Comparative Analysis of the Product Formulated in Group-1 and Group-2 Mineral Base Oil

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Abstract:
This research based on the mineral base oil formulated in different additives for Automotive engines. In this experiment, performance of two different groups of mineral base oil are investigated, one of which is Group-1 base oil while the other is Group-II base oil. Different products are prepared for automobile like Motorcycle, CNG Car and Diesel engine with the required additives. Then, the samples were used in the respective vehicles and samples it is observed that the viscosity at 100°C of Group-2 base oil's products depleted about 4.91%, 5.91% & 9.55% while of Group-1 Base oil's products are about 16.5%, 10% & 26.08% for Motorcycle, CNG engine car and Diesel engine respectively. Similarly, the flash point of Group-2 base oil's products decreases less as compare to the products of Group-1 base oil, hence the results of the samples are use shows that the products blended in Group-2 base oil perform better and run longer than the products blended in Group-1 base oil.

Keywords:
- API – American Petroleum Institute
- ASTM – American Society for Testing and Materials
- SAE – Society of Automotive Engineers
- HVI – High Viscosity Index
- CCS – Cold Crank Simulator

Introduction:
As parts of machine or engine move it creates somehow friction and heat that leads to the wear and tear. Generally, the lubrication could be done by using the lubricating oil that may be mineral and synthetic but both type of base oil required bending with some additives used for the enhancement of the base oil built-in properties that ultimately lead to increases the engine's life. Base oils are generally mineral and synthetic classified in a groups; Group I, Group-I, Group-III, Group-IV and Group-V. Some of their properties are mentioned in Table 1(1). Hydrocarbon molecules in the base oil with irregular shape causing increased friction with in the oil that great effect their thermal stability(2). This paper generally discusses their behavior with the additives and how it performs better with a cheap blending rate and also discuss the results obtained after the use of lubricating oil that which base oil group perform better with which additives in a cheaper rate.
Generally, the companies prepare their blend with very high quality Hydrocracked mineral base oils and imported carefully selected low ash additive package for use in spark ignited passenger car engines operating on CNG/Gasoline fuel. The medium ash product provides excellent lubrication to engine running on CNG with less sludge, varnish and carbon buildup under the most severe operating conditions. On the other hand, industrial products also prepared with mineral base oil and selective additives like hydraulic oil, compressor oil etc. Some of the industrial lubricants are blended without additives. These lubricants are also known as general purpose oil(3). The performance of the base oil in the engines are: High viscosity index is to enable better fuel economy and low volatility(4), Lower volatility will lead to the reduce of the oil consumption and enhance the thermal

stability, Provide good Oxidation stability, high saturates contents for improved additives response and practically zero sulfur content is not possible but try to keep it as low as possible because it lead to the formation of acid in the lubricating oil in the engine during running and ultimately lead to the corrosion.

Group	Manufacturing Process	Saturate Level	Sulfur Level	Viscosity Index
Group I	Solvent Refining	< 90%	> 0.03%	80 – 120
Group II	Hydro-processing (Hydrocracking)	≥ 90%	≤ 0.03%	80 – 120
Group III	Severe Hydrocracking (Catalytic De-waxing)	≥ 90%	≤ 0.03%	≥ 120
Group IV	Chemical Reactions (Synthesizing)	100% PAOs (Poly-Alpha-Olefins)		
Group V	As Indicated	All others not included in Groups I, II, III or IV Naphtenic oils and esters		

Table 1

Material:

In this research, two base oil is used to investigate their performance on the bases of its usage. One of which is Group-1 and the other is Group-2 base oil. Some of the additives for the enhancement of the required engine oil is used that is generally "Dispersant Inhibitor", which contain Alky Zinc dithiophosphates, Succcinides, esters or Mannich dispersant, Calcium, magnesium, sodium sulfoantes, phenates, phenolic and amine antioxidant(5), in addition with various friction modifiers such as sulfurized fatty acids.

As Zinc dithiophosphate is a multi-function additive that usually give best performance with the base oil protect the engine parts because it functions as corrosion inhibitor, anti-wear agent, and antioxidants (6).

Some of the viscosity modifier is also used to increase the viscosity and improve the viscosity index of the base oil required to manufacture the automotive oil or industrial lubricants. One the viscosity modifier is Hydrogenated Styrene Diene (7), it increases the viscosity at low temperature and also at higher temperature of base oil. One of my previous research paper, its effect on the base oil and also on the vegetable oil such as Soybean has been discussed and the results shows that by adding 4% Hydrogenated Styrene Diene in 400 HVI base oil viscosity is increased about 44.50% at 40°C and 47.5% at 100°C. Similarly, by adding 8%, viscosity is increased about 100.9% at 40°C and 97.67% at100°C. By adding 4% Hydrogenated Styrene Diene in Soybean oil, viscosity is increased about 6.24% at 40°C and 21.79% at 100°C. Similarly, by adding 8%, viscosity is increased about 13.44% at 40°C and 47% at 100°C (8).

