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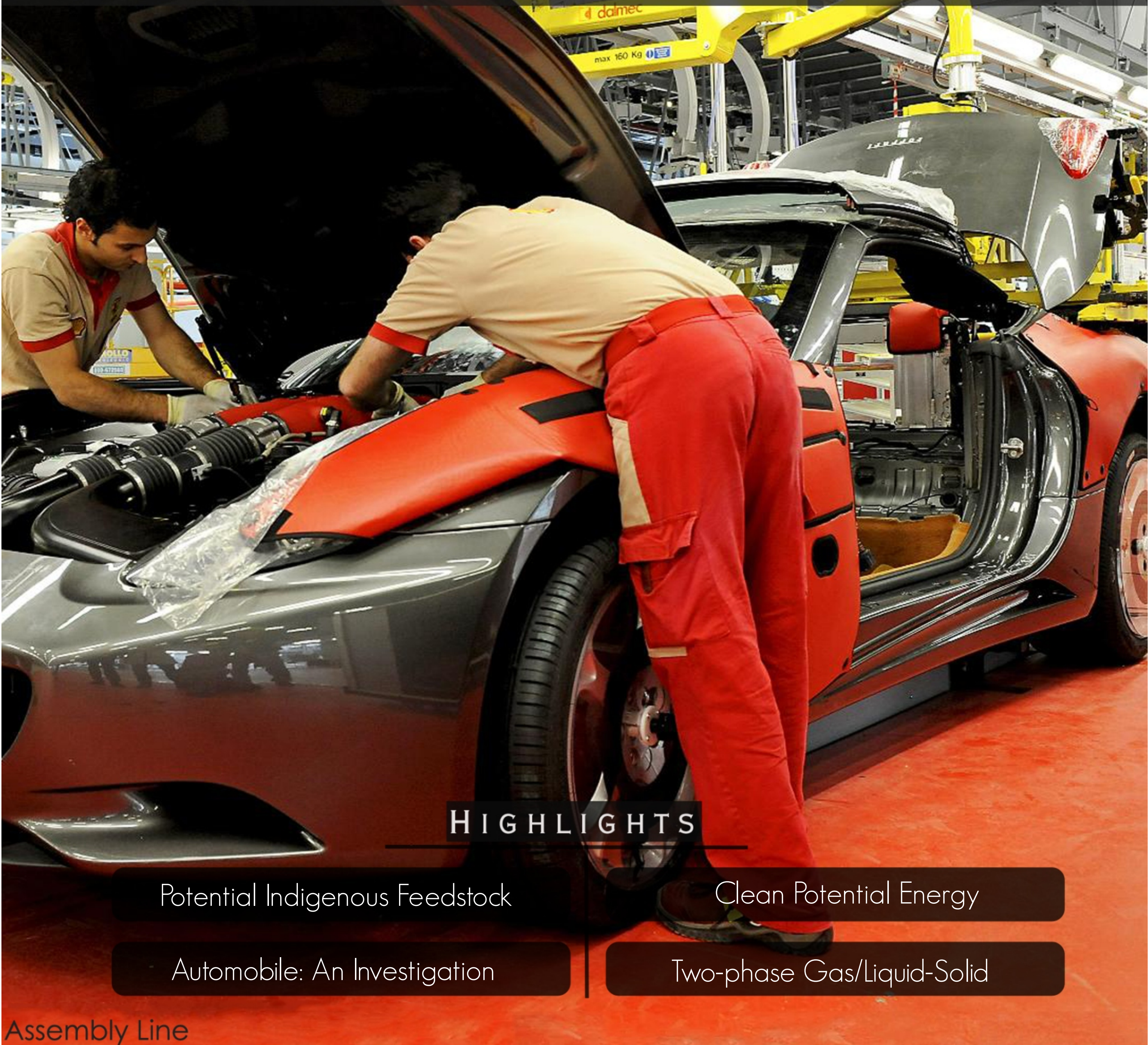
DISCOVERING THOUGHTS AND INVENTING FUTURE



HIGHLIGHTS

Potential Indigenous Feedstock

Clean Potential Energy

Automobile: An Investigation

Two-phase Gas/Liquid-Solid

Assembly Line

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Sclerocarya Birrea Plant Oil: A Potential Indigenous Feedstock for Biodiesel Production in Botswana

By Jerekias Gandure, Clever Ketlogetswe
University of Botswana

Abstract - Exploring new feedstocks for biodiesel production is now receiving widespread attention world-over. This paper presents experimental results on properties of celerocarya birrea plant oil. Chemical properties analysis of birrea plant oil were performed using gas chromatograph and mass spectrometer, while the engine performance tests were conducted on a variable compression ignition engine. Parameters such as fuel consumption, engine torque and engine brake power were recorded at different engine loads for pure diesel fuel and birrea plant oil. The experimental results indicate that birrea plant oil offer immense potential as both fuel and feedstock for biodiesel production. The performance characteristics of ignition compression engine using birrea plant oil indicate that the optimum compression ignition engine occurs at 60% engine load. Similarly, the results revealed that variations in specific fuel consumption recorded for diesel fuel (D100) and birrea plant oil (BPO) between 30% and 60% show no significant difference for the fuels under review.

Keywords : Birrea plant oil, straight vegetable oil (SVO), lipid composition, properties, Botswana.

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SCLEROCARYA BIRREA PLANT OIL A POTENTIAL INDIGENOUS FEEDSTOCK FOR BIODIESEL PRODUCTION IN BOTSWANA

Sclerocarya Birrea Plant Oil: A Potential Indigenous Feedstock for Biodiesel Production in Botswana

Jerekias Gandure[α], Clever Ketlogetswe[Ω]

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Keywords : Birrea plant oil, straight vegetable oil (SVO), lipid composition, properties, Botswana.

I. Introduction

The quest for biofuel production in Botswana is derived from several factors including volatile oil prices, potential for job creation, fuel security and economic diversification. The desire to establish national energy self-reliance and to develop alternatives to finite fossil fuel resources have resulted in the development of fuel technologies that are based on the use of renewable agriculture based materials as feedstocks. In the case of renewable fuels for compression ignition (diesel) engines, the majority of efforts to date have focused on biodiesel, which consists of alkyl esters of fatty acids found in agricultural acylglycerol - based fats and oils. Biodiesel can be produced from any material that contains fatty acids, whether bonded or free (Vicente et al., 2004). Consequently, different vegetable oils can be used as fuel or feedstock for biodiesel production depending on oil properties.

All vegetable oils and animal fats consist primarily of triglycerides (Srivastava and Prasad, 2000; Karmakaret al., 2010). Triglycerides have a three-backbone with a long hydrocarbon chain attached to each of the carbons. The differences between oils from different sources relate to the length of the fatty acid chains attached to the backbone and the number of carbon–carbon double bonds on the chain. Most fatty acid chains from plant oils are 18 carbons long with between zero and three double bonds (Misra and Murthy, 2010). Fatty acid chains with no double bonds are said to be saturated and those with double bonds are unsaturated. The number of carbon atoms and double bonds in each of the five most common fatty acid chains found in common oils and fats are shown in Table 1.

The presence of double bonds in the fatty acid chains has a significant effect on the properties of the methyl esters (Knothe, 2005). The deformation of the molecule caused by the double bonds inhibits the growth of the crystals and this lowers the methyl ester's freezing temperature. Saturated oils and fats tend to freeze at higher temperatures. Animal fats, hydrogenated vegetable oils, and some tropical oils such as palm oil and coconut oil contain approximately 35 – 45% saturated fatty acids and may be solid at room temperature (Misra and Murthy, 2010). Fatty acid methyl esters (FAME) produced from such oils may gel at relatively high temperatures. The carbon–carbon double bonds in unsaturated oils and fats are prone to oxidation by oxygen in the air.

This effect is severe when the bonds are conjugated (two double bonds separated by two single bonds) as is the case for linoleic and linolenic acids. These fatty acids will oxidise 50–100 times faster than oleic acid with an unconjugated double bond. Saturated fatty acids are not subject to this type of oxidative attack. The choice of oil feedstock determines the resulting biodiesel's position in the trade-off between cold flow, oxidative stability, and cetane number. Fatty acid methyl esters from more saturated feedstock will have higher cetane numbers and better oxidative stability, but will have poor cold flow properties. Fatty acid methyl esters from oils with low levels of saturated fatty acids will have better cold flow properties, but lower cetane number and oxidative stability (Refaat, 2009).

Engine performance profile generated using a straight vegetable oil as fuel is another important property. The nature of fatty acids largely determines their ability to burn correctly in an engine (Aluyor et al.,

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2009; Moser et al., 2009). In addition, iodine value is another important property with regards to the use of straight vegetable oil as fuel or feedstock for the production of biodiesel. The iodine value indicates the degree of unsaturation of oil (number of double and triple bonds). It corresponds to the number of grams of iodine absorbed by 100 g of oil. The more the oil is unsaturated, the higher is its iodine value. As such, low iodine value (saturated oil) is propitious to good combustion (Sidibe et al., 2010). Generally, saturated oils offer better combustion (short evaporation time, short ignition delay, fewer deposits) than unsaturated oils. Overall, quality of combustion decreases with increase in degree of unsaturation.

Using straight vegetable oils in diesel engines is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine as far back as 1910 (Balat and Balat, 2008) Literature suggests that vegetable oils can substitute for mineral diesel if reduction in viscosity is achieved by blending it with diesel or by preheating. De Almeida et al (2002) used heated palm oil as fuel in a diesel generator. The study revealed that carbon monoxide (CO) emissions increased at higher loads. This was due to lack of oxygen at higher equivalence ratios. Palm oil nitrogen oxide (NO_x) emissions were however relatively lower than mineral diesel. Masjuki et al. (2001) used preheated palm oil to run a CI engine. Better spray and atomization characteristics were obtained due to reduction in the viscosity of fuel due to the preheating processes. Torque, brake-power, specific fuel consumption, exhausts emissions and brake thermal efficiency were reported to be comparable to those of mineral diesel Wang et al. (2006) also performed experiment on blended vegetable oil with diesel. The authors reported higher exhaust gas temperature with very small variations in CO emission levels and relatively low NO_x as compared to diesel.

This work evaluated chemical properties and engine performance of birrea plant oil to assess potential for use as fuel and feedstock for biodiesel production in Botswana. Birrea tree is indigenous to most parts of Southern Africa. In Botswana, for example, it is widely distributed all over the country but concentrated in the north eastern part of the country, approximately 250 km north east of Gaborone, Botswana's capital city. The species then covers a huge part of the Central district and Tshapong Sub district. At maturity, the plant (tree) can grow up to approximately 10m tall with a sterm diameter of approximately 0.8 m and have several branches that bear fruits during the rainy season (October to April). However, because of limited scientific data, the age of the birrea plant (tree) from which plant oil used for this study was extracted is not covered in the present investigation. It is the author's view that some of these plants could be as old as 70 years and above but they still bear fruits. The tree grows in warm and dry climatic conditions, and produce oval fruits that turn pale yellow when ready for harvesting. In Botswana the harvesting period usually starts from December to the end of March. The fruit consists of a hard woody seed covered by pulp and juice which makes the fleshy part of the fruit. The hard seed contains mostly two oil rich nuts (kernel) which can be eaten as a snack. There is now a worldwide trend to explore wild plants for oil to augment the already existing sources of oil. The fact that the birrea tree grows in drier parts where common oil seeds cannot thrive has stirred interest in it as a valuable source of biodiesel feedstock. This has led to the evaluation of birrea nut oil as potential feedstock oil for biodiesel production. In evaluating the potential use of oil for this purpose, the fatty acid profile plays an important role.

II. Materials and Methods

a) Birrea plant oil

The birrea plant oil used for the current study was purchased from Kgetsi Ya Tsie, a Community Trust located in the eastern part of the country approximately 300 km east of Gaborone City. The primary objective of the trust is to promote the economic and social empowerment of rural women in the Tswapong Hills of Eastern part of Botswana, who extracts birrea plant oil mostly for cosmetic markets in Europe and America. Prior to the plant oil extraction processes, individuals members of the trust harvest yellow birrea fruits and manually remove the outer skin of the fruit. The hard woody seed is then dried under natural conditions for 6 to 8 weeks. The primary objective of drying the hard woody seed is to ensure that minimum force is applied on cracking the hard woody nut cover and to minimise damage of the oil rich nut. When the drying process is considered to be complete, the hard woody seeds are stored in a dry place followed by the cracking process. The cracking process is also done manually by individual members of the trust group. After cracking, the nuts are collected to a central oil pressing centre for oil extraction process.

In the present investigations birrea oil nuts from the Lerala village and communities within the out skirt of Lerala village approximately 300 km east of the Gaborone City was used to extract oil. The extracted oil was then bottled into a glass container, placed in a cooler box with ice gel and transported to the laboratory for chemical analysis as described in section 2.2.

b) Oil characterization

The composition of birrea plant oil was analysed using the Waters GCT premier Time of Flight (TOF) mass spectrometer (MS) coupled to the Agilent 6890N gas chromatograph (GC) system. The instrument has high sensitivity and fast acquisition rates. In addition, the National Institute for Standards and Technology (NIST) developed Automated Mass Spectral Deconvolution and Identification System

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(AMDIS) software package, (chemdata.nist.gov/mass-spc/amdis) was used for peak identification. AMDIS extracts spectra for individual components in a GC-MS data file and identifies target compounds by matching these spectra against a reference library, in this case the NIST library. AMDIS also allows creation of personal libraries where routine analyses of compounds is encountered.

i. *Gas Chromatograph Conditions*

1 μL of birrea plant oil sample extract was injected into the system using an auto-injector. The injector temperature was set at 260^0C in the splitless mode. Helium was used as the carrier gas at a flow rate of 1ml/min. Separation was achieved using a 30 meter DB5 – MS column. The oven temperature was kept at the initial 100^0C for 2 minutes, and then gradually increased from 100^0C to 290^0C at a rate of 10^0C per minute. The total run time was approximately 35 minutes.

ii. *Mass Spectrometer Conditions*

The mass spectrometer (MS) conditions that were employed were a positive polarity of electron ionization (EI), a source temperature of 180^0C, an emission current of 359μA. Other MS conditions including electron energy, resolution were set by the system auto tune function. Detection was by the micro channel plate detector (MCP) whose voltage was set at 2700 V. The oil composition was identified and quantified using the NIST (2005) mass spectral library using a combination of the Masslynx acquisition /data analysis software and the AMDIS by NIST.

c) *Engine performance analysis*

The engine performance test was conducted on a TD43F engine test rig. The test rig is water cooled, four-stroke diesel engine that is directly coupled to an electrical dynamometer. In addition to the conventional engine design, the engine incorporates variable compression design feature which allows the compression ratio to be varied from 5:1 to 18:1.

To establish that engine operating conditions were reproduced consistently as any deviation could exert an overriding influence on performance and emissions results, the reproducibility of the dynamometer speed control set points were maintained within ± 0.067 Hz of the desired engine speed. The experimental work began with engine run on pure diesel fuel. This was done to determine the engine's operating parameters which constitute the baseline that was compared with the subsequent case when the birrea plant oil was used as fuel. At the point of fuel change, the fuel lines were cleaned with pure diesel fuel and engine left to operate with the fuel under test for approximately 15 minutes to stabilise at its new condition before readings were recorded.

III. Results and Discussions

a) *Birrea plant oil characterization*

Five birrea plant oil samples were tested to establish the chemical composition present. This was done by injecting oil sample into the GC-MS system in quantities and procedure specified in Section 2.2 in a systematic study. A reference sample prepared by AccuStandards was used to calibrate the equipment. The Fatty Acids detected from the five birrea oil samples were largely similar. For simplicity, average concentration levels of fatty acids detected are presented in table 2. Table 2 also shows a number of fatty acids recorded in birrea plant oil which were not present in the reference sample.

The Fatty Acid profile of birrea plant oil indicates a range of fatty acids and esters, the majority of which were not found in the reference sample. The observation may be attributed to the uniqueness of this indigenous and unknown plant oil. Olein 2-mono and Olein 1-mono fatty acids were identified as geometrical isomers of the same compound. Oleic acid, 3-hydroxypropyl ester is very unique in that it is not found on the NIST library and has generated a lot of interest to the authors for further research work. The fatty acid that was detected to be most abundant is Trans-Oleic acid but could not be quantified because of its absence from the reference sample. The second highest peak detected is for Ethyl oleate (ethyl ester). Other compounds had substantial presence which could improve if concentrated through processing. The composition of birrea oil recorded in this analysis is largely consistent with results obtained by other researchers (Burger et al., 1987). As discussed in Section 1, the fatty acid parameters that have the greatest impact on fuel properties are the average chain length and the degree of unsaturation. To a large extend, fuel properties improve in quality with increase in carbon chain length and decrease as the number of double bonds increase, except cold flow properties. According to Knothe (2005), the optimal fatty acid profile that provides optimal fuel properties with relatively less adverse impact on the environmental is a mixture consisting of methyl oleates, esters derived from palmitic, oleic, and decanoic acids. The fatty acid mixture of birrea plant oil presented in table 2 is largely composed of these desirable compounds, depicting characteristics of a good fuel. This stimulated the need to perform thermal performance of birrea plant oil as fuel on a variable compression ignition engine. The performance results are presented and discussed in Section 3.2.

b) *Engine performance analysis*

Prior to using birrea plant oil as fuel in the compression ignition engine, the oil was neutralised using sodium hydroxide in order to minimize the possible effects of corrosion on engine parts. The oil was also filtered to eliminate possible presence of suspended matter that could form carbon deposits in

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the engine during combustion. The birrea plant oil was then used to power a variable compression ignition engine to test the engine performance of the fuel. Engine performance tests were conducted for compression ratios 13:1 through 17:1. To enable the main findings of the study to be identified clearly, only performance results for compression ratio 16:1 are presented in Section 3.2.1. The results were compared with the results for pure diesel fuel of boiling point 422 K, vapor pressure of 53 Pa, density of 860 Kg m^{-3} and cetane number of 48. The comparison was done on the basis of engine torque, engine brake power, and specific fuel consumption as mentioned earlier. The experimental data were collected as discussed in section 2.3, leading to the results presented in figure 1.

i. *Engine Performance Results*

Typical results for the variation of the engine torque, brake power and specific fuel consumption for birrea plant oil and pure diesel fuel for different engine load settings are shown in Figure 1.

