Indian Journal of Automotive Technology

Volume No. 7

Issue No. 1

January - April 2024

ENRICHED PUBLICATIONS PVT. LTD

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Indian Journal of Automotive Technology

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When outstanding advances are made in existing areas or when new areas have been developed to a definitive stage, special review articles will be considered by the editors.

Indian Journal of Automotive Technology

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(Volume No. 7, Issue No. 1, January - April 2024)

Contents

Stress Life Fatigue Approach For The Design of Automotive Engine Thermostat

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A B S T R A C T

This article presents the findings of stress life fatigue (SLF) approach for the design of automotive thermostat which is subjected to constant stress thus may cause safety concerns. In order to carry out stress life fatigue investigation, CATIA and Ansys Workbench FEA software (Finite Element Analysis) were used and linear static analysis and SLF theory were studied to evaluate fatigue life, meanwhile an experimental fatigue test was performed to obtain specific results. Fatigue failure may derive from various sources including mechanical stress, thermal stress and/or corrosion but this study concerns only mechanical fatigue damage of the thermostat and aims to establish fatigue life improvement in which combination of experimental and FEA tools and methodology. Comparison of FEA and experimental results for the evaluation of parts' fatigue behavior are presented. The integration of FEA tools and experimental test enable the designers to evaluate the parts' fatigue behavior.

Keyword- FEA, Stress life fatigue analysis, automotive component

1. Introduction

In order to remain competitive in a constantly evolving global economy, the automotive industry has ambitioned to speed up product development processes. The trends have involved the utilization of computer aided engineering technologies for accelerating the product development.

Thermostat is one of the most complex components among all engine components. Working principle of thermostat is to control and maintain the engine optimum operating temperature by regulating the flow of coolant to an air-cooled radiator. The thermostat progressively increases or decreases its opening, dynamically balancing the coolant recirculation (fig.1). This continuous movement and cyclic loading can cause material damage called fatigue which can be localized for structural damage. Because of the working principle of the thermostat, fatigue occurs when the part is subjected to repeat loading and unloading conditions [1].

High frequency, low amplitude is an elastic cyclic behavior, and large numbers of cycles have a classification called High Cycle Fatigue which usually refers to more than 100.000 cycles. Stress life approach typically deals with high number of cycles. Stress life analysis assumes that the stress always remain in elastic level however if the loads are beyond the edge of its material properties, eventually a crack can occur then it reaches a critical size, and the structure suddenly fractures. This study focuses on mechanical fatigue damage therefore safety of the part and its fatigue life was aimed to be investigated by means of FEA linear static analysis, stress life FEA fatigue analysis and experimental fatigue test, because fatigue testing alone is not adequate for fatigue design procedure. CAE (Computer Aided Design) software programs are merely used to create models and usually cannot take into consideration for all the aspects of fatigue such as corrosion, residual stress and variable amplitude loading. Thus combination of CAE analysis and experimental testing are required for safe fatigue design [2].

Brooks *et al.* carried out structural optimization study using linear static stress analysis to determine stress distribution for a double-wishbone suspension system then assessed fatigue life of the part with FEA fatigue tool [3]. Fatigue types classified in Darlington and Booker study that highlighted high-cycle fatigue emerged from their research as the most common fatigue failure in industry and commented on analytical techniques such as FEA and concluded that they are very important to assist in failure predict [4]. Kurtaran *et al.* studied hip prostheses, which was subjected to cyclic load and pointed out the benefit of stress life approach for their solution [5].

Buciumeanu *et al.* worked on fretting fatigue of the suspension formed component, fatigue test was used to finalize for the correct options of the different geometries which were evaluated by FEA results [6]. In the study of Topac, Gunalay, Kural (2008) automotive rear axle housing was investigated by using FEA tool regarding working life of the part, stress life approach was chosen due to part working conditions, study was supported by an experimental test to conclude rear axle optimum design [7].

2. CONCLUSION

Improvement of the thermostat fatigue life was the main concern of this study. Linear static analysis and subsequent stress base fatigue approach have been conducted to understand and predict the part fatigue behavior. Even though there could be additional contributors for the fatigue life of the part, experimental test results provided a sound conclusion that increasing the part thickness results in better fatigue life. Improvement of the fatigue life is closely associated with reducing of the stress concentration which was achieved by increasing of the part thickness as indicated FEA tool. It can be highlighted that the methodology leaded to scientific approach to solve fatigue life issue.

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Triacylglyceride's Transesterification for Biodiesel: A Review

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ABSTRACT

Biodiesel can be produced from various oils or TAG's by transesterification in the presence of different catalyst. Biodiesel can be used either in pure form or blended form can be directly used in diesel engine without any modification or little modification. This review presents the transesterification of oil using different catalyst and their mechanism. Homogeneous and heterogeneous catalysts are discussed along with their advantages and disadvantages. This review also gives insight on the microwave heating of reactions and traditional method of heating of reactions. Apart from this use of enzyme based catalyst and current status is explained. Now a day's nano-size catalyst also gains much attention due to large surface contact area.

Keywords- Transesterification; Catalyst; Enzyme; Nanoparticle catalyst.

1. Introduction

There are many feedstock's from which biodiesel is obtained. This oil cannot be directly used to run engine due to high viscosity and low volatility which leads to injector coking and engine deposit [1,2]. However this problem is eliminated by transesterification of oil to alkyl ester [1, 3].

Transesterification is also called alcoholysis. Transesterification is reversible reaction in which triglycerides are converted to di-glycerides and to mono-glycerides which finally gives glycerol. Biodiesel floats at the top while glycerol sinks to the bottom which is separated easily [4]. In transesterification methanol and ethanol is mainly used as alcohol due to low cost. However octanol, propanol, butanol and tert butanol can also be used but their cost is higher as compared to methanol and ethanol [5,6,7,8]. If methanol is used in reaction then process is called methanolysis. General equation for transesterification is represented as in fig. 1 [9].

This reaction generally takes place in presence of catalyst which may be acidic or basic in nature as alcohol is scarcely soluble in oil, so catalyst increase the solubility, thus accelerates the reaction [4]. The transesterification process removes the glycerin, so viscosity decreases but heating value and cetane number does not change [10].

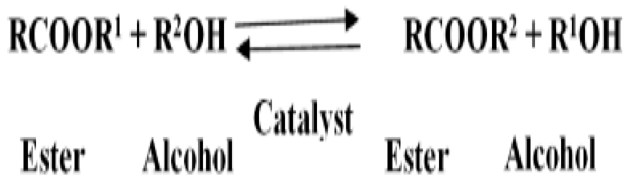

Figure1: Transesterification reaction

1.1. Kinetics of Transesterification Reaction

The oil from which biodiesel is produced is known as triglyceride (TAG). TAGs are formed by covalent bonding of carboxylic acid with alcohol. In this context, TAG is an ester formed by combining of three molecules of fatty acids covalently bonded with glycerol molecule [11]. Fatty acid has carboxylic group while glycerol has three hydroxyl group which while combining form ester or TAGs. Transesterificationis a chemical process in which carboxylic acid ester is converted into different carboxylic acid esters.

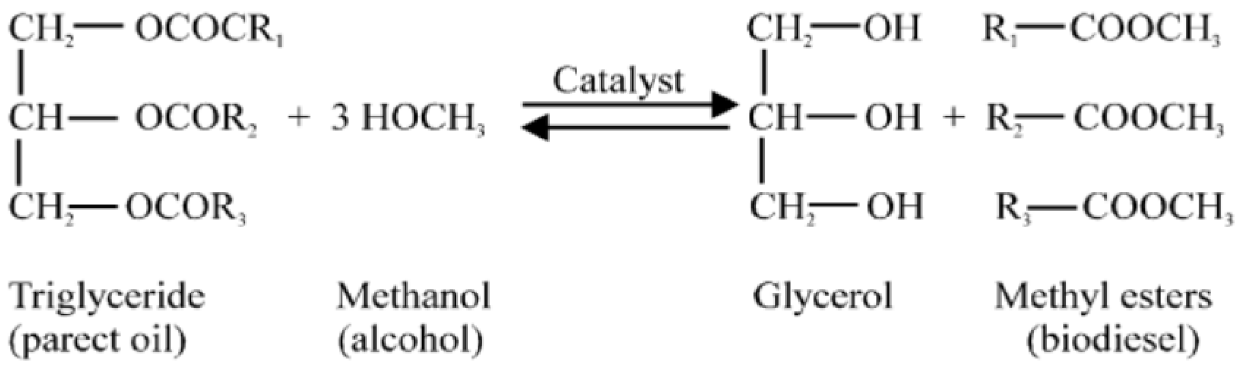

Figure2 Transesterification Reaction

2. Base-Catalysed Transesterification

Base catalyst are mostly used for transesterification of vegetable oils [12,13,14,15,16]. When the tryglyceride contains free fatty acids or excess amount of water then acid catalyst are used to reduce the soap formation [13,16, 17]. Base catalyzed transesterification reaction is 4000 times faster than acid catalyzed reaction but it is used only if trygleceride contains less than 2% free fatty acids [18]. Sodium and potassium hydroxide are mostly used for industrial purpose.

2.1. Mechanism of base catalyzed transesterification

The transesterification using base catalyst involves four step pre step or first step in which base reacts with alcohol and form protonated catalyst and an alkoxide. In the next step carbonyl group of oil is attacked by nucleophilic and forms intermediate [19, 20,12]. In third step alkyl ester and anion of diglyceride are formed. In fourth step the catalyst deprotonates, thus regenerating the base which again reacts with second molecule of alcohol and starts another cycle.

Base catalyst are mostly used because reaction takes place at low temperature and pressure that is 60°C and 20 psi and obtain high yield about 98%. However there are some shortcomings it requires high energy, to separate the catalyst from the media after transesterification pro-reaction treatment is required, difficult to recover glycerol after the reaction moreover it forms soap with free fatty acids.

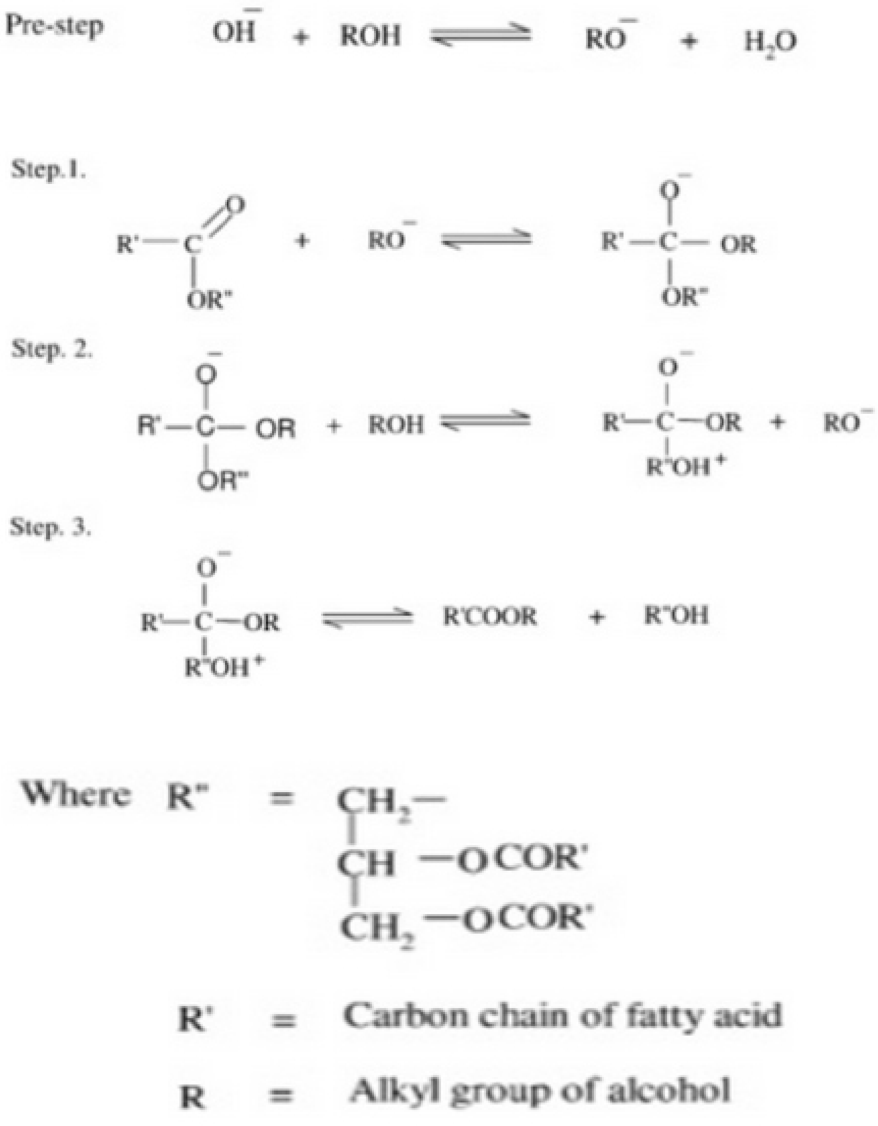

Figure 3 mechanism for base catalyzed transesterification reaction

2.2. Factors affecting base catalyzed transesterification.

Effect of alcohol to oil molar ratio: the yield of methyl esters generally depends upon methanol to triglyceride molar ratio. Theoretically three moles of methanol are required per mole of oil for transesterification. A vegetable oil [21] studied the amount of alcohol required for transesterification of vegetable oil in terms of alcohol to oil molar ratio.

Shazia sultana [22] studied transesterification on five different molar ratios in the range 2:1 to 10:1 and obtained maximum yield 92% with 6:1 methanol to oil molar ratio. On further increase in methanol to oil molar ratio the ester yield decreases.

Encinar J.M et al [23] studied different ethanol to oil molar ratio between range 3:1 to 15:1 for the transesterification of cynarer oil and reported that reaction is incomplete when molar ratio is less than 6:1. The yield of ester increases as the molar ratio increased upto 12:1 and obtained optimum value at 9:1. However many authors reported that [24,25] with increase in methanol to oil molar ratio the yield decreases, for instance, Lu et al [24] worked on different molar ratio ranges from 1:1 to 1:10 and reported that the maximum yield is obtained at 1:1 and this may be due to inhibitory effect of alcohol on lipase activity.

Similarly Li et al [25] given same trend that with increase in molar ratio yield decreases, the achieved 95% yield in 12 hour at molar ratio 4:1.

2.3 Effect of catalyst concentration

Mostly alkaline, acid and enzyme catalyst are used. If the oil contains high free fatty acids and large quantity of water then acid catalyst is used for transesterification. Sultana Shazia [22] studied the effect of NaOH concentration between the range of 0.1-0.9 wt% and obtained that yield increases with increase in catalyst concentration from 0.1-0.5%. The yield decreases with further increase in NaOH concentration and reduced to 50% with 1.5% NaOH concentration. This is because with increase in the concentration of catalyst, soap formation will take place and reduce the yield with increase in viscosity. Ma F et al [27] studied the effect of NaOH and NaoME concentration and found that at 3% and 5% w/w of catalyst to beef tallow oil maximum yield is obtained.

3. Acid-Catalyzed Transesterification

The acid catalyzed transesterification does not gain much popularity because it is 4000 times slower than the alkali catalyzed reactions [18]. Its performance does not affected by the presence of free fatty acids and can catalyze simultaneously both esterification and trans-esterification. Acid catalyst can produce biodiesel from low cost feed stock having high free fatty acid FFA. The transesterification of triglyceride consist of three reversible reactions.