A pour point depressant is also used in the engine oil formulation mainly and usually "Polymethacrylate" is used (9). Main function of the pour point depressant is to lower the pour point of the lubricants; it actually resists the formation of crystallization in the base oil that is due to the presence of wax in the base oil. The solid crystals form a lattice network that stop the remaining liquid oil from flowing.

One of another additive to resist the formation of foam in the finish product is used, known as anti-foam. The chemicals in this additive group provides low interfacial surface tension, which weakens the wall of air bubbles in oil and allows the foam bubbles to burst more readily(10). They have an indirect effect on oxidation by reducing the quantity of air-oil contact. Some of these additives are oil-insoluble silicone materials that aren't dissolved but rather dispersed finely within the lubricating oil. Very low concentrations of anti-form additives are usually required. If more than required anti-foaming additive is added, it can have a reverse effect and promote further foaming and air entrainment(11).

Methodology:

Usually an international standard equipment and standard test methods are used to test raw material and the finish product. As ASTM D-1298, ASTM D-1298, ASTM D-445, ASTM D-445, ASTM D-2270, ASTM D-1500, ASTM D-93, ASTM D-92, ASTM D-2500, ASTM D-97, ASTM D-130, ASTM D-2896, ASTM D-974 and ASTM D-189 to insure the accurate results of the finish product.

Typical properties of the base oil from Group-1 including 400 HVI and Bright Stock HVI (BSH) and Group-2 including SN-500 is shown in Table 2.

Test	ASTM Code	400 HVI (G1)	BSH (G1)	SN-500 (G2)
Density (g/cm^3)	ASTM D-1298	0.8899	0.8946	0.8735
Color Code & Appearance	ASTM D-1500	2.5 (Sunny)	4.0 (Golden)	0 (Colorless)
Viscosity @ 40°C (cSt)	ASTM D-445	85	440.71	93
Viscosity @ 100°C (cSt)	ASTM D-445	9.90	30.99	11.89
Viscosity Index	ASTM D-2270	95	100	119
Flash Point (°C)	ASTM D-93	220	264	255
Fire Point (°C)	ASTM D-92	231	310	275
Cloud Point (°C)	ASTM D-2500	-5	-1	-12
Pour Point (°C)	ASTM D-97	-6	-3	-15
Total Base Number (mgKOH/g)	ASTM D-2896	<0.05	<0.05	0
Total Acid Number (mgKOH/g)	ASTM D-974	<0.05	<0.05	0
Conradson Carbon Residue (Wt%)	ASTM D-189	0.15	1.2	0

Table 2

Automotive Products:

- **Motorcycle Engine Oil:**

For motorcycle engine oil different SAE Product is recommended like 0w-10, 5w-20, 10w-40, 20w-40, 20w-50. Now, I selected SAE 20w-50 for the usage in the bike because SAE 20w-50 with SG API performance generally recommended for motorcycle engine.

- ***Group-1 Base Oil Product: (SAE 20W-50) SG API***

So, finished product of lubricant for the motorcycle is prepared, base oil including 400 HVI and Bright Stock HVI from Group-1 is used to blend with DI-Package and Hydrogenated Styrene Diene in order to make the finish product of 20W-50 for bike engine. The complete formulation is shown in Table 3.

Sample-1

Raw Materials	Code Number	Dosage
Base Oil	400 HVI	79.18%
Base Oil	BS HVI	10%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	6%

Table 3

The base oil of two different grades that include 400 HVI and BS HVI is used because of the evaporation losses from the finished product as shown in table-2 that 400 HVI has less Flash and Fire point this cause the oil to evaporate at greater temperature in the engine on the other hand BS HVI has a greater Flash and Fire point. So the addition of BS HVI in smaller amount can reduce the evaporation less of lubricant and knock volatility too. After blending the base oil with additives, the typical properties of the base oil are a shown in Table 4.

According to SAE, most important parameters for the multi-grade engine oil is the viscosity at 100°C and the other property at lower temperature that is apparent viscosity @ -15°C obtained by Cold Cranking Simulator. 20W-50 should have viscosity in the range of (16.30 – 21.89) cSt at 100°C and apparent viscosity @ -15°C should be Max 9400(12).

Tests	ASTM Code	SAE 20W-50 (Group-1)
Density (g/cm^3)	ASTM D-1298	0.8910
Viscosity @ 40°C (cSt)	ASTM D-445	149.86
Viscosity @ 100°C (cSt)	ASTM D-445	17.43
Viscosity Index	ASTM D-2270	127
Flash Point (°C)	ASTM D-93	210
Fire Point (°C)	ASTM D-92	221
Cloud Point (°C)	ASTM D-2500	-3
Pour Point (°C)	ASTM D-97	-4
Total Base Number (mgKOH/g)	ASTM D-2896	7-8 (7.728)
Total Acid Number (mgKOH/g)	ASTM D-974	0.09
CCS	ASTM D-5293	12000

Table 4

In this blend of Sample-1, all the typical properties of engine oil meet the standard except the Cold Cranking Simulator test. As this test should have the maximum value 9400 @ -15°C but in this blend it exceeds the maximum range value.