There are several clear findings to be drawn from the data presented in figure 1(a) to (c). Firstly, the results indicate that the engine torque, brake power, and specific fuel consumption recorded for D100 and BPO for operation condition (compression ratio 16:1) compares favourably well. The data in figure 1(a) shows a steady increase in engine torque for both D100 and BPO with increase in engine load between 30 and 60%. However within the same operating window, BPO recoded relatively high engine torque compared with D100. However, it is clear from the data presented in figure 1(a) that as the engine load increase from 60% the data recorded for D100 shows a steady increase in engine torque while the data for BPO shows a slight decrease with increase in engine load.

The results in figures 1(b) and (c) also demonstrate that the data recorded for BPO compares favourably well with that for D100. The maximum variation in brake power of 0.63W was recorded at 90% engine load, while the minimum variation of 0.06W was recorded at 60% of engine load, with D100 recording 5.06W. The trends shown in figure 1(b) suggests that the optimum compression ignition engine performance using birrea plant oil occurs at 60% engine load. The data shown in figure 1(c) reinforces this observation, which shows the specific fuel consumption recorded for D100 and BPO. One of the most discernible trends connected to figure 1(c) is that the variations in specific fuel consumption recorded for D100 and BPO between 30% and 60% do not show any significant difference for the fuels under review. The minimum variation of specific fuel consumption between 30% and 60% engine load is 0.01g/kWh, while a maximum of 0.17g/kWh was recorded at the engine load of 90%. Overall, the results in figure 1 indicate that birrea plant oil is a potential fuel. The relationship between fatty acid profile and engine performance analysis results of birrea plant oil indicates potential of converting the same plant oil into quality biodiesel.

IV. Conclusions

An experimental study to examine the profile of free fatty acids found in birrea plant oil and compared against those found in the reference sample has been described. The study also carried comparative tests using B100 and D100 to assess the engine performance. From the experimental results, it can now be concluded that.

a) Birrea plant oil has properties that can enable it to function as a biofuel in IC diesel engines. This implies that transesterifying birrea plant oil under standard conditions may produce biodiesel of international biodiesel quality standards.
b) Trans-Oleic acid is the major fatty acid in birrea pant oil and is not found in reference sample prepared by AccuStandard. This suggests that further investigations on the compositionsition of the same fatty acid need to be carried out. The second most abundant free fatty acid detected was Ethyl Oleate which is an ethyl ester. Other free fatty acids detected are Oleic acid, 3-hydroxypropyl ester, Palmitic acid (methyl ester), Palmitic acid (ethyl ester), suggesting that the oil has strong characteristics required for biodiesel feedstock.
c) The results prove that the performance of IC diesel engine using birrea plant oil is close to pure diesel fuel suggesting that such oil is a potential indigenous feedstock for biodiesel production in Botswana.

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Tables

Table 1 : Fatty acid composition for common oils (% by weight)

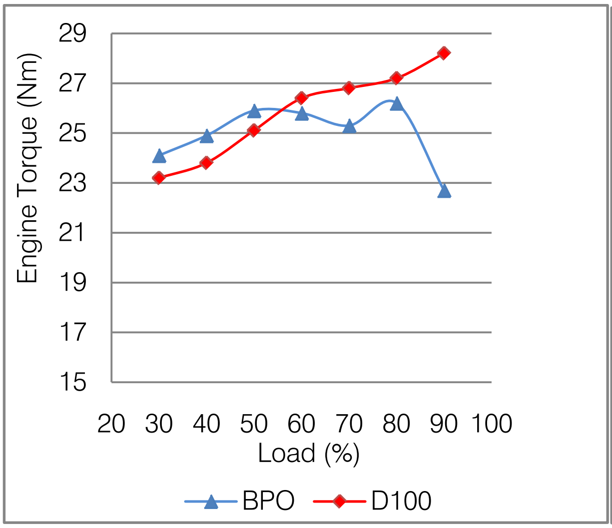
	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid
Number of carbons	16	18	18	18	18
Number of double bonds	0	0	1	2	3
Soybean	8	4	25	55	8
Canola	4	2	60	22	12
Olive oil	10	2	78	10	Trace
Palm oil	44	5	40	10	Trace
Rapeseed oil	3	1	13	14	10
Mustard oil	4	2	24	21	10

Source: Misra, 2010.

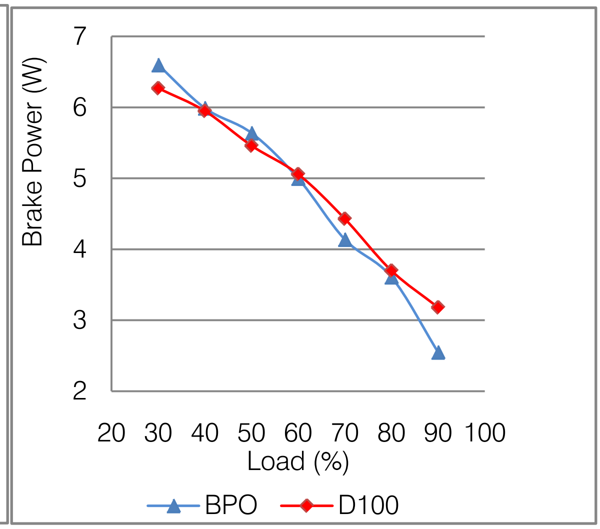
Table 2 : Birrea plant oil fatty acid profile

No.	Fatty acid detected	Status (in standard mixture)	Concentration (mg m^{-3})
1	Palmitic acid	No	-
2	Palmitic acid (ethyl ester)	Yes	115
3	Palmitic acid (methyl ester)	Yes	17.4
4	12-Octadecanoic acid	No	-
5	Trans-Oleic acid	No	-
6	Stearic acid	No	-
7	Ethyl Oleate (Ethyl ester)	Yes	223.5
8	Oleic acid, 3-hydroxypropyl ester	No	-
9	Olein, 2-mono	No	-
10	Olein, 1-mono	No	-

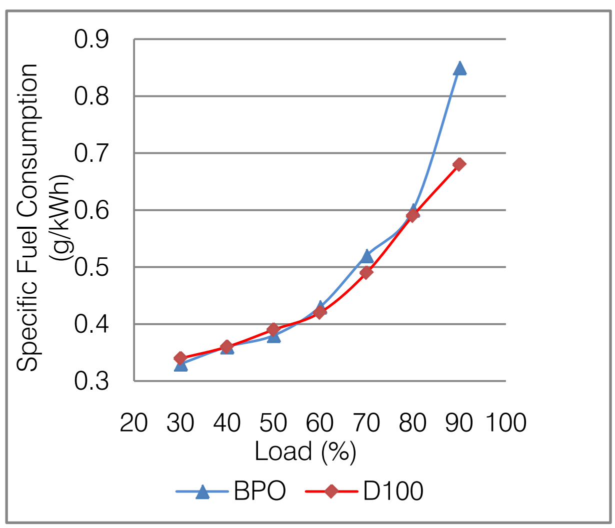
Figures



(a) Engine Torque (Nm)



(b) Brake power (W)



(c) Specific fuel consumption (g/kWh)

Legend: BPO = Birrea plant oil; D100 = 100% Petrodiesel

Figure 1 : Typical engine performance for birrea plant oil and petrodiesel fuel for different engine load settings.

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Recovery of Engine Waste Heat for Reutilization in Air Conditioning System in an Automobile: An Investigation

By Abhilash Pathania, Dalgobind Mahto
Shoolini University, Solan, Himachal Pradesh, India

Abstract - With the rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. In the same time consumers are incapable to bear the increasing operating cost of the vehicles due to continuous raise in fuel prices, component costs and maintenance costs associated with vehicles. More recently, several new philosophies for manufacturing improvement have been developed and implemented in various sectors, be it manufacturing, service or other. Keep in mind in this paper, an exploration has been done to research the possibility of waste heat recovery and its subsequent utilization in air conditioning system of a vehicle without increasing the component cost, weight, number of component and bring improvement in vehicle by making luxurious.

Keywords : Waste Engine Heat, Air Conditioning System, VCRS, VARS.

GJRE-A Classification : FOR Code: 090299, 091502

RECOVERY OF ENGINE WASTE HEAT FOR REUTILIZATION IN AIR CONDITIONING SYSTEM IN AN AUTOMOBILE AN INVESTIGATION

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Recovery of Engine Waste Heat for Reutilization in Air Conditioning System in an Automobile: An Investigation

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Abstract - With the rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. In the same time consumers are incapable to bear the increasing operating cost of the vehicles due to continuous raise in fuel prices, component costs and maintenance costs associated with vehicles. More recently, several new philosophies for manufacturing improvement have been developed and implemented in various sectors, be it manufacturing, service or other. Keep in mind in this paper, an exploration has been done to research the possibility of waste heat recovery and its subsequent utilization in air conditioning system of a vehicle without increasing the component cost, weight, number of component and bring improvement in vehicle by making luxurious.
Keywords : Waste Engine Heat, Air Conditioning System, VCRS, VARS.

I. Introduction

Industries are vying for various tools and techniques for competitive advantage over the competitors in an ever-changing global market by combining factors like quality, cost, flexibility, responsiveness, and innovation. In today's global market, there is constantly increasing pressure to make products more quickly, with more variety, at the lowest possible cost. In the end, those companies that meet and exceed customers' demands will succeed by remaining competitive. Then, the question is, how do companies become competitive and retain their competitiveness? This question may not be easy to answer because manufacturing systems are complex, and simple solutions to manufacturing problems may not exist. Therefore, companies must choose from available techniques to develop their own solutions in the existing products to attract the customers in their fold without adding extra cost.

With the rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. Air conditioning of a vehicle can be done by Vapour Compression Refrigeration System (hereinafter VCRS) and Vapour Absorption Refrigeration System (hereinafter VARS). Presently, in the vehicles VCRS is in use in most of the cases. In lieu of VCRS, if, VARS is used in vehicles the refrigeration system could be operable in a vehicle without adding running cost for air conditioning.

There is a great impact on the running cost of a vehicle due to increasing cost of fuel. The A/C system adds nearly 35 % extra cost in fuel expenses. Alternately, it is a matter of investigation that waste recovery of an engine for application in A/C can reduce the fuel economy of vehicles to what maximum extent? It has been revealed that there is great potential to reduce A/C fuel consumption because A/C systems have traditionally been designed to maximize capacity, not efficiency. From the reviews of various literatures there is an indication that reducing the A/C load decreases A/C fuel consumption. In the same line, an automobile engine utilizes only about 35% of available energy and rests are lost to cooling and exhaust system. If one is adding conventional air conditioning system to automobile, it further utilizes about 5% of the total energy. Therefore automobile becomes costlier, uneconomical and less efficient. Additional of conventional air conditioner in car also decreases the life of engine and increases the fuel consumption. For very small cars compressor needs 3 to 4 bhp, a significant ratio of the power output. Keeping these problems in mind, a car air conditioning system is proposed from recovery of engine waste heat using radiator water as source / generator for VARS.

a) Vapour Compression Refrigeration System

Heat flows naturally from a hot to a colder body. But, in refrigeration system there is opposite phenomena i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant. The refrigerant absorbs heat and hence evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. Thus, heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

The refrigeration cycle can be broken down into the following stages (ref. Figure 1):

- 1 – 2, Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings,

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usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

- **2 – 3,** The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.
- **3 – 4,** The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3 - 3a) de super heats the gas before it is then turned back into liquid (3a - 3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4); so that the refrigerant liquid is sub-cooled as it enters the expansion device.
- **4 – 1** The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

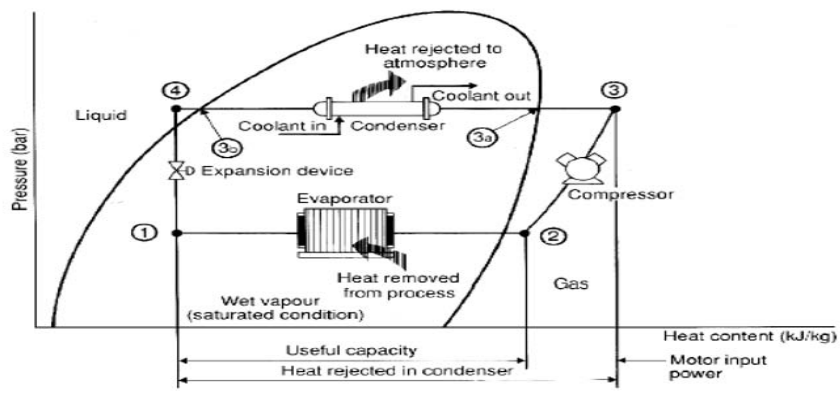

Fig. 1 : Schematic diagram of a Basic Vapour Compression Refrigeration System

It can be observed that the condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor; i.e. (1 – 2) + (2 – 3) has to be the same as (3 – 4). There is no heat loss or gain through the expansion device. The existing refrigeration system in a vehicle is shown diagrammatically in figure 2

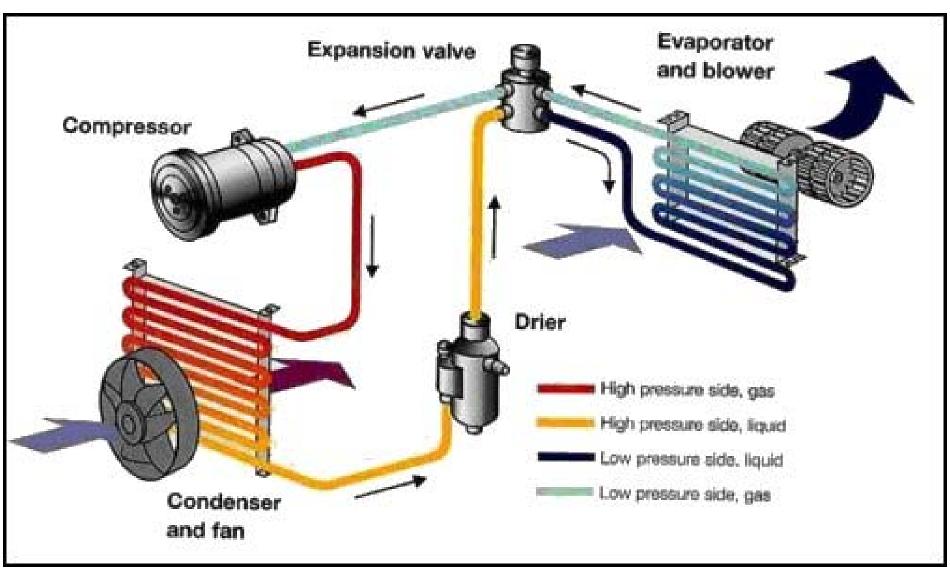

Fig. 2 : Existing Refregiration system in automobiles

b) Absorption Cooling Systems; a brief

Absorption is the process of attracting and holding moisture by substances called desiccants. Desiccants are sorbents, i.e., materials that have an ability to attract and hold other gases or liquids, which have a particular affinity for water. During absorption the desiccant undergoes a chemical change as it takes on moisture, as for example the table salt, which changes from a solid to a liquid as it absorbs moisture. The characteristic of the binding of desiccants to moisture makes the desiccants very useful in chemical separation processes.

Ammonia-water combination possesses most of the desirable qualities which are listed below:

- $1m^3$ of water absorbs $800m^3$ of ammonia (NH_3).
- Latent heat of ammonia at-15ºC = 1314 kJ/kg.
- Critical temperature of NH_3 = 132.6ºC.
- Boiling point at atmospheric pressure = -33.3ºC

The NH_3-H_2O system requires generator temperatures in the range of 125°C to 170°C with air-cooled absorber and condenser and 80°C to 120°C when water-cooling is used. These temperatures cannot be obtained with flat-plate collectors. The coefficient of performance (COP), which is defined as the ratio of the cooling effect to the heat input, is between 0.6 to 0.7. Ammonia is highly soluble in water and this ensures low solution circulation rates. Both constituents are obtainable at minimal cost. The choice of Ammonia-water combination is not made without considering certain disadvantages: ammonia attacks copper and its alloys when it has been hydrated. Therefore, all components are made from mild steel or stainless steel.

c) Engine Cooling System

The cooling system on liquid-cooled cars circulates a fluid through pipes and passageways in the engine. Temperatures in the combustion chamber of the engine can reach 4,500 F (2,500 C), so cooling the area around the cylinders is critical. As this liquid passes through the hot engine it absorbs heat, cooling the engine. After the fluid leaves the engine, it passes through a heat exchanger, or radiator, which transfers the heat from the fluid to the air blowing through the exchanger. The engine in your car runs best at a fairly high temperature. When the engine is cold, components wear out faster, and the engine is less efficient and emits more pollution. So another important job of the cooling system is to allow the engine to heat up as quickly as possible, and then to keep the engine at a constant temperature. To handle this heat load, it may be necessary for the cooling system in some engines to circulate 4,000 to 10,000 gallons of coolant per hour. The water passages, the size of the pump and radiator, and other details are designed as to maintain the working parts of the engine at the most efficient temperature within the limitation imposed by the coolant. The fluid that most cars use is a mixture of water and ethylene glycol ($C_2H_6O_2$), also known as antifreeze. By adding ethylene glycol to water, the boiling and freezing points are improved significantly. The finding of the condition of coolant and temperature is shown the table 1.

