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Design, Construction and Characterization of a Model Heat Exchanger Unit for Preheating Lubricating Oil

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ABSTRACT

This project work is the design, construction and characterization of a model heat exchanger unit for preheating lubricating oil. The experiment Heat exchanger rig was developed using a 30 liters water reservoir, oil reservoir (10 liters), PVC pipe (0.012m diameter, 0.7m long), 0.5 HP Electric pump and other fittings; with the assembly of these components at the Mechanical Engineering workshop, Caritas University, Amorji-Nike.The performance of the heat exchanger unit was evaluated by the assessment of such parameters like the convective Heat transfer of the rig, viscosity index and flash point of the oil at various temperatures ranging between 50^{0}C to 100^{0}C. It was observed that the flash points of the oil increased with increasing temperature and the kinematic viscosity increased. The design study indicated that the Heat exchanger rig performance is above seventy percent (70%).

Keywords: ***Convective Heat Transfer, Flash Point, Viscosity Index.***

INTRODUCTION

This research is a substantial experimental deduction of heat transfer to lubricating oil. Heat exchangers are devices used for transferring thermal energy from one fluid to other as a result of mainly convection and conduction. There are no external heat and work interactions during transfer of thermal energy within a heat exchanger. The thermal energy rating of a heat exchanger is dependent on several factors such as type of fluid, configuration, material selection etc and this thermal efficiency can be improved by means of heat transfer technique. The heat transfer processes in industries are mostly classified under forced convection. Convection is a mode of heat transfer in which thermal energy is been transferred as a result of bulk fluid motion on a solid body i.e. combined effect of conduction and advection. Convection exist as free and forced mechanism depending on the mode in which the fluid flow is initiated. For free and forced convection, fluid flow is as a result of buoyancy effect, i.e. the rise of warmer fluid and fall of the cooler fluid. Whereas for the forced mechanism, the fluid is pressurized to flow as a result of external means such as a pump or fan. The fluid motion through a circular cross section set up as smooth and streamlined which is called transition from laminar to turbulent flow occurs over some region which is called transition region. The efficiency of heat supplier is an important topic in these devices and provides a new way to design and analyze them. The cost of energy and material has led to a dramatic endeavor for designing more efficient and economical heat exchanger units (Cengel, 2004)|.

James et al. (2016) designed and constructed a tube type lubricating oil heat exchanger. They denoted that the application of heat transfer is in designing heat transfer equipment for exchanging heat from one fluid to another. Furthermore, tube type heat exchangers are used when a process requires large amounts of fluids to be heated or cooled. Due to their design, they offer a large heat transfer area and provide high heat transfer efficiency. Hence, the purpose of their research design was to design heat exchanger device that is economical and suitable enough to r preheating lubricating oil and with the application of automobile engine lubricatioenhance the process of exchanging heat between two fields at different temperature variations at minimal cost capable of preventing overheating, engine failure and marine engine knocking. Their methodology adopted the logarithmic mean temperature difference (LMTD) method which utilizes the principles of Tinkers model for hand calculation to determine the parameters of the exchanger. The overall heat transfer coefficient of this tube type heat exchanger obtained from the design calculation was 172.3w/°C. There is a direct proportional relationship between effectiveness of a heat exchanger and the lubricating oil temperature difference (difference between the lubricating oil inlet and outlet temperature). It was observed that the effectiveness increases as the lubricating oil temperature difference increases. A balance must be strike between the effectiveness and the difference between the inlet and outlet temperature of the lubricating oil. This is important because excessive lubricating oil temperature difference which will give a higher effectiveness can lead to sub cooling of the lubricating Oil resulting to creating thermal stress in the engine components.

Caterpillar Product Manual conveyed the importance of lubrication in an engine. They denoted that proper lubrication is critical to successful engine operation. The lubrication system of a modern engine is meant to accomplish three primary purposes: It lubricates surfaces to minimize friction losses. It cools internal engine parts that cannot be directly cooled by the engine's water- cooling system. It cleans the engine by flushing away wear particles. Furthermore, the lubricant itself performs other functions: It cushions the engine's bearings from the shocks of cylinder firing. It neutralizes the corrosive elements created during combustion. It seals the engine's metal surfaces from rust. In addition, lubricating oil systems require clean oil that is free from abrasive particles and corrosive compounds. These systems require a lubricant with sufficient film strength to withstand bearing pressures and heat exposure to cylinder and piston walls. The lubricant must have a viscosity index that is low enough to flow properly when cold. The lubricant must also be capable of neutralizing harmful combustion products and holding them in suspension for the duration of the oil change period.