This may be due to the presence of BS HVI; now next blend Sample-2 is preparing with 5% volume of BS HVI and the following additives in the required amount. As shown in Table 5.

Sample-2

Raw Materials	Code Number	Dosage
Base Oil	400 HVI	83.18%
Base Oil	BS HVI	5%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	7%

Table 5

The typical properties of blend Sample-2 prepared in the formulation of Table 5, is shown in Table 6.

Tests	ASTM Code	SAE 20W-50 (Group-1)
Density (g/cm^3)	ASTM D-1298	0.8935
Viscosity @ 40°C (cSt)	ASTM D-445	155.53
Viscosity @ 100°C (cSt)	ASTM D-445	18.53
Viscosity Index	ASTM D-2270	129
Flash Point (°C)	ASTM D-93	212

Fire Point (°C)	ASTM D-92	220
Cloud Point (°C)	ASTM D-2500	-3
Pour Point (°C)	ASTM D-97	-4
Total Base Number (mgKOH/g)	ASTM D-2896	7-8 (7.728)
Total Acid Number (mgKOH/g)	ASTM D-974	0.09
CCS	ASTM D-5293	9800

Table 6

In order to meets the standard, another product Sample-3 is also blend in 400 HVI of group-1 base oil no other base oil like BS HVI is not added to obtained the apparent viscosity (Cold Cranking Simulator). The formulation of this blend is given in Table 7.

Sample-3

Raw Materials	Code Number	Dosage
Base Oil	400 HVI	85.18%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	10%

Table 7

The typical properties of the blend prepared without BS HVI formulation shown in Table 7 is given in Table 8.

Tests	ASTM Code	SAE 20W-50 (Group-1)
Density (g/cm^3)	ASTM D-1298	0.8953
Viscosity @ 40°C (cSt)	ASTM D-445	169.4
Viscosity @ 100°C (cSt)	ASTM D-445	19.30
Viscosity Index	ASTM D-2270	130
Flash Point (°C)	ASTM D-93	215
Fire Point (°C)	ASTM D-92	228
Cloud Point (°C)	ASTM D-2500	-4
Pour Point (°C)	ASTM D-97	-6
Total Base Number (mgKOH/g)	ASTM D-2896	7.61
Total Acid Number (mgKOH/g)	ASTM D-974	0.05
CCS	ASTM D-5293	7076

Table 8

As this product (Sample-3) has all the values according to standard given by API, now this product is ready for use.

- ***Group-2 Base Oil Product: (20W-50) SG API***

SAE 20W-50 Sample-4 using a group-2 base oil is prepared by blending SN-500 Group-2 base oil with same dosage of additives as shown in Table 3. No other than SN-500 base oil is used because the Flash and Fire point and knock volatility of SN-500 is already higher as shown in Table 2 so that it can resist the evaporation at higher temperature. The complete formulation of this product is shown in Table 9.

Sample-4

Raw Materials	Code Number	Dosage
Base Oil	SN-500	89.18%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	6%

Table 9

****DI-Package is generally a mixture of required additives like anti-wear, anti-oxidant, corrosion inhibitor, Oil-Soluble Molybdenum Additive used in the automobile engines, that's why it is considered as single raw product for the formulation****

Now after blending the above base oil and additives according to the SAE at 60°C for 20 to 25 minutes the finished product is prepared and after that the required testing is done. Typical properties of the Sample-3 & Sample-4 results are shown in Table 10.

Tests	ASTM Code	SAE 20W-50 (Group-1) Sample-3	SAE 20W-50 (Group-2) Sample-4
Density (g/cm³)	ASTM D-1298	0.8953	0.8778
Viscosity @ 40°C (cSt)	ASTM D-445	169.4	162.60
Viscosity @ 100°C (cSt)	ASTM D-445	19.30	17.90
Viscosity Index	ASTM D-2270	130	122
Flash Point (°C)	ASTM D-93	215	240
Fire Point (°C)	ASTM D-92	228	255
Cloud Point (°C)	ASTM D-2500	-4	-12
Pour Point (°C)	ASTM D-97	-6	-16
Total Base Number (mgKOH/g)	ASTM D-2896	7.61	7-8 (7.728)
Total Acid Number (mgKOH/g)	ASTM D-974	0.05	0.05
CCS	ASTM D-5293	7076	7012

Table 10

- **CNG/Gasoline Engine Oil:**
  According to the manufacturing of engine SAE recommend different API performance oil like SG for engine manufactured up to 1993, SH for up to 1996, SJ for 2001 and older automotive engine (13). Now, I prepared 20w50 SG API performance in both Group-1 and Group-2 base oil for my CNG engine. Basically, 20W50 motor oil is suitable for warmer climates, where the higher temperature causes the oil to thin. It is also useful for vehicles subject to hot climate temperatures and for those used for high-stress activities such as hauling and trailers.