Table 1 : Condition of coolant and temperature

Condition of Coolant	Pure Water	**50/50, $C_2H_6O_2$** / Water	**70/30, $C_2H_6O_2$** / Water
Freezing Point	0 C / 32 F	-37 C / -35 F	-55 C / -67 F
Boiling Point	100 C / 212 F	106 C / 223 F	113 C / 235 F

Normally water boils at 212°F. However, for every pound of pressure increase, the boiling point increases by 3°F. The temperature of the coolant can sometimes reach 250 to 275ºF (121 to 135ºC). Even with ethylene glycol added, these temperatures would boil the coolant, so something additional must be done to raise its boiling point. Typical radiator cap pressure is 12 to 16 psi. This raises the boiling point of the engine coolant to about 250°F to 260°F. Many surfaces inside the water jackets can be above 212°F.

d) Comparison between Vapour Compression and Absorption system

A comparative study has been conducted between Vapour Compression and Absorption system. The salient findings are enumerated below in table 2

Table 2 : Comparison between Vapour Compression and Absorption system

S.No.	Absorption System	Compression System
1	Uses low grade energy like heat. Therefore, may be worked on exhaust systems from I.C engines, etc.	Using high-grade energy like mechanical work.
2	Moving parts are only in the pump, which is a small element of the system. Hence operation is smooth.	Moving parts are in the compressor. Therefore, more wear, tear and noise.
3	The system can work on lower evaporator pressures also without affecting the COP.	The COP decreases considerably with decrease in evaporator pressure.
4	No effect of reducing the load on performance	Performance is adversely affected at partial loads.
5	Liquid traces of refrigerant present in piping at the exit of evaporator	Liquid traces in suction line may damage the compressor
6	Automatic operation for controlling the capacity is easy.	It is difficult.

II. Objectives of the Study

The objectives of the study on the subject "Recovery of engine waste heat for reutilization in air conditioning system in an automobile: An investigation" are as follows

1. Identify the form of "muda" (waste) in traditional VCRS.
2. Compare the key characteristics of traditional VCRS and proposed VARS
3. Differentiate between existing refrigeration cost and proposed target cost
4. Identify data and tools useful for planning and assessing strategies for leadership in refrigeration quality in vehicle by use of SWOT analysis.

III. Scope of the Work

Our scope of work is confined and limited to the study of VARS in lieu of VCRS through recovery of engine waste heat using radiator water as source / generator for VARS. The arrangement of various components of air conditioning system is also a challenge because of the fix size of cars. However, the dsigning aspects will be given due consideration after intial exeperimentation. In the proposed model condenser and evaporator will be arranged same as the conventional unit.

IV. Review of Literatures

There are various works available on the Adsorption cooling with exhaust gas heat of engine. But, no significant wok has been carried out by recovering and utilizing Engine heat in refrigeration system of a vehicle.

According to Palm [1], Corberan et al.[2], Domanski and Yashar,[3]) ,most HFC refrigerants have a relatively high global warming potential (GWP) which is also being regulated by the Kyoto Protocol. They have cited that recent passage of legislation in the European Community requires the use of refrigerants with GWPs of less than 150 in all new-type vehicles starting in 2011 and in all new vehicles by 2017

Recently, Sami et al. [4] presented an improved dynamic model to study the single absorber and/or double absorber systems with heat recovery. The systems they studied employed an air cooled evaporator and an air cooled condenser. Hot oil, superheated steam or exhaust gas could be used as heating fluids for the absorbers. In these respects, they are similar to the automobile waste heat cooling system we propose. And it gave an insight into the thermodynamics for some of the system components. However, in their analysis, the cycle time was quite long and an equilibrium adsorption state was assumed.

Colbourne [5] summarized a study analyzing over 50 published technical documents comparing the performance of fluorinated refrigerants and HCs. A significantly higher number of tests showed an increase in performance when using HCs as compared to using fluorinated refrigerants (Colbourne and Suen,)[6].Similarly, Colbourne and Ritter[7] investigated the compatibility of non-metallic materials with HC refrigerant and lubricant mixtures. They performed experiments in compliance with European standards for the testing of elastomeric materials and ASHRAE material compatibility test standards.

Maclaine-Cross and Leonardi[8] compared the refrigerant performance of HCs based on refrigerant properties and concluded that the COP improvements, commonly reported in literature, were consistent with better thermodynamic properties of HCs. R600a properties and their influences on system performance were discussed. Joudi et al. [9] studied the performance of MAC systems with alternative refrigerants. A computer model was developed to determine the most suitable alternative refrigerant to R12. The influence of evaporating temperature, condensing temperature and compressor speed in an ideal cycle was considered.

Ghodbane [10] investigated the use of R152a and HCs in MACs. Based on thermo physical data. He has proposed a quantitative analysis of MACs with flammable refrigerants. Razmovski [11] and Rajasekariah [12] experimentally evaluated possible ignition sources in a car by connecting a welding torch to a HC refrigerant cylinder.

The basic adsorption cycle [13-15] has a theoretical coefficient of performance of about 0.5. Meunier [16] showed that the performance of an ideal regenerative cycle with an infinite number of cascades can be as high as 1.85, about 68% of the ideal Carnot COP. These researches are very significant in improving the market competitiveness of commercial adsorption cooling/heating machines.

Zhu et al. [17] measured the cooling capacity of a cooling element of a fishing boat diesel engine waste heat chiller and the temperature variation of the adsorbent bed. Their study was purely experimental and no numerical analysis was presented. Suzuki [18] theoretically studied the effects of UA (overall heat transfer coefficient) on SCP of a passenger car waste heat adsorption air conditioning system; however, no details were outlined with respect to the effects of other parameters which play equal important roles in adsorption refrigeration. However, in the case of automobile waste heat cooling, mechanical simplicity and high reliability will prevail on efficiency. And the waste heat recovery cannot affect the mechanical energy output from the engine. So a two-bed basic zeolite-water adsorption cycle is considered in this study. The feasibility of adsorption cooling for automobile/engine waste heat recovery was studied before [17, 18]. However, information on its dynamic performance, which is necessary for the design and optimization of the system, is insufficient.

The SL refrigeration systems are frequently used in industrial refrigeration and commercial comfort cooling and are also known as ‘‘Liquid-Chilling Systems’’ (ASHRAE) [19]. As with all the reviewed refrigerants, the environmental properties are far superior to that of R134a. R600a is in the safety classification A3 by the ASHRAE Standard 34[20], meaning that it is highly flammable and has a lower flammability limit (LFL) of 1.7 vol. %, which makes it the easiest to ignite among the reviewed refrigerants. The minimum ignition energy (MIE) needed is 0.25 mJ. The acute toxicity exposure limit (ATEL), a measure of the toxicity of a refrigerant, is 25,000 ppm and therewith the lowest of the reviewed refrigerants. The acute toxicity exposure limit (ATEL) is a value used by ASHRAE Standard 34[20] and ISO 817[21] to establish the maximum refrigerant concentration limit for a refrigerant in air.

Granryd [22] and Corberan et al. [2] summarized the environmental safety considerations and standards applied for the safe use of flammable refrigerants. Both ASHRAE Standard 34[20] and European standard prEN378 [23] classify refrigerants in three classes 1–3, where Class 1 is used for non-flammable fluids and Class 3 for highly flammable fluids. The group of Class 3 refrigerants, which includes the HCs, is limited in use for industrial applications in the USA and France. Several standards allow the use of HCs without restrictions, if the charge amount is less than 0.15 kg in hermetically sealed and safely designed systems. As a result, the use of HCs in household refrigerators, freezers and small heat pumps has increased in European countries. Furthermore, Granryd [22] compared the performance of HCs, such as R600a and R290 and their mixtures to the well Colbourne [5] summarized a study analyzing over 50 published technical documents comparing the performance of fluorinated refrigerants and HCs. A significantly higher number of tests showed an increase in performance when using HCs as compared to using fluorinated refrigerants (Colbourne and Suen)[6].

The average improvements from using HCs were 6.0% for domestic refrigeration applications, 15.0% for commercial refrigeration applications, 8.8% for air conditioning and 9.6% for heat pumping Colbourne and Ritter[7] investigated the compatibility of non-metallic materials with HC refrigerant and lubricant mixtures. Experiments were performed in compliance with European standards for the testing of elastomeric materials and ASHRAE material compatibility test standards. Test results were presented for swell rates, hardness rating, mass changes and the change of tensile strength. In a study about HC refrigerant leakages in car passenger compartments, Maclaine-Cross [8] referred to the report made by European company (Arthur D. Little Ltd), who noted that serious injury to occupants through use of flammable refrigerant would only be possible if the car crashed, due to overpressure in the compartment after a fatigue damage of the liquid line.

Ritter and Colbourne further [7] published a review on HC risk assessment from 1991 to 1998. The use of background risks as a basis for comparison of the risk of fire with HC was presented. A report from Dieckmann et al [24] for the U.S. Department of Energy was reviewed, which assessed the risk of using flammable refrigerants in MACs. Field data from car crashes and car fires was used as basis for the analysis. A similar risk assessment, performed by Elbers and Verwoerd [25], considered an R290 heat pump system used for residential heating. To provide a context for these safety estimates, Ritter and Colbourne [7] presented estimations of so-called background Risks

Jetter et al. [26] used a fault tree analysis to estimate the number of refrigerant exposures of automotive service technicians and vehicle occupants in the USA. A quantitative risk assessment model was developed by Colbourne and Suen [27] to examine the influence of design, installation of equipment and external conditions on the frequency of ignition and the associated consequences for indoor refrigeration and air-conditioning units using HC refrigerants. Safety testing of domestic refrigerators was conducted by Gigiel [28] based on the current international standard EN/ IEC 60335-2-24 (2001).

The single-phase secondary refrigerant can be divided into two categories, aqueous and non-aqueous solution (Ure, [29] Ubaldo [30]).

Melinder [31] reported the performance of aqueous secondary fluids and non-aqueous secondary fluids for indirect systems. Compared to all the water solutions, the non-aqueous fluids such as diethylbenzene mixtures, hydrocarbon mixtures, hydrofluoroether, polydimethylsiloxan require a much larger volume flow rate under the same refrigeration capacity and temperature change. Ure [29, 32] ascertained several requirements that any secondary refrigerants must satisfy:

- low viscosity
- high specific heat
- good thermal conductivity
- good chemical corrosion inhibiting
- chemically stable, no separation or degrading
- non-toxic
- non-flammable
- food grade for food refrigeration

Numerous authors presented experimental and simulation results on fundamental research of ice slurries in terms of ice particle shape and growth behaviour (Kauffeld et al., [33]; Okawa et al.,[34]; Sari et al., [35]), physical properties (Hansen et al.,[36]; Inaba, [37]; Meewisse and Ferreira,[38] and fluid dynamics (Ayel et al.,[39]; Jensen et al., [40]; Kitanovski and Poredos, [41]). Kauffeld et al. [42] published a handbook of ice slurries in 2005 as well. The main disadvantage of CO_2 appeared to be the relatively low critical temperature and the availability of components (Hinde et al.)[43]. A few applications, which utilize CO_2 as a volatile secondary refrigerant, have been implemented in low-temperature application (Melinder, [44]; Pachai, [45]; Pearson, [46]).

Palm [1] reported that HC producers listed the compressor manufactures whose compressors are compatible for HCs. Janssen and Beks[40] evaluated hermetic compressor performances when changing from R12 to a HC mixture of R600a and R290.Corberan et al.[5] investigated the performance of a positive displacement hermetic refrigerant piston compressor working with R290 as refrigerant. Cooling capacity of R22 compressor that was switched to R290 was lowered to an amount ranging from 13 to 19%. On the other hand, the COP of the system increased from 2 to 6%. Devotta and Sawant [47] carried out the life cycle test of the hermetic compressor with R12, R134a, R410A and various HCs. They found that the HC mixture was more compatible with the hermetic compressor materials than R12 and R134a, even under the retrofit conditions. Pellec et al. [48] tested two types of heat exchangers working with ammonia and silicone heat transfer fluid as the secondary refrigerant [49-52]. Setaro et al. [53] tested and compared the heat transfer and pressure drop through a brazed plate heat exchanger and a tube-and-fin coil for two different refrigerants, R22 and R290 in an air-to water heat pump system.

Hrnjak and Hoehne [54] reported that the air-to-R290 mini channel heat exchanger developed for a 2 kW cooling capacity refrigeration system needed less than 0.13 kg of R290 due to its smaller internal volume than that of traditional fin-and-tube heat exchanger. Hrnjak and Litch [55] also presented the experimental results of mini channel heat exchanger utilized as an air-cooled condenser in a prototype ammonia chiller.

Fernando et al. [56] studied liquid-to-refrigerant heat exchangers using flat multiport with 1.4mm hydraulic diameter tubes and showed a lower charge compared to plate heat exchangers. Fernando et al. [57-59] also carried out comprehensive tests on performance of mini channel aluminium tube heat exchangers working as evaporator and condenser.

Walker [60] shows the typical layout of the SL system in a supermarket refrigeration application. The primary loop is composed of the parallel compressors

- air-cooled condenser
- expansion device
- evaporator
- secondary refrigerant pump
- Secondary refrigerant coil.

Kruse [61] compared the energy consumption of DX system and an indirect refrigeration system with a secondary fluid loop. Kauffeld [62] reviewed the trends and perspectives in supermarket refrigeration and compared an indirect, distributed cascade and two-stage refrigeration systems theoretically.

Delventura et al. [63] took an evaluation of the SL supermarket refrigeration system and compared it with the traditional DX refrigeration system. Kazachki and Hinde [64] compared the SL system with the traditional centralized DX system for the supermarket. Evenmo [65] cited a supermarket in the United Kingdom using R407C as the primary refrigerant and a commercial fluid as the secondary fluid, since first used in February 1997.Horton et al. [66] tested a drop-in SL refrigeration system for medium temperature supermarket applications. Arias and Lundqvist [67] reported field test results of advanced systems in three supermarkets (floor area ranging from 720 to $2700m^2$). Minea [68,69] reported a supermarket refrigeration system with SLs installed near Montreal, Canada.

Faramarzi and Walker [70] installed and tested the performance of the SL refrigeration system in U.S. supermarkets. Nyvad and Lund [71, 72] reported that a supermarket in Denmark replaced its existing (H) CFC-plant with a new indirect SL system. Rolfsman [73] also reported that a supermarket in Sweden had been converted to a SL system. NH_3 was used as the primary refrigerant and CO_2 was used as the secondary refrigerant for freezing. Thomas [74] cited the supermarket in the United Kingdom that installed a SL refrigeration system. In this system, NH_3 was used as the primary refrigerant and propylene glycol as the secondary refrigerant.

Rivers [75] reported for a SL refrigeration system designed for a supermarket in Greenwich, England. The HC was chosen as the primary refrigerant. Baxter [76] reported a case study for a small Danish supermarket where the old refrigeration plant has been replaced with a cascade plant. Pearson [77] submitted patents on the use of CO_2 as a volatile secondary refrigerant, including a novel hot gas defrost system. Pearson [46] used CO_2 as a volatile secondary refrigerant in supermarket systems for the Swedish market. Christensen [78] investigated the SL system using CO_2 as primary and secondary refrigerant in supermarket applications. Tests and measurements have been carried out and compared with the original cabinet.

Pachai [45] reported a SL system installed in Helsingborg, Sweden. The primary refrigerant was HC, a mixture of R290/ R170, and the low- and intermediate-temperature side secondary refrigerants were CO_2 and propylene glycol, respectively. Nilsson et al.[79] reported an ice rink refrigeration system with CO_2 as the secondary fluid. Hinde et al. [43] reported that at least nine low-temperature CO_2 systems were operational in the U.S. and Canada in early 2008. Kaga et al. [80] developed a compact variable capacity refrigerating system with an inverter compressor using R600a as the primary refrigerant and CO_2 as the secondary refrigerant, which is circulated by ''thermosiphon'' effect.

Wang and Goldstein [81] installed the district heating and cooling system with ice slurry generation system in Osaka, Japan. The total energy consumption was reduced by 19%. Wang et al.[82] installed a SL ice slurry system using ethylene glycol/water binary solution in the Ritz Carlton Plaza in Japan. Christensen and Kauffeld [83] described the application of ice slurry as the secondary refrigerant in a SL with ice slurry accumulation tank.

Meewisse and Ferreira [38] compared two freezing point depressants, sodium chloride and ethanol. Soe et al. [84] studied two milk-cooling systems utilizing R290 as the primary refrigerant that were installed in Demark. Ballot-Miguet et al. [85] tested and compared the energy efficiency of the R22 DX system, single-phase secondary refrigerant system, SL system using ice slurry and two-phase CO_2 as the secondary refrigerant. Fukusako et al. [86] reviewed studies related to the cold thermal storage systems and components using ice slurry and recent research activities on ice slurry in Japan. Saito [87] reviewed the recent research on cold thermal energy storage including the SL ice slurry system.

Choi et al. [88] evaluated the performance of R22, R290, R290/600a (70/30%), and R32/152a (50/50%) used in a water-to water residential heat pump for space cooling and heating. Chang et al. [89] reported the performance and heat transfer characteristics of a heat pump system filled with HC refrigerant (R290, R600a, R1270 and binary mixture of R290/R600a and R290/R600). The secondary fluid was ethyl alcohol. Pelletier and Palm [90] tested a domestic heat pump using R290 as compared to the R22 baseline system. For R290, the heating capacity was 7–10% lower, while the heating COP was 4–5% higher than R22. Payne et al. [91] investigated and compared the performance of R22, R290 and zeotropic mixtures of R32/R290 and R32/152a. The SL fluid was 70/30% mixture of water and ethylene glycol. Stene [92] investigated the performance of a residential brine-to-water CO_2 heat pump for combined low-temperature space heating and hot water heating. Yanagisawa et al. [93] investigated a SL refrigeration system, using a vapour compression NH_3 cycle as the primary loop and a CO_2 thermo siphon loop almost all of currently manufactured air-conditioning systems for automobile and light duty truck vehicle use R134a as the refrigerant.

Natural refrigerants, such as HCs, present a potential alternative option to R134a due to their good thermodynamic and transport properties, heat transfer characteristics, material compatibility, low cost, low toxicity and low GWP (Domanski and Yashar,[3]; Fernando et al.,[56]; Mani and Selladurai,[94];Palm, [1]). Ghodbane [10] investigated the potential of R152a and HC refrigerants as alternative refrigerants to R134a, and a comparative assessment of a SL when applied to MACs. Dentis et al. [95] compared the SL system with R152a and HC refrigerants and the R134a system in a test bench, and demonstrated that the performance of SL system was similar to, and in some cases exceeded the performance of the R134a system. Ghodbane [96] also compared the performance of SL system to conventional R134a system used in a small size passage car under the same test conditions.

