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Experimental Study on Influencing Parameters of HPHX on Viscosity of Preheated Higher Blends of Pongamia Methyl Ester

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Abstract - *The main objective of all these experiments is to explore the effect of geometrical, physical and operational parameters of Heat pipe heat exchanger (HPHXs) on biodiesel viscosity in comparison with diesel at full engine load. The preheating is one of the effective methods to reduce the viscosity of biodiesel and its blends. Further, the viscosity of fuel is a function of temperature and will influence the fuel air mixing due to evaporation and consequently influence the combustion, performance and emissions of the engine. The engine waste heat is diverted to preheat the biodiesel by means of HPHXs developed with different geometrical parameters and operated at different operational parameters. These waste heat recovery (WHR) HPHXs 1-36, investigated experimentally to study the influence of preheat on biodiesel temperature and viscosity in comparison with diesel. The experiments were conducted and analyzed at full engine load. The HPHXs experimented with different configurations developed with different tube layout to preheat the POME blends (B50 & B100). Further, the effect of geometrical, physical and operational parameters studied and the results are discussed.*

Key Words: HPHX, Preheating, Biodiesel Viscosity, Higher Blends, Pongamia Methyl Ester.

INTERODUCTION

The waste heat that generated in a process of fuel combustion is "dumped" into the environment even though it could be still re-used for some useful and economic purpose (Rabghi *et al.* [1]). A heat engine can never have perfect efficiency, according to the 2nd law of thermodynamics; heat engines always produce a surplus of low temperature heat. The most unrecovered waste heat is at low temperatures. About 60% of waste heat losses are at temperatures below 230 °C, and nearly 90% of waste heat is below 316°C. The single largest unused heat from the engines is the exhaust gas heat, which contains about 30% of the fuel energy. The diesel engine exhaust gases are rich in quality and quantity among varies points of heat rejection in engines.

Over the past two decades, much of the researches efforts directed into energy conservation. Reay [2] witnessed that, the WHR is not only economical, but it also reduces pollution. Energy may be recovered in many ways using WHR components, such as recuperators, regenerators, heat pipes, economizers and heat exchangers. The heat pipe application in engine is called VAPIPE as shown in Figure 1. Heat pipes can used to preheat the fuel with the aid of the exhaust gases before it enters the engine. The preheat reduces viscosity and improves the combustion (Nag [3]; Arora *et al.* [4]).

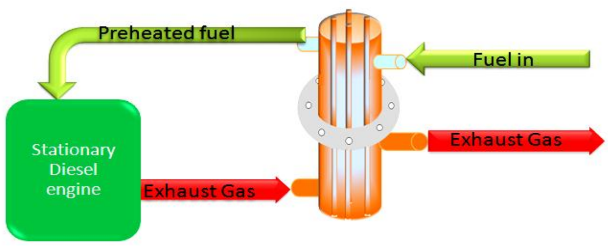

Figure 1: Schematic of the waste heat utilization.

The HPHX are the devices with heat pipe bundle that transfer heat to achieve the desired heating or cooling application. These operated with their evaporator section in the high-temperature fluid stream and the condenser section in the low temperature fluid stream as shown in Figure 2 (Noie *et al.* [5]). The HPHXs, because of their high effectiveness in heat transfer, simplicity in design and manufacturing they are widely applied in WHR as air pre-heater and economizer in bakery, hospitals, boilers, furnaces, dryers, refrigeration and air conditioning especially for energy recovery in industry.

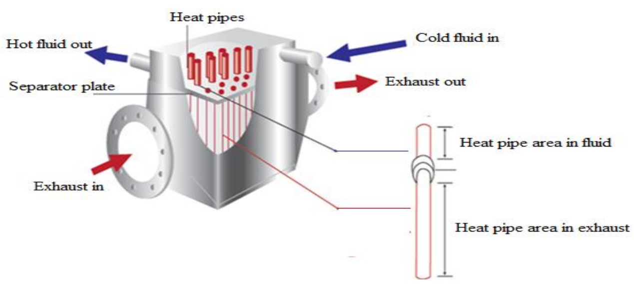

Figure 2: Schematic of a typical HPHX.

