram

The steam fuel heating method is often applied in oil tankers to warm cargo oil and heat FO fuel in the tanks simultaneously before being injected into the engine. Nevertheless, it is not easy to set up a steam heating system in small diesel engines. Additionally, the temperature requirement for heating oil in each tank is different and it is difficult to control the steam temperature or pressure. Furthermore, sensor devices to measure the temperature and viscosity of fuel before being injected into the cylinder are necessary to be fabricated in engines that use HFO of FFO. An electrical heater or high-temperature steam is also needed to ensure fast heating.

3.2 Thermal Liquid Fuel Heating Method

Thermal oils or thermal liquids for heat transfer are widely used in preheating fuel, machining metal, and applications cool machines. They are mostly applied in high-temperature equipment and systems where the optimum temperature of a thermal oil or thermal liquids ranges from 150ºC to 400ºC. Using thermal liquids is safer and more effective than the above methods **(Figure 4**).

The application of thermal oils is unstable if the temperature is higher than the preset steady temperature over operating periods. This leads to the thermal oil pipes broken, and thermal oil is oxidized and thermally unstable. Therefore, the thermal oil system gets troubles during the operation period. In practice, thermal oil systems are easier to design and safer than boiler systems, maintaining and stabilizing temperatures well for selected applications. Synthetic substances, or aromatic compounds, are liquids not produced by nature, specially designed for heat exchangers. Their structure contains benzene, diphenyl oxide/biphenyl liquids, diphenylmethane, dibenzyltoluenes, and terphenyls (**Figure 5**). The advantages of synthetic substances are high temperature and heat transferability. The safe operating temperature of synthetic substances is up to 400ºC, whereas non-synthetic substances are lower than 300ºC. The organic compounds include light hydrocarbons, and high molecular weight species are the main elements of crude oil (Senel et al., 2018). Compared to synthetic substances, the advantages of thermal oils are cost and processing processes (Zou et al., 2021). Additionally, petroleum-based liquids do not form dangerous toxins or unpleasant odors. However, thermal oils are not stable at high temperatures because of unsaturated substances with double bonds. They also are easily oxidized (Gopalan et al., 2021). To a greater extent, silicone-based fluids and glycol hybrid fluids are primarily used in specialized applications where process-product compatibility is required. The efficiency and cost are more disadvantageous than synthetic substances and heating oil in the temperature range. The selection of silicones and other specialty fluids is not easy for most applications (Arslan et al., 2021).

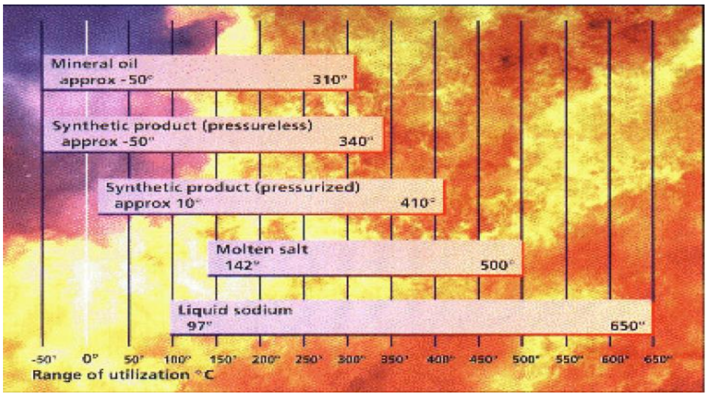

Figure 4: Operating temperature ranges of some thermal fluids

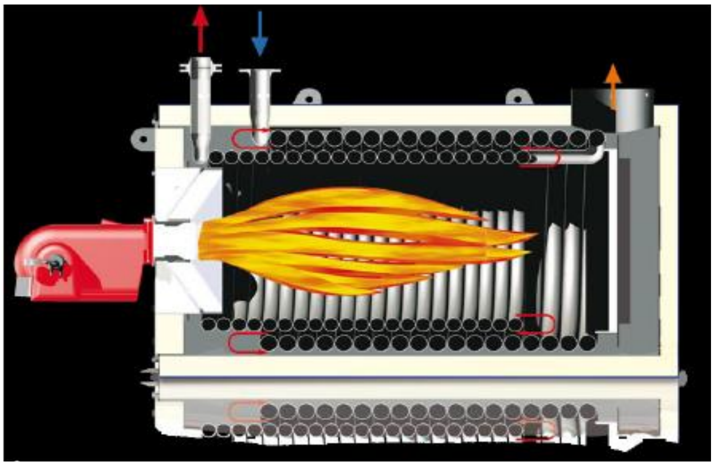

Figure 5: Thermal oil furnace

In general, the main components of a thermal oil system include a furnace where fuel is burned, a heat exchanger for transferring heat, a vent, an expansion tank, and pumps (Tayakkoli Osgouei et al., 2018). Liquid oxidation can be avoided by coating an inner gas like nitrogen in expansion tanks, and vents to the outside are also used in some cases.