According to Srikhirin et al. [97] the absorption refrigeration system went through ups and downs, being the antecessor of the vapor compression refrigeration system in the 19th century. Systems operating on lithium bromide–water were commercialized in the 1940's and 1950's as water chillers for large buildings air conditioning (Costa[14]; Perez-Blanco [98]). Substitution of petroleum-based combustion fuels in the 1970's affected the application of absorption refrigeration, but, at the same time, new opportunities arose, such as usage of solar energy to operate this system (Costa [14]; Zhai et al. [99,100]). Increasing energy costs and other factors has contributed to frequent use of low temperature energy waste from chemical and commercial (supermarket) industries to operate absorption refrigeration systems (Horuz and Callander [101]; Varani [102]; Maidment et al. [103]).

Among the most applied working fluids are the pair ammonia refrigerant– water absorbent (NH_3–H_2O) and water refrigerant–lithium bromide absorbent (H_2O–LiBr). A limitation of the pair water–lithium bromide is the difficulty to operate at temperatures lower than 0°C. Besides, lithium bromide crystallizes at moderate concentration, and, at high concentration, the solution is corrosive to some metals and is of high cost (Horuz [104]; Srikhirin et al. [97]). The system water–lithium bromide operates below atmospheric pressure, resulting in system air infiltration, which requires periodical purge.

On the other hand, operation above atmospheric pressure is a considerable advantage. Though ammonia–water systems were previously applied to refrigeration and ice production, recent applications are predominantly on air conditioning, for which the pair water–lithium bromide can also be employed (Chuaa et al. [105]; Costa [14]; Lazarrin et al. [106]). Wu and Schulden [107] presented a modified Carnot cycle for a heat engine using high-temperature waste heat. The authors adopted the power per heat exchanger surface unit area for performance analysis of the heat engine. The relation between the maximum obtainable specific power and the temperature range in which the high-temperature waste heat engine operates was found. Koehler et al. [108] designed, built and tested a prototype of an absorption refrigeration system for truck refrigeration using heat from the exhaust gas. The refrigeration cycle was simulated by a computer model and validated by test data.

Zhao et al. [109] studied two combined absorption/compression refrigeration cycles using ammonia and water as the working fluid. The combined cycle with one solution circuit was a conventional absorption chiller with a mechanical compressor, using both the work and heat output from an engine. The combined cycle with two solution circuits was a generalized version of the previous cycle, which condenser and evaporator were replaced by a second absorber and a second generator. The primary energy ratio, defined as the ratio of the design cooling capacity and the total energy input to the engine, increased considerably for the combined cycles compared to a conventional engine driven compression cycle working with pure ammonia. The authors concluded that the combined cycle with two solution circuits was the best option.

Jiangzhou et al. [110] presented an adsorption air conditioning system used in internal combustion engine locomotive driver cabin. The system consists of an absorber and a cold storage evaporator driven by the engine exhaust gas waste heat, and employs zeolite–water as working pair. The mean refrigeration power obtained from the prototype system was 5 kW, and the chilled air temperature was 18°C. The authors described the system as simple in structure, reliable in operation, and convenient to control, meeting the demands for air conditioning of the locomotive driver cabin.

Qin et al. [111] developed an exhaust gas-driven automotive air conditioning working on a new hydride pair. The results showed that cooling power and system coefficient of performance increase while the minimum refrigeration temperature decreases with growth of the heat source temperature. System heat transfer properties still needed to be improved for better performance.

V. Proposed Methodology

The proposed model is based on three fluid vapour absorption systems. It will contain basic components needed for vapour absorption system as shown in Fig. 3.

- The three fluid used in this system will be ammonia, water and hydrogen.
    - The use of water is to absorb ammonia readily.
    - The use of hydrogen gas is to increase the rate of evaporation of the liquid ammonia passing through the system.
- Even though ammonia is toxic, but due to absence of moving part, there will be little chance for the leakage.
- The hot radiator water will be used to heat the ammonia solution in the generator. To remove water from ammonia vapor, a rectifier will be used before condenser. The ammonia vapor is condensed and flows under gravity to the evaporator, where, it meets the hydrogen gas.The hydrogen of gas, which is being feed to the evaporator, permits the liquid ammonia to evaporate at low pressure and temperature.
- During the process of evaporation, the ammonia will absorb the latent heat from refrigerated space and produces cooling effect. The mixture of ammonia vapor and hydrogen will be passed to the absorber where ammonia will be absorbed while hydrogen raises the top and flows back to the evaporator.

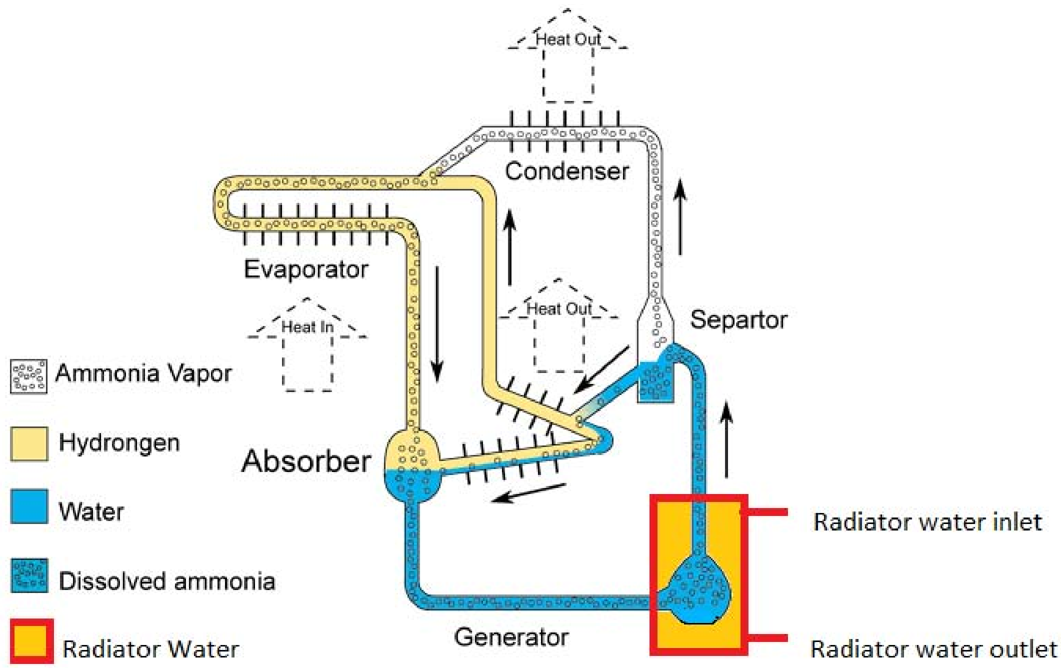

Fig.3 : Schematic of a triple fluid vapours absorption refrigeration system

a) Development of A Mathematical Model

The mathematical model will be developed considering the following elements

- Thermodynamic properties
- Absorption equation
- Conservation of energy
- Absorption process, and
- The coefficient of performance

The relation will be developed through mathematical model that what is the extent of heat generated in the engine and what quantity could be transferred for utilizing at the A/C system by recovery of waste engine heat

VI. Conclusion

The study of waste heat cooling system analyzed in this article will be experimentally investigated and the data will be captured for further analysis. This will be supported by a suitable mathematical model and a simulation tool. The study reveals that it comprises four heat exchanges, namely, an air finned forced convection condenser, an air finned forced convection evaporator, and a pair of shell and tube type absorbers, plus four one-way refrigerant valves, an expansion valve, and an exchange valve. For a refrigerant system the following things are needed

- Specific Cooling Power (SCP)
- Coefficient of Waste Heat Recovery (CWHR)
- Coefficient of Waste Heat Cooling (CWHC)

At present, for an automobile waste heat absorption cooling system, the demand for CWHC can be easily met, but for SCP, further research is needed, which will be studied in part II of this project.

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Study of Compressed Air Storage System as Clean Potential Energy for 21st Century

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Abstract - Worldwide transport sector alone releases billion tonnes of excessive carbon dioxide in the atmosphere through tail pipe emissions thereby causing serious threat to global warming. It is also leading to fast depletion of hydrocarbon fuel. On account of such challenges, continued researches are being carried out to supplement the energy by renewable resources and alternate energy to sustain hydrocarbon fuel. Now a days the major thrusts are being laid upon the utilization of wind energy, hydro-power, tidal and nuclear power generation. Simultaneously efforts are also made towards storage of the energy and appropriate conversion system and its better utilization. This paper focuses on study of some energy storage and energy conversion systems. Special focus is laid on use of compressed atmospheric air as a viable alternative energy source. Such energy storage system can be used as clean energy source as zero pollution sources, and help in mitigating the global warming.

Keywords : zero pollution, compressed air, air turbine, energy conversion, energy storage, injection angle.

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STUDY OF COMPRESSED AIR STORAGE SYSTEM AS CLEAN POTENTIAL ENERGY FOR 21ST CENTURY

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Bharat Raj Singh [α], Onkar Singh [Ω]

Abstract - Worldwide transport sector alone releases billion tonnes of excessive carbon dioxide in the atmosphere through tail pipe emissions thereby causing serious threat to global warming. It is also leading to fast depletion of hydrocarbon fuel. On account of such challenges, continued researches are being carried out to supplement the energy by renewable resources and alternate energy to sustain hydrocarbon fuel. Now a days the major thrusts are being laid upon the utilization of wind energy, hydro-power, tidal and nuclear power generation. Simultaneously efforts are also made towards storage of the energy and appropriate conversion system and its better utilization. This paper focuses on study of some energy storage and energy conversion systems. Special focus is laid on use of compressed atmospheric air as a viable alternative energy source. Such energy storage system can be used as clean energy source as zero pollution sources, and help in mitigating the global warming.

Keywords : zero pollution, compressed air, air turbine, energy conversion, energy storage, injection angle.

Glossary

CAE	compressed air energy
CAES	compressed air energy storage
DER	distributed energy source
EC	electrochemical capacitors
EDL	electric double layer
ESA	energy storage association
ISEP	iowa stored energy park
MDI	metuore development international
PCS	power conversion source
UPS	uninterrupted power supply
PNM	public service Company of New Mexico

Nomenclature

d	diameter of rotor ($2r$) in meter
D	diameter of outer ($2R$) cylinder in meter
E	stored energy
I	moment of inertia of thin rim cylinder
L	length of rotor having vanes in meter
n	no. of vanes=(360/θ)
m	rim cylinder mass
N	no. of revolution per minute
P	pressure in bar
p_1, v_1	pressure and volume respectively at which air strike the Turbine,
p_4, v_4	pressure and volume respectively at which maximum expansion of air takes place,
p_5	pressure at which turbine releases the air to atmosphere.
r_r	radius of rim cylinder
v	volume in cu-m
v_r	linear rim velocity
w	theoretical work output in Nm
w_r	rotational velocity of rim cylinder(rad/sec)
W	theoretical power output (Nm/s)
X_{1i}	variable extended lengths of vane at point1
X_{2i}	variable extended lengths of vane at point 2

Subscripts

1, 2...4, 5	subscripts – indicates the positions of vanes in casing
i or *imp*	impingement
e or *exp*	expansion
t or *total*	total

Greek Symbols

α	angle BOF - see Fig. 5
α_1	angle LOF(=180-ϕ) - see Fig. 5
α_2	angle KOF(=180-θ-ϕ) - see Fig. 5
β	angle BAF – see Fig.5
γ	1.4 for air
θ	angle between 2-vanes(BOH) – see Fig. 5
ϕ	angle at which compressed air enters into rotor through nozzle
ξ_d	eccentricity *(R-r)*

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I. Introduction

Worldwide utilization of hydrocarbon fuel in transport sector, power sector and other industries is causing serious problem of global warming, air pollution, likely depletion of fossil fuel reserves and threat to the survival of mankind. This fact was predicted in 1956, by US based Chief Consultant and Oil Geologist Marion King Hubert [1] who stated that if oil is consumed with high rate, US Oil production may peak in 1970 and thereafter it will decline. It was also predicted that other countries may attain Peak Oil day within 20-30 Years and may suffer with oil crises within 40 years, when Oil wells are going to dry. The projection is illustrated with a bell shaped *Hubert Curve* based on the availability and consumption of the fossil fuel.

In India, vehicular pollution was estimated to have increased eight times over the earlier two decades. This source alone was estimated to contribute about 70 per cent of total air pollution. With 243.3 million tonnes of carbon released from the consumption and combustion of fossil fuels in 1999, India is ranked fifth in the world behind the U.S., China, Russia and Japan. India's contribution to world carbon emissions has increased many folds, due to the rapid pace of urbanization, shift from non-commercial to commercial fuels, increased vehicular usage and continued use of older and more inefficient coal-fired and fuel power-plants.

Billion tonnes of release of carbon dioxide and other pollutants, and their implications upon the environment and ecology are compelling force to search for an environment friendly alternative to oil [2-9]. Such an alternative should ideally have a zero or near zero pollution level, low initial cost and running expenses, high degree of reliability, convenience and its versatility of utilizations. The use of compressed air for running prime mover like air turbines / engines offers a potential solution to these issues, which does not involve combustion process for producing shaft work. Thus the great advantages in terms of free of cost availability of air as a fuel and no emissions such as; carbon dioxide, carbon monoxide and nitrous oxides etc., are apparent from such air driven prime movers. Compressed air driven prime movers are also found to be cost effective compared to fossil fuel driven engines. It has perennial compressed air requirement which needs some source of energy for running compressor. The overall analysis shows that the compressed air system is quite attractive option for light vehicle applications [10] as well as wind turbine farm for clean energy storage and it's availability at the time of peak hour power requirement and improvement of thermal power generation efficiency by storage of compressed air energy at non-peak hour and use of such clean energy at peak hours.

The paper focuses towards the compressed air energy storage (CAES) and its uses in the transport technology, power generation by wind turbine farm and CAES during non peak hours and its availability for meeting the peak hour power requirement which could not be met otherwise through the thermal power plants. The running of light vehicles / motorbikes could curb emission by 50-60% in developing countries such as India, China, Taiwan, Romania etc. It is expected that CAES will be the major contributor of the clean energy potential during the 21st century.

II. Power Conversion / Energy Storage System

The power conversion system (PCS) is a vital part of all energy storage systems. It interfaces the energy storage device and the load (the end-user). PCS cost is significant and it can be greater than 25% of the overall energy storage system. PCS cost ranges from Rs.4500/kW for UPS markets to Rs.55000/kW for standalone market. Some of the major PCS markets include:

- Motor drives
- Power supplies
- UPS (uninterrupted power supply)
- Electric vehicles
- Inverters/Converters for solar-hybrid systems, Micro-turbines, Fuel cells, Wind turbines

Power conversion system technology has been evolving slowly due to the limited distributed energy resource (DER) market. As a result, Energy Storage System cost has been high with low profit margins and the manufacturing volume has been low impacting reliability and quality of the Power Conversion System designs. What is needed is the significant reduction in overall cost with improved reliability, and development of state-of-the-art Power Conversion System with multiple uses, which increases production volumes for DER applications, improve controls and adaptability, and improve manufacturing.

a) Batteries Energy Storage System

These storage systems operate in varying environments and electrical conditions. In these storage systems there are many different types of battery technologies. The different storage technologies are having advantages under specific operational conditions and thus have their own capabilities and limitations. Some of these are as given ahead.

- Lead-Acid Battery- short cycle life
- Li-Ion -Lithium Ion Battery-High energy and 100% efficiency
- NaS -Sodium Sulfur Battery- can run at high temperature of 300 deg centigrade.
- PSB - Polysulfide Bromide Flow Battery- 75% efficiency
- VRB -Vanadium Redox Flow Battery- 85% efficiency

b) Super Capacitor Energy Storage

Electrochemical capacitors (EC) store electrical energy in the two series capacitors of the electric double layer (EDL), which is formed between each of the electrodes and the electrolyte ions. The distance over which the charge separation occurs is just a few angstroms. The capacitance and energy density of these devices is thousands of times larger than electrolytic capacitors. The electrodes are often made with porous carbon material. The electrolyte is either aqueous or organic. The aqueous capacitors have a lower energy density due to a lower cell voltage but are less expensive and work in a wider temperature range. The asymmetrical capacitors that use metal for one of the electrodes have a significantly larger energy density than the symmetric ones and have lower leakage current.

c) Fly Wheel Energy Storage

Most modern flywheel energy storage systems consist of a massive rotating cylinder (consisting of a rim attached to the shaft) that is substantially supported on a stator by magnetically levitated bearings that eliminate bearing wear and increase system life. To maintain efficiency, the flywheel system is operated in a low vacuum environment to reduce drag. The flywheel is connected to a motor/generator mounted onto the stator that interacts with the utility grid. Some of the key features of flywheels are little maintenance, long life (20 years or 10s of thousands of deep cycles) and environmentally inert material. Flywheels can bridge the gap between short term ride-through and long term storage with excellent cyclic and load following characteristics. The choice of using solid steel versus composite rims is based on the system cost, weight, size, and performance trades of using dense steel (200 to 375 m/s tip speed) vs. a much lighter but stronger composite that can achieve much higher rim velocities (600 to 1000 m/s tip speed). Actual delivered energy depends on the speed range of the flywheel as it cannot deliver its rated power at very low speeds. For example, over 3:1 speed range, a flywheel will deliver ~90% of its stored energy to the electric load.

While high-power flywheels are developed and deployed for aerospace and UPS applications, there is an effort, pioneered by Beacon Power, to optimize low cost commercial flywheel designs for long duration operation (up to several hours). 2kW / 6kWh systems are in telecom service today. Megawatts for minutes or hours can be stored using a flywheel farm approach. Forty 25kW / 25 kWh wheels can store 1MW for 1 hour efficiently in a small footprint.