Acid catalyzed transesterification mechanism is shown in fig for monoglyceride. Carbonyl group protonation leads to carbocation which forms tetrahedral intermediate after the nucleophilic attack of alcohol. The glycerol is separated and forms new ester. These reactions should be carried in the absence of water because carbocation reacts with water to form carboxylic acids.

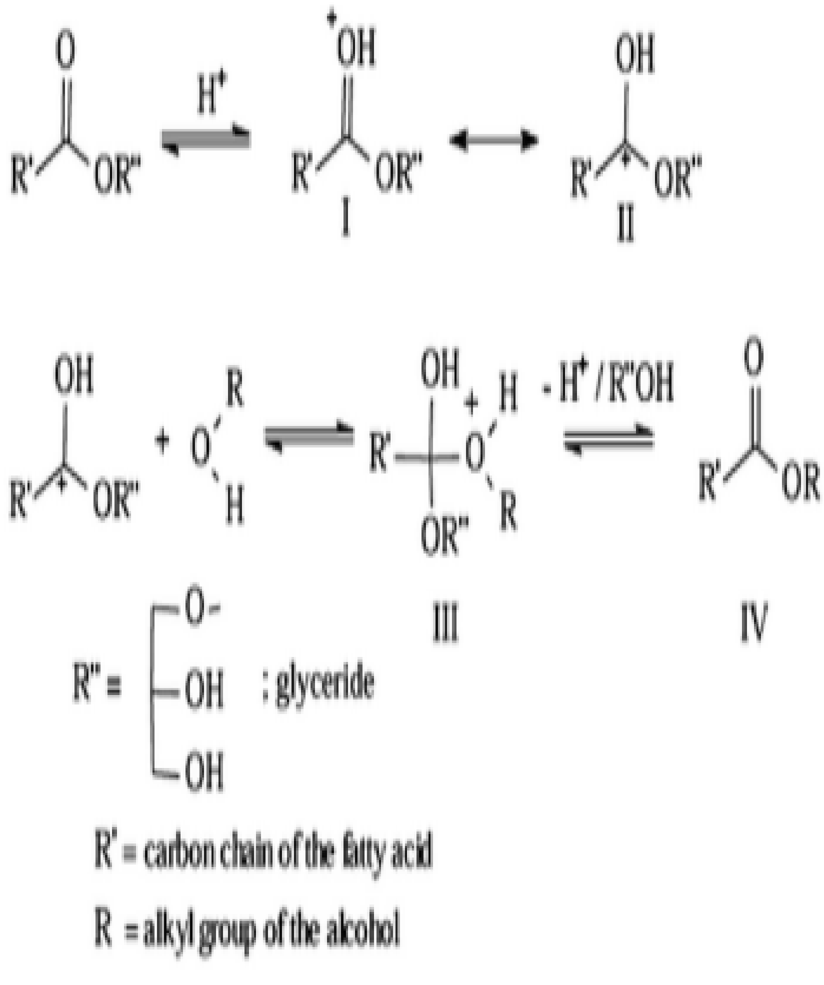

Figure 4. Mechanism of acid catalyzed reaction.

4. Catalyst for transesterification process

For transesterification following catalyst are investigated, heterogenous, enzymatic and homogenous or alkali catalyst like potassium and sodium hydroxide are mostly used in industrial transesterification because they promote reaction at low temperature also [28].

4.1. Homogenous catalyst

Homogeneous catalysts are further divided as homogeneous acids and homogeneous base catalyst. Homogeneous base catalysts are commonly used for transesterification of triglyceride. Homogeneous base catalyst such as carbonates [29], alkaline metal hydroxide [30,31] and alkoxides [17, 32] are most commonly used [28] the alkoxide are more difficult to handle then hydroxide because alkoxide are hygroscopic in nature. Alkoxide does not form soap from triglyceride saponification due to the presence of hydroxide ion which act as an impurity in alkoxide [28]. While using alkaline catalyst the free fatty acid content should not increase 0.5% by wt. otherwise soap formation will takes place which hampers the production of biodiesel. Various authors reported that 90% yield is obtained by using potassium hydroxide and boiler ashes in the methanolysis and ethanolysis of coconut and palm oil [3323, 34, 35]. Ma et. al. [27] found that alkaline catalyst Naoh perform better than NaoMe. However to obtain higher yield the concentration of naome is slightly higher as compared to Naoh Ma et. al. [27]. Singh et al. [36] studied about alkaline catalyst (NaoH, KoH, KoMe and NaoMe) and found that better yield is obtained by potassium based catalyst as compared to sodium based catalyst. Where methoxide based catalyst produces higher yield compared to hydroxide based catalyst.

4.2. Homogeneous acid catalyst

For the transesterification of free fatty acid (FFAs) homogeneous acid catalyst are more effective as compared to base catalyst. Acid catlysed reactions proceed 4000 times slower than the base catalyzed reaction[15]. However acid catalyzed reactions have lower moisture sensitivity as well as non-appearance of soap formation. Acid catalysts are used where oil has higher FFAS [28]. If base catalyst are used it will form soap. Acid catalyzed reactions are two stage processes, in first stage esterification takes place in the presence of acid catalyst while in the second stage reaction takes place in the presence of base catalyst.

The acid catalyst mostly used are, sulphonic acid, organic sulfonic acid, hydrochloric acid, and phoshphoric acid. Freedman et al. [32] uses sulphuric acid as catalyst with alcohol oil ratio 30:1 and found that to obtain 90% yield reaction took 50h to complete at 65°C. Zullaikah et. al. [37] uses sulphuric acid as catalyst for the transesterification of rice bran oil between temperature range of 60-80°C.

4.3. Heterogeneous Catalyst

It is difficult to separate homogeneous catalyst from the reaction mixture so heterogeneous catalysts are developed. Heterogeneous catalyst. heterogeneous catalyst are advantageous because they does not form soap through saponification of triglyceride and eliminate corrosion problems and reaction requires high temperature and pressure. However there are some limitations like, they have poor performance compared to homogeneous catalyst, and due to less surface contact catalyst does not participate effectively in reaction so catalyst must be in porous state. The surface of heterogeneous catalyst must be hydrophobic in nature so that it adsorb triglyceride and to avoid adsorption of polar by products like water and glycerol on surface. Solid catalyst which are mostly used are, alkaline earth oxide, solid organic base, basic oxides supported, basic zeolite, insoluble metal salt and hydroxide, basic metal oxide, hydrotolerite and hetropolyacids [38].

4.3.1 Alkaline earth oxide

Ca and Mg are alkaline earth metals which are most widely used as heterogeneous base catalyst. Gryglewicz [31] found that alkali earth metal oxides successfully catalyzed the transesterification reaction. Alkaline earth oxides are basic due to M^{2+} and O^{2-} ion pairs [39]. Various authors reported the use of Cao as catalyst for the transesterification of sunflower, and rapeseed oil with methanol [40, 41]. Moreover, strontium oxide, Cao, Mgo also investigated as catalyst for transesterification with high basicity [42, 43, 44].

Martyanov and Sayari [45] used calcium methoxide as catalyst for the transesterification of triglyceride and found that initially reaction is slower as compared to homogeneous sodium methoxide and magnesium methoxide, but at later stage the rate of reaction is higher than magnesium methoxide. Alkaline earth metal oxides assimilate with metal oxide and form composite oxide [46] which can be used as solid base catalyst for transesterification. Composite oxides are more stable and easy to separate from the reaction media.

4.3.2. Acid Zeolite

Zeolites are most widely used as solid acid catalyst for transesterification of oil and made hydrophobic by elimination of water of hydration. Shu et al, [47] uses La/Zeolite beta catalyst for the batch transesterification of soybean oil and found that La/Zeolite base catalyst have higher conversion rate than zeolite beta heterogeneous acid catalyst used in biodiesel production are mostly mesoporous [48, 49].

Subsume of microporous H-β- Zeolite with secondary mesoporosity create a heterogeneous solid catalyst which accelerates microalgae transesterification by reducing the diffusion barriers [50, 51] uses zeolite catalyst for the transesterification of waste cooking oil and found that yield is independent of porosity of zeolite and found that yield increases with increase in strength of the acid.

4.3.3. Hetropolyacids

Hetropolyacids attains much attention due to its superacidic nature (PK H^+> 12) and porous structure. They are highly soluble in polar media in their native form which make their contribution in reaction as homogeneous catalyst [52]. Chai et al, [53] uses heterogeneous catalyst ($CS_{2.5}$ $H_{0.5}PW_{12}O_{40}$) for transesterification of eruca sativa gars oil and obtained the same result as by using sodium hydroxide or sulphuric acid with one advantage of easy separation of catalyst from media and its reuse. Cao et al [54] use the hetroppolyacids ($H_{35}PW_{12}O_{40}$. $6H_2O$) catalyst for transesterification of waste cooking oil. In 10h 87% yield is obtained using hexhydrate catalyst. The catalyst would be separated easily and was reused many times.

5. Microwave irradiation effect on biodiesel production

Traditionally organic reactions are heated by various equipments such as sand bath, heating jackets and oil baths. These techniques are not effective because they are slower and temperature gradient took place. But now a days microwave dielectric heating is preferred in microwave heating radiation passes the wall and only heat the solvent and reactants without heating the vessel [55].

Patil et. al., [56] used micro-algal oil to produce biodiesel by transesterification by heating with microwave radiation and observed that microwave irradiation effect the reaction in two way 1. reaction is boosted by thermal effect. 2. Vaporization of methanol due to strong microwave radiation. Ma et al, [57] observed that microwave heating reduce energy and reaction time due to volumetric heating. Ma et al, [57] produced biodiesel by transesterification of micro-algal oil in the presence of KOH by conventional heating and microwave heating method and find that with conventional heating system reaction completes in 210 minute while with microwave heating reaction completes in 5 min, obtained 96.54% conversion using KOH 1% wt, 1:8 oil to methanol at 65°C.

6. Nanoparticle Catalyst in Transesterification

For the conversion of triglyceride to methyl esters transesterification takes place in the presence of catalyst. Catalysts used are either base catalyst or acid catalyst. Base catalyzed reactions are much faster than that by acid catalyzed reaction.

However basic catalyst have some drawbacks such as loss of catalyst, some catalyst remain in the biodiesel does not separated. To overcome this drawback heterogeaneous catalyst are used but require long reaction time and large volume. Therefore, to improve the conversion of free fatty acid, lots of efforts are done to produce catalyst with high surface area. Highest methyl esters can be produced by catalyst with high surface area [58]. Many authors investigated that Nano sized catalyst have large contact area. For instance, Wang et. al., [59] produced biodiesel from waste cooking oil in the presence of nano-sized catalyst (Aluminum dode catungs to phosphate AIPW) and observed that ≈ 96% conversion was achieved at 55° C due to large surface area of nano paticle.

6.1. CaO/ MgO catalyst

Calcium oxide is heterogeneous base catalyst mostly used for transesterification reaction. It has many advantages, such as easy availability, higher activity, reusability, low cost and mild reaction condition. Pretreatment temperature range between 700-1000 K is used to remove water and CO_2 which is adsorbed on the surface of CaO [60]. Most of the catalyst has adverse effect on yield of methyl ester in the presence of water. However CaO catalyst performs well in the presence of water, it forms methoxide ion in the presence of methanol which is highly active. Mechanism of transesterification with CaO as catalyst is given in fig [61].

As shown in equation 1, Ca^{2+} extracts OH^- and O_2^- extracts H^+ from water so they are easily extracted by reactants during chemical reaction. As shown in equation 2, methoxide anion and H_2O forms when OH^- extracts H^+ methanol. In equation 3 again O^{-2} extract H^+ and form surface methoxide anion. If water exceed by 2.8 wt% of oil it hydrolyze the methyl esters and forms fatty acid and methanol. Liu et. al., [61] obtained 95% yield at temperature 65° C by using CaO catalyst. Hsiao [75] used nano powder CaO as catalyst and obtained 96.6% yield at 1:6 oil to methanol ratio, reaction time 1 hour, 338 K temperature and 3 wt% catalyst.

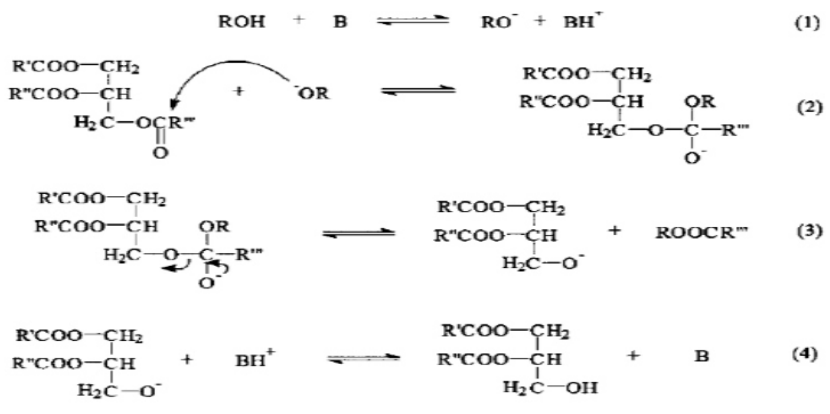

Fig 5. Transesterification mechanism in the presence of water using CaO as catalyst.

Due to easy preparation and low cost researcher focus attention on MgO and CaO catalyst. Huaping [62] obtained 93% yield using CaO as catalyst. Di serio [63] achieved 92% yield by using MgO as catalyst. Dossin [64] use MgO as catalyst in batch work reactor and found that satisfactorily at ambient condition. Magnesium oxide is identified as good homogeneous catalyst for transesterification of ethyl acetate with methanol [64].

6.2. CaOZnO Catalyst

The combination of Cao and ZnO (CaOZnO) catalyst in palm kernel oil **transesterification is studied**. The mixture of CaO and ZnO has small particle size which result in large surface contact area as compared to individual oxides. Ngamcharussrivchai [53] used CaOZnO catalyst with Ca/Zn ratio 0.25 for the transesterification of palm kernel oil and obtained greater than 94% yield at reaction temperature 60^{o}C, methanol to oil ratio 30 and reaction time 60 minute. CaOZnO catalyst is used for the transesterification of sun flower seed oil and 90% yield is obtained [65]. The CaO and ZnO are synthesized by Co-precipitation method or impregnation method. Ngamcharussrivchai [53] found that the catalyst synthesized by the co precipitation method result in higher yield (94.2%) compared to impregnation method (90%). The literature shows that the activity of reaction depends on Ca to Zn atomic ratio it is synthesized between ratio, from ¼ to 4. At atomic ratio of 0.25 the CaOZnO catalyst produce 93.5% of esters which is larger as compared to other atomic ratio.

7. Enzyme catalyzed transesterification

The problem related to conventional catalytic process, like removal of catalyst, treat large amount of waste waterand high energy requirement are solved by using enzymes. Enzyme do not form any soap like alkaline catalyst and without the need of washing they esterify both FFA and TAG in single step. These are biological catalyst and can catalyze different chemical reactions. They can be either used in free or immobilized form in transesterification that leads to the production of biodiesel [66]. A wide range of enzymes such as lipase has been used for esterification [67]. Lipase from fungi and bacteria are mostly used for process and they belong to group of hydrolytic enzymes which is also known as hydrolases.

The lipase catalyzed reaction is classified as [68].