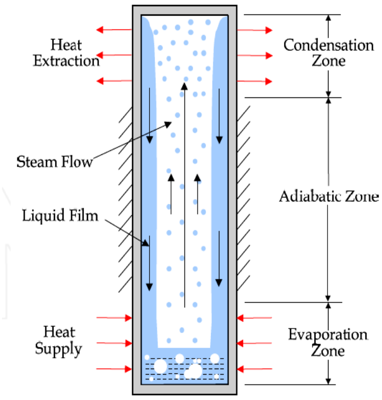

Figure 3: A typical heat pipe

The added merits of HPHXs, which tend to further encourage their use.

- They eliminate cross-contamination.
- The heat transfer control by of adjusting the tilt angle.
- They are still in operation, if any individual heat pipe fails (Redundant in design).
- Highly reliable, no moving parts and no additional power required to run.
- They are completely reversible (Dube *et al*. [6]).

The idea of such heat pipe (two-phase closed thermosyphon) was first suggested by Gaugler in 1942. They transport thermal energy based on a combination of boiling and condensation heat transfer (Figure 3). The research efforts have helped to maximize performance of heat pipes in various applicable fields. They performed various experimental investigations with the aim of parametric study of heat pipes (parametric optimization). The parameters that most influences the performance of heat pipes are categorized as: geometric parameters, physical parameters and operational parameters.

The amount of heat that can be transferred by the HPHX, in turn depends on each individual heat pipes. The performance of each individual heat pipe depends on; the effects of geometrical shape and size of the heat pipe, physical characteristics of the working fluid used including its filling volume ratio (FR) and the operational flexibilities and limits of the field of application.

A. Factors influencing thermal behavior of HPHXs

From the literature survey it's found that many factors influences the thermal behavior of HPHXs. Gadge [7] classified the most influencing factors as controllable and uncontrollable and the adequate group of parameters chosen based on field of application for best result. Further, the parameters that influence the performance of HPHXs classified into: geometrical, physical and operational parameters as shown in Figure 4.

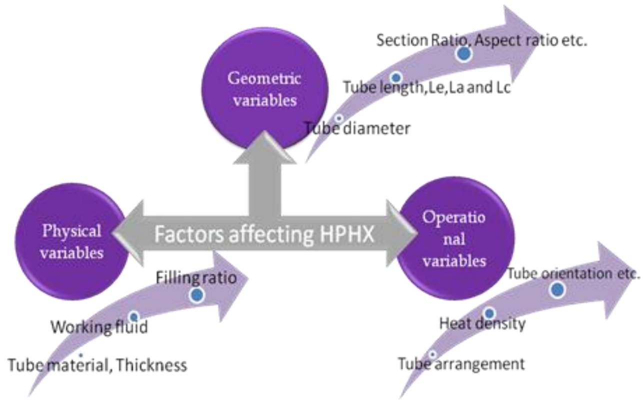

Figure 4: The influencing factors on thermal behavior of HPHXs

Effect of geometrical parameters: The geometric parameters include aspect ratio (AR), section ratio (SR), length of various sections of the heat pipe, diameter of heat pipe and the thickness of container material etc. Rittidech *et al.* [8] investigated the effect of the evaporator length on the heat transfer capability of heat pipes. Yamamoto [9] concluded that, the decreased evaporator length, increase the heat flux. Peterson [10] stated that, the liquid transport length of the working fluid has a significant influence on the heat transport capability. Thus, the geometrical parameters like; tube diameter, overall length and the length of different sections of heat pipe affects the rate at which the vapor travels.

Effect of physical parameters: These include the volumetric fill ratio (FR) and the type of working fluid. The heat pipe filling ratio is constricted by two operational limits. At 0% FR, a heat pipe with no working fluid and bare tubes only, is a heat transfer device in pure conduction mode with high thermal resistance. At 100% FR, heat pipe operates like a single phase thermosyphon. Mozumder et al. [11] study the performance using water, methanol and acetone as working fluids. The higher fill ratio shows the best result with minimum temperature difference. Park et al. [12] investigated the effect of the FR of the working fluid and they found that the increased fill ratio results higher heat transfer in the condenser. Majeed et al. [13] optimized the fluid inventory and observed is 87% as optimum filling ratio with lower thermal resistance and higher heat transfer coefficient. Further, it's reported that the dry out of the evaporator does not occur with a filling ratio of 80% acetone.

Effect of operational parameter: Effect of power densities (Input heat flux), Inclination angles and tube patterns etc. Apart from the above variables, the heat pipe performance is also strongly influenced with the various tube flow patterns inside the HPHXs.