The stored energy can be approximated by:

$$E = (Iw_r^2)/2 = (mr_r^2w_r^2)/2 = (mv_r^2)/2$$

where w_r is the rotational velocity (rad/sec), I is the moment of inertia for the thin rim cylinder, m is the cylinder mass, r_r is the radius of the rim cylinder and v_r is linear rim velocity.

d) Pumped Hydro Storage

Pumped hydro storage is the most widespread energy storage technology used in the world, according to the energy storage association (ESA). There are about 90 GW of pumped storage in operation, which equals about 3 percent of worldwide generation capacity. The system works by pumping water from a lower reservoir to a higher reservoir and then allowing the water move downhill to produce electricity when needed. Traditional iterations of the technology are ideal for populations that live close to high altitude terrain, like Switzerland, where pumped hydro has been used for a century.

e) Compressed Air Energy Storage

The Technology of air engine is not new. The Sterling air engine was developed in 1790-1810, but due to its limitation no much work was carried out. In view of fire problems in Coalmines and other volatile places, where high flammable fuel like fossil fuel vehicles are not adviseable, compressed air operated vehicles are normally being put in use.

III. Various Options of Uses of Compressed Air Energy Storage (CAES)

a) Power Plant backup with CAES

Compressed air is not very old technology which takes excess energy from a power plant or renewable energy and uses it to run air compressors, which pump air into an underground cave or container where it is stored under pressure. When the air is released, it powers a turbine, creating electricity.

The technology, which involves storing off-peak-generated energy in the form of compressed air, usually in an underground reservoir, can trace its roots to the early 1960s, when the evaluation of gas turbine technology for power production began. It gained momentum during the next decade because of its promising thermal efficiency and response capabilities for providing load-following and peaking power support.

But since the commissioning only two existing CAES plants in the world-the 290-MW Huntorf plant in north Germany in 1978 and the 110-MW Alabama Electric Corp. plant in McIntosh, Ala., in 1991 have come up. One reason for this is that setting up a CAES facility is costly and requires finding a geologic formation that can support it. For example, both the German and Alabama plants store compressed air in mined salt caverns.

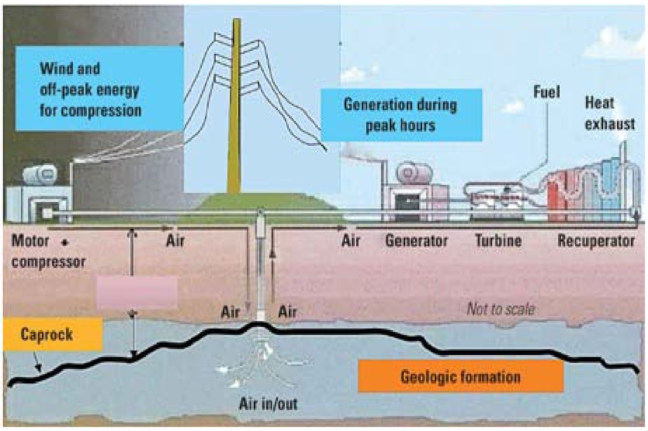

Figure 1 : Underground CAES backup by non Peak Hour Compression

CAES plants work like big batteries. electric motors drive compressors that compress air (at perhaps 1,100 psi) into an underground geologic formation during off-peak hours. When the electricity is needed most, the pre-compressed air (essentially replacing the compressor in a traditional combustion turbine) is used in modified combustion turbines to generate electricity (Figure 1). Natural gas or other fossil fuels are still required to run the turbines, but the process is more efficient-using up to 50% less natural gas than standard production, according to Sandia National Laboratories.

b) Wind Turbine Farm backup with CAES

Prompted CAES is being reviewed by the staggering growth of wind-powered capacity for its use as a load management tool as well as its capability to function as a stand-alone intermediate generation source for capturing energy arbitrage, capacity payments, and ancillary services.

As per recent announcement, Sandia was developing a stored energy park in an aquifer near Des Moines, Iowa, in collaboration with Public Service Co. of New Mexico (PNM) and more than 100 municipal utilities in Iowa, Minnesota, and the Dakotas. The Iowa Stored Energy Park (ISEP, www.isepa.com) will be a nominal 269-MW CAES plant with about 50 hours' worth of stored energy. As per the estimates, using Iowa's abundant wind power, it could account for 20% of the energy used annually at a typical municipal utility and save cities and their utilities as much as $5 million each year in purchased energy.

ISEP Project Manager Georgianne Peek said the project, expected to be operational by 2012, was "pretty far along." By June, ISEP developers were 95% certain that they had the right formation (based on seismic testing at the site), computer modeling, and data from a sister formation. The team is planning to conduct an analysis of the site's rock mechanics-a study similar to the one they did in 2000 for a 2,700-MW CAES plant proposed by CAES Development Co. for construction in Norton, Ohio and the project is still under development.

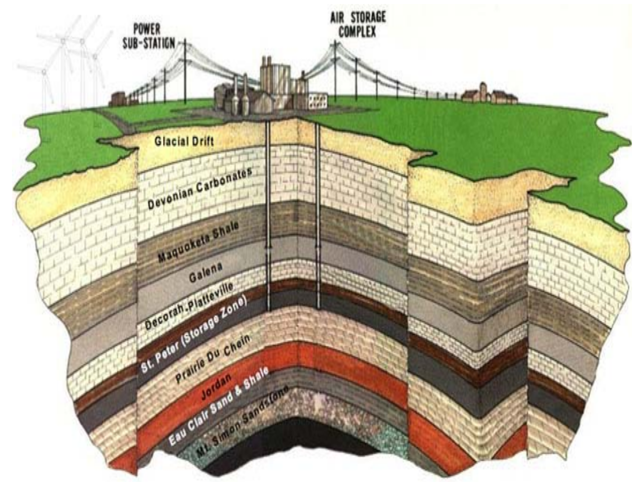

Figure 2 : Underground CAES backup by Wind Turbine Farm

c) The Submerged CAES

Recently in Europe, German generation giant E.ON gave an engineering professor at Nottingham University, Seamus Garvey, £236,000 ($333,500) to build two CAES prototypes-the first on land and then an underwater wave-powered version. Garvey, who thinks the idea makes abundant engineering sense, envisions large amounts of compressed air being stored under the sea in gigantic cone-like flexible containers, dubbed energy bags. Renewable energy primary harvesting machines would collect the energy in the form of compressed-air, then if the energy available exceeds the demand for electricity at that time, some air is inducted into storage, but the heat is extracted from that and fed into a small fraction of air that is being expanded. This presupposes that your 'wind farm' or 'tidal energy farm' or 'wave energy farm' or integrated mix of all of these is set up to deliver 'base load' most of the time, Garvey told *POWER*. At a depth of about 1,970 feet, he calculates that the bags could store some 6,945 MWh of energy for every cubic meter. Garvey's prototypes are in the process of development.

f) Compressed Air Engine / Turbine

Now from last two decades major thrust is being given by the researchers for development of compressed air engine. Some technical developments, which may be considered to work on 21st Century Energy Storage system and can work on compressed air or hybrid system as an alternative to fossil fuel for running light vehicles, are listed below:-

i. *Reciprocating Compressed Air Engine*

Guy Negre, a French Scientist, in 1998 developed compressed air- 4- cylinders engine run on air and gasoline, claims zero pollution cars and got 52-patents registered since 1998 to 2004.The car was demonstrated *in* Oct.'2004 publically **[11].** The Air Car, developed by Luxembourg-based MDI Group founder and former Formula One engineer Guy Negre, is powered by a compressed air engine (CAE). It uses compressed air to push its pistons when running at speeds under 35 mph. At higher speeds-it can run up to 96 mph-the compressed air is heated by a secondary fuel source (biofuel, gasoline, or diesel) and expands before it enters the engine. The Air Car claims a fuel efficiency of about 100 mpg. The air is compressed using power from a regular electric outlet.

ii. *Rotary Hot Air Motor (Quasi-Turbine)*

Saint Hilaire G., an inventor developed zero pollution cars using Quasiturbine with a set of 14-engines parameters and disclosed on Sept'2005 using gasoline [12]. In the basic single rotor Quasiturbine engine, an oval housing surrounds a four-sided articulated rotor, which turns and moves within the housing. The sides of the rotor seal against the sides of the housing, and the corners of rotor seal against the inner periphery, dividing it into four chambers.

iii. *Vaned type Air Turbine*

In an effort to curb pollution, a revolutionary motorcycle engine that runs on air is under development. The prime mover is a vaned type air turbine. The prototype in question uses a compressed air tank to power a turbine and provide motive power to the motorcycle. The compressed air tanks can get recharged with pumps running off solar or other renewable energy, thus making them a cheaper, eco-friendly alternative to hybrid electric vehicles. The engine works by pushing compressed air into a small turbine. The air expands and turns the turbine, powering the motorbike. No fossil fuels are required, and the only waste product is the expended air.

The developers of the engine, states that the technology is commercially viable and could be available to consumers within a year. As of now, the only major challenge is to develop a compressed air tank that can withstand the demands of long journeys. The current technology allows for 30 minutes of running time and the researchers are now working to develop a high-pressure tank that is good enough to power the bike for six hours. Numerous studies for optimizing efficiency of these air turbines have been done [13- 17].

IV. Vaned Type Novel Air Turbine as Prime-Mover to Motorbike

In this study a vaned air turbine shown in Fig. 3, has been considered. This air turbine is tested in order to get an output of 6.50 to 7.20 HP for meeting starting torque requirements at 500–750 rpm at 4-6 bar air pressure. The average running torque is available at normal speed of 2000–2200 rpm at 2-3 bars air pressure. The air turbine with single inlet and exhaust has spring loaded vanes to maintain regular contact with the elliptical bore. The various efforts have been made to get optimum shaft output produced [18-22].

a) Mathematical Model

The high pressure jet of air at ambient temperature drives the rotor in novel air turbine due to both isobaric admission and adiabatic expansion. Such high pressure air when enters through the inlet passage, pushes the vane for producing rotational movement through this vane and thereafter air so collected between two consecutive vanes of the rotor is gradually expanded up to exit passage.

This isobaric admission and adiabatic expansion of high pressure air contribute in producing the shaft work from air turbine. Compressed air leaving the air turbine after expansion is sent out from the exit passage. It is assumed that the scavenging of the rotor is perfect and the work involved in recompression of the residual air is absent. Similar type of mathematical modeling is considered in earlier publications by authors and it is being reproduced here for maintaining continuity and benefits to the readers [23-36].

From Fig. 4, it is seen that work output is due to isobaric admission from E to 1, and adiabatic expansion from 1 to 4 and reference points 2, 3 in the figure shows the intermediate position of vanes. Thus, total work output due to thermodynamic process may be written as:

[Area under (E145CE)] = [Area under (E1BOE) +Area under (14AB1) – Area under (4AOD4) + Exit steady flow (45CD4)]

or

Total work output = [Thermodynamic expansion work (w_1)] + [Exit steady flow work (w_2)]

or $$w = [(w_1) + (w_2)] \tag{1}$$

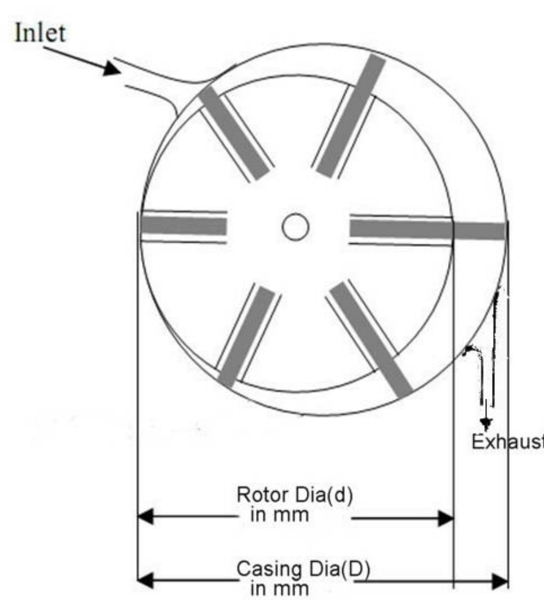

Figure 3 : Air Turbine Model

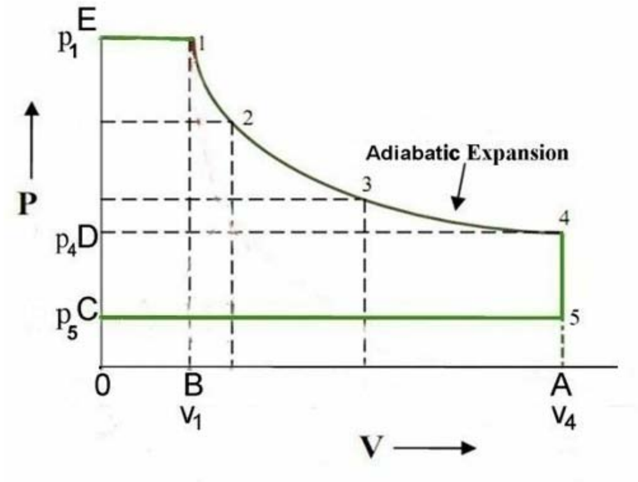

Figure 4 : Thermodynamic Processes (Isobaric, adiabatic and Isochoric Expansion)

Now thermodynamic expansion work (w_1), can be written as:

$$w_1 = p_1.v_1 + \left(\frac{p_1.v_1 - p_4.v_4}{\gamma - 1}\right) - p_4.v_4$$

or

$$w_1 = \left(\frac{\gamma}{\gamma - 1}\right)\left(p_1.v_1 - p_4.v_4\right)$$

For adiabatic process, $p.v^{\gamma} = p_1.v_1^{\gamma} = p_4.v_4^{\gamma}$ = constant or $v_4 = \left(\frac{p_1}{p_4}\right)^{\frac{1}{\gamma}}.v_1$

Thus thermodynamic expansion work output would be:

$$w_1 = \left(\frac{\gamma}{\gamma - 1}\right).p_1.v_1.\left\{1 - \left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad (2)$$

The process of exit flow (4-5) takes place after the expansion process (E- 4) as shown in Fig. 4 and air is released to the atmosphere. In this process; till no over expansion takes place pressure p_4 can't fall below atmospheric pressure p_5. Thus at constant volume when pressure p_4 drops to exit pressure p_5 , no physical work is seen. Since turbine is functioning as positive displacement machine and hence under steady fluid flow at the exit of the turbine, the potential work is absorbed by the rotor and flow work (w_2), can be written as:

$$w_2 = \int_4^5 v.dp = v_4(p_4 - p_5) \quad (3)$$

Applying equations (2), (3) into equation (1), therefore net work output will be:

$$w = (w_1 + w_2) = \left(\frac{\gamma}{\gamma - 1}\right).p_1.v_1.\left\{1 - \left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} + (p_4 - p_5).v_4 \quad (4)$$

when air turbine is having *n* number of vanes, then shaft output [37] can be written as:

$$w_n = n.\left(\frac{\gamma}{\gamma - 1}\right).p_1.v_1\left\{1 - \left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} + n.(p_4 - p_5).v_4 \quad (5)$$

where w_n is work output (in Nm), for complete *ne cycle.*

From Fig. 5, shows that when two consecutive vanes at OK and OL move to position OH and OB, the extended vane lengths varies from SK to IH and LM to BG, thus the variable length BG at variable α_i is assumed as $X_{at'variable'\alpha}$ can be written from the geometry:

$$BG = x_{at,variable'\alpha'} = R.\cos\left[\sin^{-1}\left\{\left(\frac{R-r}{R}\right).\sin\alpha\right\}\right] + (R-r).\cos\alpha - r \quad (6)$$

where 2R=D is diameter of casing and 2r=d is diameter of rotor, α is angle ∠BOF, β is angle ∠BAF and θ is angle ∠HOB or ∠H'OF or ∠KOL, between two consecutive vanes and ϕ is angle ∠KOJ at which injection pressure admits to the air turbine.

Variable volume of cuboids B-G-I-H-B can be written as:

$$v_{cuboids} = L.\left\{\frac{(X_{1i} + X_{2i})(2r + X_{1i})}{4}\right\}.\sin\theta \quad (7)$$

where BG= X_{1i} and IH= X_{2i} variable length of vanes when rotate into turbine as shown in Fig. 5 and i stands for min or max length.

