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Investigation on Tribological Characteristics of Bio-Nanolubricants For Textile Ring Frame Spindles

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Abstract. Energy loss due to friction is one of the most prominent problems in the industry. Most of the textile industries have this prominent problem and uses lubrication to minimize it. Mineral oil-based lubrication has been widely used but there seen no such significant improvement in performance of the system. This investigation aims to provide the solution of efficient and eco-friendly bio-nanolubricants. An optimum level of nanoparticles with biodegradable oil as base oil with a surfactant combination, with its physical and tribological properties could replace the conventional oil with improvement in performance. The nanoparticles and base oils which are taken for the investigation are titanium dioxide (TiO_2), graphene, copper oxide (CuO), sesame oil, coconut oil and pongamia oil. The physical characterization reveals that all the developed bio-nanolubricants show higher viscosity, flash and fire points and cloud and pour points and in tribological characterization sesame + CuO nanolubricant has shown 79% less friction than the conventional lubricant. Based on conclusion of characterization sesame + CuO nanolubricant, pongamia + graphene nanolubricant and pongamia + TiO_2 nanolubricant are the most suitable for textile ring frame spindles. Additionally, dispersion stability, thermal conductivity and anti-corrosion test of the developed nanolubricants are also favorable. In the field test, pongamia + TiO_2 nanolubricant has shown more heat transfer which in turn less heat generation due to its low coefficient of friction (COF) than the conventional lubricant Servospin EE10 and in the power consumption test, pongamia + TiO_2 nanolubricant has shown 5.5% less energy loss than the conventional lubricant and it is evident that pongamia + TiO_2 nanolubricant is suitable for this application. Furthermore, this study highlights the potential of utilizing the biodegradable oils as environmentally friendly and sustainable alternatives to mineral oil.

Keywords: Bio-nanolubricants, ring frame spindles, friction mechanisms, power consumption, heat generation.

Introduction

Energy losses due to friction are incredibly high. Energy losses in any mechanical part due to friction result in heating and promote the wear on the surfaces of moving part. Energy losses due to the friction can be reduced by a few technologies such as the design of tyres and bearings, tribology, and additives. [1] Further, in order to overcome the energy losses, the lubricant which imparts the best lubrication is essential. [4]

The lubrication of the ring frame spindle, an indispensable component within the textile industry, plays a paramount role in ensuring seamless operation and optimal yarn production. This intricate cylindrical apparatus, comprising various elements like bearings, shafts, and gears, necessitates meticulous lubrication to minimize friction and wear. Adequate lubrication guarantees the smooth rotation of the spindle, reducing mechanical strain and extending its lifespan.

1 Preliminary field study

1.1.1 Energy study of a textile industry

Energy study was performed at Supertex mills Pvt ltd, India. The primary focus is to identify the areas of high-power consumption.

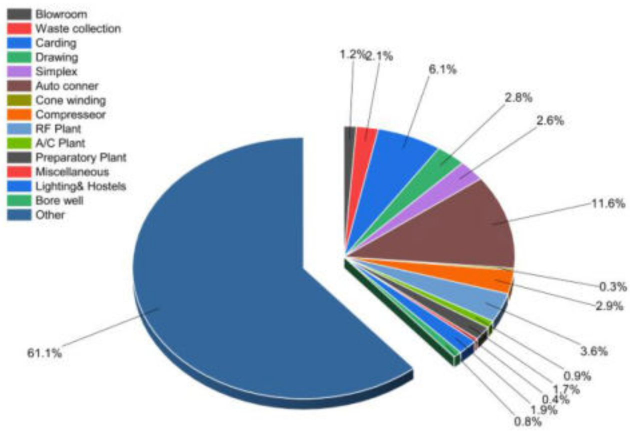

Fig.1. - Power distribution of textile mill

The figure 1 shows that 61.1% of total power consumption is in the ring frame machines. Around 58% of power consumption in a single ring frame machine is because of spindles. From the energy study it is evident focusing on the spindles with consideration of different factors can lead to efficient energy saving.