1. Hydrolysis

2. Synthesis a) esterification b) transesterification.

1) Hydrolysis

$R^1COOR^2 + H_2O \rightleftharpoons R^1COOH$
$+R^2OH$

Esterication

$R^1COOH + R^2OH \rightleftharpoons R^1COOR^2$
$+H_2O$

Transesterification

Alcoholysis

$R^1COOR^2 \rightleftharpoons R^3OH$
$R^1COOR^3 + R^2OH$

Acidolysis

$R^1COOR^2 + \rightleftharpoons R^3COOH$
$R^3COOR^2 + R^1COOH$

7.1. Immobilization of Lipase

Immobilization of lipase is the state of arrest of the enzyme in region [69]. Immobilization provide number of benefits such as enzyme reuse, easy separation of product from enzyme [70]. Many other properties are also improved such as chemical, thermal and mechanical properties making them to use in harsher environmental condition [71,72].Salah [73]obtained 25% conversion with immobilized lipase and 3% conversion with free lipase while butanolysis of acetic acid. General technique used for immobilization are 1). Adsorption 2) Entrapment 3) Cross linking 4) Encapsulation . Adsorption is simplest method; in this enzymes are attached to the surface by combination of Vander wall or electrostatic forces.

7.2. Effect of presence and absence of solvent enzyme based transesterification

Using enzyme as catalyst for biodiesel production of oil is tried in the presence and absence of solvent. Nelson [74]done methanolysis of tallow oil using hexane as solvent in the presence of Mucormehei lipase and obtained 77.8% yield. But many workers favours solvent free reactions. Furthermore toxicity and inflammability of solvents, prevent the use of solvent enzyme based transesterification. Oznur [76] done transesterification of cotton seed oil using immobilized lipase and obtained 92% of yield in a solvent free medium.

8. Conclusion

This review includes the transesterification of oil using alkali and acid catalyst. The effect of parameters such as, molar ratio, catalyst concentration and methanol to oil ratio are discussed. Selection of homogeneous, heterogeneous and enzymatic catalyst is explained. Homogeneous base catalysts are commonly used for industrial purposes whereas heterogeneous and homogeneous acid catalysts have lesser use. Homogeneous acid and base catalyst require excess alcohol. Homogeneous catalyst is mainly used for batch mode process, followed by catalyst separation. Moreover homogeneous alkali catalysts are sensitive to free fatty acids and H_2O, results in saponification. The feed stock having FFA require acid and base catalyst which is two stage process in which acid catalyst are firstly used and then removed before the use of alkaline catalyst. However the use of acid catalyst increases the corrosiveness. Now a days much more attention is focused on enzyme based catalyst instead of chemical catalyst because enzyme based catalytic reaction proceed at moderate conditions, require low alcohol to oil ratio, and easy product recovery. Use of nano- particle catalyst and heating reactions with the help of microwave is discussed.

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Computer Aided Design & Experimental Validation of Engine Metal Pallet

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ABSTRACT

In industrial transportation, material handling and packaging plays an important role. To achieve the faster transportation new approach is needed. This requires the material handling without the damage of main product. In production process different types of small and larger types of pallets are used for transportation. The 3D concept design of engine handling metal pallet for both internal storage and external transportation is designed and validated, easy to assembly and disassembly processes with manufacturing variable techniques are discussed with proper and safe transportation. For designing the pallet, standard procedure is adopted in worldwide. But it's not suitable in every case like the dissimilar shape of finished product. The proposed model is a combination of standardize process and the simplicity ideas

Keywords: 3D cad design of metal pallet, Concept design of engine pallet, Engine metal pallet, Metal rack, Experimental validation of metal pallet.

1. Introduction

The basic purpose of pallet design is to safely transport the engine with safe handling procedure. Also focus on those points that are involved in the engine peripheral safety in packaging. In industry different types of pallets are used. Like wooden pallets, metal pallets and plastic pallets. After the consideration of the pros and cons pallet packaging material is to be decided. But in such country the wooden pallet and plastic pallets tear down is very difficult. And in this situation the many companies are prefer the metal pallet for transportation.

In the metal rack or metal pallet design standards form and sections are used like "I sections", "H sections", "circular sections" and "a rectangular type sections" etc. Such cases it is difficult to use the standards sections as it is. In that case use the non standards sections. These non standards sections are properly designed and consider with all requirements about engine peripheral, mounting provisions, engine PTO side etc. Normally the designed optimized with the based on the loads coming on it and the space availability constrain.

The metal pallet is subjected to under the stresses of compression, tension and bending, when the pallets moved from one place to another place with the engines. The material selection with standard sections is depends upon the primary criteria of engine load.

To keep a fine balancing between engine and pallet design optimization of weight is required. Therefore normally the overall peripheral design of engine needs to be considered in designing of pallet for engine. This paper dealt with design concept of multi cylinder engine pallet. It also included with pallet CAD modeling for ease to assemble engine.

1.2 History of Pallets

It is the structural foundation and sustains the unit load which allows to handle and storage efficiently. Finished goods or shipping containers are often placed on a pallet secured with strapping, stretch wrap or shrink wrap and shipped.

In general most pallets are wooden pallets can also be made of plastic, metal, and recycled materials. Each material has advantages and disadvantages relative to the others.

Figure1 Wooden pallet, plastic and metal pallet

In figure 2 shows the wooden pallets with engine packaging for external transportation. This type of packagings was to used from the earlier decades. This process is manual process and its take long time for packaging. Because every wooden riff is to assembled by nailing process and the card board box assembled on it. Due to long time duration and this process is lengthy at continuous production.

(a) (b)

Figure 2 (a) Engine packaging in wooden cardboard box (b) The old packaging methods with wooden pallet and card board box packing inside the containers with nylon taps

2. Literature Review

Claudio Bernuzzi et al [1] part 1 deal with the selection of the method of analysis, i.e. 1st or 2nd order elastic analysis, depending on the rack deformability to horizontal loads. Internal forces and moments on members are significantly influenced by the effects of lateral displacements as well as by the type of the beam formulation adopted in the finite element analysis program. Static design rules currently adopt in Europe for steel storage pallet racks. No univocal rules are provided by the European Rack code for routine design. The system length approach for buckling check leads to unsafe design. Improvements for the evaluation of the elastic critical load are urgently expected. Claudio Bernuzzi et al [2] theoretically studied the design of rack and consider serviceability lateral displacements of the whole rack and both resistance and stability ultimate limit states for the uprights. Underline the weak points of the European rack standards and are of practical interest for structural engineers, stressing clearly when the recommended procedures fail, hence leading to an unsafe and uneconomic design. Benoit P. Gilbert et al [3] improved 2D model to accurately reproduce the bending moment distributions obtained using 3D advanced finite element analysis. Improve the 2D model of steel drive-in racks. The effect of pallets on the bending moment distribution in the uprights is checked. The influence of the pallets on the capacity of the racks is investigated. This paper clarifies the loading scenario(s) governing the design. The strength of a device required to prevent the pallets from sliding is determined. Sangle et al [4] worked on the elastic stability analysis of cold-formed pallet rack structures with semi-rigid connections. With the help of experimental study & FEA is carried out on Pallet Rack Structure. It also includes three dimensional finite element modeling and elastic buckling analysis. Original open upright sections are torsionally strengthened by external stiffeners. External stiffeners are found very useful for increasing the load carrying capacity. To calculate accurate buckling load, 3-D finite element modeling is recommended.

Teh et al [5] designed double-sided high-rise steel pallet rack frames and made analysis with the help of 3D linear buckling analyses; it demonstrated that the global buckling behavior of high-rise steel storage rack frames may not be revealed by 2D buckling Analyses as 3D interaction modes are involved. Soury et al [6] worked on the Design, optimization and manufacturing of wood–plastic composite pallet. FEA and experimental method use for optimize the design of an I-shape profile with wood–plastic composite (WPC) pallet. Comparison of simulations and experimental results indicated that the given (WPC) design method is reasonably reliable.

Godley et al [7] investigated of the effects of looseness of bracing components in the cross-aisle direction on the ultimate load-carrying capacity of pallet rack frames. With the help of Experimental load tests fully cyclic loading for determine the stiffness of the frame and also the effect of looseness in the connection. Yaman et al *8+ studied on the manufacturer's mixed pallet design problem and formulate the problem as a mixed integer linear program. Using company data to conduct a computational study to investigate the efficiency of the formulation and the impact of mixed pallets on customers total costs.

Brown [9] studied the seismic design of pallet racking systems and calibrated according to the experimental results. And found that thin walled cold formed sections are not generally considered suitable for plastic deformations, or resistance to seismically induced loadings. Design approaches suggested that will enable the capacity design requirements of to be considered, while keeping with the cold formed sections traditionally used for pallet rack construction. Mitzner et al [10] studied the Metal and wood composite design and using the Experimental -Impact test, provide design information for ease choosing appropriate panel for application, metal with plywood overlays. Baldassino et al [11] conducted the analysis of the experimental monotonic test & results shows that the beam to column joints are very flexible, to the cyclic tests, it has been pointed out the relevant differences in the form of the hysteresis loops of rack joints in comparison with the ones associated with traditional steel components and the non-negligible influence of the connection systems on the joint behavior. This stresses the importance of the definition of an appropriate design philosophy for pallet racks in seismic zones.

From the above literature review it is found that the chance to increase the study in 3D cad modeling with concept design for special requirement of pallet. Also need to improvement in the metal pallet for storage and transportation of engines.

Many of the researchers are worked on the static condition modeling of steel rack with the rack joint by nut and bolts.

This paper focuses on the concept design, check with FEA analysis, result validated by experimentally.

3. Design considerations

Design related consideration is required before the pallet model preparation. Once it finalized model checked with FEA analysis.
Followings are the some of the metallic pallet design consideration for special requirements like engine transportation.

Material of pallet

Generally steel pallet made from the cold rolled steel sheet. This material is suitable for sheet metal bending, punching operation etc. As well as standard steel hollow square sections according to the IS 4923:1997.

Channel Selection

Generally the circular pipes are easily available on the market. Therefore it is easy to prefer circular hollow pipe for the pallet side column design. In addition it's available in standards size. Selection of appropriate diameter & thickness of circular pipes in pair for insertion is important.

Only one drawback is welding of circular section is difficult with side channel because circular pipe surface are in a line contact with other side. Figure 3(a) shows the circular cross section of pipe engagement.

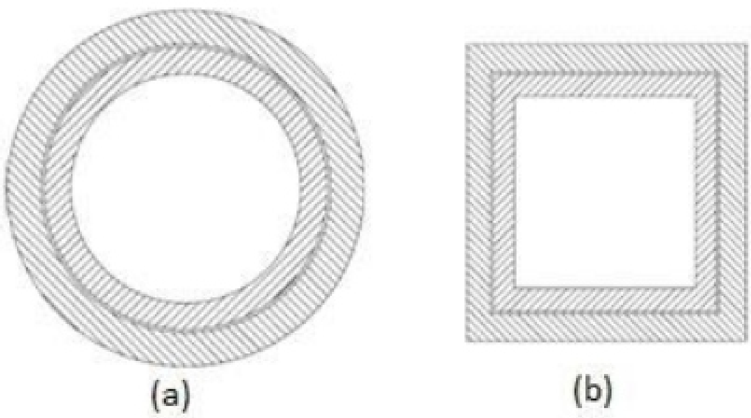


Figure 3 (a) Circular section hollow channel (b) Square section hollow channel

Alternatively the square hollow channel tube is the better pair option for the insertion. Because of square channel has flat faces are directly contact with the side channels. Therefore for guiding and welding fully contact area available. Figure 3 (b) shows the square hollow channel cross section of tube engagement.

Engine packaging precautions

Following are the engine packaging precautions

1. Engine is properly mounted on the pallet with fasteners
2. Suitable tighten torque apply on the bolting and verify it.
3. Use the vibro mount if it is necessary in design so reduce the vibration in transport
4. Electrical system like wiring harness well pack with tie
5. Pressure sensor, temperature sensor terminals protect with guards
6. Radiator front side protect with the cardboard paper
7. Engine coolant line is properly sealed or caped
8. Fuel lines are properly tied and protected.
9. Remove the fuel from fuel filter before the transportation and protected fuel filter from protection cover.

Engine mounting provision for pallet

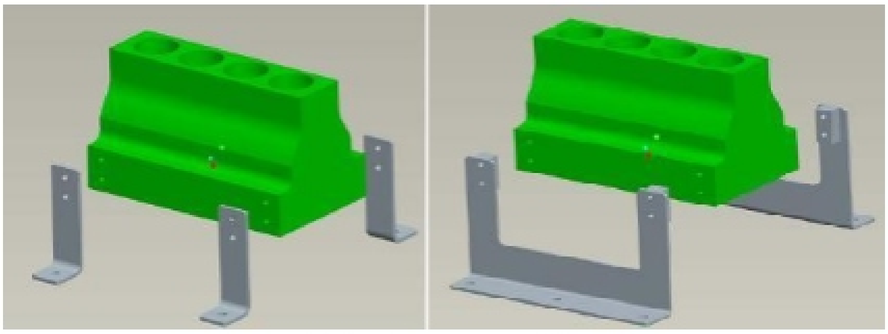


Figure 4 Engine mounting Legs

Preferably engine leg is design according to the crankcase mounting holes provision and peripheral component constraint. These legs are mounting on the pallet and locking with nuts and bolts.

Internal and external transportation

Internal transportation used the powered fork lift trucks. Meant for designing the pallet use the fork dimensions. Important dimensions of fork in figure 5.

For external transportation used the fork truck for transportation. This fork is adjustable as compare to the manual fork lift. And these dimensions and movement of fork is to be specified and standards all over.

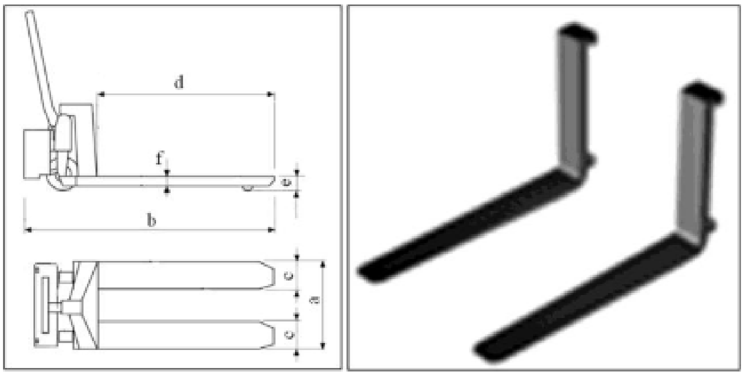


Figure 5 Power fork lift truck dimensions

Easy to assembly and disassembly

On engine assembly line limited time for the engine packaging and dispatch. Therefore engine assemble and disassemble on the pallet easily. It also considers the overall space limit so the more than one engines assembled on single pallet.

Manufacturing Process selection

Before designing the pallet manufacturing process is to be decided. Sometimes it's to be changed after the concept study completed or thereafter the analysis study completed. Followings are the observations related to the welding, riveting and screwed joints process of pallets.

Special pallet requirements

Special Pallets are required for the variable shape of finished product packaging. Engine properly fitment, locking is essential to safely transportation. Pallets are used for the multipurpose use. Some time it's used only for the internal transportation, like trolley and wheels type. Sometime it's only for storage or only for assembly line raw material handling.

Table 1 Manufacturing process selection criteria for concept design

	Welding process used for metal pallet	Riveting used for metal pallet	Bolted joints used for metal pallet
Machine & Special Equipments for Joining process required	Yes	Yes	No
Labor skill level	Skilled	Semiskilled	No skilled
Safety in process	High	low	Low
Strength of joint	High strength	Comparative weld less strength	Comparative weld less strength
Disassembly of Joint	Permanent joint	Possible to disassembly	Possible to disassembly
Level of assembly joints	Less	More	More
Assembly time	Less	More	More
Cost of Pallet	Low	High	High
Chance of the joint loose	No	No	Yes

4. Pallet size & weight calculation

Pallet size calculation

Pallet size is depends upon the following various factors,

1. Engine overall size
2. Feasibility to assembly and disassembly of the engine on pallet. Means space for tightening the engine mounting bolts.
3. Floor area to storage the pallets.
4. Engine qty per pallet
5. Fork insertion and resting area also to be consider for height calculation of pallet
6. Engine quantity in container for space constrain.
7. Number of rows and columns of pallets in container.
8. Pallet weight & engine weight consideration for the balancing and storey levels of pallets
9. Engine CG is required for the balancing of pallet.