They documented that the centrifuge preheated size which is also a part of the centrifuge package is determined by pump capacity and required temperature rise between the sump and the final centrifuge. The final outlet temperature is determined by the centrifuge manufacturer, but will range between 80 and 90°C (176 and 194°F), depending on the grade and type of oil used. Other heater sizing considerations are: Oil temperature should be

98°C (210°F) for engines centrifuging during engine operation. The denoted that if the centrifuges operate when the engines are not running the heater must be oversized to account for the heat normally supplied by an operating engine. The heater must be thermostatically controlled to maintain the oil temperature to the centrifuge within 2°C (14°F). Note: Heating elements in direct contact with lubricating oil are not recommended due to the danger of coking. To avoid coking when heating, heater skin temperature must not exceed 150°C (100°F) and heater elements must have a maximum heat density of 1.24 w/cm2 (8w/in2)

Anh Tuan Huang (2018) designed and fabricated a heat exchanger for recovering exhaust pus energy from small diesel engine fueled with preheated bio-oils. He denoted that among the main power in the transportation, construction, fishery and agriculture machinery, engine has played an important part and consumed more than 60% of fossil fuel, thus it was able to result in exhausting the fossil fuel. He documented that Waste Heat (WH) was heat generated by the fuel combustion or chemical reaction.

METHODOLOGY AND DESIGN CALCULATIONS

In the development of the oil preheater, several dealings were undertaken.

i. The production of practical design solutions starting from limited definition of requirements taking into account many factors.
ii. The production of design schemes, analysis, manufacturing drawings and related documentation within defined timescales.
iii. The assessment of design requirement of a particular component, system, assembly in consultation with other components
iv. The production of design which will influence the cost and functional quality of the product.
v. Negotiation with vendors on aspect of bought components.
vi. The assessment of the work of others
vii. Assembly of parts by means of fabrication and plumbing.
viii. Testing of developed heat exchanger.
ix. Also practical design calculations were carried out so as to generate exact operating conditions for pumps, valves and other parts..