3.3 Electric Fuel Heating Method

For electrical heating systems, this is done by allowing oil to contact conductive parts, majorly the busbars. The disadvantages of the steam heating method can be overcome by this method. There are both direct and indirect electrical heating (Ezekwem and Dare, 2020). There are both direct and indirect electrical heating. The direct heating method consists of bar-type thermistors placed in the fuel tank. Bar-type thermistors are contacted directly to fuel in direct electrical heating, or fuel will flow through the heater (**Figure 6**). Meanwhile, additional devices transfer heat to fuel through the tank walls in the indirect electrical heating method. The location of the heater normally is at the lowest fuel level in the tank. In this method, the heating efficiency can be reached near 100% because the fuel receives heat directly, which speeds up the healing process and reduces thermal lag time. Heat loss is lower than in the indirect method because of no need for an intermediate heat transfer part. This method has the disadvantage of limitation of liquid surface area. Hence, when designing the system, it needs to prevent contact between the heater and air during the operation time, if not the heater can be destructed due to excessive temperature. Additionally, it needs to ensure no corrosion or electrical leakage. Moreover, to avoid fouling at the tank's bottom, the heater has to be installed at a certain distance from the bottom of the tank.

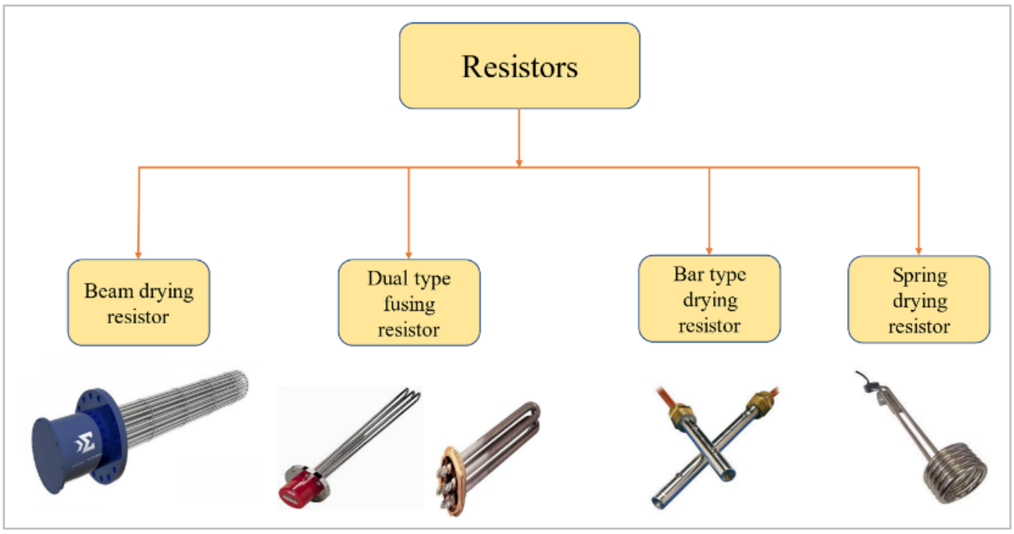

Figure 6: Types of resistors

The heat is transferred to the fuel tank walls in the indirect reheating method. This temperature can change from the outside by using the tank wall as a heater. The main benefit of the indirect reheating approach is that the heating and drying process can take place continuously without removing the tank from the tank (Chintala and Kumar, 2021). Additionally, in indirect fuel reheating, the heat is transferred through a larger surface area, reducing the current density in contact with the fuel. Furthermore, overheating can be prevented by controlling the temperature of the heat transfer medium. Meanwhile, increased heat loss and thermal hysteresis are drawbacks of this method.