Standard container size and weight is the main constrain of pallet size finalization. Example of pallet weight and size calculation is given below.

Standards size of container according to the CTU guideline,

Table 2 Container 40 feet standard size

40 ft. Standard Container			
Dimensions	Length	Width	Height
Internal	12022	2352	2395

Below is the concept of pallet fitment in the container with the two by two rows.

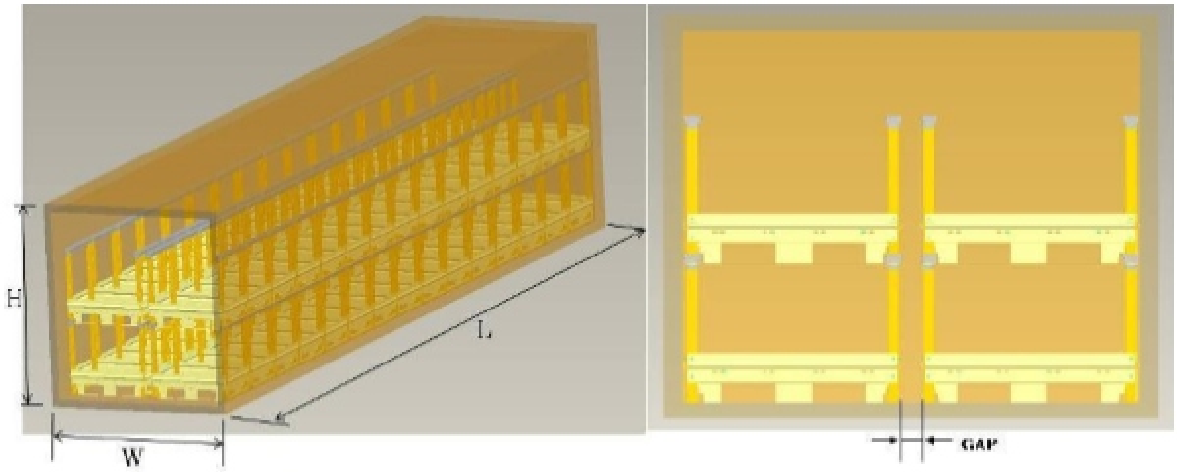


Figure 6 L x W x H Size of container and Internal Gap between two pallet rows

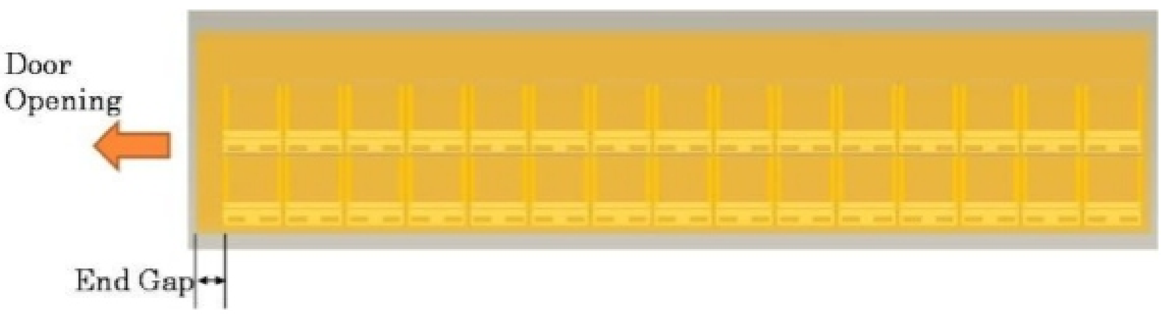


Figure 7 End gap after the all pallets packaging inside the container

Number of pallets per container = Nos. of rows of pallet in container X Nos. of columns of pallet X Nos. of storey= 10 X 2 X 2

= 40 Nos. of pallets are assembled inside the one container If the engines per pallet is 4 quantity,

Nos. of engines per container = Number of pallets per container X Number of pallets per container

= 4X40

=160 Nos. of engine dispatch in one time in single container.

Table 3 Pallet and engine size calculation inside the container

	Std size container	Actual size of container (A)	Model pallet size (B)	Total pallet in one row (C)	Space for pallet (D=BXC)	Container Pallet end gap in mm (E=A-D)
L	12022	11960	1135	10	11350	610
W	2352	2330	1135	2	2270	60
H	2395	2390	801	2	1602	788

Total no of engines per row is 40 and total no. of engines in container is 160 nos. On the above data seen that concept model pallet size (B) is sufficient and end gap also enough for handling.

Weight Calculation

Standards 40 feet length container max pay load is given below. According to this limit engine and pallet load calculation is shown below.

Table 4 40 Feet container max payload

Weight	
Max. payload	26580 kg

Table 5 Total weight calculation for container

Total engines weight inside the container	100 X 160	16000 kg
Total pallets weight inside the container	70 X 40	2800 kg
Total engines + Pallets weight		18800 kg (Approx.)

5 Pallet concept design

Engine transportation usage on flat plastic or metal pallet (Figure 1) is difficult because locking provision not available on it. Engine quantity per pallet is depending on the size and weight. That means single, double or four engines per pallet.

Welding conceptWelding is the one of the best method of joining. Welded joint is good strength than the bolted joints. Below figure 8 shows the concept of welded type of pallet. This type of pallets are beneficial because of minimum time involve for pallet assembly and manufacturing

Only one drawback is it cannot be dismantle with all joints similar to the bolted joints.

Welded type pallet is better strength therefore this type of pallet is helpful for the small capacity engines transportation.

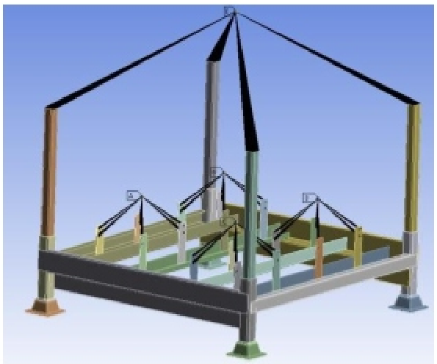


Figure 8 Welding concept pallets for four engine mounting

In figure 8 four engines mounting provision on the single pallet and the storey building at two, three and four level.

Concept for of engine locking at storey build

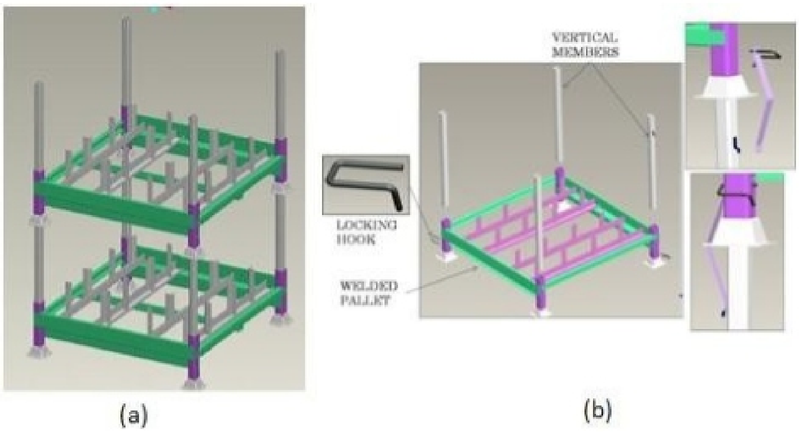


Figure 9(a) Level 2 storey pallets for container (b) Locking provision of vertical hollow square bar

Pallet storey building is to be considering at the time of concept design. The above figure 9(a) shows the two storey pallets are placed for the container packaging. Design it should be locked with each other means whenever it move it cannot be crash.

In figure 9(b) shows the simple designed locking pin with self locking concept alternatively standards locking pins are available in the market.

Disassembly of the Pallet:

Assembly and disassembly is also important in the engine transportation pallet due to the space constrain in continues production.

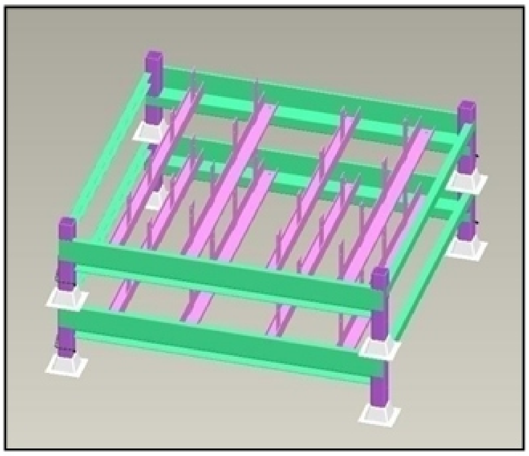


Figure 10 Welded engine pallets after disassembly

The above figure 10 shows the pallet disassembly after removed vertical square hollow bar. This is the advantages of the minimum space requirement in storage area after it use.

Welding fixture for weld & Quality check

In welding type pallet accuracy of engine mounting legs is very important. Because, if dimensions are deviated its damage the thread of engine mounting.

Therefore the checking fixture required before the engine direct assembly on pallet. Below figure 11 is the four mounting provision checking fixture.

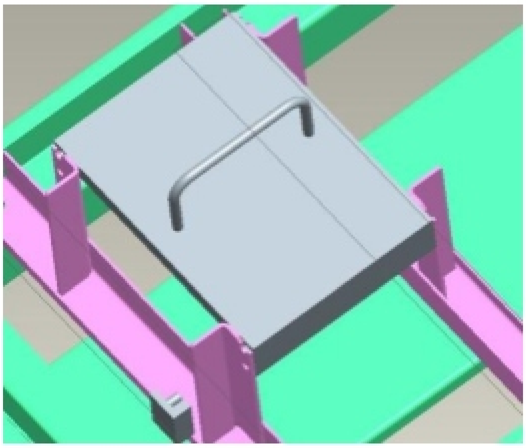
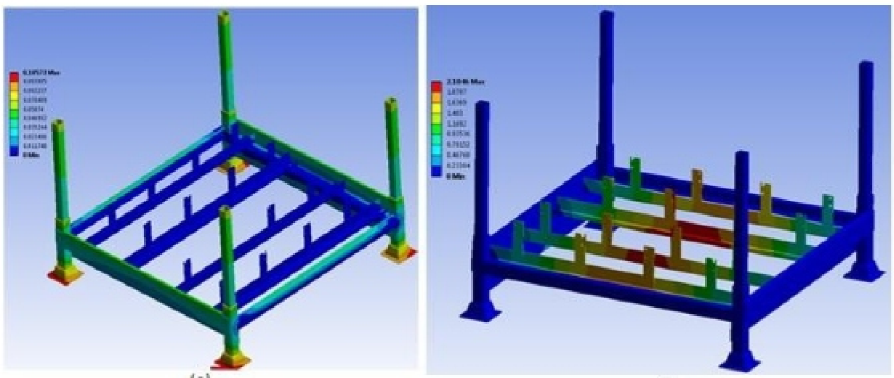


Fig. 11 assembly fixture before the engine assembled

6. Analysis of pallet

FEA analysis conducted in the Ansys software. Followings are the primary results observed on welded metal pallet.

Analysis conducted for the handling and fork lifting conditional stress plot with applying specific load.



(a) (b)

Figure 12(a) Max stress at the end of the bottom cup (b) Max stress at the center of the channel

	Analysis Intent	Analysis Type	Load KN	Deformation (mm)	Stress (MPa)
1	Handling Stock	Structural	8.397.36	2.7112	242.5
2	Stacking Check	Structural	16.794	0.1587	238.1
3	Forklift supporting check	Structural	8.397.36	1.7354	302.02

On the above result stress observed higher than the yield stress 240 Mpa. As per the above result following changes are corrected in the model.

1. Increase thickness of bottom cups.
2. Introduce guide member into cups for more stability against wobbling of upper pallet.
3. Increase thickness of transverse members
4. Replace current engine legs with a L-shaped member instead.
5. Additional C-member below all engine carrying cross-members

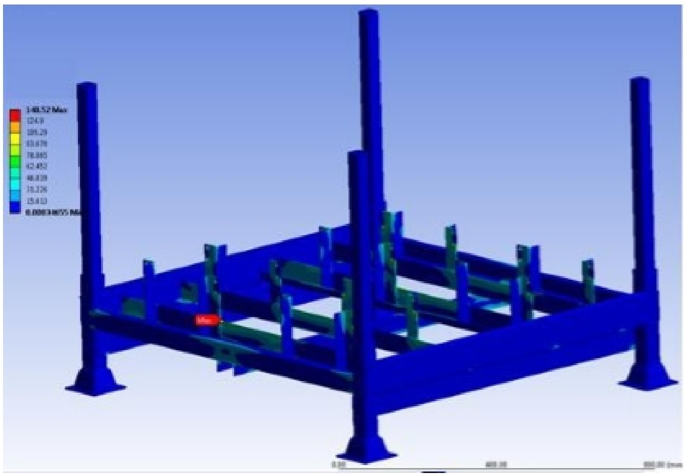


Figure 13 minimize the stress after the correction in model

Table 6 Deformation and stress

	Analysis intent	Analysis type	Load KN	Deformation (mm)	Stress (MPa)
1	Handling Stock	Structural	8.397.36	2.1046	206.94
2	Stacking Check	Structural	16.794	0.10573	204.73
3	Forklift supporting check	Structural	8.397.36	1.4387	294.67

After the correction above graph shown the better result and design is freeze for the proto development.

7. Experimental Setup

In experimental analysis two types of setup prepared. One is for the handling and fork lifting deflection check in the main engine mounting member and another for the stationary stacking up to 4 levels setup.

In the below figure 14 the four engines are mounted on the pallet. Pallet is under the loaded condition. Loading condition is the same considered as in analysis.

Handling stock & fork lifting

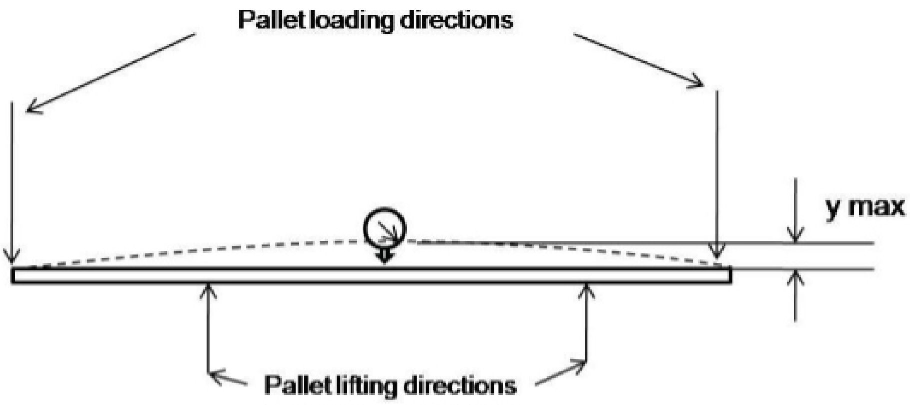


Figure 14 Pallet handling and fork lifting deflection in the member

Table 7 Load and deflection result in the main engine member

Engines per pallet	Load kg	Load in KN	Deflection mm (y Max.)
1	143	1.40283	0.3
2	238	2.33478	0.8
3	333	3.26673	1.4
4	428	4.19868	1.8
Double storey with 8 engines	856	8.39736	2.7

Load considers in the kg and test carried out on single pallet and double storey level of pallet.