1.1.2 Effect of lubrication on spindle power consumption

As there are many factors influencing the power consumption in the textile ring frame spindle, it is important to study all of it. Lubrication which is used for reduction of friction, and by optimizing the lubricant can further reduce friction and the power consumption too. An energy study was carried out by considering the factor as lubricant and the results are shown in table 1.

Table 1. Power consumption comparison

Power consumption comparison		
Description	**EE10 (Old)**	**EE10 (New)**
Number of spindles per machine	1008	
Spindle wharve diameter (mm)	19	
Ringframe speed (rpm)	18020	
Study duration (hrs)	2	
Units consumed for 2 hrs (kW)	25.76	25.4
Units consumed per hour (kW)	12.88	12.7
Power saving for new oil per hour (kW)	0.18	

The study was carried out in LMW LR6 machine where lubricant used in ring frame spindle was Servospin EE10. The machine consists of 1008 spindle and runs at idle condition for the energy study. Study was carried out for two hours. The study shows that over a period, the power consumption increases and may be due to degradation of lubricant. This study is evident that the lubricant also influences the energy losses.

2 Literature review

P. Nallasamy et al., 2015 [6] studied the performance of PAO (Polyalphaolefin) + 1wt% MoS_2 nanolubricant and found it was better than standard slideway lubricant ISO VG 32. Reduction of 24% in COF was observed. P. Nallasamy et al., 2018 [5] studied on the tribological properties of 0.1% wt. of CuO based nanolubricants for machine tool slideway. Eswaraiah. V et al., 2011 [8] prepared graphene based engine oil nanofluids and performed their frictional characteristics (FC), antiwear (AW), and extreme pressure (EP) properties and determined that 0.025 mg/mL of graphene in engine oil, COF and WSD were reduced by 80 and 33%, respectively. Wu, H et al., [9] determined that 0.8 wt.% TiO_2 water-based lubricant leads to the lowest COF and the best anti-wear ability under all the lubrication conditions at room temperature.

Zulkifli et al., 2013 [10] studied that the nanoparticle also improved WSD of the TMP esters especially at low load (40kg) by creating an additional protective layer. Koshy C P et al., 2015 [13] focuses on the tribological performance of coconut oil with MoS_2 nanoparticles and observed enhanced thermal and tribological properties. Shafi W K et al., 2018 [15] studies highlight the use of bio-degradable nanolubricants and provides the reason for replacement of mineral oils.

Kiu, S. S. K. et al., [7] studied the tribological behaviors of graphene nanoparticles as lubricant additive in vegetable oil were investigated as a function of nanoparticle concentration. The results showed that 50 ppm is the optimum concentration that recorded the lowest wear scar diameter and friction coefficient as compared to control sample. Shaari et al., [11] studied that nanoparticle TiO_2 as additive has slightly improved the lubricating properties of palm oil biolubricant.

Azman et al., 2018 [12] observed that the presence of copper (II) oxide nanoparticles of 0.34 wt.% in PKO has improved the tribological properties by reducing the COF and WSD by 56 and 48% respectively. Virwal Harsh Rajubhai et al., [14] studied minimum friction coefficient and wear was observed at 0.075% concentration which gets further increased at 0.1% concentration of CuO with pongamia oil.

Mohamed Kamal Ahmed Ali et al., [2] performed analysis with 5W30 engine oil and Al_2O_3 and TiO_2 nanoparticles with oleic acid as surfactant. Uflyand et al., [3] the tribological properties was evaluated using different test experiments under different operating conditions. The results showed a decrease in the friction coefficient and wear. It was also found that the better performance of the nanolubricant was due to formation of tribo films on the surface.

It is to be noted that no studies have been carried out so far for the application of textile ring frame spindle using biodegradable oil based nanolubricants. This research work thrives to bridge the gap to develop the high-performance biodegradable based nanolubricant for the textile spindle with comparison to the conventional lubricant.

2 Experimental investigations

2.1 Preparation of nanolubricants

The biodegradable oils selected were sesame oil, coconut oil and pongamia oil. The nanoparticles choose were TiO2 at 0.8wt%, CuO at 0.34%, graphene at 0.0025% and surfactant was oleic acid. The nanoparticles, base oil and surfactant mixture was stirred manually for 10 minutes and to obtain good dispersion stability the mixture was subjected to ultra-sonication for 4 hours. The conventional ring frame spindle lubricants Servospin EE 10 and Servospin EE 22 were chosen for comparing the tribological performance of nanolubricants.