B. The challenges in use of higher biodiesel blends

The use of biodiesels creates new challenges of reducing the viscosity related issues. Many researchers have reported the use of vegetable oil and their derivatives. Their higher viscosity affects; fuel droplet formation, atomization, vaporization and air-fuel mixing process. These may cause important engine failures such as; piston ring sticking, injector choking, fuel filter clogging, carbon deposits and rapid deterioration of lubricating oil (Hazar [14]; Karabektas *et al.*[15]; Pugazhvadivu *et al.* [16]; Khalid *et al.* [17]). The high viscosity fuels also lead to high smoke, HC and CO emissions.

So far many authors reported that, the use of B20 found as an optimum blend as replacement for diesel. The viscosity of higher biodiesel blends, limits their use in the engines. Several researchers (Bari *et al.* [18]; Pramanik [19]; Misra *et al.* [20]) investigated different vegetable oils and their derivatives of higher blends on conventional engines and pointed out the poor performance.

The exhaustive experiments were conducted by many authors Banapurmath *et al.* [21]; Magin et al.[22]; Venkatramn *et al.*[23]) with different biodiesel and reported the compatible performance with diesel. Further, they reveal the drawbacks of using greater biodiesel mix with diesel call for fuel modification. The **higher viscosities of higher blends** can be reduced by applying suitable techniques. Usually the preheating had done using electric heaters, shell and tube heat exchangers, fuel line heating and gas burners. Till now no such effective works reported in the previous literatures to preheat the biodiesel using HPHXs.

The fuel modification usually aimed at viscosity reduction to eliminate the atomization and vaporization related problems. Pramanik [19] reported various methods to overcome the viscosity related problems; blending or dilution, transesterification, micro emulsion, heating or pyrolysis or thermal cracking, engine setup modification. Among the various methods the concept of preheating is the most suitable method to reduce the problems related to viscosities and bring it equivalent to diesel. Typically the aid of engine exhaust gas found better for preheating, as it utilizes waste heat and therefore involves no additional running costs.

EXPERIMENTAL SETUP AND MATERIALS

Figure 5, presents the schematic experimental test set up with heat exchanger assembly (9) and the necessary instrumentation for online data measurement. It consists of a stationary diesel engine (1), dynamometer (2), duel fuel tank, different sensors, data acquisition system, thermostat, a personal computer, panel board, flue gas analyzer, smoke meter and the temperature data logger etc.

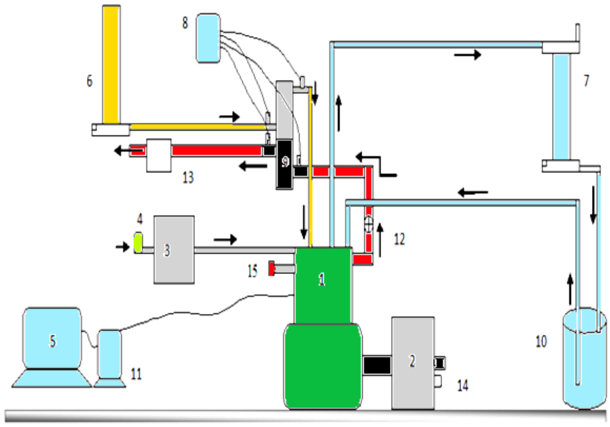

Figure 5: The schematic diagram of experimental set up

1. Diesel Engine 2. Eddy current dynamometer

3. Air box 4. Anemometer

5. Personal computer 6. Fuel flow measuring load cell

7. Water flow measuring load cell 8. Temperature data logger

9. Heat pipe heat exchanger 10. Water storage

11. Engine data logger 12. Engine exhaust pipe

13. Flue gas analyzer 14.Torque sensor

15. Pressure sensor

The individual heat pipes were fabricated first using the design data according to Table 1 and then the HPHXs assembly was developed.

Table 1: The geometry and other parameters of heat pipe

Parameter	***Symbol***	***Value***
Heat pipe material	Copper	
Working fluid	Distilled water(DW) and acetone(AC)	
Wick material	Wickless heat pipe	
Heat pipe length	L	300 mm
evaporator length	L_e	225,150,75
condenser length	L_c	75, 15,225
adiabatic length	L_a	2 mm
Tube dia.	d	1/2, 3/4 & 1 inch
Outside diameter of the heat pipe	d_o	12.7 mm,19.05 mm,25 mm
Inside diameter of the heat pipe	d_i	10.2,16.5 ,22.5
Thickness of the heat pipe	t	2.5 mm
Vacuum inside heat pipe	Pr.	0.13 bar
Saturation	T_{sat}	51°C

temperature inside heat pipe				
Section ratio(SR)	L_c/L_e	SR_1 1:3	SR_2 1:1	SR_3 3:1
Aspect ratio(AR) i.e Le/di	d_i=22.5 mm	10	6.66	3.33
	d_i=16.5 mm	13.63	9.09	4.54
	d_i=10.2 mm	22.05	14.7	7.35