Stacking check

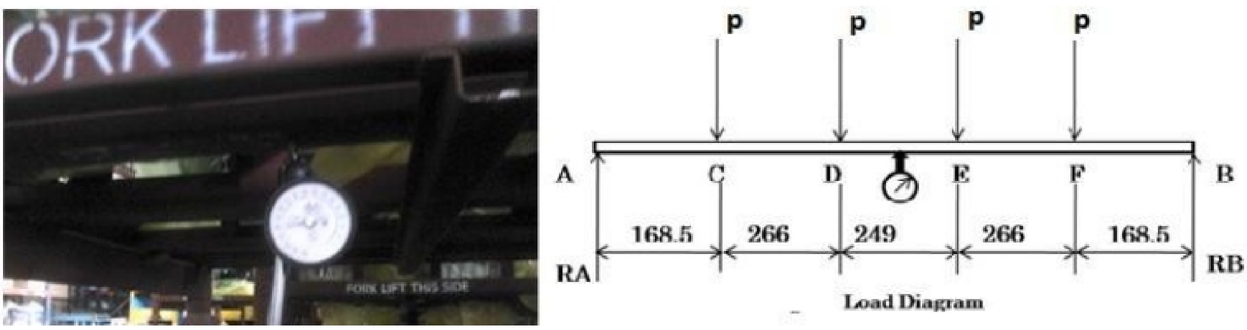


Figure 15 Setup for Engine mounting channel deflection

Table 8 Load vs. deflection result of engine mounting main member

Engines per pallet	Load Kg	Load in KN	Deflection mm (y max)
1	143	1.40283	0.1
2	238	2.33478	0.15
3	333	3.26673	0.164
4	428	4.19868	0.17

Same the figure 15 shows the stacking deflection when engines are mounted on the pallet means under loaded condition.

8 Result & Discussion

Table 6 shows the stress produced in the engine mounting member are more than the yield stresses 240 Mpa. After the modification in the model table 7 shows obtained stress is under the yield stress. That means the model is under the safe condition. This deflection results check with the experimentally. This test is carried out only the handling, fork lifting and the stacking condition. Deflection result table 7 is the maximum 2.1mm in handling and the actual deflection measured is the Max 2.7 mm it included manufacturing flatness of the channel. As well as stacking result is also similar in both case.

And figure 16 and figure 17 is the load verses deflection graph plotted at Handling stock with fork lifting and stacking respectively.

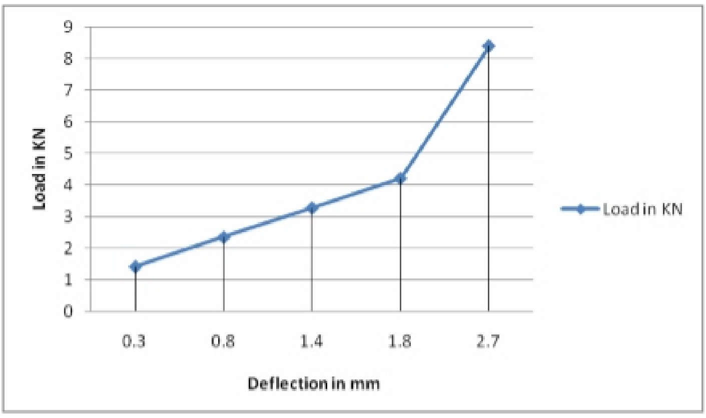


Figure 16 Load vs. Deflection graph of main engine mounting member

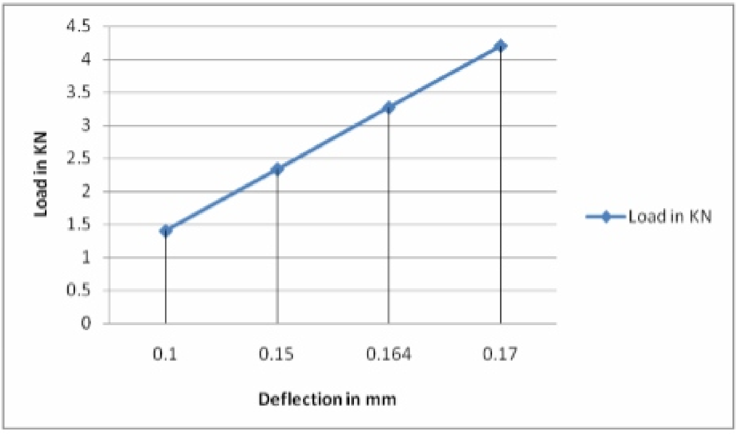


Figure 17 load vs. deflection in the engine member at single pallet in stationary condition

Welded pallet design is suitable for small and large quantity of engines to dispatch. Selection of the pallet assembly process is to be direct effect on cost and weight.

The 3D CAD model of the metal pallet is prepared on the Pro-E wildfire software. After development of model the CG is found out. Parametric design approach is used of modeling of metal pallet. The round, corners and joints are smooth and minimize the concentration inside the pallet model. Include the chamfers at bolt hole are removed in order to reduce the model meshing problems & size. It can be expected that these simplification would lead to great amount of savings in the solution time, without compromising on the accuracy of the solution. The Steel pallet mass is measured on 3D software for analysis. 42.7 Kg weight observed on the software.

8 Conclusions

On the analysis result and the practical work it seen that the welded design is safer in the small capacity engine at large qty transportation. Because of strength, reused and recycled are the benefits of this type of pallet.

Experimental result and analysis result approximately match. Just small variation observed due to the setup arrangement constrain. Therefore we have to conclude that this type of pallet is safer for the transportation and storage of engines.

Overall the special pallets designs are depend on the base of the engine mounting provision that is available on the engine crankcase and the space is the limitations. Also seen that in the conceptual stage it is necessary to consider the engine packaging, pallet manufacturing process, storage and space constrain, container fitment, per quantity of engine on pallets etc.

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Computational Flow Analysis of Carburetor Venturi Effecting On Obstacles

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A B S T R A C T

A computational fluid dynamics (CFD) is used to develop a three dimensional, fully turbulent model of the compressible flow across a complex-geometry venturi, such as those typically found in small engine carburetors. An attempt is made in this paper to carry- out three dimensional CFD analysis of effecting on carburetor venturi with obstacles and fuel tube to draw various types' contours of the static pressure, velocity, total pressure and turbulent kinetic energy. First is to model the carburetor venture using CFD tool and meshed by volume mesh with 84, 605 Tetrahedron elements. Then the CFD analysis is carried–out and presented results, is observed result drawn for various types of static pressure, velocity, total pressure and turbulent kinetic energy is effecting the fuel tube and venturi without obstacles and effecting on modified obstacles, It is observed that the obstacles located at converging nozzle of the venturi do not cause significant pressure losses, while those obstacles wakes on the flow. Significantly, once the mass flow rate is corrected using an overall discharge coefficient, the knowledge of the actual Cross-sectional area at the venturi throat is enough to calculate the static pressure and Stagnation Pressure(total pressure) at the tip of the fuel tube. The evaluated results are validated with mathematical model, its good agreement.

Keywords: CFD, carburetor, venturi

INTRODUCTION

Carburetor: The carburetor is a device that mixes fuel into the incoming air. The airflow into the carburetor is controlled by a butterfly valve, and the fuel is added to the mixture through venturi. In a carburetor equipped engine. The air comes in to the space for air filter. Air passes through the air filter and then into the carburetor where the fuel is blended with it. Through the intake manifold, it passes. And then it is drawn into the cylinders.

Large volumes of small engines (two wheelers) are being sold in India every year. Its emissions comprise a significant percentage of total pollutants in India. As demonstrated by the automotive industry, significant reductions in emissions are technologically possible, particularly with the use of electronic fuel injection. However, due primarily to cost constraints, small engine manufacturers rely on small, inexpensive Carburetors to generate the fuel mixture for their engines. Thus, a better understanding of carburetor performance and modeling could lead to better fuel mixture control and lower emission

From small engines

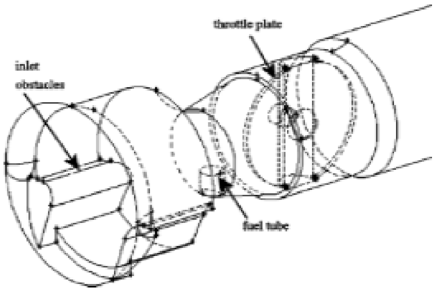


Fig 1: Details of carburetor parts inside the venturi

A real carburetor venturi has details in its geometry that create disturbances in the flow and may cause pressure losses that cause deviations from an ideal isentropic flow. These carburetor parts are the choke plate, throttle plate, fuel tube, side passages to secondary systems, and, sometimes, an additional concentric fuel tube in the venturi throat. Some details of typical carburetors used in small engines are shown in above figure1.

LITERATURE REVIEW

This Literature review section provides an insight into the research in the present paper the inlet obstacles, fuel tube, and throttle plate were modeled with in order to gain a better understanding of the flow in complex venturis. Several studies have addressed the modeling of fuel flow in carburetors: Experimental studies performed by Furuyama and Ohgane [1] and Moss [2] showed that the pulsating nature of the air flow affects the amount of fuel delivered by the carburetor. Furuyama found that the effect of pulsating air flow on fuel flow may be classified as: i) when the throttle plate opening is large and air flow is low, the fuel flow is higher at pulsating flow than at steady flow, and ii) when the throttle plate opening is large and air flow is high, the fuel flow is lower at pulsating flow than at steady flow. Moss' experiments [1] agreed with the conclusions for the first case. Both researchers proposed that the fuel flow under dynamic air flow may be calculated by using the steady state prediction, and then corrected with a pulsation- correction factor. Two special considerations must be taken when predicting the fuel flow from the carburetor circuits: the characterization of the two-phase flow inside the emulsion tube and the characterization of the small metering orifices.

The only known work that has used CFD for the characterization of the flow across the carburetor was done by Wu, Feng and Liu [3]. But in their work, the carburetor was represented as a two-dimensional channel where the fuel tube was a large obstacle in the flow field. The only results shown in this work are the static pressure drop along the axis of the carburetor.

Thus, it can be inferred from these works that the flow through a carburetor can be successfully modeled using pressure variation as boundary conditions and the standardized k-epsilon turbulence model is competent enough to model the turbulence behavior in the flow.

OBJECTIVE OF THE PAPER

To carry out three dimensional CFD analysis of carburetor venturi to understand the effect of the various obstacles present in the flow domain like the fuel-tube, throttle plate and to optimize the design of carburetor by carrying out geometrical changes based on results obtained from CFD analysis of existing model.

- To perform CFD analysis by considering the following models.

a) Ideal carburetor venturi
b) Existing carburetor venturi
c) Modified carburetor venturi

MODELING INTRODUCTION

Basic steps of modeling:

Stage 1: preprocessing

Geometry definition: the physical boundaries of the objects are defined in a 3-dimensional space.

Meshing: the volume bound by the body or the fluid domain is discretised into finite elements that are uniform or Non-uniform as the problem demands.

Model definition: the type of fluid modeling is defined in terms of the flow equations adopted or the energy Transfer models etc.

Boundary conditions: the boundary or end conditions of the flow are defined in the software module The inlet boundary condition was defined with the isentropic stagnation pressure and temperature, and the outlet boundary condition was defined with the outlet static pressure. An ideal gas model was used in order to take into account the compressibility of the airflow.

Method

A three-dimensional model of a carburetor venturi was generated in CFD tool, The model build option crate line and create surface, by using extrude surface and then we create that venture geometry, this model saved In IGS for met and then it is export to using ICM software for meshing and element type Tetrahedron the mesh is created. This file is saved in *mesh for met and it is used CFX for CFD analysis.

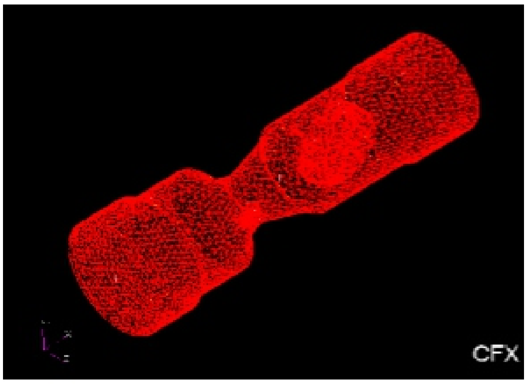


Fig 2. Meshed model

Meshing Model Details:

Element type : Tetrahedron
Global Element Scale Factor : 4.3
Mesh Type : Volume mesh
No. of elements : 84,605

Mathematical Modelling

Air is used as fluid media, which is assumed to be steady and incompressible. High Reynolds number k-ε turbulence model was used in the CFD model. This turbulence model is widely used in industrial applications. The equations of mass and momentum were solved using SIMPLE algorithm to get velocity and pressure in the fluid domain. The assumption of an isotropic turbulence field used in this turbulence model was valid for the current application. The near-wall cell thickness was calculated to satisfy the logarithmic law of the wall boundary. Other fluid properties were taken as constants. Filter media of intake system and air sensor were modeled as porous media using coefficients.

For porous media, it is assumed that, within the volume containing the distributed resistance there exists a local balance everywhere between pressure and resistance forces such that

$-K_i u_i = \frac{\partial p}{\partial \xi}$

Where ξ_i $(i = 1, 2, 3)$ represents the (mutually orthogonal) orthotropic directions.

K_i is the permeability

u_i is the superficial velocity in direction ξ_i

The permeability K_i is assumed to be a quasi linear function of the superficial velocity magnitude of the form

$$\alpha_i \left|\vec{v}\right| + \beta_i$$

Where α_i and β_i are user-defined coefficients

Superficial velocity at any cross section through the porous medium is defined as the volume flow rate divided by the total cross sectional area (i.e. area occupied by both fluid and solid). In this analysis, α_i and β_i are assumed to be same.

ANALASIS INTRODUCTION

CFD : Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Until 1960's we would have been operating in "two approach world" theory and experiment. Later an important new third approach in fluid dynamics is introduced.

The ANSYS CFX : solver uses the most modern solution technology with a coupled algebraic multi-grid solver and extremely efficient parallelization to help ensure that solutions are ready for analysis quickly and reliably. Solution analysis with the ANSYS CFX post-processor then gives users the power to extract any desired quantitative data from the solution; it also provides a comprehensive set of flow visualization options. Animations of flow simulations are easily generated, and 3-D images can be directly created using the freely-distributable 3-D viewer from ANSYS CFX.

CFX-5 consists of five software modules which are linked by the flow of information required to perform a CFD analysis.

In this pressure losses created by these elements reduce the mass flow rate that could be driven through the venturi for a given pressure difference between the inlet of the venturi and the intake manifold. The inlet obstacles, fuel tube, and throttle plate were modeled with in order to gain a better Understanding of the flow in complex venturis.

The RNG K-E turbulence model is used, with standard wall functions for near-wall treatment. The discretisation scheme used was second order in space. The convergence criteria were set to a maximum residual equal to $1x10^{-6}$ for the energy equation and to $1x10^{-4}$ for the other equations.