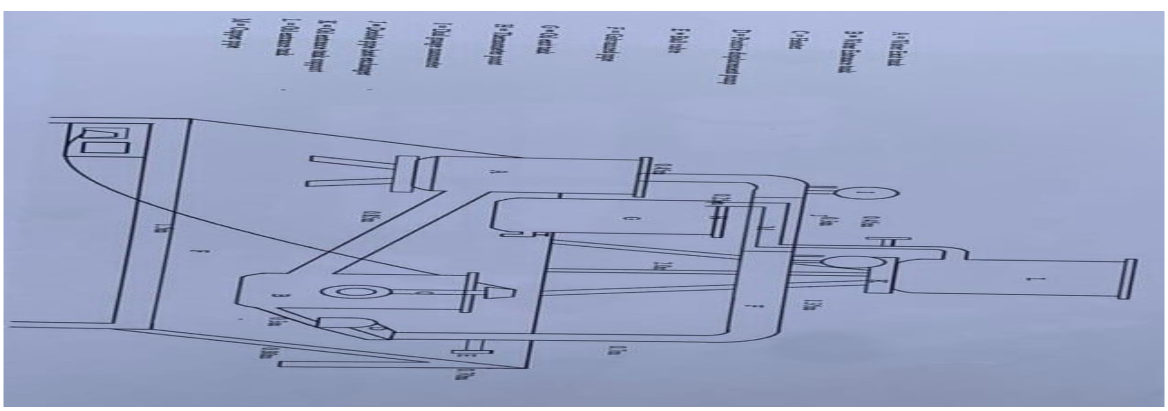

Fig 2.1: Schematics of designed oil preheater

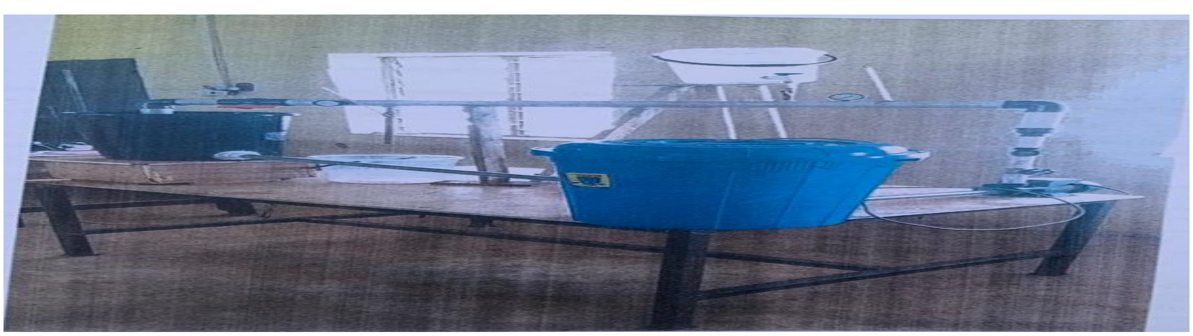

Fig 2.2: Pictorial view of the Experimental Rig

Parameters in experimental investigation: Following are the parameters that were involved in the experimental procedure:

I. Reynolds number of hot fluid: The Reynolds number of hot fluid was varied between 5000 and 30000. The desired values of Reynolds number were obtained by controlling the mass flow rate through the water flow meter with the help of control valves and gate valve.
II. The oil was supplied at constant rate of 5 Lpm (liters/minutes)
III. Two types of inserts were used.

Experimental Procedure followed: The experimental analysis was carried out at the Mechatronic Laboratory, Department of Mechanical Engineering, Caritas University, Enugu. The details of experiment are explained with steps 1 to 4 shown below::

1. After fabrication of experimental setup, the preliminary test run was conducted in order to eradicate any sort of leakages in the pumps, pipes and joints; and this enabked the components such as U tube manometer and thermometer to be calibrated.

2. The experimental procedure was carried out for the heat exchanger without any insert inorder to standardize the results of the heat transfer characteristics of double pipe heat exchanger according to Dittus Boelter equation and friction factor values according tgo Blasius correlation. These theoretical values were compared with the results obtained from this experimental procedure and the error was found to be within permissible limits

3. In the beginning of experiment, the heater was turned on to achieve the desired inlet temperature of the hot fluid. Once the hot fluid reached the desired temperature, the pumps were turned on. Hot fluid was pumped in to the heat exchanger by the monoset pump. The discharge of hot fluid was controlled by the valves to achieve the certain value of Reynolds number. The hot fluid after passing through the heat exchanger was again made to flow into the hot fluid tank and it formed a closed cycle for the hot fluid. The cold fluid was pumped into the annulus of the heat exchanger by the monoset pump. The cold oil was made to flow at same discharge for all the experimental analysis. After exchanging the heat with the hot fluid, the cold oil was not brought into the cold fluid tank as the chiller arrangement was not installed in the test setup. Hence, the cold oil was ejected into the drain and the fresh cold oil was circulated for each set of experiment.

RESULTS AND DISCUSSIONS

Quality Characterization of Preheated Engine Oil

In order to determine the nature and extent of the preheated oil and the suitability of the engine oil for usage, its physical properties were determined by standard methods.

Physical properties of virgin engine oil

In order to evaluate the quality of the virgin oil, the content of the oil samples were subjected to physical properties analysis. The results obtained are shown in Table 4.1. At room temperature, the virgin engine oil samples were light green liquids. The specific gravity of Mobil oil was 0.910, while that of Total oil was 0.928 and that of GS Motor oil was 0.8997. The viscosity at 40°C, (cSt) for Mobil oil, Total oil and GS Motor oil were 105.31, 121.58 and 112.5 respectively while their viscosity at 100°C were obtained as 11.40, 12.41 and 11.83. The flash points obtained for each of the samples were 195, 212 and 220 respectively. The pour points were obtained to be -15, -11 and -21 for Mobil, Total and GS Motor oils respectively.

Quality Characterization of Preheated Oil

To verify that the preheated base oil satisfies the ASTM standards for engine Oil, its physical properties were determined by standard methods.