The working fluid and the tube materials are selected based on the working temperature range as per Amir Faghri [24]. Thus distilled water and acetone were selected as working fluids for the present study and the compatible tube material for water and acetone are; copper, stainless steel, Nickel, Titanium.

Figure 6 (a) and (b) shows the instrumentation and interfaced HPHX assembly to the engine exhaust to recover the high temperature waste heat. The HPHX assembly can be interface in square tube pattern (SQ) or rotated square tube pattern (RSQ) in line with exhaust stream.

(a) (b)

Figure 6: The instrumented and interfaced HPHX assembly

RESULTS AND DISCUSSIONS

A. The effect of geometrical and operational parameters on biodiesel viscosity

Heat Pipe Heat Exchangers 1-9: Figure 7 shows the variation of viscosity for HPHXs 1-9 charged with 40% DW at varied tube pattern and biodiesel blend.

It is reported that the HPHXs of D_3 diameter and B50RSQ shows the best results with the viscosity reduced by 60.78%, 47.05% and 36.47% respectively for section ratio SR_1, SR_2 and SR_3. Similarly the viscosity of pure biodiesel (B100) reduced by 58.82%, 47.35% and 35.58% respectively for section ratio SR_1, SR_2 and SR_3.

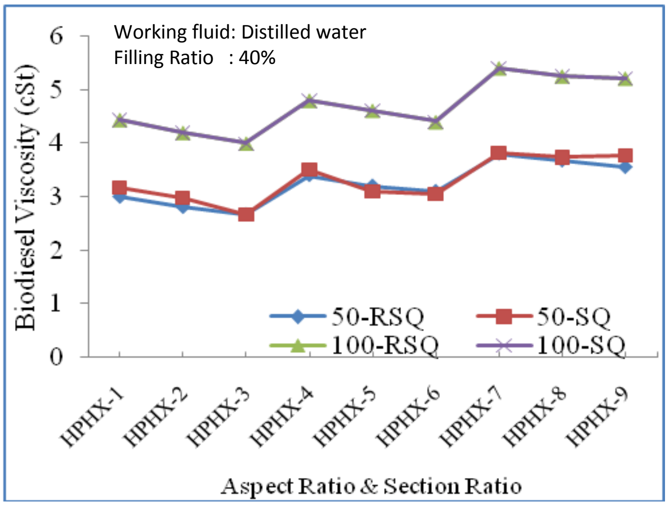

Figure 7: Variation of biodiesel viscosity with varied AR & SR using 40% DW charged HPHXs at full load

Heat Pipe Heat Exchangers 10-18: Figure 8 shows the variation of viscosity for HPHXs 10-18 charged with 80% DW at varied tube pattern and biodiesel blends. The similar trend observed as in HPHXs charged with 40% distilled water. It is reported that the HPHXs of D_3 diameter and B50RSQ (rotated square tube pattern) shows the reduced viscosity by 54.90%, 41.13% and 29.41% respectively for section ratio SR_1, SR_2 & SR_3. Similarly the viscosity of B100 reduced by 54.41%, 39.7% & 26.47% for section ratio SR_1, SR_2 & SR_3 respectively.

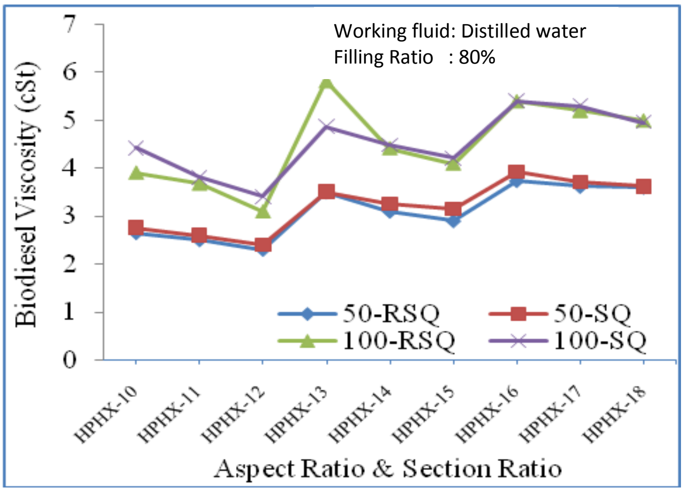

Figure 8: Variation of biodiesel viscosity with varied AR & SR using 80% DW charged HPHXs at full load