Governing Equations

Commercial CFD solver CFX was used for this study. It is a finite volume approach based solver which is widely used in the industries. Governing equations solved by the software for this study in tensor Cartesian form are following:

Continuity:

$$\rho\left(\frac{\partial u_j}{\partial x_j}\right) = 0$$

Momentum:

$$\rho\frac{\partial}{\partial x_j}(u_j u_i) = -\frac{\partial P}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_j} + S_{cor} + S_{cfg}$$

Where ρ is density, u_j is j the Cartesian velocity, p is static pressure, τ is viscous stress tensor. The RNG model was developed using Re-Normalization Group (RNG) methods by Yakhot et al to renormalise the Navier-Stokes equations, to account for the effects of smaller scales of motion. In the standard k-epsilon model the eddy viscosity is determined from a single turbulence length scale, so the calculated turbulent diffusion is that which occurs only at the specified scale, whereas in reality all scales of motion will contribute to the turbulent diffusion. The RNG-approach, which is a mathematical technique that can be used to derive aturbulence model similar to the k-epsilon, results in a modified form of the epsilon equation which attempts to account for the different scales of motion through changes to the production term.

Transport Equations

There are a number of ways to write the transport equations for k and, a simple interpretation where bouyancy is neglected is

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[(\mu - \frac{\mu_t}{\sigma_t})\frac{\partial k}{\partial x_j}\right] + P_k - \rho\epsilon$$

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j}\left[(\mu - \frac{\mu_t}{\sigma_e})\frac{\partial \epsilon}{\partial x_j}\right] - C_{1e}\frac{\epsilon}{k}P_k - C_{2e}{}^{*}\rho\frac{\epsilon^2}{k}$$

$$\text{Where } C_{2e}{}^{*} = C_{2e} + \frac{C_\mu \eta^3 (1 - \frac{\eta}{\eta_0})}{1 + \beta \eta^3}$$

$$\text{And } \eta = \frac{S_k}{\epsilon} \text{ and } S = (2 S_{ij} S_{ij})^{\frac{1}{2}}$$

With the turbulent viscosity being calculated in the same manner as with the standard k-epsilon model.

Boundary conditions

The carburetor venturi had an inlet diameter of 25 mm, a throat diameter of 12 mm and exit diameter of 20 mm. This venturi had inlet obstacles, a fuel tube. The inlet boundary conditions in CFX were set to the laboratory conditions (T0=293 K and P0=1 atm) and the outlet boundary condition to the outlet pressure in the low-pressure plenum in the flow bench _Pout=94.5 KPa, Four The CFD is used for assessing the details of the flow, the values of the discharge coefficients, and localized values of the flow variables; specifically, the static pressure at the tip of the fuel tube. The following sections present a systematic study of the effect of different carburetor parts. First, carburetor venturi is modeled without obstacles. Second, the inlet obstacles were added, and then the fuel tube was added to the geometry. Finally, how to effect of obstacles is study.

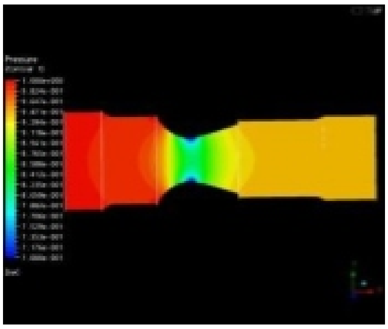
RESULTS AND DISCUSSION

INTRODUCTION

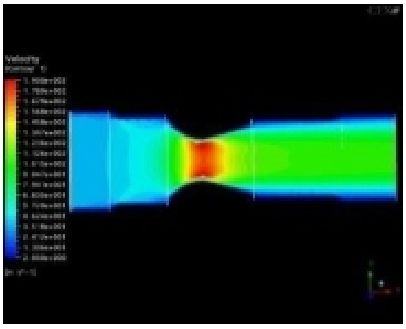
By observing various types of the static pressure, velocity, total pressure and turbulent kinetic energy, for effecting on venturi with obstacles, effect on fuel tube, modified obstacles and effect on modified obstacles model, Figures are shown below

5.1 Venturi without obstacles:

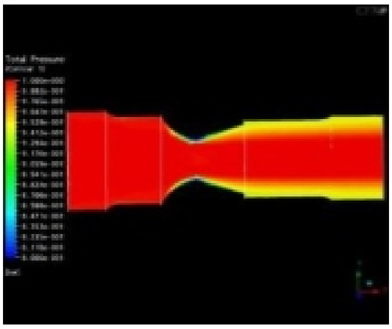
The following figures shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and Velocity vector for a compressible air flow across the venturi without obstacles i.e. fuel tube and throttle plate. In fig 5.1 the Static Pressure is almost uniform in the radial direction except at the throat where it changes next to the wall. After venturi the pressure variation is almost constant (no pressure fluctuation). In fig 5.2 the velocity increases at the converging nozzle and then separates from the wall at the diffuser in the region of adverse pressure gradient. The velocity is almost constant behind the venturi.



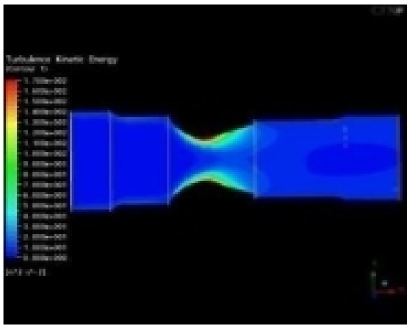
Static Pressure



5.2 Velocity Pressure



5.3 Total Pressure



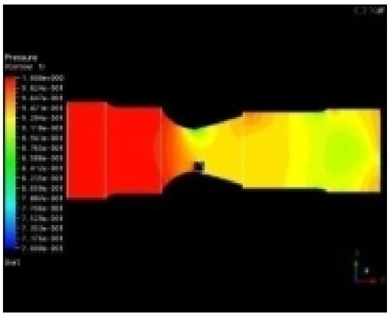
5.4 Turbulence Kinetic Energy

In fig 5.3 the total pressure (stagnation pressure) shows that it is uniform throughout the flow except at the wall of the throat. Generally the reduction in stagnation pressure creates wake region (turbulence region). In fig5.4 the turbulence kinetic energy field shows that the intensity of turbulence created. The highest turbulence region created at near wall throat.

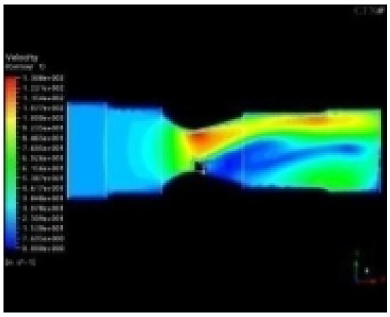
Effect of fuel tube

The following figure shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and Velocity vector for a compressible air flow across the venturi with fuel tube of 3mm diameter with projection of 3mm at throat section i.e. 1/4th of throat diameter.

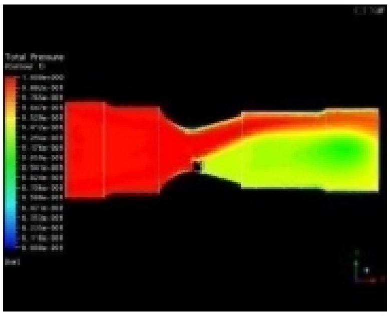
In fig 5.5 the presence of fuel tube strongly affects flow field and static pressure drop in the venturi. It reduces the cross sectional area and also comparatively lower pressure drop at throat in the radial direction. In addition, a sharp leading edge of the fuel tube creates a separation region, which results in a lower pressure at the tip of the fuel tube. Downstream of fuel tube, it is almost uniform in radial and axial directions



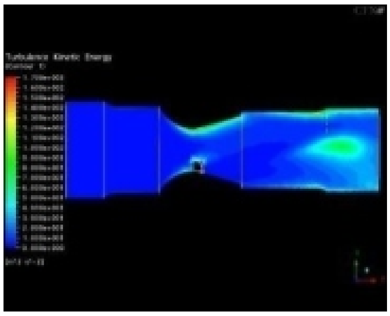
5.5 Static Pressure



5.6 Velocity Pressure



5.7 Total Pressure



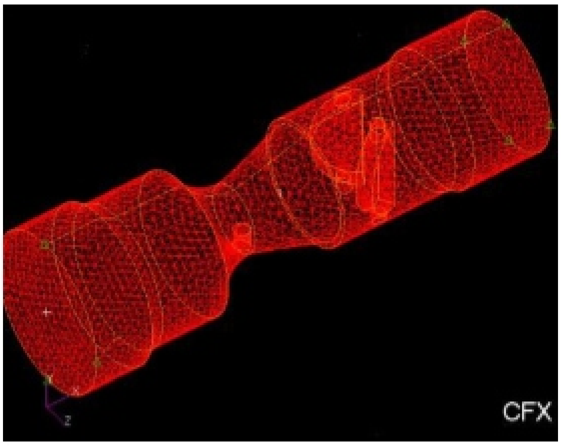
5.8Turbulence Kinetic Energy

In fig (5.6 & 5.7) the presence of fuel tube effectively reduces the velocity and creates the wake region (fluctuating velocity field) behind the venturi. This wake zone may be responsible for fuel puddling after the carburettor; once the fuel droplet is captured in this region; there is no momentum to drive it to the manifold.

In fig 5.8 the stagnation pressure shows that there is a considerable reduction behind the venturi with the presence of fuel tube and ultimately creates turbulence region. The kinetic energy field shows that the wake is created in the downstream of fuel tube. The intensity of turbulence is high at the downstream and is moderate at the near wall throat.

Modified Design of obstacles

The obstacles is modeled with its body divided in two identical half-plates with individual screws for them as shown in Fig 5.9 They were located at the same downstream location from the venturi throat as the original obstacles.

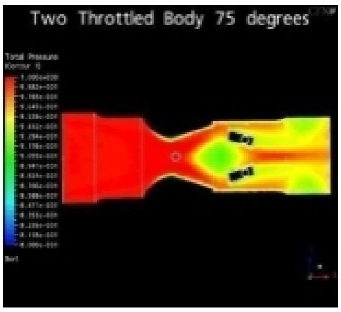


5.9 Modified Model

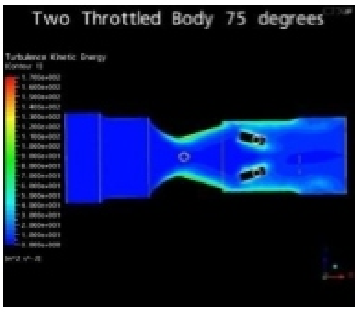
The carburetor model modified with throttle plate position of 75 degrees as shown. The volume mesh of the model has been generated with tetrahedron element of 1.5mm of size.

5.4 Effect of modified obstacles:

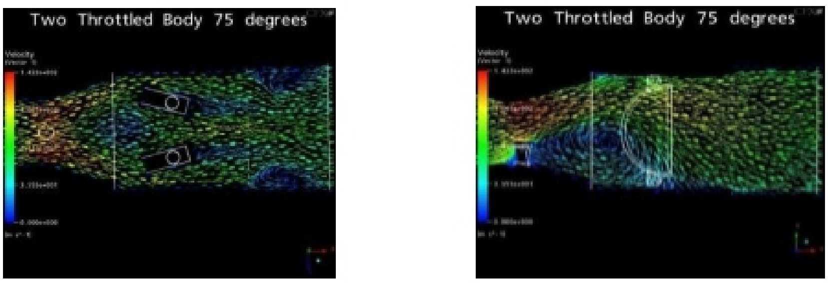
The models were analyzed for the same boundary conditions. The analyses of results for 75 degrees show that reduced stagnation pressure loss at downstream. The kinetic energy field shows that it is almost constant throughout the flow. The velocity vectors clearly shows that reduced flow recirculation at downstream



5.10 Gauge Total Pressure



5.11 Turbulent Kinetic Energy



5.12 Velocity Vector

The above figures Steady air flow across carburetor venturi with fuel tube (3mm) and double throttle at 75 deg (a) Gauge Total Pressure (bar) (b) Turbulent Kinetic Energy (m2/s2) (c) Velocity Vector (m/s)

Calculation of localized discharge coefficient:

In addition to getting the information about the overall discharge coefficient to correct the mass flow rate across the carburetor venturi given a pressure drop, it is possible to calculate a local discharge coefficient that may be used to get the static pressure at a particular location in the carburetor venturi. It is of great interest to use the information from the CFD simulations to set the appropriate boundary condition at the tip of the fuel tube in a fuel flow network. This result indicates that the assumption of isentropic flow is valid for the converging side of the carburetor venturi.

S.No	Description	Static Pressure at throat in bar P_t	Stagnation Pressure at inlet venturi in bar P_0	Mass flow rate in kg/sec M	Coefficient of Discharge C_d
1	Plain venture	0.75563	0.999292	0.002914	0.473
2	Fuel tube without throttle	0.98055	0.99969	0.001189	0.324
3	Two Body throttle- 60 deg	0.98668	0.999892	0.001873	0.394
4	Two Body throttle- 75 deg	0.97829	0.999656	0.002123	0.4012

TABLE-1: shown the static pressure, mass flow rate, coefficient discharge improvement

CONCLUSION

CFD analysis is done using commercial CFD solver CFX software to analyze the flow behavior of the existing carburetor body used in small engines. The result of conventional throttle body positions indicates that flow recirculation at downstream which causes pressure fluctuations and increased stagnation pressure loss which is undesirable. More over the velocity vectors for various throttle body positions shows that the recirculation in the flow just before throttle body. Further increased discharge coefficient has been observed for the modified model.

The analyses of results for 75 degrees show that reduced stagnation pressure loss at downstream. The kinetic energy field shows that it is almost constant throughout the flow. The velocity vectors clearly show that reduced flow recirculation at downstream shown in modified model.

The results of these simulations indicate that CFD simulations can be used to understand the nature of the flow field in ventures with various positions and to find quantitative information that can be used as boundary conditions for additional systems coupled to the venturi.

Future work should focus on the analysis of the static pressure at different inlet obstacles, as well as next to the throttle plate, in order to improve on the design of flow systems incorporating complex venturis.

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6. *V. Ganesan - Indian Institute of Technology Madras have utilized pressure based boundary conditions in their paper on CFD analysis of carburettors. This lends credibility to the use of pressure based boundary conditions in this project.*
7. *Sanatian and Moss used standard k-epsilon turbulence models to predict the flow through a carburetor under steady state conditions and found the results to be in agreement with the real world tests.*

Characterization of Motor Lubricating Oils

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A B S T R A C T

Very important component for safe and undisturbed functioning of any internal combustion engine is a sound lubrication of vital parts with engine (motor) oil. Simultaneously with engines development, new requirements were also set for engine oils in order to get more power from the engines to withstand higher working temperatures, wear and load and to last longer. At first mineral engine oils were used, but synthetic engine oils that could fulfil the highest requirements are more and more implemented. Nowadays, technically and commercially, engine oils have gained more than 60% of market share on the global market of lubricants. For proper functioning of the engine, engine oil must fulfil requirements: minimizing wear, assisting in cooling, keeping the compression ratio, reducing corrosion and friction and controlling the deposits. Lubricant characteristics and performances are managed by standard or industrial organization as API, ACEA, and SAE through specific norms. Each norm defines technical requirements as physical properties, engine tests results and other various criteria. This paper describes the importance of grade of engine oil as per SAE and compare various properties of engine oil as per their grade and brand of engine oil. It gives idea about the selection of engine oil depends on the climate condition, load, speed, driving condition and local availability etc.

Key words: lubrication, lubricants, engine oil, properties, additives

1. Preliminary Observation

Introduction

The principle of supporting a sliding load on a friction reducing film is known as lubrication. The substance of which the film is composed is a lubricant, and to apply it is to lubricate. A lubricant (sometimes referred to as "lube") is a substance (often a liquid) introduced between two moving surfaces to reduce the friction between them, improving efficiency and reducing wear [1]. Lubricants are comprised of a base fluid, usually of petroleum origin, combined with added chemicals that enhance performance. Base fluids are collected from two main sources. Refined crude oil (the crude oil is refined into gasoline, diesel, kerosene, LPG, naphtha and base stocks (Lube) or a mixture of chemical compounds that perform the same task. Typically lubricants contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives [2]. Lubricants play a vital role in every industry including: Electronic, Automotive, Aerospace, Forestry, Naval and numerous others. Lubrication failure may result in thousands of dollars of production losses including downtime and equipment failure.