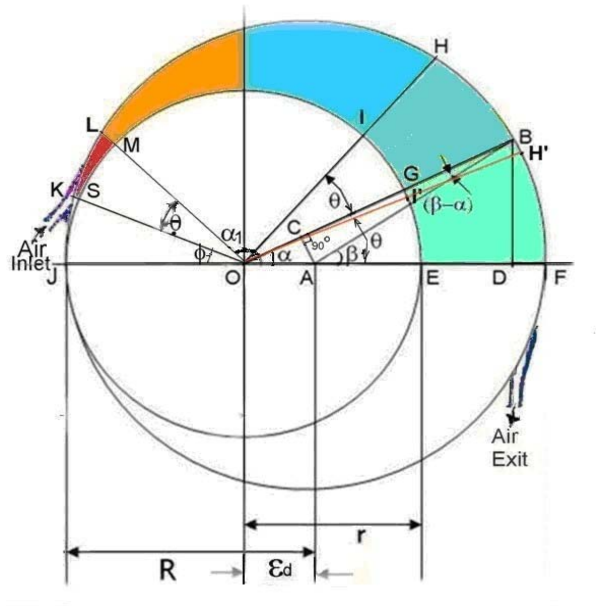

Figure 5 : Variable length BG and IH and injection angle ϕ

Thus the volume at;

a). inlet v_1 or $v_{\min}$ will fall between angle $\angle$ LOF= $\alpha_{1\min} = (180 - \theta - \phi)$ and angle $\angle$ KOF= $\alpha_{2\min} = (\alpha_{1\min} + \theta) = (180 - \phi)$ as seen in **Fig. 5**, when air is admits into turbine at angle ϕ .

b). exit v_4 or $v_{\max}$ will fall between angle $\angle$ BOF $\alpha_{1\max} = \alpha = 0$ and angle $\angle$ HOF $\alpha_{2\max} = (\alpha_{1\max} + \theta) = \theta$

Applying above conditions into equations (6), then LM=X_{1min} , SK=X_{2min}, FE=$X_{1\max}$=Corresponding to BG at α =0 degree and I'H'=$X_{2\max}$=Corresponding IH at $(\alpha + \theta) = \theta$ degree

Applying values of X_{1min} and X_{2min} to equation (7),

$$v_{\min} = v_1 = L.\left\{\frac{(X_{1\min} + X_{2\min})(2r + X_{1\min})}{4}\right\}.\sin\theta \quad (8)$$

Applying values of X_{1max} and $X_{2\ max}$ to equation (7),

$$v_{\max} = v_4 = L.\left\{\frac{(X_{1\max} + X_{2\max})(2r + X_{1\max})}{4}\right\}.\sin\theta \quad (9)$$

Applying values of v_1 and v_4 from equations (8) and (9) to equation (5), the total power output available W_{total} can be written as:

$$W_{total} = n.(N/60).\left(\frac{\gamma}{\gamma-1}\right).\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}p_1.\left[L.\left\{\frac{(X_{1\min}+X_{2\min}).(2r+X_{1\min})}{4}\right\}.\sin\theta\right]$$
$$+n.(N/60).(p_4 - p_5).\left[L.\left\{\frac{(X_{1\max}+X_{2\max}).(2r+X_{1\max})}{4}\right\}.\sin\theta\right] \quad (10)$$

V. Present Work

A novel air turbine has been conceived for being used as prime mover for very light vehicle applications like; motorbike engine. Based on the above mathematical model, performance of proposed air turbine is analyzed and results are obtained and plotted for different independent and dependent parameters. For optimum design values, the air turbine has been fabricated suiting to the requirements of motorbike. The novel air turbine is fabricated for optimum dimensions and run on compressed air for its performance evaluation. Experimental set up consisting of a reciprocating compressor, compressed air storage tank, air flow regulator cum filter, air turbine and dynamometer is used for validation of the performance predicted by theoretical analysis. The independent and dependent variable considered for present study are detailed below:

a) Independent Variables

i) Number of vanes (n=360 / θ)
ii) Diameter of the rotor (d) in m
iii) Diameter of the casing (D) in m
iv) Length of the rotor (L) in m
v) Speed of rotor (N) rpm
vi) Inlet / admission pressure of air (p_1 in bar)
vii) Admission / injection angle (ø) in degree

b) Dependent Variables

i) Volume of two consecutive vanes (v_1) in m^3
ii) Volume of maximum expansion (v_2) in m^3
iii) Exit pressure (p_4) in bar
iv) Torque (T) in Nm
v) Total power output (W_{total}) in kW
vi) Expansion power output (W_{exp}) in kW
vii) Flow power output (W_{flow}) in kW

The various parametric investigations carried out in present work include optimization of vane angle (number of vanes in rotor), air admission / injection angles, rotor and casing diameter ratio and relation between vane angle and air injection angle with respect to different injection pressure 2-7 bar (15- 100 psi).

VI. Theoretical and Experimental Results of Novel Air Turbine

The air engine is conceptualized as a novel vaned type air turbine is shown in Fig. 6. The air turbine is considered to work on the reverse principle of vane type compressor. It is assumed that the total shaft work of the air turbine is cumulative effect of compressed air jet on vanes and the expansion of high pressure air. The compressed air at 20 bar is utilized for running air turbine which is stored in a storage cylinder. It is proposed to have storage capacity of 30 minutes duration. The compressed air cylinder is attached with filter, regulator and lubricator for regulating and maintaining the constant pressure during air admission so as to produce high torque at low speed of revolution. The vanes of novel air turbine are spring loaded to maintain their continuous contact with the casing wall to minimize leakage.

a) Theoretical Analysis

In present study the thermodynamic modeling of the air turbine has been carried out for the considered model. Theoretical analysis is carried out for varying compressed air injection pressure, number of vanes, casing diameter, rotor diameter, speed of rotation. Based on the theoretical result and analysis the final dimensions of the air turbine were fixed. A prototype of air turbine was developed and checked for its functionality. It has a casing of CI material with liner of high tensile steel. The vane rotor is also of high tensile steel and having 8 slots to accommodate 4 mm thickness vanes of self lubricating fiber material. The fiber vanes are spring loaded to maintain regular contact with casing liner.

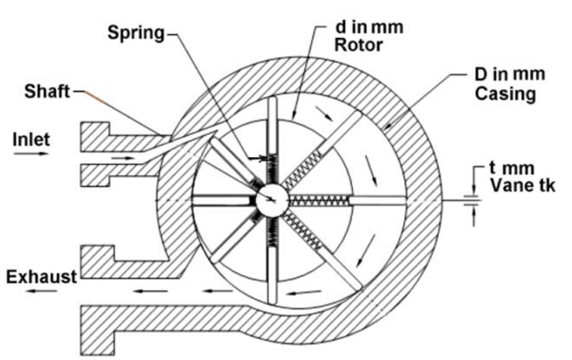

Figure 6 : Air turbine- schematic model

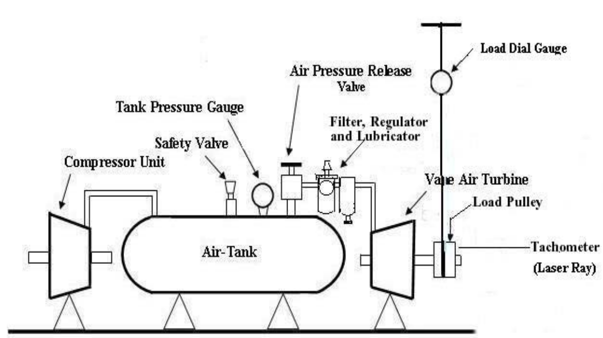

Figure 7 : Experimental test setup

b) Experimental Setup

The complete schematic of test setup is shown in Fig. 7. It consists of compressor, compressed air storage cylinder, supply of compressed air through air filter, regulator and lubricator to air turbine. The dynamometer consisting of load pulley, weight load and load dial gauge are also shown in the set up.

The experimental setup consisting of a heavy duty two stage compressor with suitable air storage tank, air filter, regulator and lubricator, novel air turbine, rope dynamometer has been created for validation of theoretical results.

The actual setup of test rig of air engine / turbine was fabricated and air turbine was tested in the laboratory. The compressed air is produced by a heavy duty two stage compressor and stored in a suitable capacity of air tank to maintain nearly constant supply pressure of 300 psi. The compressed air is connected to air filter, regulator and lubricator to produce desired air pressure for testing. The data is recorded with various parametric conditions and performance evaluation of the prototype air turbine is carried out.

As shown in Fig. 7, it consists of a compressor and storage unit. The said unit comprises of the specifications of components used to perform the validation of Air Engine/Turbine.

i. *Compressor Unit*

As shown in Fig. 8, the specification of the 2-stage compressor is as under:

- The air compressor is of M/s ELGI Equipment ltd., Coimbatore, India's make. It is of two stage intercooled type and has specifications such as; TS 05 120H, Manufactured: 04/2003; 500 LPM, Maximum working pressure. 12Kgf/Cm^2, Speed; 925 RPM;
- The compressor is connected with an electric motor. The electric motor is of 05 HP (3.7 kW) - 3 phase, speed of rotation 1420 rpm, and runs at 415V, 8.2 Amps and 50 Hz frequency.

ii. *Compressed Air Storage Tank*

Compressed air storage cylinder / receiver is made of M/s ELGI Equipments Ltd., India's make and connected with 6 mm heavy duty steel tube attached with compressor unit exit nozzle point. The storage container has a capacity of 250 Ltrs (8.8 cuft) at atmospheric pressure and can attain 5000 Ltrs (176 cuft) of atmospheric air, when filled up to test pressure of 20 bar= (20.4 Kg f/Cm^2).

iii. *Safety Valve and Air Pressure Gauge*

Safety valve is introduced on storage tank to gauge the pressure and release automatically the pressure if it goes beyond the specified level of pressure 40 bar. The pressure gauge indicates the pressure attained in the storage tank for monitoring purpose.

iv. *Air Release Valve*

It is a unit by which compressed air is taken out. In this set up it is a manual pressure release link / latch which is rotated to regulate the air quantity to the air filter, air regulator and lubricator unit.

v. *Air Filter, Regulator and Lubricator (FRL)*

The filter, regulator and lubricator unit which ensures the life of air engine by filtering, regulating the desired pressure and lubricating the air engine to prevent the Tafcon 4 mm Vanes already fitted in to the slots of rotor. The filter, regulator and lubricator unit is used of SHAVO Make OLYMPION Filter, Regulator (BL set MAJ-200-M7EC); Model SB 13; ¼" BSP, Poly Bowl, 24 Micron and 0-20 bar regulator. It suits to regulate the desired pressure needed to be given to air engine through inlet pipe.

vi. *Construction of Air Engine*

The inner construction of air engine has following parts:

1. Housing / Casing of Air Engine

It is made of cast iron with liner fitted inside to receive regular contact of vanes which prevents the leakage and develops rotational load on rotor.

2. Rotor and Vanes

It is made of high tensile carbon steel of homogeneous material. Rotor length is decided depending upon the power load required and slots over the rotor periphery and to full length is cut to the depth more than the off-centre of Casing liner and Rotor diameters difference. Preferably CNC machine milling tools are to be used for very high precision and slots are made of 4+ (four plus) mm. size and accuracy is to be maintained to the order of micron. Tafcon vanes are fitted inside rotor slots and should be of exactly 4 mm. Vanes are required to slide inside the slots against centrifugal force and also loaded under spring to maintain regular contact with liner to avoid / reduce leakage between liner and vane contact once high pressure air enters to space of off centre between two consequent vanes as shown in Fig. 6.

3. Shaft and Load Pulley

A pulley/sprocket is fitted with key over the extended portion of shaft. The shaft diameter is considered depending upon the load desired and for this novel engine it is of 17-18 mm (¾ ") diameter and extended about 35 mm 1 ½" approx.).

Fig. 8 : Heavy Duty 2-Stage Compressor

The actual setup of test rig of air engine / turbine was fabricated and air turbine was tested in the laboratory as shown in Figs. 8, 9, 10 and 11. The compressed air is produced by a heavy duty two stage compressor and stored in a suitable capacity of air tank to maintain nearly constant supply pressure of 20 bar.

Fig. 9 : Air filter, regulator and lubricator

The compressed air is connected to air filter, regulator and lubricator to produce desired air pressure for running the air turbine and its testing. The data is recorded with various parametric conditions as shown in Figure 2(e) and performance evaluation of the prototype air turbine is carried out.

Fig. 10 : Actual test rig of air turbine

The most important aspects of design and analysis of the novel air engine are of optimizations of following parameters:

a) Size of air engine liner diameter (*D*), rotor diameter (*d*) and its relation (*d/D*).
b) Compressed air at which angle it should enters the air engine.
c) Number of vanes into the rotor depends upon angle between 2- consecutive vanes.

d) Air pressure is considered 2- 7 bar for operation.

e) Exit port is considered to be placed at an angle where re-compression should not start after expansion of air inside the air engine. The exit air is released at an angle 225° or more with reference to which casing liner and rotor gap is nearly zero.

vii. *Validation of Experimental Results*

The above experimental set up was used at HBTI, Kanpur in the fluid mechanics lab and compressor was used after attaining its pressure 300 psi. The nylon pressure tube was connected to storage tank outlet nozzle. Other end of pipe was connected to inlet of FRL attached with air engine test setup. The release valve of storage tank was regulated and Regulator of air engine FRL unit was adjusted at air pressure of 2 bar. The load on rope pulley attachment was adjusted with spring balance after adjusting the rope tension screw.

Under this condition speed of air engine / turbine was recorded with the help of laser dynamometer. Again the pressure regulator was adjusted at 3 bar and reading of air turbine speed was recorded. Similarly regulator pressure was again adjusted for 4, 5, 6 bar air pressure under same loading conditions and speeds were recorded for all pressure conditions.

This process was continued after increasing the loading on spring balance and speed of air turbine were recorded at 2, 3, 4, 5, 6 bar pressure. The process was repeated for different set of loadings and experimental readings were then compared with theoretical values. It was observed that at low air pressure, performance of turbine was about 97 % and at high pressure and heavy loading it was to the order of 72%. Thus the innovative novel turbine was found to develop maximum performance than the any available air motors developing same power.

Fig 11 : Actual air turbine under test

(Note: All the measuring tools / instruments were validated within the specified limits of its tolerances before the record of reading and errors were not accounted for).

c) *Input Parameters*

For comparison of theoretical and experimental power output parameters are listed in Table-1.

Table-1

Input parameters for comparison of theoretical results with experimental values

Symbols	Parameters
D=2R, d=2r	(100 mm,75 mm) i.e.(d/D)=0.75
p_1	20 psi (=1.4 bar), 40 psi (=2.7 bar), 60 psi (=4.1 bar), 80 psi (=5.5 bar), 100 psi (=7.0 bar)
p_4	$=(v_1/v_4)^{\gamma}.p_1$ $> p_5$ assuming adiabatic expansion
p_5	$(p_4/1.2)$ >1 atm = 1.0132 bar
n	Number of vanes (360 / θ)
N	500 rpm, 1000 rpm, 1500 rpm, 2500 rpm, 3000 rpm
L	45 mm length of rotor
γ	1.4 for air
θ	45^0 angle between 2-vanes, (i.e. rotor contains correspondingly 8 nos. of vanes)
Ø	60^0 angle at which compressed air through nozzle enters into rotor

VII. Results and Discussion

Variation of performance efficiency = (variation in experimental and theoretical power divided by theoretical power) with respect to different injection pressure 2-7 bar is shown in Fig. 12.

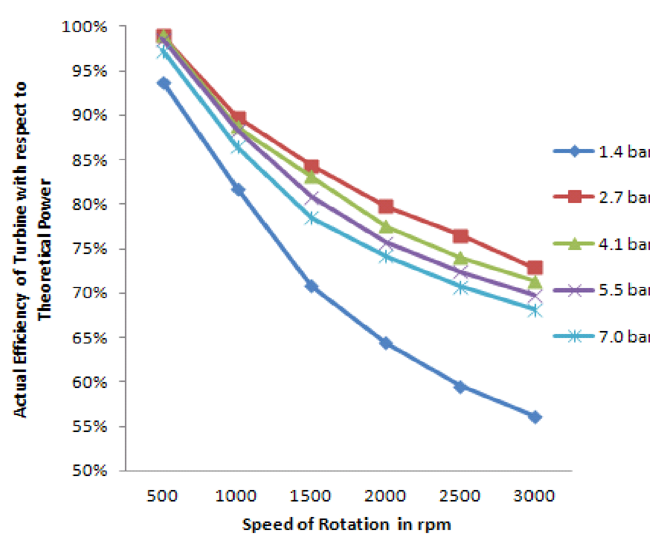

Figure 12 : Performance of vane turbine with respect to experimental power

Figure 12 depicts the variation of efficiency of air turbine for different injection pressure at different speeds of rotation. It is evident that at every injection pressure the efficiency goes down with increasing speed of rotation. This is due to the increase in friction losses on account of higher speed of rotation for a constant injection pressure. There also occur leakage losses at the mating surface of vane and casing which increase with increasing injection pressure. This higher leakage helps in overcoming the frictional resistance and reduces friction losses. On account of these factors, the efficiency of air turbine varies as shown below:

- 93% to 99% with variation of 6%, at speed of rotation 500 rpm for injection pressure 20 psi to 100 psi.
- 81.8% to 89.8% with variation of 8%, at the speed of rotation 1000 rpm for injection pressure 20 psi to 100 psi.
- 70.8% to 84.3% with variation of 13.5%, at the speed of rotation 1500 rpm for injection pressure 20 psi to 100 psi.
- 64.4% to 79.8% with variation of 15.4%, at the speed of rotation 2000 rpm for injection pressure 20 psi to 100 psi.
- 59.5% to 76.5% with variation of 17%, at the speed of rotation 2500 rpm for injection pressure 20 psi to 100 psi.
- 56.2% to 72.9% with variation of 16.7%, at the speed of rotation 3000 rpm for injection pressure 20 psi to 100 psi.

This shows that at lower speed of rotation, performance efficiency is higher and variation is small; whereas at higher speed rotation performance efficiency of turbine goes down and variation is also large. The graph at 20 psi (1.4 bar) shows the large variation in performance efficiency whereas for 40 -100 psi (2.7-7 bar), the variation in the performances are closer. This may be due to overcoming the frictional losses between vanes and casing. Thus overall performance of air turbine for working pressure ranging from 2.7-6 bar is found varying from 72%-97%.

VIII. Conclusions

On the basis of above studies, following conclusions are drawn:

- Apart from all other options of storage of energy, the compressed air energy storage (CAES) is the option to improve upon the peak hour requirement of electric power generation.
- Wind turbines farm could be used as CAES system and from CAES, electric power can be generated during peak hour requirements and it can be utilized as a source for filling the compressed air storage tank for running the air engine of light vehicles without using electricity for compressor.
- The performance efficiency of the novel compressed air engine is found varying from 72%-97% and is suitable to run motorbike's air engine as zero pollution.
- If the compressed air technology is implemented in the light transport vehicles such as: motorbikes etc., it will practically generate zero pollution and compressed air engine technology will reduce the emission up to 50-60% as presently 80 % of pollution is generated due to the transport sector.

Thus CAES is definitely going to be the most attractive and efficient clean energy option for 21^{st} century.