➢ ***Group-1 Base Oil Product: (SAE 20W50) SG API***
  Now, Sample-5 20W50 SG API for CNG/Gasoline engine is also prepared in the same way with the help of 400 HVI from Group-1 mineral base oil while on the other hand some required additive for it also added with specific composition as shown in Table 11.

Sample-5

Raw Materials	Code Number	Dosage
Base Oil	400 HVI	84.88%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	10%
PPD	PPL-8899	0.3

Table 11

Here, Pour Point Depressant is used to avoid the crystallization in the oil that ultimately lower the pour point of the lubricants.

- ***Group-2 Base Oil Product: (SAE 20W50) SG API***
  Similarly, this product (Sample-6) is also prepared in the same way as previous one but the 40o HVI is replaced by SN-500 from Group-2 base oil. No other than SN-500 base oil is used because the Flash and Fire point and knock volatility of SN-500 is already higher as shown in Table 2 so that it can resist the evaporation at higher temperature. The complete formulation of this product is shown in Table 12.

Sample-6

Raw Materials	Code Number	Dosage
Base Oil	SN-500	89.18%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-2233	4.8%
Hydrogenated Styrene Diene	PPL-7900	6%

Table 12

****DI-Package in this formulation is also generally a mixture of required additives like anti-wear, anti-oxidant, corrosion inhibitor, Oil-Soluble Molybdenum Additive used in the automobile engines, that's why it is considered as single raw product for the formulation****

Now, similarly after blending the above base oil and additives according to the SAE at 60°C for 20 to 25 minutes the finished product is prepared and after that the required testing is done.

According to SAE, most important parameters for the multi-grade CNG engine oil is the viscosity at 100°C and the other property at lower temperature that is apparent viscosity @ -15°C obtained by Cold Cranking Simulator. 20W-50 should have viscosity in the range of (16.30 – 21.89) cSt at 100°C and apparent viscosity @ -15°C should be Max 9400(12). All typical properties of the products Sample-5 & Sample-6 results are shown in Table 13.

Tests	ASTM Code	SAE 20W-50 (Group-1) Sample-5	SAE 20W-50 (Group-2) Sample-6
Density (g/cm^3)	ASTM D-1298	0.8948	0.8856
Viscosity @ 40°C (cSt)	ASTM D-445	168.03	170.43
Viscosity @ 100°C (cSt)	ASTM D-445	19.02	19.11
Viscosity Index	ASTM D-2270	129	127
Flash Point (°C)	ASTM D-93	214	238
Fire Point (°C)	ASTM D-92	228	251
Cloud Point (°C)	ASTM D-2500	-9	-17
Pour Point (°C)	ASTM D-97	-12	-20
Total Base Number (mgKOH/g)	ASTM D-2896	7.21	7-8 (7.728)
Total Acid Number (mgKOH/g)	ASTM D-974	0.05	0.05
CCS	ASTM D-5293	7089	7015

Table 13

Now products named Sample-5 & Sample-6 has all the properties in range according to SAE. So these products are ready for use in CNG engine.

- **Diesel Engine Oil:**

Modern clean diesel technology brought with it the need for higher-quality motor oils. The American Petroleum Institute (API) introduced the current CJ-4 oil standards back in 2006 so diesel motor oils would be compatible with 2007 model year engines equipped with exhaust gas recirculation (EGR) and exhaust after treatment systems, and would be designed to burn ultra-low sulfur (less than 15 ppm) diesel fuel. The higher operating temperatures and tougher emission requirements for clean diesel engines meant the oil had to provide better oxidation resistance, higher temperature stability and soot control (14).

- ***Group-1 Base Oil Product: (20W-50) API CF-4 SG***

  Now, Sample-7 20W50 API CF-4 SG for Diesel engine is also prepared in the same way with the help of 400 HVI from grpup-1 mineral base oil while on the other hand, specially required additive for diesel engine also added like, TBN booster, DI package for this grade of oil with specific composition as shown in Table 14.

Sample-7

Raw Materials	Code Number	Dosage
Base Oil	400 HVI	82.78%
Anti-Foam	PPL-889	0.02%
PPD	PPL8899	0.3%
DI-Package	PPL-7788	6.9%
Viscosity Modifier	PPL-7900	9%
TBN Booster	PPL-6688	1%

Table 14

TBN Booster in some quantity is required in diesel engine in order to neutralize the formation of acid due to the presence of greater quantity of Sulphur in diesel fuel. PPD is added to lower down the pour point of the oil because the 400 HVI having a pour point -6°C that can cause the problems related to the fluidity of oil because this oil is used in the diesel engine vehicle that travel through different region Pakistan having a low temperature atmosphere. That's why, PPD allows the oil to have fluidity even at a lower temperature.