In this research paper only four wheeler gasoline engine oil is included for review purpose. It includes comparison between kinematic viscosity at 40˚C and 100˚C for different brands of engine oil, characterization of properties for different grade engine oil and takes a case study about maruti gasoline passenger car.

Properties of Lubricating Oil and its Additives [3]

The quality of a lubricating oil is tested for the following various properties like viscosity, Flash point, Pour point, Total Base Number (TBN) and Viscosity Index (VI) etc to evaluate its suitability and merits for certain service conditions.

Additives [4] are chemical compounds added to lubricating oils to impart specific properties to the finished oils. Some additives impart new and useful properties to the lubricant; some enhance properties already present, while some act to reduce the rate at which undesirable changes take place in the product during its service life. Table 1 shows the different additives, its purpose and typical compounds contained by it.

Table 1: Classification of additives

Additives	Purpose	Typical Compounds
Viscosity Index Improvers(VI)	Reduce the rate at which oil viscosity decreases with increasing temperature	Polyisobutylene, methacrylate polymers, olefin copolymers
Pour Point Depressants	Modify wax crystal formation to reduce interlocking	Alkylated naphthalene and phenolic polymers, polymethacrylates, maleate/fumerate copolymer esters
Emulsifiers	Promote formation of stable mixture (emulsion) of water & oil by changing interfacial tension	Soaps of fatty acids, sulfonic & napthenic acids, certain animal & vegetable oils
Friction Modifiers	Reduce or modify friction	Long chained polar compounds (amides, phosphates, phosphites, acids, etc)
Dispersants	Keep oil degradation by products, and/or combustion related by products in small suspended state within the bulk oil by preventing agglomeration	Alkylsuccinimides, alkylsuccinic esters, and mannich reaction products
Detergents	Keep surfaces free of deposits	Metallo-organic compounds of sodium, calcium and magnesium phenolates and phosphonates
Corrosion and Rust Inhibitor	Prevent corrosion and rusting of metal parts in contact with the lubricant	Zinc dithiophosphates, metal phenolates, basic metal sulfonates, fatty acids and amines
Anti-Wear (AW) additives	Reduce friction and wear and prevent scoring and seizure	Zinc dithiophosphates, organic phosphates, acid phosphates, organic sulfur and chlorine compounds, sulfurized fats, sulfides and disulfides

2. Lubricants market in India[5]

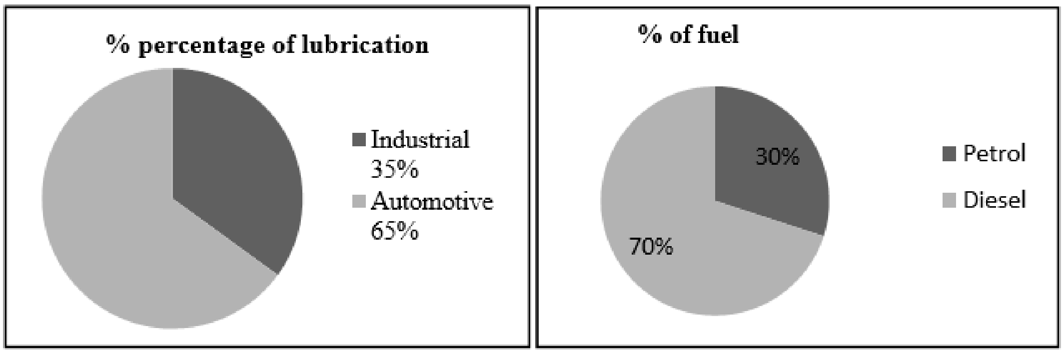

Figure 1: Indian Automotive lubricants market

India is the fifth largest lubricant market globally in volume terms behind the US, China, Russia and Japan. India is a net base oil deficit market and many additives used in lubricants are mostly imported. Volume consumption of lubricants in India has consistently declined over past few years as a result of improving lubricant and engine quality. Following figure 1 shows the market condition of the Indian Automotive Lubricants.

Lubricant companies in India [6]

The India auto lubricant manufacturer produces classified into two types:

Table 2: Public sector units of engine oil

Company Name	Brand Name	Major Product
Indian Oil Corporation Ltd.	SERVO	Servo super mg, Maruti genuine oil, Servo superior xee
Bhara Petroleum Corporation Ltd.	MAK	MAK classic, MAK supreme, MAK ultima
Hidustan Petroleum Corporation Ltd.	HP	HP extra super motor oil, HP SGX, HP cruise classic

Table 3: Private sector units of engine oil

Company Name	Brand Name	Major Product
Castrol India Ltd.	Castrol	Castrol GTX , Castrol EDGE, Castrol Magnatec
Gulf Oil Corporation Ltd.	Gulf	Gulf Formula GX, Gulf MAX Supreme, Gulf Multi GTS
Shell oil corporation Ltd	Shell	Shell helix HX3, Shell helix HX5 , Shell helix HX7

The oil PSUs (IOC, HPCL and BPCL) along with Castrol control ~80% of the market, with 15 other players competing for the remaining pie. IOC is the market leader in the overall lubricants industry in PSU.

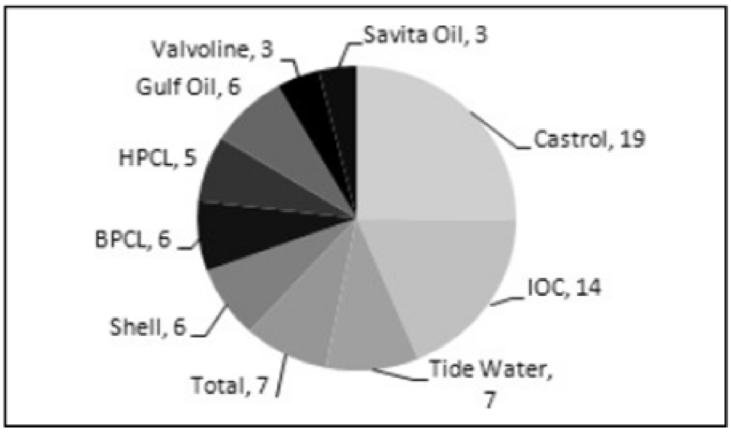

Figure 2: % of consumption in Indian market

Engine oil designation and standards [7]

Lubricant characteristics and performances are managed by standard or industrial organization as American Petroleum Institute (API), Association des Constructeurs Européensd' Automobiles (ACEA), Japanese Automotive Standards Organization (JASO) and International Lubricant Standardization and Approval Committee (ILSAC). Each standard defines technical requirements as physical properties, engine tests results and other various criteria. The Society of Automotive Engineers (SAE) established a viscosity grading system for engine oils. According to the SAE viscosity grading system all engine oils are divided into two classes: monograde and multigrade [8]:

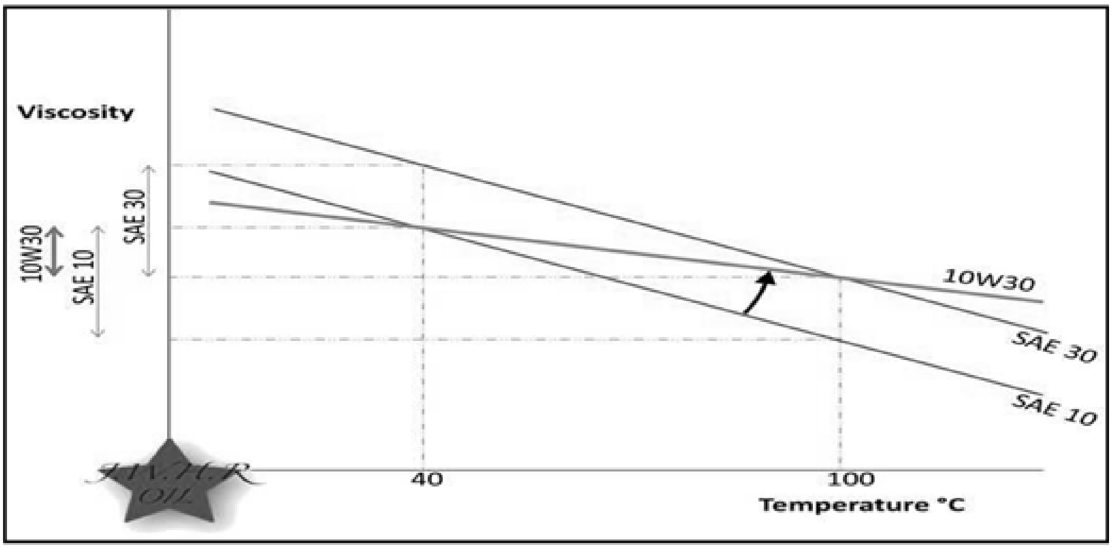

Figure 3: Monograde V/S multigrade oil

3. Characterisation of different engine oil

There are number of manufacturers with number of brands available in the market with specific properties. The selection of the lubricants for the particular engine is dependent on the number of factors [13] [15].

Compare kinematic viscosity at 40˚C and 100˚C for different brand

Figure 4 is showing the relationship between different viscosities. It is observed that at the low temperature test (at 40˚C), the viscosity variation is almost 60% but as the oil warms up, they get very close to each other. Notice that the lines do not cross even though there are only two data points, the viscosity of oil has a linear behaviour so the oil that you select is going to be important from that standpoint.

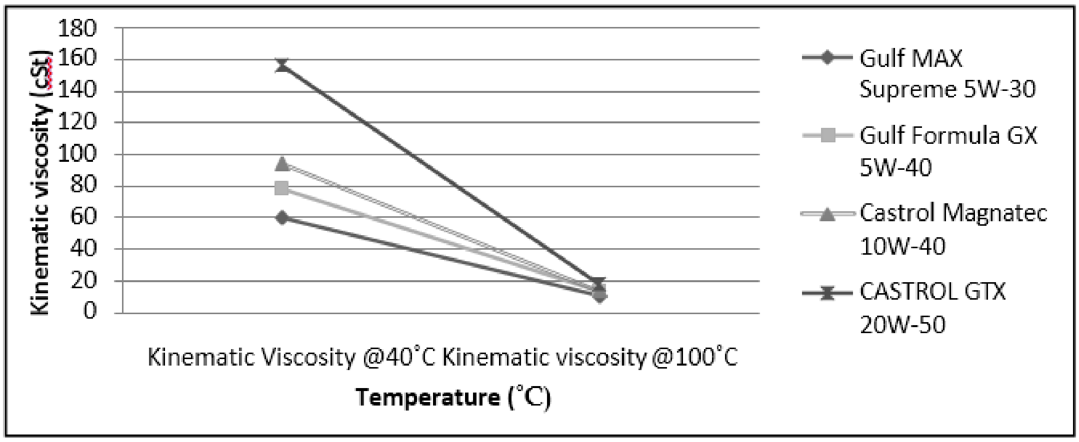

Figure 4: Oil viscosity v/s Temperature for different brand

3.2 Compare various properties of 20W-50 with 10W-30 engine oil

Kinematic Viscosity (D 445)

The kinematic viscosity determines the value at which the fluid can flow. With the higher grade of engine oils (20W-50), the value of kinematic viscosity is 62% to 77% higher because the engine oil is thick hence more internal deformation and shear is present. This graph shows that there is a little difference in kinematic viscosity for all types of products [9]

Flash point (D 92)

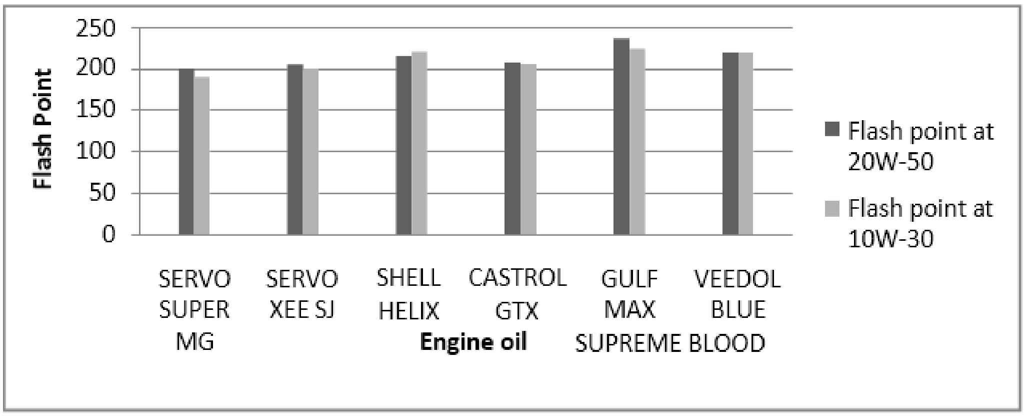

Figure 6: Flash Point v/s Engine oil for different grade

Figure 6 shows that there is only 0% to 5% change in value of flash point due to change the grade of engine oil. A higher FP is better for engine oil. Servo, Castrol and Shell have almost similar values while Gulf and Veedol have a higher flash point at the same grade of engine oil. Gulf has the highest flash point value because it is Saudi Arabian product, so the engine oil prefers more value of flash point for the particular grade.

Pour Point (ASTM D-97)

From the figure 7, it is observed that the value of the pour point for a higher grade of engine oil (20W50) is 12% to 55% lower as compare to the low grade of engine oil (10W30). The lower a lubricant's pour point better protection it provides in low temperature service.

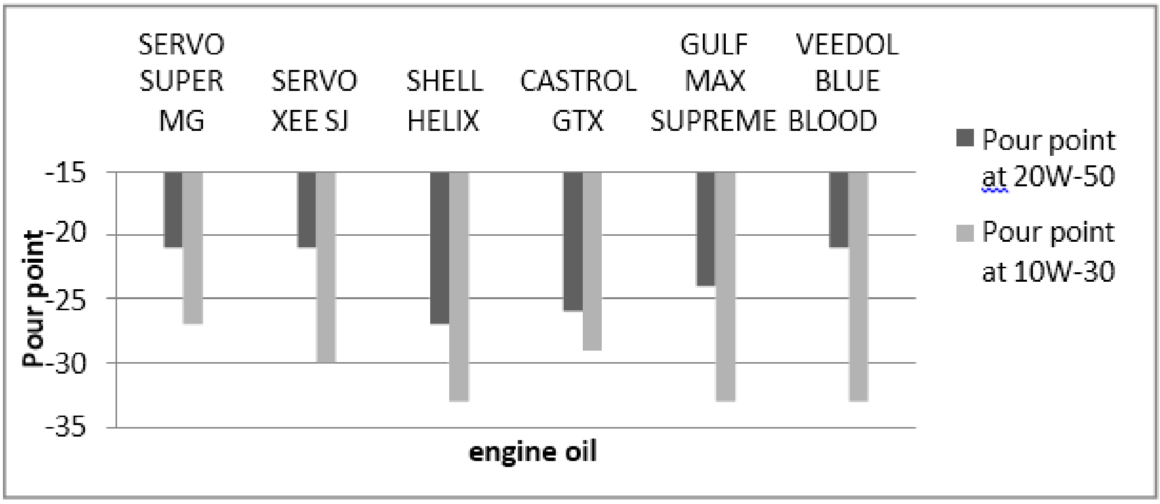

Figure 7: Pour point v/s Engine oil for different grade

Viscosity Index (VI) (D 2270)

It is observed from figure 8 that lower grade of engine oils have 2% to 12% higher value of viscosity index compare to higher grade of engine oils because lower grade of engine oil is suitable for cold countries where the temperature difference is quite more. A low VI means a relatively large viscosity change with temperature and a high VI denotes a smaller change of viscosity with temperature [10].