Heat Pipe Heat Exchangers 19-27: Figure 9 shows the variation of viscosity using 40% acetone charged HPHXs 19-27 at varied tube pattern and biodiesel blend. It is reported that the HPHXs of D_3 diameter and B50RSQ shows reduced viscosity by 56.66%, 49.01% and 30.78% respectively for section ratio SR_1, SR_2 and SR_3. Similarly the viscosity of pure biodiesel reduced by 54.26%, 46.76% and 30.88% respectively for section ratio SR_1, SR_2 and SR_3.

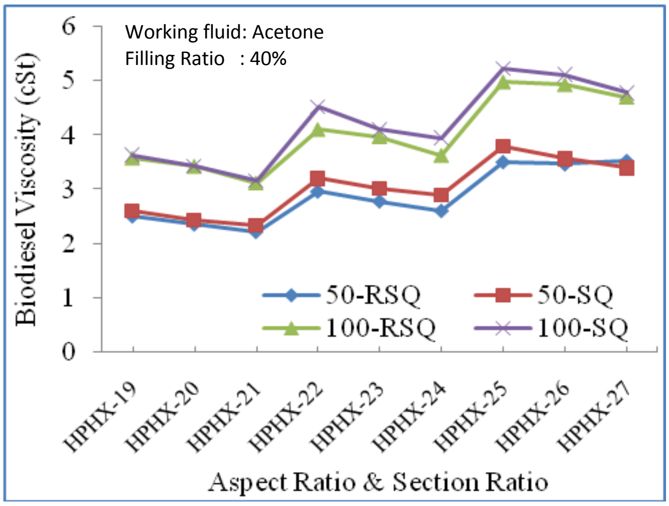

Figure 9: Variation of biodiesel viscosity with varied AR & SR using 40% AC charged HPHXs at full load

Heat Pipe Heat Exchangers 28-36: Figure 10 shows the variation of viscosity for HPHXs 28-36 charged with 80% Acetone at varied tube pattern and biodiesel blend.

It is reported that the HPHXs of larger tube diameter (D_3) and B50RSQ configuration shows the best results with the viscosity reduced by 60.78%, 47.05% & 36.47% respectively for section ratio SR_1, SR_2 and SR_3. Similarly the viscosity of B100 reduced by 58.82%, 47.35% and 35.58% for section ratio SR_1, SR_2 and SR_3 respectively.

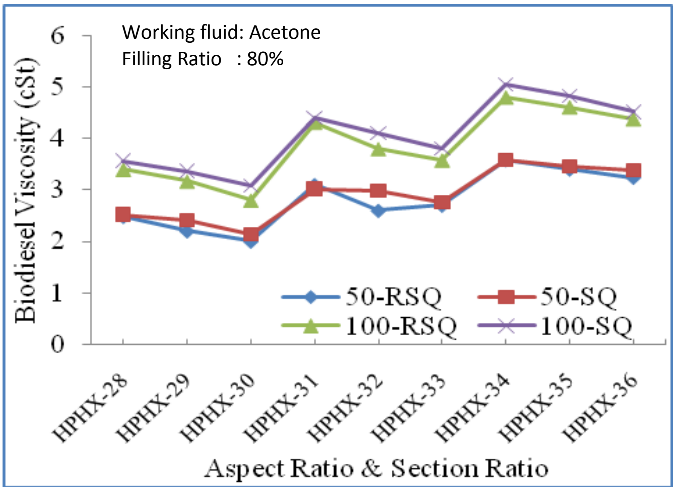

Figure 10: Variation of biodiesel viscosity with varied AR & SR using 80% AC charged HPHXs at full load

B. The effect of physical and operational parameters on biodiesel viscosity

The viscosity of a biodiesel is higher than the viscosity of diesel and the biodiesel viscosity is up to 2.125 times that of diesel at 30 ºC. This ratio still increases for lower temperature conditions. The blending of the biodiesel with diesel and preheating improves the viscosity characteristics.