4. Design Theory Of The Base Bio-Oil Fuel System

The integrated electro-exhaust gas reheat method initially recirculates the fuel through the exhaust heat recovery system, then pumping back into the tank. Here, the fuel continuously is heated by electricity to reach the requested temperature before injecting into the engine. If the fuel is not reached the required temperature through the exhaust heat recovery system, the electric heater will heat the fuel. The heat of exhaust gas energy is usually utilized in the boilers or turbines frequently set up on large transportation mode installed boilers or turbochargers (**Figure 7**). Because of the above reasons, the fuel-exhaust integrated fuel heating system is difficult to apply on heavy vehicles with a long operating time of engines. Nevertheless, the study's object is small engines fabricated on vehicles or agricultural machines with long service life and short time operation. Generally, there is no system to utilize exhaust gas heat, hence, it is better to use an electric-exhaust integration type that not only helps the engine to start in cold conditions but makes use of the engine's waste heat also. Liquid-gas-smooth tube bulkhead heat exchanger (liquid goes in the tube, gas cross-section outside the tube) is used to absorb energy from the exhaust gas of diesel engine for bio-oil fuel. origin in the tube (**Figure 8**). Here the fuel needs to be heated in the smooth pipes, and the smoke from the combustion process cuts across the outside of the pipes, the smoke is arranged to go outside the pipes because it is easy to clean the outer surface of the pipes when dust from smoke clings. The total number of winding pipes n is determined when the fuel flow G_2 is known:

$$G_2 = n\frac{\pi d_1^{\ 2}}{4}\rho_2.\omega_2$$

$$n = \frac{4.G_2}{\pi d_1^{\ 2}\rho_2\omega_2} \qquad (1)$$

Where:
d_1 - inner diameter of the pipe, m
ρ_2 - fuel density, kg/m ^{3}
ω_2 - speed of the fuel in the pipe, m/s
The length of a meandering pipe l_1 is determined when knowing the entire heat exchanger surface area F of the device (surface area outside the tubes); we have:

$$F = n.l_1.z_i.d_2$$

$$l_1 = \frac{F}{nzd_2} \qquad (2)$$

d_2 - outside diameter of the pipe, m
z – number of rows of pipes; z = 2m (if staggered pipes), z = m (if parallel pipes)
m - number of times the pipe bends
The heat exchanger surface area is determined from the equation $F = \frac{Q}{k.\Delta t}$ and if by convention the calorific value of smoke Q_1, of liquid fuel Q_2, heat loss to the environment Q_1 and heat loss efficiency of the device η_t, we have:

$$F = \frac{Q}{k\Delta t}$$

$$Q_1 = Q_2 + Q_l$$

$$Q = Q_2 = \eta_t.Q_1 \qquad (3)$$

Here the mean temperature difference Δt can be approximated as the reverse device and determined:

$$\Delta t = \frac{\Delta t_1 - \Delta t_2}{\ln\frac{\Delta t_1}{\Delta t_2}} \qquad (4)$$

Where

t_1, t_2: the temperature difference between the two fluids entering and leaving the device. Heat transfer coefficient k can be calculated for the flat wall when $d_2 / d_1 < 1.4$

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \quad (4a)$$

δ – wall thickness = 0.5(d_2-d_1)
λ - coefficient of thermal conductivity of the pipe wall
α_1 – coefficient of heat transfer of smoke to the outer surface of the pipe, W/m ^{2}. K
α_2 – coefficient of heat transfer of the surface in the tube to the liquid fuel, W/m ^{2}. K
The heat emission coefficient of smoke α_1 here must include the radiation effect of the smoke

$$\alpha_1 = \alpha_{1đ} + \alpha_{1b} \quad (5)$$

α_{1d} - coefficient of convective heat of the smoke, W/m ^{2}. K
α_{1b} - radiant heat coefficient of smoke, W/m ^{2}. K
In general, the convection heat dissipation coefficient α_{1d} must take into account the influence of fouling on the outer surface of the pipe, so we have:

$$\alpha_{1đ} = \varphi . \alpha'_1 \quad (6)$$

With smoke stains on the outer surface of the pipe can choose φ = 0.8. The convective heat dissipation coefficient of the entire tube beam α'_1 is determined by:

$$\alpha'_1 = \frac{\alpha_1 + \alpha_2 + (z-2)\alpha_3}{z} \quad (7)$$

While ignoring the influence of the pipe in which the standard equation determines coefficient α heat 3 of the 3rd-row tube:

$$Nu_f = 0{,}41 . Re_f^{0{,}6} . Pr_f^{0{,}33} . A. . \varepsilon_s \text{ - with staggered hoses} \quad (8)$$

Or

$$Nu_f = 0{,}26 . Re_f^{0{,}65} . Pr_f^{0{,}33} . A. . \varepsilon_s \text{ - with parallel tubes} \quad (9)$$