2.2 Physical properties

2.2.1 Viscosity testing

The kinematic viscosity was measured for all the developed nanolubricants using Redwood viscometer. The testing was performed at three different temperatures which are 26°C (room temperature), 40°C and 80°C. The results are plotted in form of graph as shown in Figure 2.

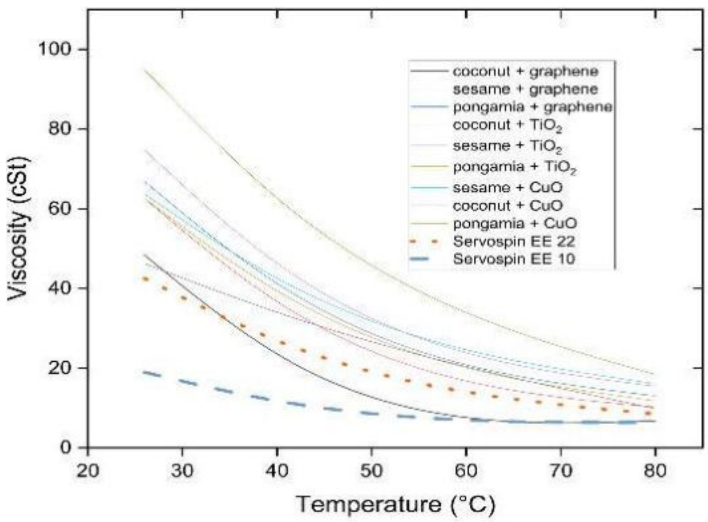

Fig.2. - Viscosity of nanolubricants

It is found that the kinematic viscosity of the developed nanolubricants is higher than the conventional lubricants, which shows a significant improvement in the viscosity. From literature study, for high-speed applications viscosity of 30 cSt to 50 cSt is considered as optimal value. The nanolubricants such as sesame + graphene, pongamia + graphene, sesame + TiO_2, pongamia + TiO_2, sesame + CuO, pongamia + CuO are considered to have most suitable viscosity for the application. The viscosity of all the nanolubricants decrease with increase in the temperature.

2.2.2 Flash point and fire point test

The flash point and the fire point of all the developed nanolubricants shown in figure 3 are higher than the conventional lubricant. The flash point and fire point of all developed lubricants lies above 200°C. Coconut + TiO_2 nanolubricant shows 50% higher flash point than conventional lubricant. And sesame + TiO_2 nanolubricant shows 51% higher fire point than conventional lubricant.

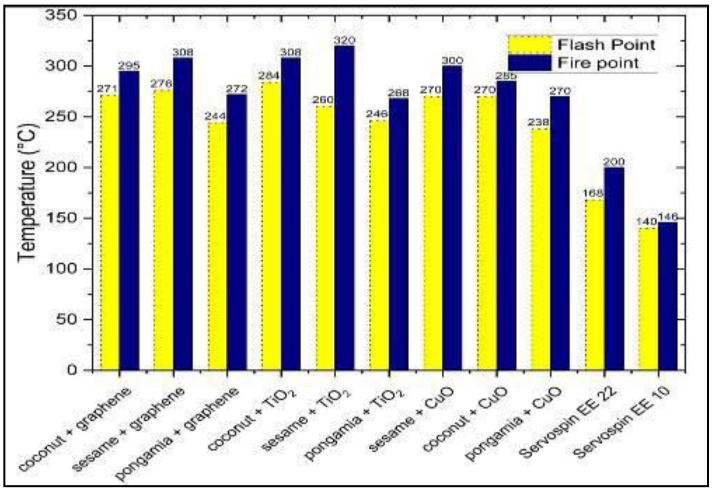

Fig.3. - Flash point and fire point

2.2.3 Cloud point and pour point

The cloud point of all the developed nanolubricants is closer to the room temperature and it will not affect the efficiency in the application. And the pour point of the all the nanolubricants lies below 0°C as shown in figure 4 which is considered for colder conditions too.