- ***Group-2 Base Oil Product: (20W-50) API CF-4 SG***

Similarly, this product (Sample-8) is also prepared in the same way as previous one but the 400 HVI is replaced by SN-500 from Group-2 base oil. No other than SN-500 base oil is used because the Flash and Fire point and knock volatility of SN-500 is already higher as shown in Table 2 so that it can resist the evaporation at higher temperature. The complete formulation of this product is shown in table-15. PPD is not added in this blend because SN-500 base oil having a pour point nearly -18°C. So, this pour point allows the oil not cease its fluidity at the regions of Pakistan having lower temperature atmosphere.

Sample-8

Raw Materials	Code Number	Dosage
Base Oil	SN 500	84.08%
Anti-Foam	PPL-889	0.02%
DI-Package	PPL-7788	6.9%
Viscosity Modifier	PPL-7900	8%
TBN Booster	PPL-6688	1%

Table 15

****DI-Package in this formulation is also generally a mixture of required additives like anti-wear, anti-oxidant, corrosion inhibitor, Oil-Soluble Molybdenum Additive that meets the API specification of CF-4 SG used in the automobile Diesel engines, that's why it is considered as single raw product for the formulation****

Now, similarly after blending the above base oil and additives according to the SAE at 60°C for 20 to 25 minutes the finished product is prepared and after that the required testing is done.

According to SAE, most important parameters for the multi-grade CNG engine oil is the viscosity at 100°C and the other property at lower temperature that is apparent viscosity @ -15°C obtained by Cold Cranking Simulator. 20W-50 should have viscosity in the range of (16.30 – 21.89) cSt at 100°C and apparent viscosity @ -15°C should be Max 9400 (12). All typical properties of the products Sample-7 & Sample-8 results are shown in Table 16.

Tests	ASTM Code	SAE 20W-50 (Group-1) CF-4 SG Sample-7	SAE 20W-50 (Group-2) CF-4 SG Sample-8
Density @ 15°C (g/cm^3)	ASTM D-1298	0.8923	0.8847
Viscosity @ 40°C (cSt)	ASTM D-445	166.65	161.98
Viscosity @ 100°C (cSt)	ASTM D-445	18.94	19.58
Viscosity Index	ASTM D-2270	129	139
Flash Point (°C)	ASTM D-93	218	238
Fire Point (°C)	ASTM D-92	230	262
Cloud Point (°C)	ASTM D-2500	-6	-15
Pour Point (°C)	ASTM D-97	-9	-18
Total Base Number (mgKOH/g)	ASTM D-2896	11.89	11.98
Total Acid Number (mgKOH/g)	ASTM D-974	<0.05	<0.05
CCS	ASTM D-5293	8011	7098

Table 16

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Results and Discussion:

- **Motorcycle Engine Oil:**

Sample-3 Motorcycle engine oil is blended in 400 HVI Group-1 mineral base oil according to the formulation set in Table 7 is used in the motorcycle of Honda Manufacturer model 2018. The product is used in the Bike for 1000 km with the region of Karachi. After the drain of oil, used oil sample is tested and the results are shown in Table 17. Sample-4 Motorcycle engine oil is blended in SN-500 Group-2 mineral base oil according to the formulation given in Table 9 is also used in the same motorcycle with same conditions. But this product is drained after the running of 1800 km. the drained oil sample is tested and the results are shown in Table 17.

Sr. #	Test Parameter	Method	Units	Results(Sample-3)	Results(Sample-4)
1.	Viscosity @ 40°C	ASTM D445	cSt	160	155
2.	Viscosity @ 100°C	ASTM D445	cSt	16.1	17.01
3.	Viscosity Index	ASTM D2270	-	105	118
4.	Total Base Number	ASTM D2896	mgKOH/g	6.59	6.90
5.	Total Acid Number	ASTM D664	mgKOH/g	1.42	1.11
6.	Flash point	ASTM D92	°C	198	229
7.	Water Content	ASTM D95	Vol%	<0.05	<0.05
8.	Oxidation/Nitration	FTIR	Ab/cm	2.50/1.00	2.50/1.00
9.	Iron (Fe)	ICP-OES	ppm	35	28
10.	Chromium (Cr)	ICP-OES	ppm	<1	<1
11.	Nickel (Ni)	ICP-OES	ppm	<1	27
12.	Aluminum (Al)	ICP-OES	ppm	13	13
13.	Copper (Cu)	ICP-OES	ppm	1	2
14.	Lead (Pb)	ICP-OES	ppm	2	3
15.	Tin (Sn)	ICP-OES	ppm	<1	<1
16.	Silicon (Si)	ICP-OES	ppm	12	19
17.	Titanium (Ti)	ICP-OES	ppm	<1	<1
18.	Zinc (Zn)	ICP-OES	ppm	663	550
19.	Fuel Dilution	By viscosity Diff.	%	25.05	15.95