Where:

A - factor taking into account the influence of heat flow direction,

$$A = \left(\frac{Pr_f}{Pr_w}\right)^{0{,}25} \quad (10)$$

ε_s - coefficient mentions the impact of the stepped tube,
With staggered tube:
ε_s = 1.12 when $s_1/s_2 \geq 2$

$$\varepsilon_s = \left(\frac{s_1}{s_2}\right)^{1/6} \text{ when } s_1/s_2 < 2 \quad (11)$$

With parallel tubes:

$$\varepsilon_s = \left(\frac{s_1}{d_2}\right)^{0{,}15} \quad (12)$$

The radiant heat coefficient α_{1b} is determined as follows:

$$\alpha_{1b} = \frac{q_b}{t_K - t_W}$$

$$q_b = C_h \left[\left(\frac{T_k}{100}\right)^4 - \left(\frac{T_W}{100}\right)^4 \right]$$

$$C_h = \frac{C_0}{\frac{1}{\varepsilon_k} + \frac{1}{\varepsilon_W} - 1} \quad (13)$$

Here
T_k - the average temperature of the smoke, K
T_w – average outside surface temperature of the pipe, K
ε_k – the blackness of smoke
ε_w - the black surface of the tube
C_o – radiant coefficient of the face of the absolute black body, C_o = 5.67
The blackness of smoke is calculated according to the average smoke temperature if $T_k > T_w$ or calculated according to the temperature of the pipe wall if $T_k < T_w$ and is determined by the formula:

$$\varepsilon_k = \varepsilon_{CO2} + \beta . \varepsilon_{H2O} \quad (14)$$

Here the black ε_{CO2} of CO_2 and H_2O is determined according to the graph depending on the temperature of the gases t_k, the product between the distribution of pressure p_i of gas and the average length of radiation l. The formula calculates the average length of the radiation beam:

$$\varepsilon_k = \varepsilon_{CO2} + \beta . \varepsilon_{H2O} \quad (15)$$

Where
d_2 – outside diameter of pipe, cm
s_1, s_2 – horizontal pipe pitch and longitudinal pipe pitch, cm
The pressure division p_i of the gas in the smoke is determined according to the volume composition r_i and the pressure p of the smoke:

$$p_i = r_i . p \quad (16)$$

β - correction factor in formula (2.14), including the dependence on pressure fraction p_{H2O} in the smoke here, normally ignores this effect, so β = 1.
The heat dissipation coefficient α_2 of the fuel in the pipe is determined by:

When laminar flow $Nu_f = 0{,}15 . Re_f^{0{,}33} . Pr_f^{0{,}43} . (Gr_f . Pr_f)^{0{,}1} . A. . \varepsilon_L . \varepsilon_R$ (17)

When turbulent flow $Nu_f = 0{,}021 . Re_f^{0{,}8} . Pr_f^{0{,}43} . A. . \varepsilon_L . \varepsilon_R$ (18)

Where
ε_l - coefficient mentions the influence of the pipe length,
ε_l = 1 when l ≥ 50d

$$\varepsilon_l = 1 + \frac{2d_1}{l} \text{ when } l < 50d \quad (19)$$

ε_R - a factor that takes into account the effect when the tube is bent,

$$\varepsilon_R = 1 + 1{,}77\frac{d_1}{R} \quad (20)$$

The Reynolds criterion of liquid fuel is calculated by the following formula:

$$Re = \frac{\omega_d d_1}{\nu_d} \quad (20a)$$

ω_n - speed of fuel in the pipe, m/s;
ν_n - viscosity of the fuel in the pipe, m ^{2}/s.
To calculate hydraulic impedance use the following formulas:

$$\Delta p = \Delta p_0 + \Delta p_m + \Delta p_c + \Delta p_g \quad (21)$$

Gravity impedance p_0

In an open system, when the medium is in contact with the atmosphere, the gravitational impedance is calculated by the following formula:

$$\Delta p_0 = \pm g.h(\rho - \rho_0) \quad (22)$$

Where
g – acceleration due to gravity g=9.81 m/s ^{2}
h – height between the input and output sections of the device, m
ρ – density of the atmosphere, kg/m ^{3}
ρ_0 – density of the atmosphere, kg/m ^{3}
Friction impedance p_m
With isothermal (T=const) or non-isothermal (T≠const) flow inside the tube, the frictional impedance is determined by the formula

$$\Delta p_m = \xi \frac{1}{d} \rho \frac{\omega^2}{2} \quad (23)$$

Here

d - inner diameter of the pipe, if the tube is not round, we use the equivalent diameter d_{ef}, m.

l – length of pipe or channel, m.