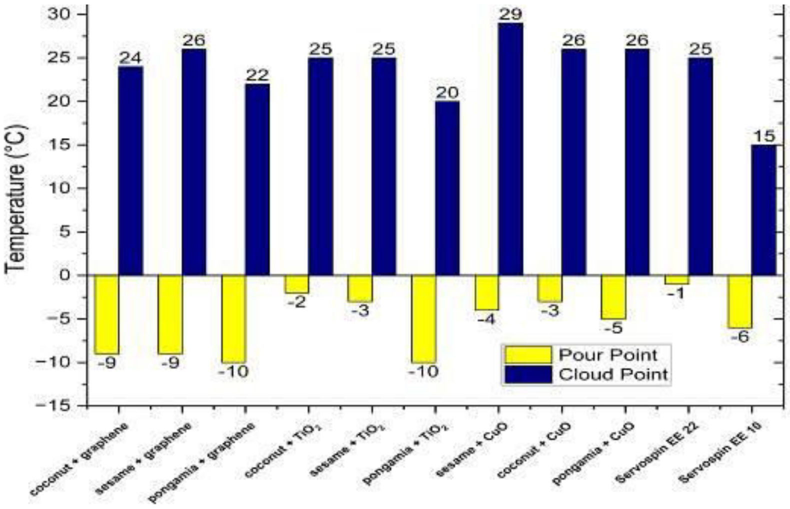

Fig.4. - Cloud point and pour point

2.3 Tribology property test

2.3.1 Determination of friction and wear

The pin on disc wear test rig (DUCOM) is used study the friction characteristics of the lubricant as per ASTM G99-05 standard is shown in figure 5. The experiments were carried out with the following conditions:
Speed: 1500 rpm
Applied Load: 5 N
Time duration: 5 minutes
Track diameter: 80 mm
Pin material: Aluminum alloy
Track material: EN31

Fig.5. - Pin on disc wear test rig

This tester is used to determine the friction and wear characteristics of the specimen under lubrication. It is interfaced with the computer through WinDucom software for viewing the results. The specifications of the pin on disc equipment are listed in the Table 2.

Table 2. Specifications of pin on disc wear test rig

S.No	Parameters	Description	Remarks
1	Normal Load (N)	5-200	Dead weights 0.5,1&2Kg
2	Frictional Force (N)	Up to 200	Button or Beam type sensor
3	Wear measurement (microns)	5000	LVDT sensor
4	Disc Speed (rpm)	100±2000	Variable
5	Motor and drive	AC motor with drive	2 kW
6	Test duration	Pre set Timer	99 Hr:59 Min:59 Sec
7	Machine dimensions (feet)	3 x 2.5 x 3	

3.4 Field test

3.4.1 Heat generation test

A) Test after a week of time

The heat generation test was performed at Supertex mills India private limited, Coimbatore. The spindle used for testing heat generation is HD spindle of LR6 machine of LMW make shown in figure 6. The instrument used for measurement is FLIR E4 infrared thermal camera, specification given in table 3, which is an industrial instrument for the measurement of heat generation. In this test, the developed nanolubricants are filled inside the spindle and after a week of run, the temperature was measured continuously at an interval of one hour for 12 readings. The neck region of the bolster was taken for the heat generation as it has high heat generation than any other region. Each lubricant was filled with two spindles of the machine.

Table 3. FLIR E4 Specification

Measurement	Description
Object temperature range (°C)	–20 to +250
Accuracy (°C)	±1 of reading, for ambient temperature 10°C to 35°C (+50°F to 95°F) and object temperature above +0°C (+32°F)

B) Test after a month of time

In this test, the developed lubricants are left unchanged at the textile ring frame spindles for a month with continuous run at production. Same procedure was followed and the measurement of heat generation was taken.

Fig. 6. - FLIR E4 measuring Spindle heat

3.4.2 Volumetric change test

The volumetric change test is the observation of volume of the developed nanolubricants after a month of run using dip stick shown in figure 7. This test is also known as dip stick analysis. Due to degradation or evaporation, the volume of bio-oils may change and it is necessary to monitor the volume of the lubricant in the spindles.