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Two-phase Gas/Liquid-Solid Flow Modelling in 90° Bends and Its Effect on Erosion

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Abstract - Sand particles present in the fluid flows extracted from oil wells causes many problems for oil and gas production companies. Collision of sand particles to the wall of oil transfer pipes and process equipment reduces wall thickness which is considered as a cause of erosion. One of the consequences of this problem is frequent failures and loss of valuable production time. Bends installed in the path of oil and gas pipelines are at risk of such erosion as mentioned. This paper is a study of computational fluid dynamics to predict erosion in the bend geometry. It uses Lagrangian approximation which includes modeling of continuous flow of fluid, Lagrangian particle tracking and calculation relating to erosion. In this work, the effect of various parameters such as flow velocity, particle diameter, and bend geometry and particle-fluid density ratio on the particle motion and consequently erosion resulting from the collision of particle to bend wall is studied.

Keywords : Lagrangian approximation; Physical erosion; Erosion modeling; Particle-Fluid two-phase flow.

GJRE-A Classification : FOR Code: 030103

TWO-PHASE GASLIQUID-SOLID FLOW MODELLING IN 90 BENDS AND ITS EFFECT ON EROSION

Strictly as per the compliance and regulations of:

Two-phase Gas/Liquid-Solid Flow Modelling in 90° Bends and Its Effect on Erosion

M. R. Ansari [α], S. Mohammadi [Ω], M.Khalaiji Oskouei [β]

Abstract - Sand particles present in the fluid flows extracted from oil wells causes many problems for oil and gas production companies. Collision of sand particles to the wall of oil transfer pipes and process equipment reduces wall thickness which is considered as a cause of erosion. One of the consequences of this problem is frequent failures and loss of valuable production time. Bends installed in the path of oil and gas pipelines are at risk of such erosion as mentioned. This paper is a study of computational fluid dynamics to predict erosion in the bend geometry. It uses Lagrangian approximation which includes modeling of continuous flow of fluid, Lagrangian particle tracking and calculation relating to erosion. In this work, the effect of various parameters such as flow velocity, particle diameter, and bend geometry and particle-fluid density ratio on the particle motion and consequently erosion resulting from the collision of particle to bend wall is studied.

Keywords : Lagrangian approximation; Physical erosion; Erosion modeling; Particle-Fluid two-phase flow.

I. Introduction

Erosion relates to the details of particle moving before and after the collision, accurate prediction of erosion is a very complex problem. Flow transmission and pipeline systems are not always straight; they include bends, T-junctions, joints and connections. This is apparent and problematic in design and application of Heat Exchangers, heaters, boilers, condensers and oil and gas transfer pipelines. Predicting erosion is a combination of fluid flow modelling, Lagrangian particle tracking and application of empirical correlations can be obtained by numerical methods. Flow modelling is used to obtain the flow field geometry and the particle tracking model is applied in order to obtain released particle path in the fluid flow. Particle collision data obtained from the empirical equations presented results in estimates of wall erosion. The above description including numerical and experimental data presents a prediction of erosion in pipes and fittings.

Eulerian and Lagrangian approaches for solid particle tracking have been conducted by some researchers [1 ~ 3]. Durst and et al. analyzed two approaches and then compared them with each other [4]. They found that the Lagrangian approach has many benefits on particle tracking in high velocities in compare to Eulerian approach. The particle tracking calculation has been conducted by several investigators [5 ~ 11]. Different forces act on a solid particle during its movement in the fluid. These forces determine the particle course in the fluid. Machaelides presented basic equation for hydrodynamic force acting on a spherical particle accelerating from a stationary state inside a fluid [6]. This equation is valid for low velocity and high acceleration; however it was not applicable for a restricted Reynolds numbers of a particle. There is a general method to overcome this restriction. This could be conducted by defining experimental coefficient especially for drag at steady-state condition. Hamilton and Odar defined these coefficients [6].The mentioned equation can be only used for a particle in the stationary liquid. There are other forces affected on particle moving through fluid. They used the force generated from the pressure gradient as a required force for accelerating the equal volume fluid substituted with particle during its absences. Clift and et al. presented this force in the general form [7]. Two lift forces effect on a particle in the fluid. Magnus force forms from particle rotation at low Reynolds number can be resulted from the non linear terms of Navier-Stokes equations. Jayanti and Hewitt presented the related Magnus force formula [11]. Saffman declared that a small sphere in a laminar shear flow senses a lift force in perpendicular direction to the flow field that is known Saffman force [8]. The other forces effect on a particle are volumetric forces related to gravity and buoyancy forces. Some of the mentioned forces can be neglected in some conditions with acceptable accuracy. Meng and Van der Geld studied on mentioned forces and compared their numerical values. They concluded that the Saffman force can be neglected because of its small value [9]. The added mass force can be included in the calculation when the particle is big. In the present article, the Saffman force was not included in the erosion calculation because of its small value.

Recently, some research has been conducted on erosion in pipe bends. Edward et al. used the commercial CFD code of CFX for erosion prediction due to a particle impact by applying appropriate procedure [12]. The erosion model of Ahlart and its extension by McLauray (1996) was used for prediction of erosion for Aluminum [13]. Also, they used LDA method for measurement of flow in the bend in order to validate

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their theoretical obtained results. Comparison of the model results with experimental results shows a reasonable agreement.

Keating and Nesic were studied a 180-degree bend using the commercial CFD code PHOENICS with a separate code for tracking a particle by Lagrangian method in 2000 [14]. They compared their results for flow field with experimental results and showed that their results are valid. However, they used the upgraded model of Finnie, but no comparison or suggestion was given. Hansen and Petal used PHOENICS code to study erosion in bends of air lifting channels [15]. Their work is somehow different with the other recent studies. They also investigated the scratch shape by erosion. Zhong and Hengshuan worked on rectangular cross section bends, two dimensional non viscous flow with and without secondary flow in 1990 [16]. They also used the Finnie model for erosion prediction. Wang and Shirazi studied erosion on 90° bends in 2003 [17]. They compared their numerical results with the experimental result of Eyler conducted for penetration rate in 1987. Even though their results have enough accuracy, however, they showed that their analysis differs from experimental results. They found the reason behind this, is that the particle flow rates is high in most of the experiments. They also found in long radius bends the erosion rate reduces as the main flow is gas. In the case of liquid flow, they showed that the squeeze film, secondary flow and an oscillation generated from turbulence flow has important role on the erosion rate. In addition, the authors presented a 1st order approximate correlation based on CFD analysis for engineering calculation to estimate the bend radius effect on erosion in long-radius bends.

Fashami worked on particle motion at outside of a pipe and its effect on erosion at outer surface of the pipe [19]. The objectives of this paper is a single particle trace in a two dimensional bend, determining of velocity and impact angle with bend wall and finally prediction of erosion rate by using an erosion model. A statistical study of the most probable impact location in the bend will be presented. With respect to the fore mentioned points, the solution procedure will be as follows:

- Obtaining the flow field in the bend
- Particle tracking in the flow field of the inside of the bend obtained from the previous part
- Obtaining the required information of the particle impact on the wall and erosion probability rate calculation.

II. The Governing Equations

a) The continues phase

For modelling of incompressible steady-state flow in the polar coordinate system in the radial and tangential directions, the mass and momentum conservation equations are as [20]:

$$\frac{1}{r}\frac{\partial ru}{\partial r}+\frac{1}{r}\frac{\partial v}{\partial \theta}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial r}+\frac{v}{r}\frac{\partial u}{\partial \theta}-\frac{v^2}{r}=-\frac{1}{\rho}\frac{\partial P}{\partial r}+\nu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial ru}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v}{\partial \theta}\right] \qquad (2)$$

$$u\frac{\partial v}{\partial r}+\frac{v}{r}\frac{\partial v}{\partial \theta}+\frac{uv}{r}=-\frac{1}{\rho r}\frac{\partial P}{\partial \theta}+\nu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial rv}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial u}{\partial \theta}\right] \qquad (3)$$

u and v are the velocities at radial and tangential direction, respectively.

b) The discrete phase

The particle velocity equation at tangential direction is:

$$\frac{dv_P}{dt}=F_k\left(v_f-v_P\right)-\left(1-\frac{\rho_f}{\rho_P}\right)g_\theta-\frac{u_P v_P}{r_P} \qquad (4)$$

The last term of the RHS of the above equation is the quasi coriolis force caused by the curvature effect of polar coordinate system on the particle.

The particle velocity on radial direction is:

$$\frac{du_P}{dt}=F_k\left(u_f-u_P\right)-\left(1-\frac{\rho_f}{\rho_P}\right)g_r+\frac{v_P^2}{r_P} \qquad (5)$$

The last term of the RHS in the above equation is the centrifugal force effecting on the particle at the radial direction. F_k is the momentum transfer coefficient between the particle and fluid and can be obtained from:

$$F_k=\frac{18\mu}{\rho_P d_P^2}C_D\frac{Re_P}{24} \qquad (6)$$

To calculate the drag coefficient, Wang and et al. declared an equation as presented by the following in 2003 [21]:

$$C_D=\begin{cases}\dfrac{24}{Re_P} & Re_P\le 1\\[2ex] \dfrac{24\left(1+0.15Re_P^{0.687}\right)}{Re_P} & 1<Re_P\le 1000\\[2ex] 0.44 & Re_P>1000\end{cases} \qquad (7)$$

In the above equation, the drag coefficient is a function of the particle Reynolds number and is defined as:

$$Re_P = \frac{\rho_f d_P \left|\vec{V}_f - \vec{V}_P\right|}{\mu_f} \quad (8)$$

c) Erosion model

At the present work, the model suggested by Wallace and Peters for erosion estimation is selected. They declare their equation by using the formula found experimentally by Neilson and Gilchrist in 1968 as [10]:

$$\begin{cases} E\times 10^{-6} = \dfrac{1}{N_P}\left[\dfrac{(1/2)\left|\vec{V}_P\right|^2 \cos^2\alpha \sin 2\alpha}{\gamma} + \dfrac{(1/2)\left|\vec{V}_P\right|^2 \sin^2\alpha}{\sigma}\right]; \alpha \le 45^o \\ E\times 10^{-6} = \dfrac{1}{N_P}\left[\dfrac{(1/2)\left|\vec{V}_P\right|^2 \cos^2\alpha}{\gamma} + \dfrac{(1/2)\left|\vec{V}_P\right|^2 \sin^2\alpha}{\sigma}\right] \quad ; \quad \alpha > 45^o \end{cases} \quad (9)$$

In this equation, E is the erosion rate and its unit is mm3/gr. γ and σ are the cutting wear and deformation wear coefficient and are related to material properties or the body material specification. For carbon steel, their values are 33316.9 and 77419.7

III. Numerical Solution Procedure

To solve continuous phase equations, the solution domain is divided to a large number of control volumes and then discredited equations are solved using the finite volume method. The details of the solution process have been presented by Patankar [22]. It should be noted that SIMPLE algorithm is used for decoupling of pressure and velocity. The grid size becomes finer near the bend wall as shown in Fig. 1.

To demonstrate mesh independency of the numerical results, the tangential velocity at the radial cross-section of the bend is shown in Fig. 2.

The figure shows that the developed code mostly behaviour independent of grid and mesh 40*40 is used because of formation of a complete curvature in the bend area.

Also, Fig. 2 can be applied for validation of continuum phase solution that needs to solve of Navier-Stokes PDEs. It has been observed that velocity in the centre line of channel reaches to 1.5 times of fluid average velocity (Fluid input velocity). This result has a good agreement with presented analytical solutions in the flow solution references [20]. See Fig. 3 for the bend curvature grid configuration.

For equations solution of the particle, the Range-Kutta of fourth order is applied.

IV. Results and Discussion

Since Stokes number is used in the solution method, a brief definition is given as ratio of the particle response time to fluid time-scale characteristic. The Stokes number is related to three parameters as:

- Densities ratio
- Second order of the particle diameter to hydraulic diameter of channel ratio
- Reynolds number of fluid flow

In modelling of the particles motion the following assumptions are used:

- Particles have spherical shape
- The surface roughness is not included in the calculation

In this paper the collision probability of particle at different area of the bend is considered first and then obtained results are used for erosion estimation by particle. The particle track is presented for different Stokes numbers. The continuous phase is considered for two different fluids as water and air. The Reynolds numbers for the both air and water are kept same and in the laminar flow range. It should be mentioned that the density ratio is bigger than one for air and water cases. In all calculation cases the particle is started to move from the stationary condition and from the centre of distance between of the two side' walls and slightly before the bending start. See Fig. 4.

The results analysis show:

By comparing the particle path for the same Stokes numbers in air and water the results showed that the liquid cannot move (push) the particle in the flow direction and the particle changes its direction at the first half of the bend because of low flow velocity. Reynolds number is the same in both cases and assumed at laminar flow condition. It was concluded that the Stokes number is not a suitable parameter for comparison of a particle movement in two different fluids.

Comparison of particle collision location (point) in a fluid for different Stokes numbers showed that as Stokes number increases the particle impact at smaller angle of bend increases. To analyze this finding, it must be mentioned that the all three effective parameters of Stokes number have direct dependency with the particle inertia. In this paper the Reynolds number are kept constant and at the laminar flow area, thus the Stokes number change can be obtained by the change of two

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first parameters. So, by increasing Stokes number, the particle inertia increases and the particle have more tendencies to keep its movement direction without following the flow stream lines. This makes the collision angle reduces in the bend.

The other important parameter studied in this paper is the impact probability of particle at different location of bend. For this purpose change of the main three parameters of Stokes number as Reynolds number of the fluid flow, the particle diameter and the densities ratio were considered and presented in the following figures.

Fig. 5 shows the particle impact probability at different bend angle for different Reynolds number in the laminar flow field and density ratio of higher than one. With the mentioned conditions and knowing that the impact is in inner wall in density ratio greater than one, the most impact is happened between 0 up to 30°. The probability of not impacting in the bend wall and pass the bend is less than 10 percent.

Fig. 6 shows the particle impact probability at different location of bend for the different particle diameter from 50 to 500 microns. It shows that the particles with smaller diameter have higher probability to pass the bend without impact.

Fig. 7 shows the particle impact probability at different location of bend when the densities ratio changes from 100 to 700. The most impact probability happens at angles between 60 to 90°.

Finally, based on superposition of all probabilities and the final result for the particle impact probability at different bend location with respect to Stokes number it was concluded that the result for the all three location is almost similar. However, at 30 to 60° the impact is slightly lower than the other impact angles and the most impacts happens at the outer area of this zone, see Fig. 8. The velocity and the impact angle on the bend surface with respect to Stokes number were calculated and presented in Figs. 9 and 10 These figures show as the Stokes number which is particle inertia characteristic increases the impact velocity of the particle against the wall increases, but the impact angle (the tangent line direction at the same point on the bend wall) decreases. For the lower Stokes number (e.g. smaller diameter of a particle), the particle inertia is lower, so the particle can respond faster for velocity value changes near the wall that its result is lower impact velocity. On the other hand, the particle direction change in respect to wall will be delayed which cause the bigger impact angle.

The erosion rate by the particle impact, as mentioned before was estimated from Wallace and Peters' model declared in 2000. On this basis the volumetric erosion rate for a unit mass of eroded material (eroded carbon steel) was calculated by equation 9 and shown with respect to Stokes number in Fig. 11. The impact angle of particle at the bend was also shown on the same figure.

As it can be noticed from the figure, by increasing the Stokes number the particle inertia increases, so the particle deviate from its path at smaller angles and impacts the wall with higher inertia that means the erosion rate will increase.

V. Conclusion

In the present research, CFD simulation conducted on two-phase gas/liquid-solid flow in the bends by using two dimensional conservation equations at steady-state conditions. Different parameters of two-phase flow and the bend geometry and their effect on each other were considered by developing a computer code and finally the erosion rate on the wall were predicted. The following points were concluded:

- The main parameter for the study of particle motion within the fluid, which is the Stokes number, depend on flow Reynolds number, particle to fluid density ratio and the ratio of particle diameter to channel hydraulic diameter. As a result, with increasing Stokes number the particle inertia increases.
- As the Stokes number increases, the particle inertia increase will be resulted. So, the particle deviation from the flow direction and the probability of impact with wall will be increased.
- The angle of impact depends on the particle inertia and can be between 20° to 90°.
- The Stokes number for the condition that the particle can move through the bend without impacting the wall is different for the density ratio of bigger than one and smaller than one and should not be used for comparison basis.
- The erosion rate obtained from the particle impact with wall at higher Stokes number is bigger because of higher particle inertia and this happens mostly at smaller angles of the bend.
- The erosion increases with increasing the impact velocity and decreases with increasing the approach angle.