ρ – density calculated according to the average temperature of the medium, kg/m^3

- an average speed of the fluid flowing in the pipe, m/s

ξ - the following formula determines the coefficient of friction

When the fluid flows laminar,

ss$Re_f \leq 2.10^3$; $$\xi = \frac{64}{Re_f}\varphi \quad (24)$$

Re_f is Reynolds criterion calculated according to the average temperature of the medium φ = 1 if the tube is round, φ = 1.5 if the tube is not round

When the fluid flows turbulent $Re_f > 1.10^4$;

$$\xi = \frac{1}{(1{,}82.\log Re_f - 1{,}64)^2} \quad (25)$$

Local impedance p $_c$

The formula determines the local impedance

$$\Delta p_c = \xi\rho\frac{\omega^2}{2} \quad (26)$$

where

- density of the medium, kg/m ^{3}
- speed of the medium, m/s
- overall local impedance factor =∑ξ $_i$

ξ_i - coefficient of local impedance is determined by the experiment

When the flow through the straight valve ξ_i = 5 6.3

When the flow through the curved valve ξ_i = 3.2 5,3

When the flow through the inclined valve ξ_i = 2.5

As the flow enters and exits the chamber ξ_i = 1.5

When the flow rotates 180^0 in the U-tube ξ_i = 0.5

When the flow flows through the bend of the pipe ξ_i = 0.5

Acceleration impedance p_g

The formula calculates the acceleration impedance caused by the acceleration of the flow:

$$\Delta p_g = \rho_2.\omega_2^{\,2} - \rho_1.\omega_1^{\,2} \quad (27)$$

Where

ρ_1, ρ_2 - the density of the refrigerant into and out of the device, kg / m ^{3}

ω_1, ω_2 – speed of the medium entering and leaving the device, m/s

The acceleration impedance with droplet fluids has a very small value compared to other components, so it is often ignored (figures 7 and 8).

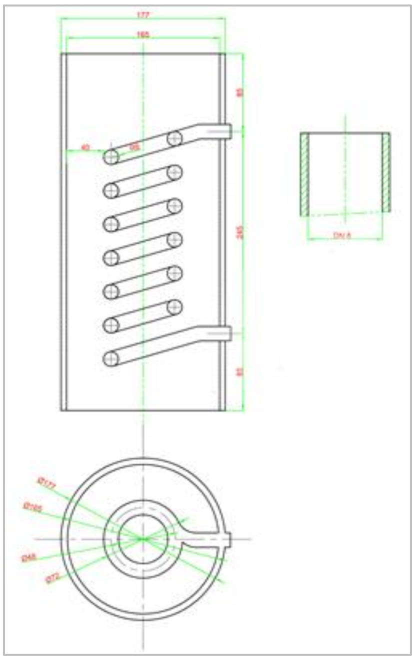

Figure 7: Structure of equipment utilizing exhaust heat

Figure 8: Heating oil system fabricated in a laboratory

5. Conclusion

For the last few years, the strategic task of effective use of energy along with environmental protection has become an urgent global requirement. Almost all nations, especially developed countries, have had significant progress in applying biofuel in the transportation sector. This paper has reviewed technological solutions for applying biodiesel to diesel engines. Among technologies, Preheating biodiesel is a simple and easy method to reduce the viscosity of biodiesel to equal that of diesel fuel. However, this method has disadvantages related to engine technical and economic problems, causing corrosion, deposit formation, destruction of gaskets, sealing, and engine life. Additionally, the heating efficiency of the direct reheat method can be received at almost 100%, but its disadvantages are the limitation of liquid surface area and large surface area request. Moreover, the indirect reheating method has the advantage of taking place continuously in both the heating and drying processes. Still, this method suffers from some drawbacks, such as an increment of heat loss and thermal hysteresis. Furthermore, the use of heat pipes for fuel heating is difficult to calculate, design and install in the system and its heat capacity is not high, but it can be used for waste heat to install for small engine needs. The 50% biodiesel percentages in the fuel blend are suitable for cruise ships and short navigation. Mixed fuel is mixed and available to supply to the consumer, but this mixed fuel is not sustainable or delaminated, especially in ambient temperature conditions. Short. This obstacle is to using biofuel as an alternative fuel in diesel engines.

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