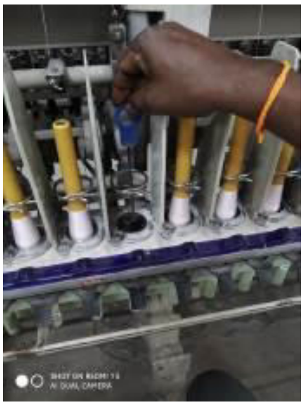

Fig.7. - Dip stick analysis

3.4.3 Power consumption test

The power consumption test was performed at Supertex mills India private limited, Coimbatore. The machine used for power consumption test was LR6 machine of 144 spindles shown in figure 8. The spindles of the machine are manually filled with the developed nanolubricants.

Fig. 8. LR6 Machine

The power consumption always varies with speed of spindles and it necessary to test at various speed, so the test was taken at speed of 18000 rpm for 4 hours and 14000 rpm and for 2 hours.

3 Results and discussion

3.1 Results of friction and wear test

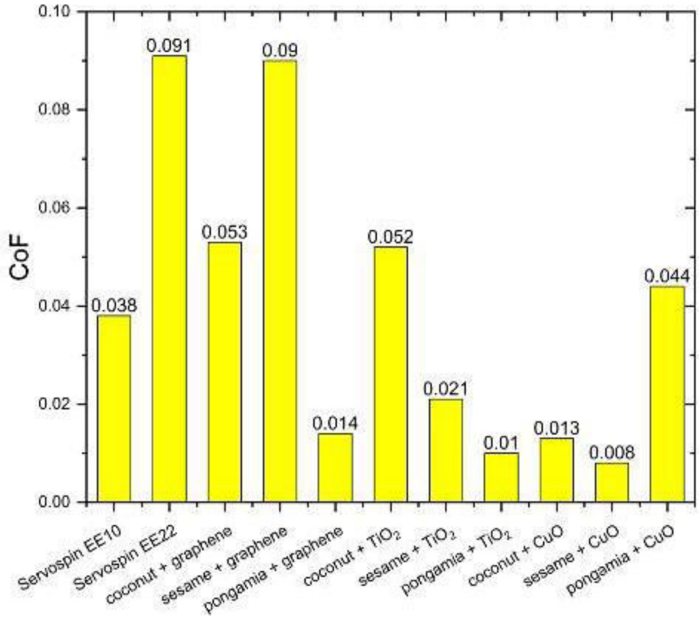

Fig. 9. - COF of nanolubricants

From the graph 9, it is evident that nanolubricants such as pongamia + graphene, sesame + TiO_2, pongamia + TiO_2, coconut + CuO, sesame + CuO have shown lesser COF than the conventional lubricants. The mechanism behind for the reduction in friction of pongamia + graphene is the protective film formation [18], for pongamia + TiO_2 is rolling effect [16] and for sesame + CuO is the self-repairing effect called as mending effect [17]. Sesame + CuO has shown 79% less COF than the conventional lubricant.