The POME blends B100 and B50 have viscosity of 6.8 cSt and 5.1 cSt respectively. The Figure 11 shows that, the preheated blends report lower viscosity for all the configurations of HPHXs operated at rotated square tube pattern.

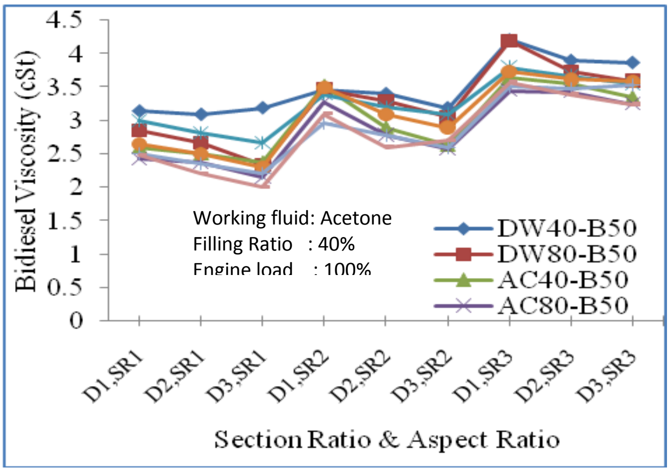

Figure 11: Variation of biodiesel viscosity with AR & SR at different working fluid and its filling ratio

The acetone charged HPHXs results lower viscosity of biodiesel for all the aspect ratio and section ratios. Further, the HPHXs with lowest aspect ratio shows 70.58%, 60.29% and 52.35% decrease in biodiesel viscosity for SR_1, SR_2 and SR_3 respectively when operated with B100. Further, it's noticed that the B100 with acetone charged HPHXs shows lower viscosity than B50, this is attributed to the higher EGT of B100 due to larger ignition delay.

CONCLUSIONS

- It's noticed that the HPHXs designed with larger tube diameter in each section ratio witnessed the higher reduction in biodiesel viscosity.
- The 80% acetone charged HPHXs found superior than the HPHXs with DW and 40% AC.
- It is reported that the HPHXs of D_3 diameter and section ratio SR_1 shows the best results with all the four configurations. The B50RSQ configuration shows the lowest viscosity values closer to standard diesel.
- The B50RSQ & B50SQ shows the best results with maximum temperatures raised to 148 °C & 138 °C respectively. The HPHXs with SR_1 shows 20-30 °C higher temperature than SR_2 irrespective of engine load.
- Further, the 80% acetone charged HPHXs with lowest aspect ratio shows 70.58%, 60.29% and 52.35% decrease in biodiesel viscosity for SR_1, SR_2 and SR_3 respectively when operated with B100 at full engine load.
- The temperature of B50 and B100 raised to 156 °C and 144 °C respectively using 80% AC charged HPHXs of lowest AR_1 and lowest section ratio SR_1 at full load. This temperature rise ensure the reduction in viscosity of POME blends near to diesel fuel. These results are in accordance with many researcher, preheated the

pongamia oil upto 200 °C and the different biodiesels upto 158 °C: pongmia biodiesel B40 preheted at 110 °C by Dinesha et al. [25]; cottonseed oil methyl ester (COME) at 120 °C by Karabektas et al. [26]; Rice bran oil (RBME) Raised to 158 °C by Raghu et al. 27]; Cotton seed oil methyl ester (COME) up to 90 °C by Ingle et al. [28] ; Cottonseed methyl ester up to 150 °C by Mohod et al. [29]; Mustard oil ethyl ester 120 °C by Hasib [30] to bring its viscosity closer to diesel.

- Similarly preheating of karanja oil at 200 °C by Mitra and Basu [31]; karanja oil at 100 °C by Kadu et al. [32]; karanja oil at 160 °C by Panigrahi et al. [33]; karanja oil at 130 °C by Acharya et al. [34].
- The highest viscosity of B50 reduced by 60.78%, 47.05% & 36.47% respectively for section ratio SR_1, SR_2 and SR_3. Similarly the viscosity of B100 reduced by 58.82%, 47.35% and 35.58% respectively for section ratio SR_1, SR_2 and SR_3.
- The viscosity reduced to 2 cSt and 2.8 cSt respectively when the engine run with B50 and B100 using RSQ tube pattern charged with 80% acetone.
- The higher reduction of viscosity reported using 80% acetone charged HPHXs. Thus, the acetone charged HPHXs emerged as better at higher filling ratio.

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