Table 17

As the results obtained after the use of sample-3 and sample-4, it has been observed Table 17 that viscosity at 100°C of Sample-3 depleted from 19.30cSt to 16.1cSt means there is decrement in the viscosity at 100°C of about 16.5% and the Sample-3 can't be used further more in the motorcycle because its viscosity at 100°C is out of the range for 20w-50 according to SAE while on the other side, Sample-4's viscosity at 100°C is also depleted but not like Sample-3, the viscosity at 100°C of Sample-4 depleted from 17.90cSt to 17.01cSt that is about 4.91% decrement and Sample-4 can be further used because its viscosity is in the range of 20w-50 according to SAE. While comparing the flash point of the samples before and after use it has been observed that the flash point of Sample-3 is depleted from 215°C to 198°C and the flash point of Sample-4 is decreased from 240°C to 229°C that is about 7.90% and 4.58% decrement respectively. TBN and TAN is also changed of both of the samples in which the TAN is increased while TBN is decreased. TAN of Sample-3 is increased from 0.05 mgKOH/g to 1.42

mgKOH/g while of Sample-4 has been increased from 0.05 mgKOH/g to 1.11 mgKOH/g while the TBN of Sample-3 is decreased from 7.61 mgKOH/g to 6.59 mgKOH/g and of Sample-4, it is from 7.728 mgKOH/g to 6.90 mgKOH/g, this shows that the Sample-3 which is blended in group-1 base oil is oxidized more than the Sample-4 which is blended in group-2 base oil and more acid formation in the blend of group-1 is due to the presence of higher concentration of Sulphur content as shown in Table 1. Much better results of Sample-4 are obtained when we compare the wear metal analysis of both the samples after use as mentioned in Table 17 that Sampe-3 causes a more metal wear as compared to the Sample-4. Concentration of (iron & zinc) after use in Sample-3 and Sample-4 is about (35ppm & 663ppm) and (28ppm & 550ppm). This shows that blend of group-1 base oil causes more wear and tear in the parts of engine as compare to the blend of group-2 base oil.

- **CNG/Gasoline Engine Oil:**

Sample-5 CNG engine oil is also blended in 400 HVI Group-1 mineral base oil according to the same formulation that is set for the automotive product blended in Group-1 base oil as shown in Table 11. This CNG engine product is used in the CNG based Cultus car of Suzuki Manufacturer model 2013. The car travel within the Karachi and Hyderabad throughout the running of oil. Used oil sample is drained from the car after 2200 km of use. After draining the used oil, it is tested and the results are shown in Table 18. Now Sample-6 blended in Sn-500 Group-2 Mineral base oil as set formulation shown in Table 12 is also used in the same car and same environment. This blend is used in the car during the running of 4000 km. After that, used oil sample is drained from the car and tested. Whereas the results of the used oil sample are shown in Table 18.

Sr. #	Test Parameter	Method	Units	Results (Sample-5)	Results (Sample-6)
1.	Viscosity @ 40°C	ASTM D445	cSt	161.81	168.5
2.	Viscosity @ 100°C	ASTM D445	cSt	17.00	17.98
3.	Viscosity Index	ASTM D2270	-	113	118
4.	Total Base Number	ASTM D2896	mgKOH/g	6.49	6.80
5.	Total Acid Number	ASTM D664	mgKOH/g	1.45	1.32
6.	Flash point	ASTM D92	°C	201	228
7.	Water Content	ASTM D95	Vol%	<0.05	<0.05
8.	Oxidation/Nitration	FTIR	Ab/cm	2.50/1.00	2.50/1.00
9.	Iron (Fe)	ICP-OES	ppm	33	29
10.	Chromium (Cr)	ICP-OES	ppm	<1	<1
11.	Nickel (Ni)	ICP-OES	ppm	<1	<1
12.	Aluminum (Al)	ICP-OES	ppm	13	13
13.	Copper (Cu)	ICP-OES	ppm	1	1
14.	Lead (Pb)	ICP-OES	ppm	2	2
15.	Tin (Sn)	ICP-OES	ppm	<1	<1
16.	Silicon (Si)	ICP-OES	ppm	12	12
17.	Titanium (Ti)	ICP-OES	ppm	<1	<1
18.	Zinc (Zn)	ICP-OES	ppm	621	506
19.	Fuel Dilution	By viscosity Diff.	%	25.05	25.05