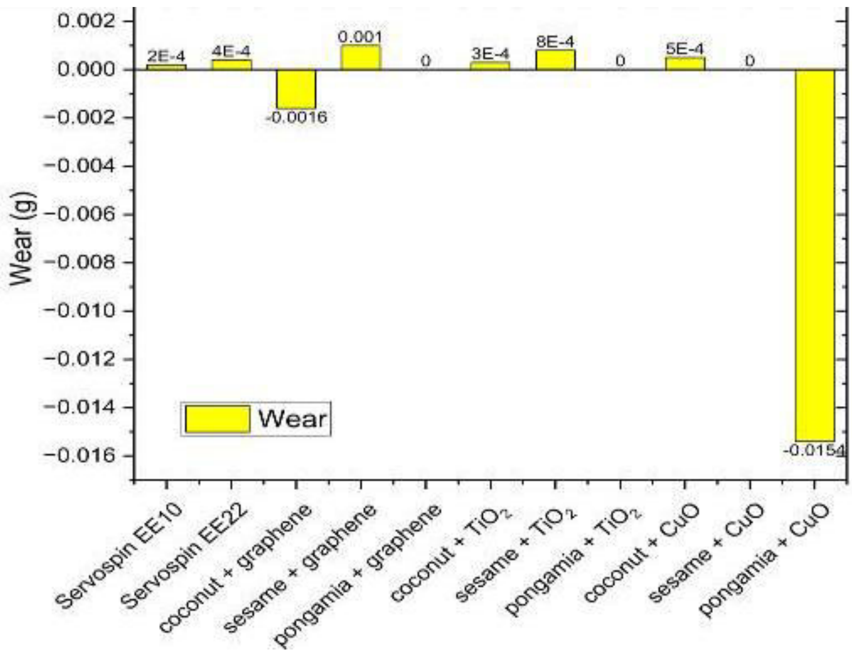

Fig. 10. – Wear

The wear of the pin materials due to friction in wet lubrication condition is shown in figure 10. Results show that pongamia + graphene, pongamia + TiO_2 and sesame + CuO nanolubricants have zero wear.

From the test results of viscosity, flash point and fire points, cloud point and pour points, friction and wear, the following bio-nanolubricants are found to be more suitable for the application:

- Sesame + CuO nanolubricant;
- Pongamia + graphene nanolubricant;
- Pongamia + TiO_2 nanolubricant.

3.2 Results of thermal conductivity test

The thermal conductivity of the nanolubricants is found to be higher than the conventional lubricant Servospin EE10 as shown in figure 11.

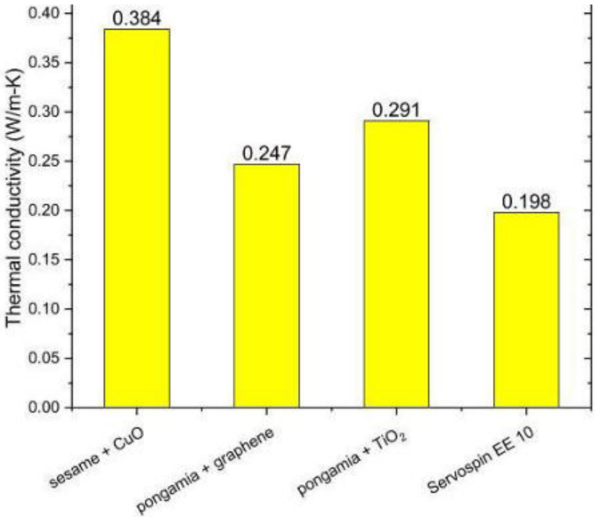

Fig. 11. - Thermal conductivity of nanolubricants

The sesame + CuO nanolubricant shows 48% higher thermal conductivity than the conventional lubricant Servospin EE10. Therefore, implementation of these nanolubricants would enhance the carrying away of heat from the application.

3.3 Results of anti-rust test

The nanolubricants are tested for pH level to determine the nature of the lubricant. The pH level of all the selected nanolubricants lies between 6 to 8 pH which is neutral. The neutral pH is more satisfactory for the anti-rust property. Synthesis chemical laboratory, Coimbatore certified that the nanolubricants have anti-corrosive property through salt spray analysis.

3.4 Results of dispersion stability

For better dispersion stability of nanoparticles in nanolubricants, the zeta potential value should not lie between -25 mV to +25 mV and from the figure 12 it is clear that zeta potential value of all the nanolubricants lie well outside the limit.

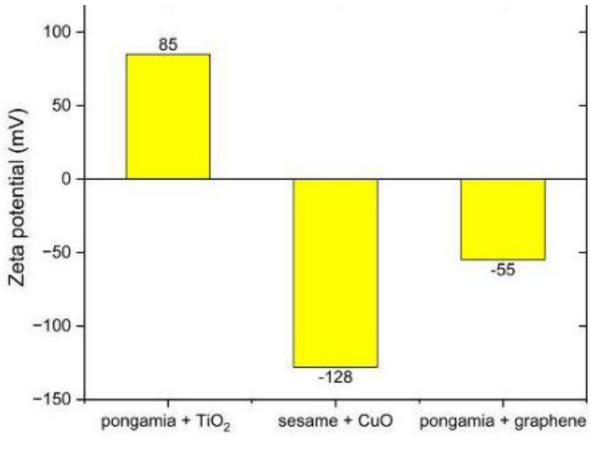

Fig. 12. - Dispersion stability of nanolubricants

3.5 Results of field test

3.5.1 Heat generation test results

The heat generation test results of the ring frame spindle after a week (figure 13) shows that pongamia + TiO_2 nanolubricant has better heat transfer capacity than the conventional lubricant due to its high thermal conductivity and less coefficient of friction. Sesame + CuO and pongamia + graphene nanolubricants show equivalent heat transfer as of the conventional lubricant Servospin EE10.