Table 3.1 Physical properties of Virgin Oil samples

SPECIFICATIONS	E1	E2	E3
Specific gravity at 15.36°C (ASTM D-1296)	0.9100	0.9280	0.8997
Kinematic viscosity at 100°C, St	11.40	12.41	11.83
Kinematic viscosity at 40°C, cSt (ASTM D445)	105.31	121.8	112.5
Viscosity index (ASTM D2270)	94	92	93
Flash point, ^{0}C (ASTM D92)	195	212	220
Pour point, ^{0}C (ASTMD97)	-15	-11	-21

Physical properties of preheated oil

In order to evaluate the quality of the preheated oil from the heat transfer rig extraction process and hence determine its suitability for use, the content and composition of the heated base oil was subjected to analysis of its physical properties. These properties an obtained from standard methods are shown in Table 4.2. The discussion of these result are given below.

Viscosity

The results obtained for viscosity at 100°C, cSt for E1, E2 and E3 are 14.19, 15.33 and 14.52 respectively. An increase in viscosity values at this temperature from the initial values of 11.4, 12.41 and 11.83 for the virgin nil samples was observed. Similarly the kinematic viscosity at 40°C for E1, E2 and E3 is seen to increase from the initial values of 105.21, 121.58 and 112.5 10 138.92, 165.10 and 154.1. This is due to change in fluid property in the preheated oil which was removed during the heat transfer process. In general, oil is considered unfit for service if its viscosity increases or decreases to the next SAE number. Viscosity increase can occur due to oxidation or contamination (Scapin 2007). Viscosity decrease can be caused by dilution with light fuel. The increase in viscosity values therefore shows that the preheated oil had lost its viscosity due to heat which is suitable for usage in automobiles

Flash point

The flash point of the oil increased from 195°C, 212°C, and 220°C, for samples of E1, E2 and E3 to 222°C, 216°C, and 239°C, respectively for the preheated oil. This implies that there was an initial decrease in value of flush point for virgin oil from that of the preheated oil which was improved by the heating process.

Specific gravity

From the results shown in Table 4.1 and 4.2, the specific gravity of virgin oil is greater than those of the preheated one. The specific gravities for preheated E1, E2 and E3 oil samples are 0.8865, 0.8844 and 0.8853 respectively. The specific gravity of virgin eil can be higher or lower than that of fresh lube oil depending on the nature of its ideal properties (Chevron Lubricating Oil FM ISO 100).

Pour point

From the results obtained, the pour point for the virgin oil is high when compared to that of the preheated base oil. This is because of the degradation of additives in the lube oil. Pour point especially is of interest when an oil must be under relatively cold condition. Pour point will vary widely depending on the base, the source of the lube oil and the method of refining, especially if dewaxing has been done (Firms and Dumitru, 2006; Chevron Lubricating oil FMISO 100),

Table 3.2 Properties of Preheated Base Oil

SPECIFICATIONS	E1	E2	E3
Specific gravity at 1556°C (ASTM D1298)	0.8865	0.8844	0.8853
Kinematic viscosity at 100°C, cSt.	14.19	15.33	14.52
Kinematic viscosity 40°C, cSL (ASTMD445)	138.92	165.10	154.1
Viscosity index (ASTM D2270)	99	93	91
Flash point, °C (ASTM D92)	222	216	239
Pour point, "C (ASTMD97)	-9	-9	-11

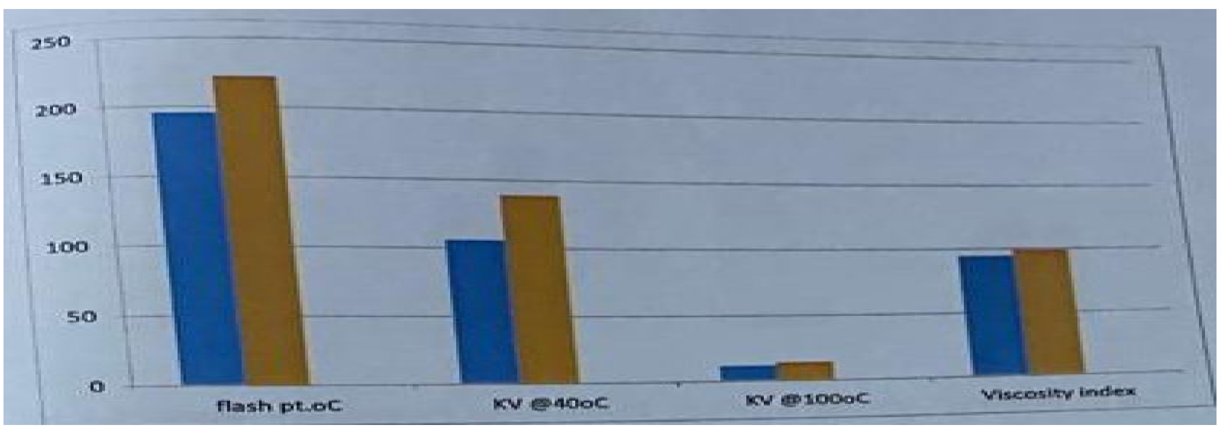

Fig 3.1 Comparison between properties of virgin oil (E1) and Preheated oil (E1)