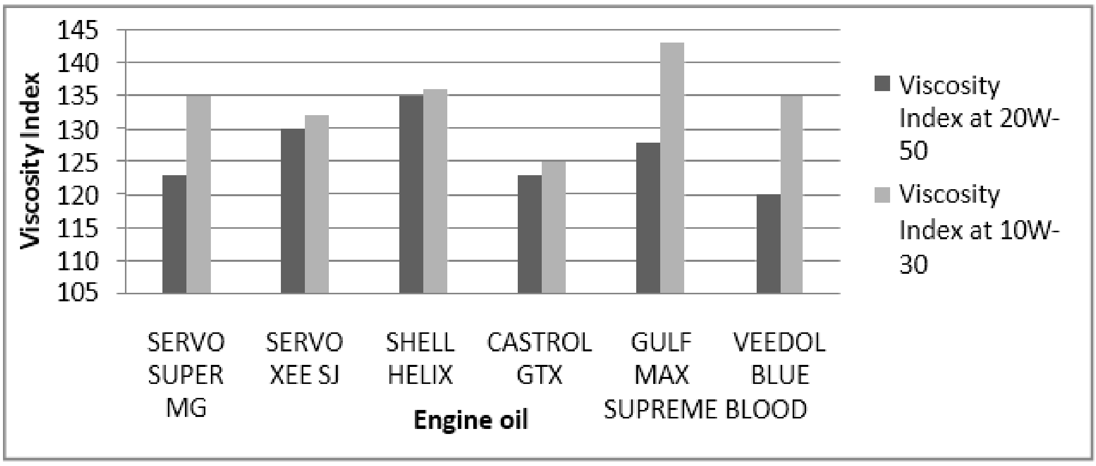

Figure 8: Viscosity Index v/s Engine oil for different grade

Total Base Number (ASTM D-2896)

Total Base Number (TBN) is the measurement of a lubricant's reserve alkalinity, which aids in the control of acids formed during the combustion process. Generally engine oils have a minimum TBN of about 6. Dangerously low would be 2. Oils rated for diesel have a higher TBN, around 10, because they contain more detergents.

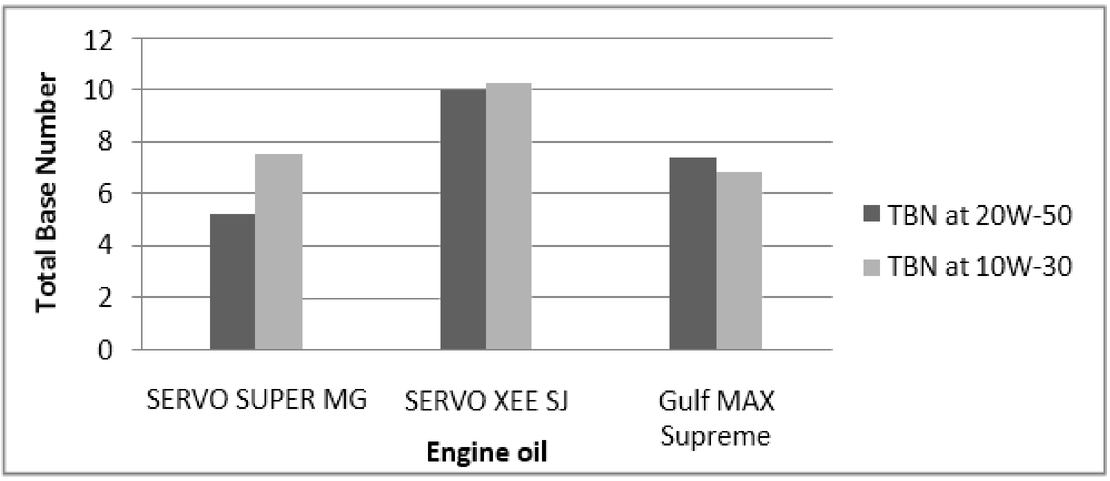

Figure 9: Total base numbers v/s Engine oil for different grade

The high TBN of Motor Oil allows it to effectively combat wear-causing contaminants and acids, providing superior protection and performance over extended drain intervals.

CASE STUDY

Engine oil 5W-30 (used in modern car) and 20W-40 (used in before 2008 model) used in maruti gasoline passenger car.

As per maruti user's manual, newer vehicles will specify lower viscosity oils such as 5W-30 while older vehicles will specify higher viscosity oils such as 20W-50. This is because today's engines are built with tighter bearing clearances to take advantage of the fuel economy benefits of lower viscosity oils. It is not really a good idea to use thicker oil in one of these engines because it will disrupt the oil flow characteristics of the engine and may create excessively high oil pressure. In an older engine that was designed with larger bearing clearances, it is appropriate and recommended to use a thicker oil to maintain proper oil pressure and provide adequate bearing film thickness.

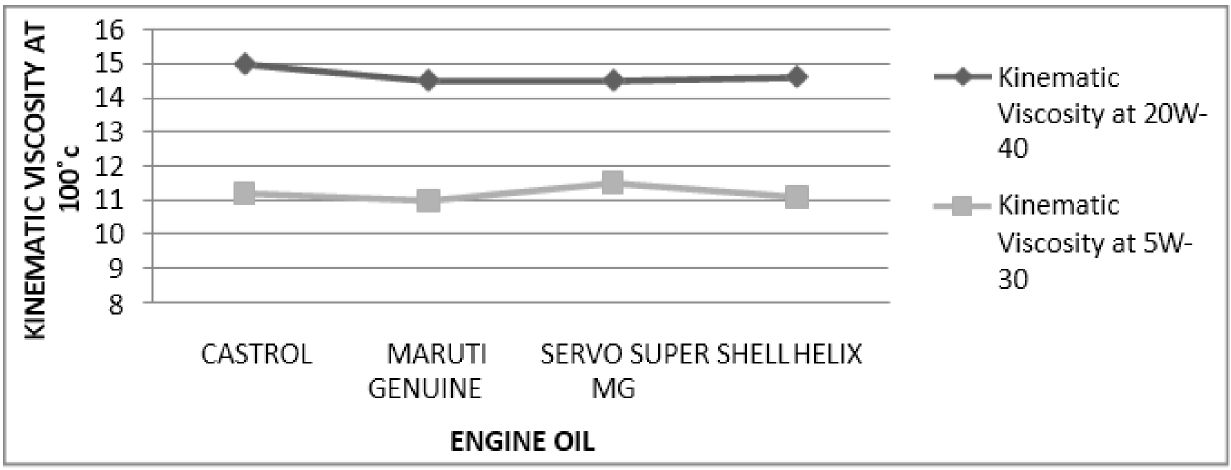

Figure 10: kinematic viscosity v/s Engine oil for 20W-40 and 5W-30

Figure 10 shows the comparison of kinematic viscosity at 20W-40 and 5W-30 grade engine oil. For both the grades of engine oil, it will follow the same trend and there is 3.5% to 4.5% variation in values which is found from the graph it indicates that we can use any brand of engine oil.

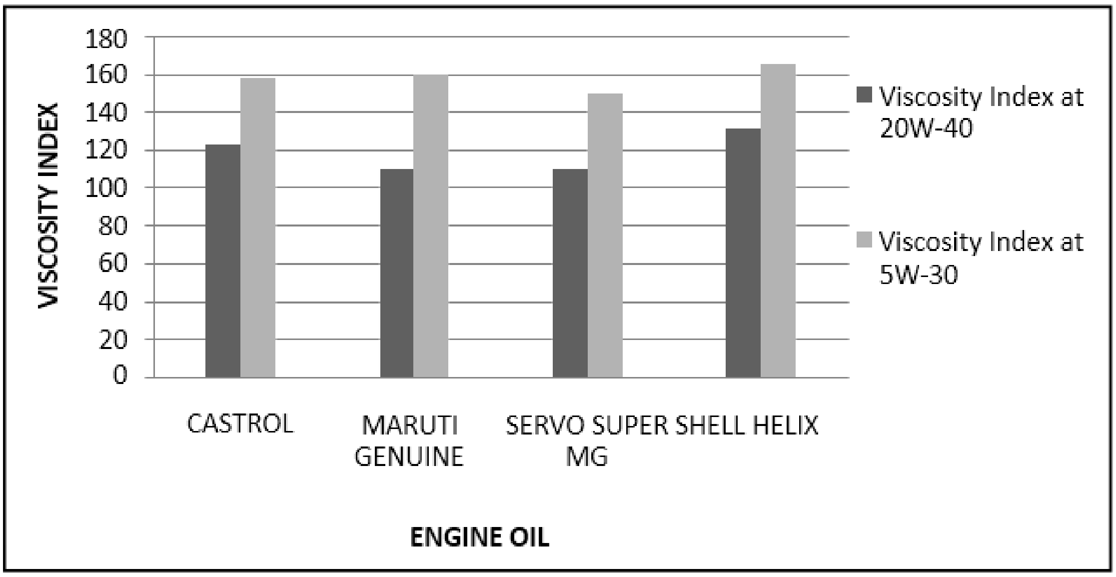

Figure 11: Viscosity Index v/s Engine oil for 20W-40 and 5W-30

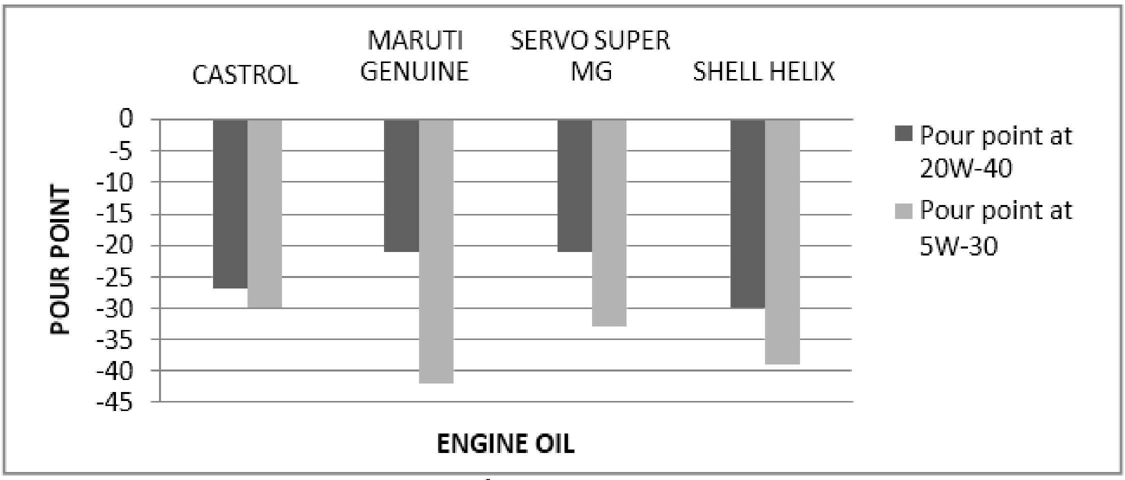

Figure 12: Pour Point v/s Engine oil for 20W-40 and 5W-30

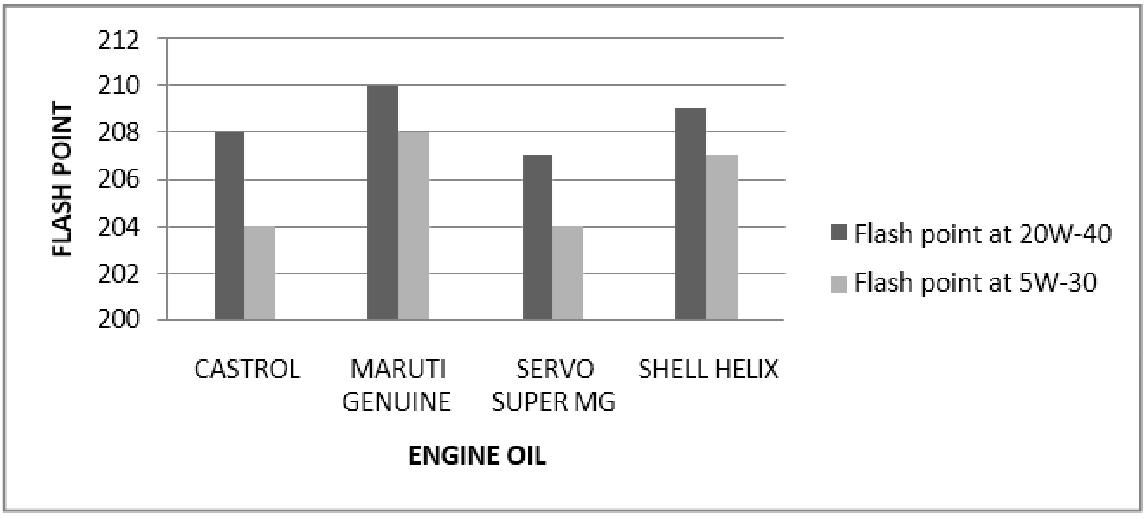

Figure 13: Flash Point v/s engine oil for 20W-40 and 5W-30

Synthetics engine oil like 5W-30 grade can be used in wide temperature extreme, not just cold weather but heat as well. So due to wide temperature range

- High viscosity index (like 25% to 45%) improver is required to take a small change in kinematic viscosity of engine oil.
- Lower value of pour point is required to take the benefits of cold condition in winter hence the variation is 5% to 20%. Maruti genuine engine oil with servo brand has the lowest value of pour point.
- The figure 13 shows that there is only 1.5% to 2% variation in flash point and it is due to change in grade only.

What type of motor oil to use, it is actually recommended by the owner's manual of the vehicle and it depends on the climate condition and clearance between the components of the engine. Maruti engine generally prefers IOC Company with servo brand. Servo has provided special name Maruti Genuine Engine Oil with 20W-40 and 5W-30 to avoid confusion with different brands and grades of engine oil. They also prefer Castrol and Shell lubrications as per the availability of engine oil with same grade.

CONCLUSION

Using the correct oil keeps your engine running smoothly and gives better performance. The selection of appropriate engine oil depends upon load, speed and driving condition of a car. However, their applicability strongly depends on the local availability and atmospheric condition.
Some of the concluding remarks based on the comparisons are given below:

- Thinner oils have a water-like consistency and pour more easily at low temperature hence it can be used for lower starting and/or operating temperature, lighter the load and faster the operating speed of an engine.
- Thick engine oil is better for maintaining film strength and oil pressure at high temperatures and loads hence it can be used where higher the starting or operating temperature, higher load and slower the operating speed of an engine.
- With the higher grade of engine oils like 20W-50, the value of kinematic viscosity 62% to 77% higher as compare to 10W-30 because the engine oil is thick hence more internal deformation and shear is present.
- It is observed that lower grade of engine oils like 10W-30 have 2% to 12% higher value of viscosity index as compare to 20W-50 because they are suitable for cold countries where wide temperature difference is there[9].

- A higher FP is better for engine oil. About 400ºF (204˚C) is the lowest acceptable FP for new oil. With the change of grade, the variation in flash point is only 0 % to 5% because it is the temperature which effect at the operating condition of an engine.
- The lower a lubricant's pour point, the better protection it provides in low temperature service. With the change of grade, the variation is quite more (depends on the grade) because it depends on the lowest temperature of an engine which depends on the climate condition of the particular region.
- The higher a motor oil's TBN, the more effective it is in suspending wear-causing contaminants and reducing the corrosive effects of acids over an extended period of time. Generally engine oils have a minimum TBN of about 6. Dangerously low would be 2.

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