The heat generation test results of the ring frame spindle after a month (figure 14) shows that that pongamia + TiO_2 and sesame + CuO nanolubricants have more heat transfer capacity due to its higher thermal conductivity than the conventional lubricant. Pongamia + graphene nanolubricant shows equivalent heat transfer capacity as of the conventional lubricant Servospin EE10.

Sample A, B, C are pongamia + TiO_2, sesame + CuO, Pongamia + graphene and the Serco spin EE 10 is mentioned as regular.

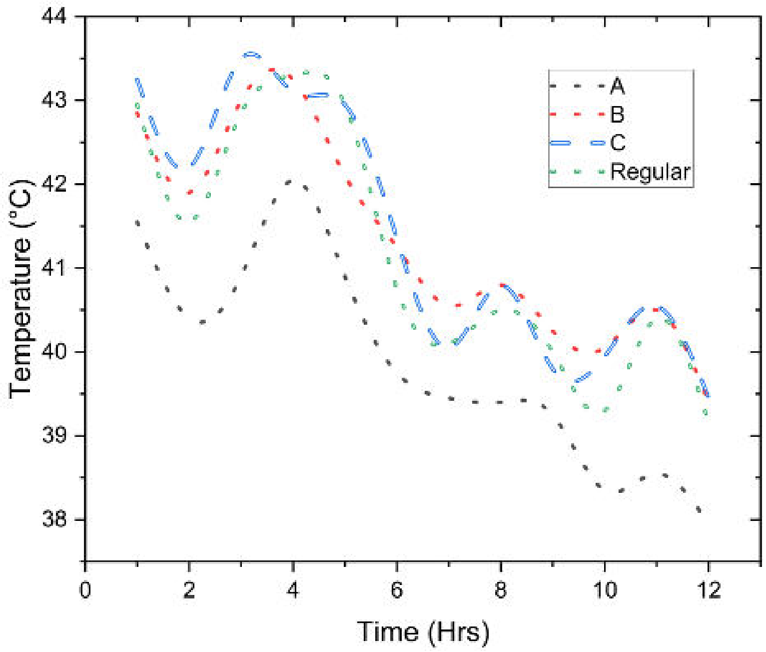

Fig. 13. - Heat generation after a week of time

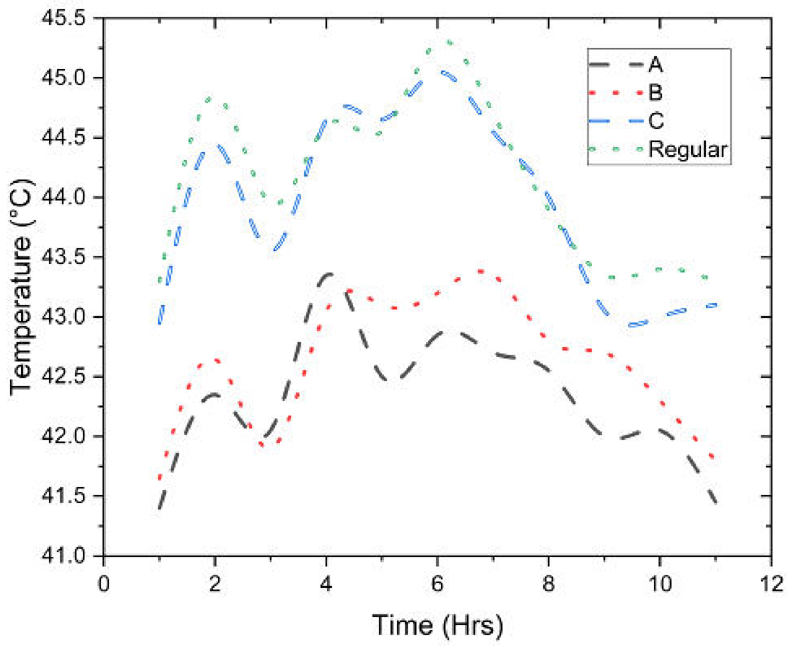

Fig.14. - Heat generation after a month of time

3.5.2 Volumetric change test

The volumetric change test of the nanolubricants after a month of run using dip stick shows that there is no volumetric change for the selected nanolubricants such as pongamia + graphene, pongamia + TiO_2 and sesame + CuO.