Table 18

Similarly, when the results obtained after the use of sample-5 and sample-6, it has been observed Table 18 that viscosity at 100ºC of Sample-5 depleted from 19.02cSt to 17.0cSt means there is decrement in the viscosity at 100ºC of about 10% while on the other side, Sample-6's viscosity at 100ºC is also depleted, the viscosity at 100ºC of Sample-6 depleted from 19.11cSt to 17.98cSt that is about 5.91% decrement and Sample-5 & Sample-6 can be further used because its viscosity is in the range of 20w-50 according to SAE. While comparing the flash point of the samples before and after use it has been observed that the flash point of Sample-5 is depleted from 214ºC to 201ºC and the flash point of Sample-6 is decreased from 238ºC to 228ºC that is about 6.07% and 4.20% decrement respectively. TBN and TAN is also changed for both of the samples in which the TAN is increased while TBN is decreased. TAN of Sample-5 is increased from 0.05 mgKOH/g to 1.45 mgKOH/g while of Sample-6 has been increased from 0.05 mgKOH/g to 1.32 mgKOH/g while the TBN of Sample-5 is decreased from 7.21 mgKOH/g to 6.49 mgKOH/g and of Sample-6, it is from 7.728 mgKOH/g to 6.80 mgKOH/g, this shows that the Sample-5 which is blended in group-1 base oil is oxidized more than the Sample-6 which is blended in group-2 base oil and more acid formation in the blend of group-1 is due to the presence of higher concentration of Sulphur content as shown in Table 1. Similarly, much better results of Sample-6 are obtained when we compare the wear metal analysis of both the samples after use as mentioned in Table 18 that Sampe-5 causes a more metal wear as compared to the Sample-6. Concentration of (iron & zinc) after use in Sample-5 and Sample-6 is about (33ppm & 621ppm) and (29ppm & 506ppm) respectively. This shows that blend of group-1 base oil causes more wear and tear in the parts of engine as compare to the blend of group-2 base oil.

- **Diesel Engine Oil:**

(Sample-7) Diesel engine product blended in 400 HVI group-1 mineral base oil according to the formulation shown in table-14 is used in the 3.0-liter EURO IV diesel engine with engine horsepower of 136hp of HINO manufacturer model 2009. After the running of 2400 km from Karachi to Islamabad and back to shukkur vehicle go through different region that have different environment. Oil is drained at the running of 2400 km. Used oil sample is tested and the results are shown in Table 19. Now the Samle-8 diesel engine product that is blended in SN-500 Group-2 mineral base oil according to the formulation shown in Table 15 is used in the same diesel engine vehicle with same region travelling. First sample of used oil is drained from the vehicle after 2400 km and top-up the oil of Sample-8 in the vehicle. After that second oil drained sample is obtained after 4800 km. Both the used oil sample is tested and the results are shown in Table 19 and Table 20.

Sr. #	Test Parameter	Method	Units	Results(Sample-7)	Results(Sample-8)
1.	Viscosity @ 40ºC	ASTM D445	cSt	141.5	159.1
2.	Viscosity @ 100ºC	ASTM D445	cSt	14.00	17.70
3.	Viscosity Index	ASTM D2270	-	95	122
4.	Total Base Number	ASTM D2896	mgKOH/g	10.48	11.01
5.	Total Acid Number	ASTM D664	mgKOH/g	3.42	2.30
6.	Flash point	ASTM D92	ºC	198	225
7.	Water Content	ASTM D95	Vol%	<0.05	<0.05
8.	Oxidation/Nitration	FTIR	Ab/cm	2.50/1.00	2.50/1.00
9.	Iron (Fe)	ICP-OES	ppm	51	39
10.	Chromium (Cr)	ICP-OES	ppm	<1	<1
11.	Nickel (Ni)	ICP-OES	ppm	<1	27

12.	Aluminum (Al)	ICP-OES	ppm	13	13
13.	Copper (Cu)	ICP-OES	ppm	1	2
14.	Lead (Pb)	ICP-OES	ppm	2	3
15.	Tin (Sn)	ICP-OES	ppm	<1	<1
16.	Silicon (Si)	ICP-OES	ppm	12	19
17.	Titanium (Ti)	ICP-OES	ppm	<1	<1
18.	Zinc (Zn)	ICP-OES	ppm	964	650
19.	Fuel Dilution	By viscosity Diff.	%	25.05	15.95