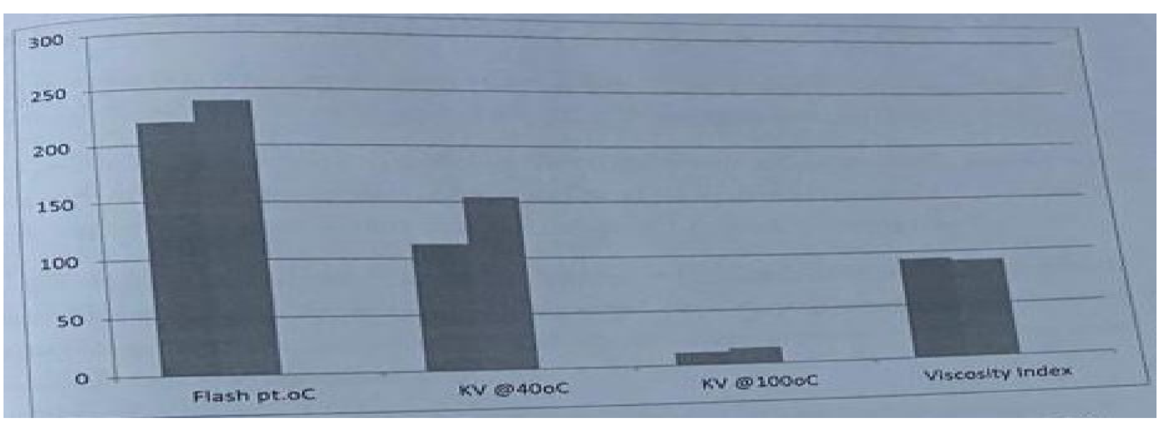

Fig 3.2 Comparison between properties of virgin oil (E2) and Preheated oil (E2)

Fig 3.3 Comparison between properties of virgin oil (E3) and Preheated oil (E3)

Suitability of Preheated Base Oil for Reuse

The suitability of oil heated from virgin engine oil by preheater rig is determined by comparing its physical properties shown in Table 4.2 with standards for engine oil

The results of kinematic viscosity at 100°C falls well within the SAE standard for monograde oil SAE 40 of greater than 12.5 and less than 16.3 as shown in appendix A. Sample 13 has viscosity of 15.33 which is close to lower limit of 16.3 for SAE 10 monograde oils.

The viscosity index of 99, 93 and 1 as observed for E1, E2 and El respectively falls within de range of viscosity Index for monogrades. This shows that at varying temperature, there would be a slight change in the viscosity of the oils. Addition of viscosity improvers and however make available for use as multigrade oils

Flash points of 222, 216 and 239 show the suitability of each sample of preheated oils These values are adequate for use as lubricating oils

The result for specific gravity as observed is 0.8865 for: E1, 0.8844 for 12 and 0 8853 for Et. These result show specification of mono grade oils and implies that the oils will pump and circulate better throughout the engine

Figure 4.1, 4.2 and 4.3 shows the effect of the preheated process on the physical properties of oils as compared to standard specification of SAE 20, SAE 30 and SAE 40 as given in Table 4.3

The properties of preheated base oil recorded in this study can however be improved by additives such as Zine Dialkyl Dithiosulphate as demonstrated by Kannan et al. (2014)

CONCLUSION

This study concludes that:

i. The Host exchanger rig is efficient in the preheating of the lubricating oil.
ii. The Heat exchanger used in the preheating process for this study produces base oils that compare favorably with virgin oils. The inability of copper pipe as a flow tube for the oil ensured proper thermal diffusivity of the virgin samples which produced acceptable level of preheated samples.

iii. The Heat exchanger allows for the study of the physical properties of preheated base oil, which compares favorably with oil standards. This indicates that the Heat exchanger for this preheated base oil is suitably designed and characterized and the oil is good for use

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