3.5.3 Power consumption test

Power consumption test results at 18000 rpm is tabulated in table 4 and the result shows that pongamia + TiO_2 nanolubricant has 3.39% reduction in the power consumption per hour due to less friction [16] than the conventional oil.

Table 4. Power consumption at 18000 rpm

Parameters	Servospin EE 10	Pongamia + TiO_2	Sesame + CuO	Pongamia + graphene
No of spindles per machine	144	144	144	144
Main motor capacity - kW	7.5	7.5	7.5	7.5
Spindle type	HS	HS	HS	HS
Spindle wharve dia - mm	18.5	18.5	18.5	18.5
Spindle speed – rpm	18020	18020	18020	18020
Study duration - hours	4	4	4	4
Units consumed during study – kW	7.36	7.11	7.23	7.42
Units consumed per hour - kW	1.84	1.78	1.81	1.86

Power consumption test results at 14000 rpm is tabulated in table 5 and the result shows that pongamia + TiO_2 nanolubricant has 2.92% reduction in the power consumption per hour due to less friction [16] than the conventional oil.

Table 5. Power consumption at 14000 rpm

Parameters	Servospin EE 10	Pongamia + TiO_2	Sesame + CuO	Pongamia + graphene
No of spindles per machine	144	144	144	144
Main motor capacity (kW)	7.5	7.5	7.5	7.5
Spindle type	HS	HS	HS	HS
Spindle wharve diameter (mm)	18.5	18.5	18.5	18.5
Spindle speed (rpm)	14000	14000	14000	14000
Study duration (hours)	2	2	2	2
Units consumed during study (kW)	3.42	3.32	3.37	3.39
Units consumed per hour (kW)	1.71	1.66	1.69	1.70

Conclusion

Based on the preliminary studies and literature review it was found that there exist excessive heat generation in the ring frame spindles due to degradation of lubricant over a period and causes energy losses.

Biodegradable base oils such as sesame oil, coconut oil and pongamia oil were selected for the research due to their excellent tribological properties. Nanoparticles such as TiO_2, CuO and graphene, surfactant such as oleic acid were selected for the research.

In order to study the performance of the nanolubricants, various tests have been carried out such as viscosity test, flash point and fire point tests, cloud point and pour point tests, friction test and wear test. The test results show that all the nanolubricants show 52-82% higher in the viscosity than the conventional nanolubricant servo spin EE 10. Coconut + TiO_2 nanolubricant shows 50% higher flash point than conventional lubricant. And sesame + TiO_2 nanolubricant shows 51% higher fire point than conventional lubricant. The cloud point and pour point of our nanolubricants are most suitable for this application. Sesame + CuO nanolubricant has shown 79% less COF than the conventional lubricant.

Overall, from the results of viscosity, flash and fire points, cloud and pour points, friction and wear test the following samples are found to be more suitable for the application:

- Sesame + CuO nanolubricant;
- Pongamia + graphene nanolubricant;
- Pongamia + TiO_2 nanolubricant.

The nanolubricant sesame + CuO shows 48% higher thermal conductivity than the conventional lubricant Servospin EE10. The pH level of all the selected nanolubricants lies between 6 to 8 pH which is neutral. The neutral pH is more satisfactory for the anti-rust property.

The final field tests such as heat generation test after a week and after a month of time, power consumption test at 18000 rpm for 4 hours and 14000 rpm for 2 hours and volumetric change observation after a month of run are performed at supertax mills Coimbatore. Based on the results of all the tests, pongamia + TiO_2 nanolubricant is selected as the most suitable lubricant for the textile ring frame spindle application.

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