Table 19

Similarly, when the results obtained after the use of sample-7 and sample-8, it has been observed Table 19 that viscosity at 100ºC of Sample-7 depleted from 18.94cSt to 14.0cSt means there is decrement in the viscosity at 100ºC of about 26.08% while on the other side, Sample-8's viscosity at 100ºC is also depleted, the viscosity at 100ºC of Sample-8 is depleted from 19.58cSt to 17.70cSt that is about 9.55% decrement now in this case Sample-7 can't be used further because its viscosity at 100ºC is out of the range & Sample-8 can be further used because its viscosity is in the range of 20w-50 according to SAE(15). While comparing the flash point of the samples before and after use it has been observed that the flash point of Sample-7 is depleted from 218ºC to 198ºC and the flash point of Sample-8 is decreased from 238ºC to 225ºC that is about 9.17% and 5.46% decrement respectively. TBN and TAN is also changed for both of the samples in which the TAN is increased while TBN is decreased. TAN of Sample-7 is increased from 0.05 mgKOH/g to 3.42 mgKOH/g while of Sample-8 has been increased from 0.05 mgKOH/g to 2.30 mgKOH/g while the TBN of Sample-7 is decreased from 11.89 mgKOH/g to 10.48 mgKOH/g and of Sample-8, it is from 11.98 mgKOH/g to 11.01 mgKOH/g, this shows that the Sample-7 which is blended in group-1 base oil is oxidized more than the Sample-8 which is blended in group-2 base oil and more acid formation in the blend of group-1 is due to the presence of higher concentration of Sulphur content as shown in Table 1 but in diesel engine oil one more factor is involved in the greater increase in TAN, which is the presence of Sulphur content in the diesel fuel also. Similarly, much better results of Sample-8 are obtained when we compare the wear metal analysis of both the samples after use as mentioned in Table 19 that Sampe-7 causes a more metal wear as compared to the Sample-8. Concentration of (iron & zinc) after use in Sample-7 and Sample-8 is about (51ppm & 964ppm) and (39ppm & 650ppm) respectively. This shows that blend of group-1 base oil causes more wear and tear in the parts of engine as compare to the blend of group-2 base oil.

When the Sample-8 is further used till the running of 4800km, the following results are obtained as shown in Table 20.

Sr. #	Test Parameter	Method	Units	Results
1.	Viscosity @ 40ºC	ASTM D445	cSt	150.1
2.	Viscosity @ 100ºC	ASTM D445	cSt	16.70
3.	Viscosity Index	ASTM D2270	-	119
4.	Total Base Number	ASTM D2896	mgKOH/g	10.35
5.	Total Acid Number	ASTM D664	mgKOH/g	3.50
6.	Flash point	ASTM D92	ºC	219
7.	Water Content	ASTM D95	Vol%	<0.05
8.	Oxidation/Nitration	FTIR	Ab/cm	2.50/1.00

9.	Iron (Fe)	ICP-OES	ppm	49
10.	Chromium (Cr)	ICP-OES	ppm	<1
11.	Nickel (Ni)	ICP-OES	ppm	27
12.	Aluminum (Al)	ICP-OES	ppm	13
13.	Copper (Cu)	ICP-OES	ppm	2
14.	Lead (Pb)	ICP-OES	ppm	3
15.	Tin (Sn)	ICP-OES	ppm	<1
16.	Silicon (Si)	ICP-OES	ppm	19
17.	Titanium (Ti)	ICP-OES	ppm	<1
18.	Zinc (Zn)	ICP-OES	ppm	920
19.	Fuel Dilution	By viscosity Diff.	%	15.95

Table 20

Similarly, when the sample-8 results obtained after the running of 4800km, it has been observed in Table 12 that viscosity at 100°C of Sample-8 depleted further from 17.70cSt to 16.70cSt means there is decrement in the viscosity at 100°C of about 5.64%. Now the viscosity @ 100°C is near to out from the range for 20w-50 according to SAE(15). While the flash point of the of Sample-8 is also further depleted from 225°C to 219°C that is about 6.07%. TBN and TAN is also changed of the Sample-8 in which the TAN is increased while TBN is decreased. TAN is increased from 2.30 mgKOH/g to 3.50 mgKOH/g while the TBN is decreased from 11.01 mgKOH/g to 10.30 mgKOH/g. Both the decrement ton the viscosity and TBN shows that the oil is further oxidized. Similarly, when we compare the wear metal analysis Sample-8 after the running of 4800km, as mentioned in Table 20 shows that the concentration of (iron & zinc) increased after use in Sample-8. Concentration of iron is increased from 39ppm to 49ppm while the concentration of zinc increased from 650ppm to 920ppm. This means that now the Sample-8 of group-2 base oil is also oxidized to such level that is cause great wear and tear in the parts of engine.

Conclusion:

After the investigation of the results of the different samples it is observed that the viscosity at 100°C of Group-2 base oil's products depleted about 4.91%, 5.91% & 9.55% while of Group-1 Base oil's products are about 16.5%, 10% & 26.08% for Motorcycle, CNG engine car and Diesel engine respectively. Similarly, the flash point of Group-2 base oil's products decreases less as compare to the products of Group-1 base oil, such as; flash point of Sample-4, Sample-6 & Sample-8 (Group-2 base oil's products) decrease about 4.58%, 4.20% & 5.46% while of Sample-3, Sample-5 & Sample-7 (Group-1 base oil's products) decreased about 7.90%, 6.07% & 9.17%. Similarly, products of Group-2 base oil cause less wear and tear in the parts of engine which shown by the wear metal analysis, such that the concentration of iron and zinc in all the samples of group-2 base oil is less as compare to the products of group-1 base oil. We conclude that the products blended in Group-2 mineral Base oil is long lasting because Sample-4, Sample-6 & Sample-8 products used for longer period of time than the Sample-3, Sample-5 & Sample-7 and oxidized less as compare to the products blended in Group-1 mineral base oil.

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