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Figures

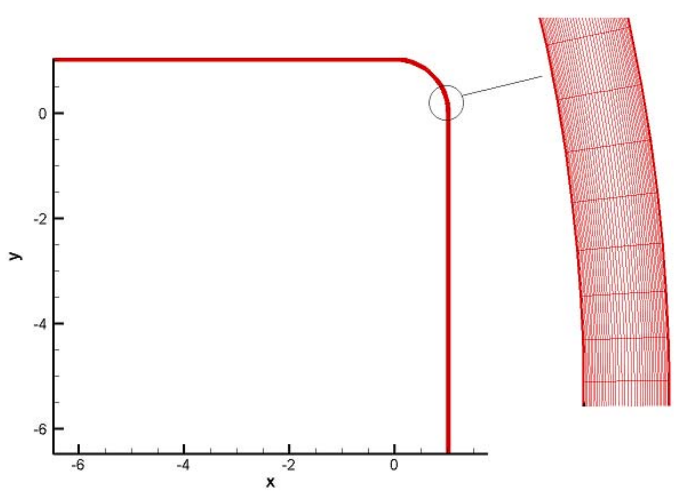

Fig. 1 : Grid configuration for flow field equations solution

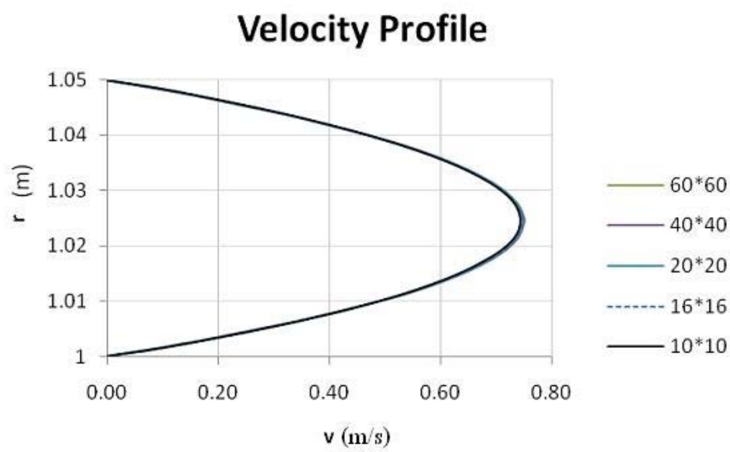

Fig. 2 : Velocity profile for grid independency study using different meshes

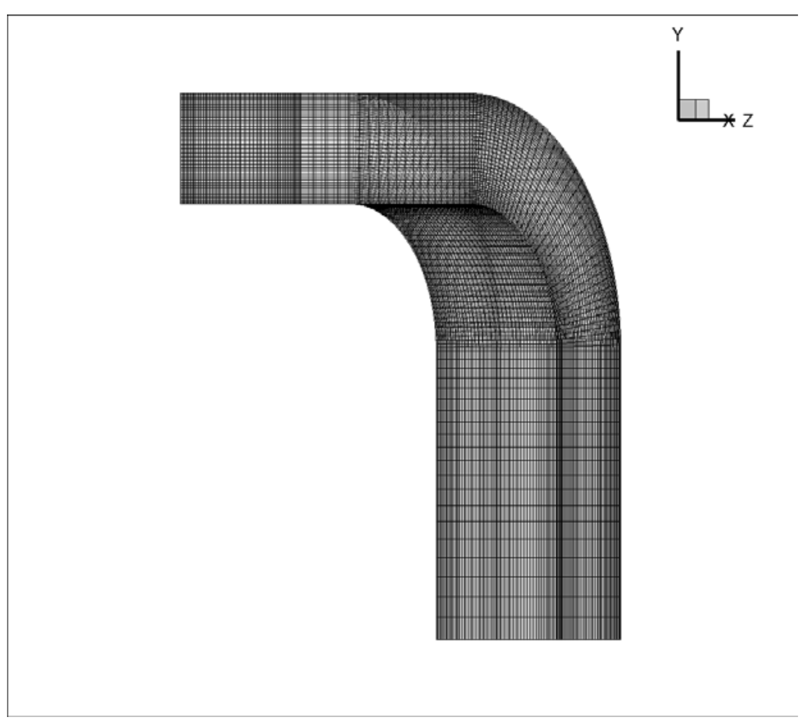

Fig. 3 : The bend curvature mesh configuration

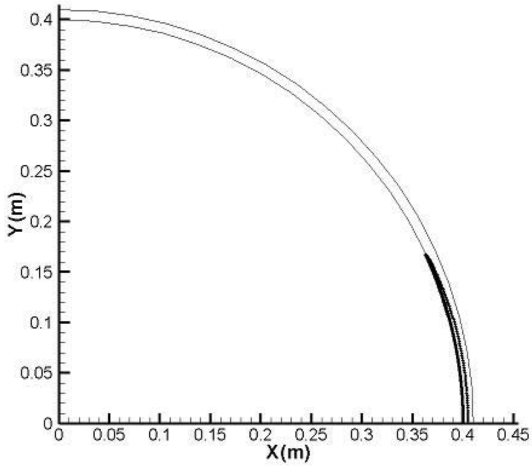

Fig. 4f, St=0.34

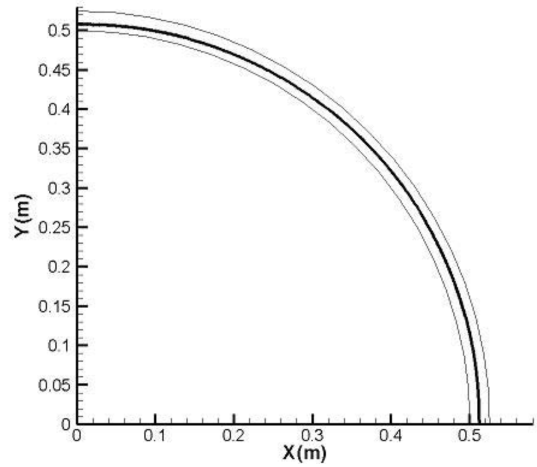

Fig. 4a, St=0.34

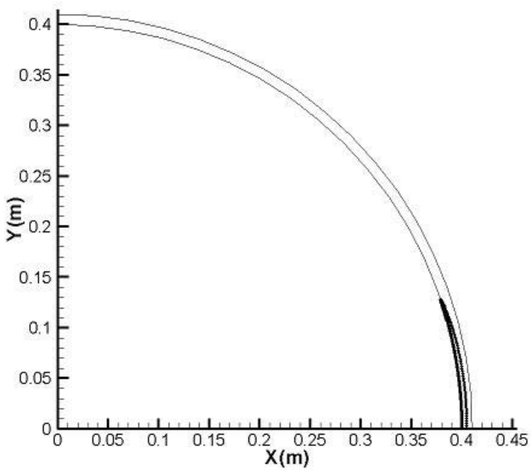

Fig. 4g, St=0.78

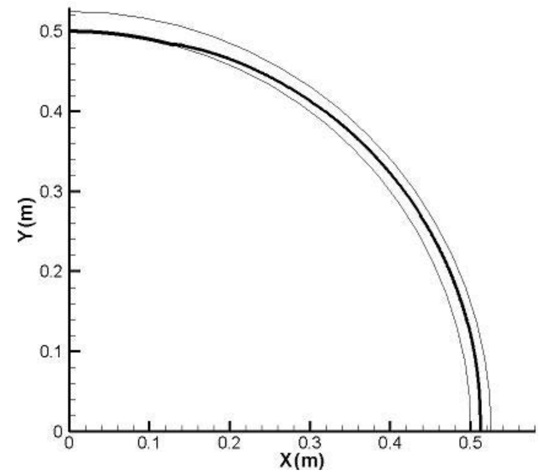

Fig. 4b, St=0.78

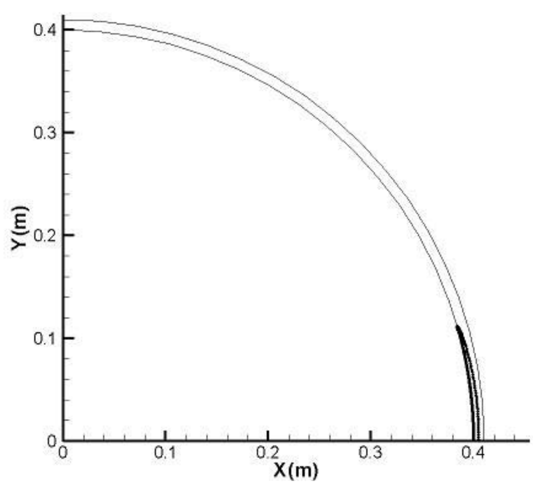

Fig. 4h, St=1.1

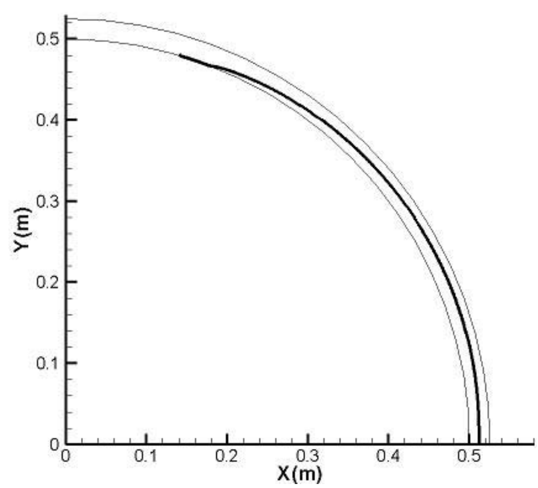

Fig. 4c, St=1.1

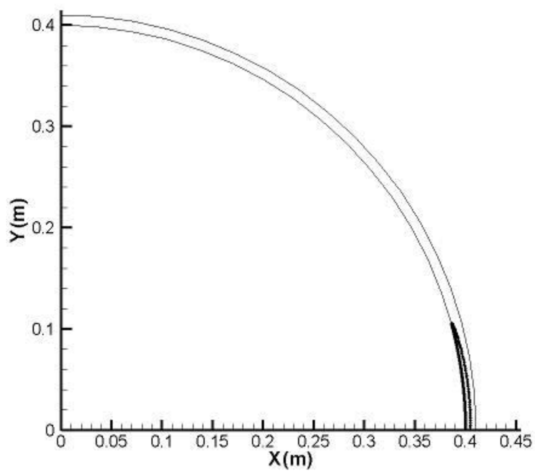

Fig : 4i, St=1.27

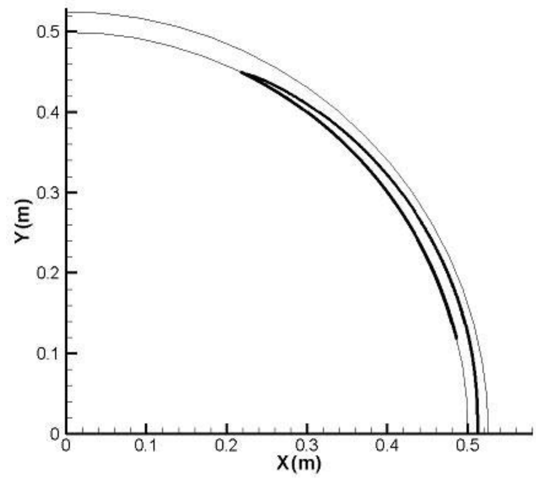

Fig : 4d, St=1.27

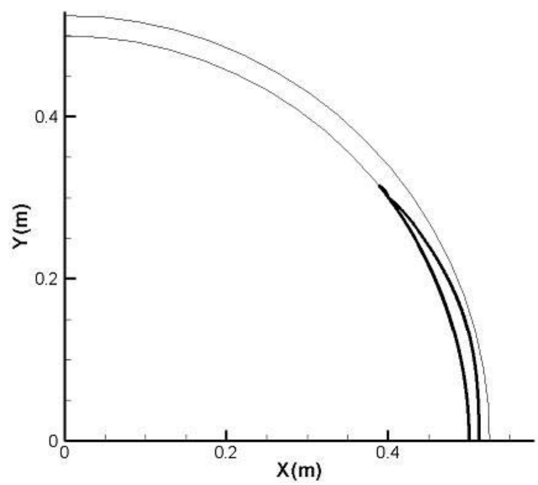

Fig : 4e, St=5

Fig. 4 : Particle movement path inside the bend for different Stokes number of 0.34, 0.78, 1.1, 1.27 and 5; a, b, c, d and e for air and f, g, h and i for water

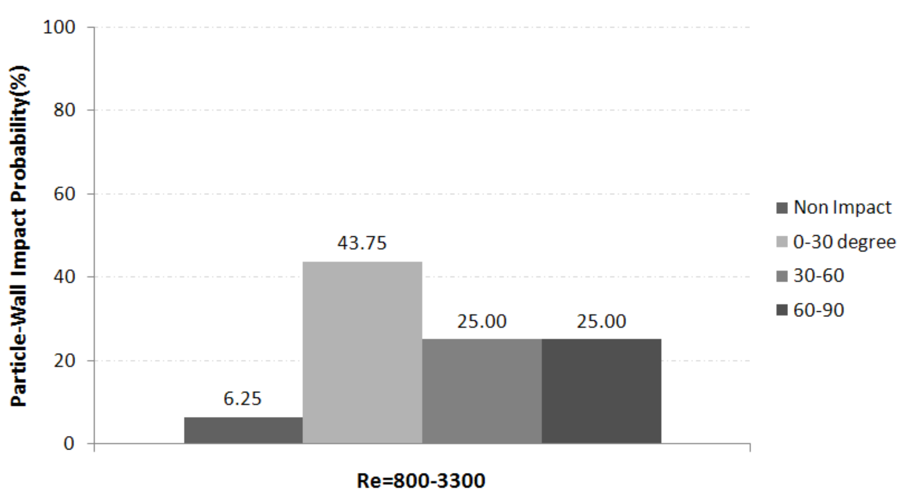

Fig. 5 : The particle impact probability at different area of bend wall by changing Reynolds number

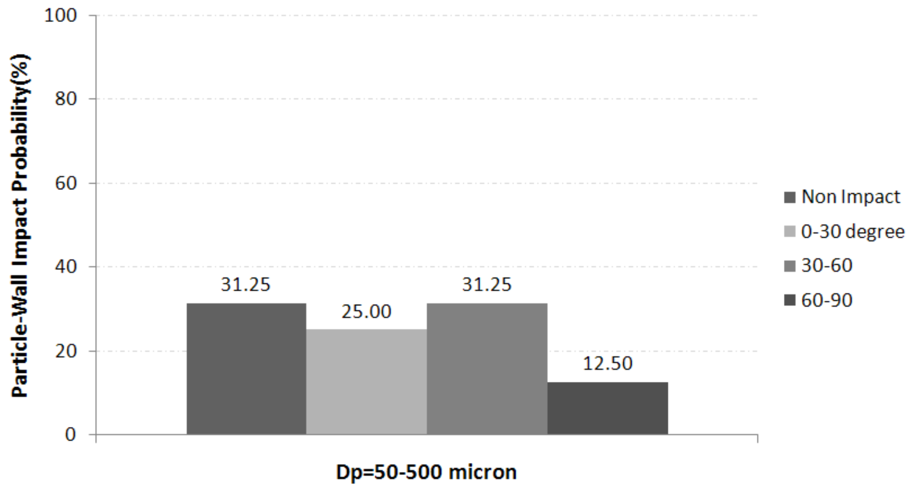

Fig. 6 : The particle impact probability at different area of bend wall by changing the particle diameter

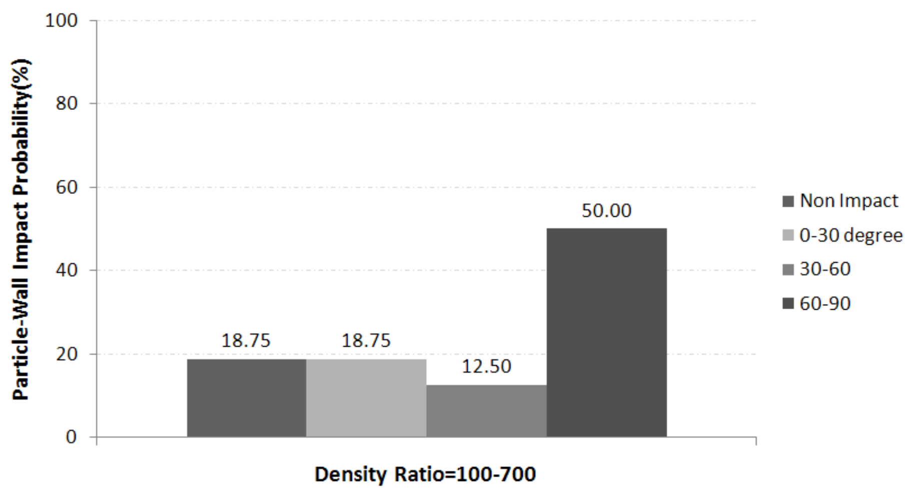

Fig. 7 : The particle impact probability at different area of bend wall by changing the density ratios

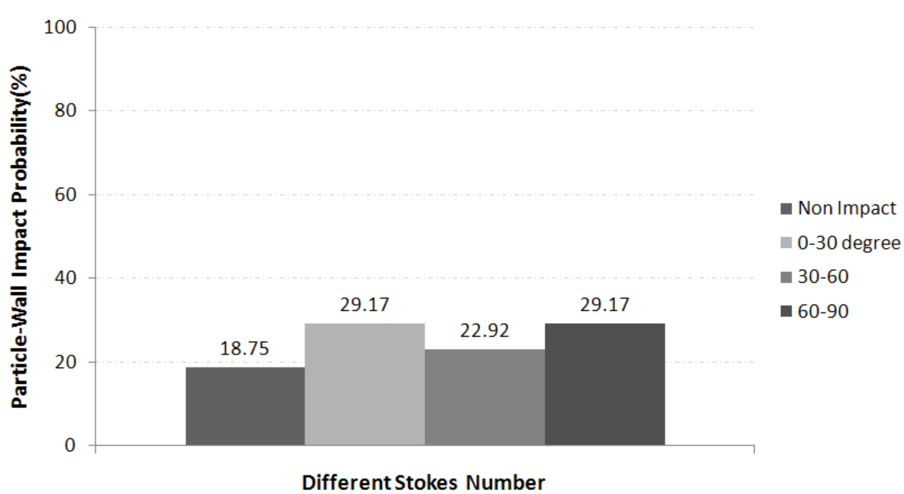

Fig. 8 : The particle impact probability at different area of bend wall for different Stokes number

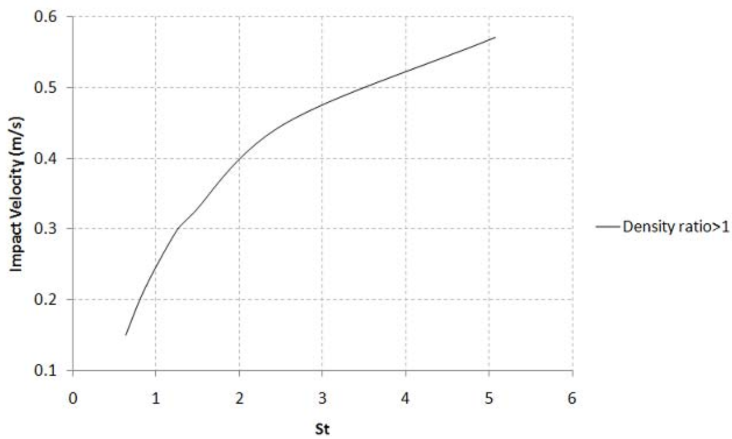

Fig. 9 : The particle impact velocity with the bend surface for different Stokes number considering the density ratio is bigger than one

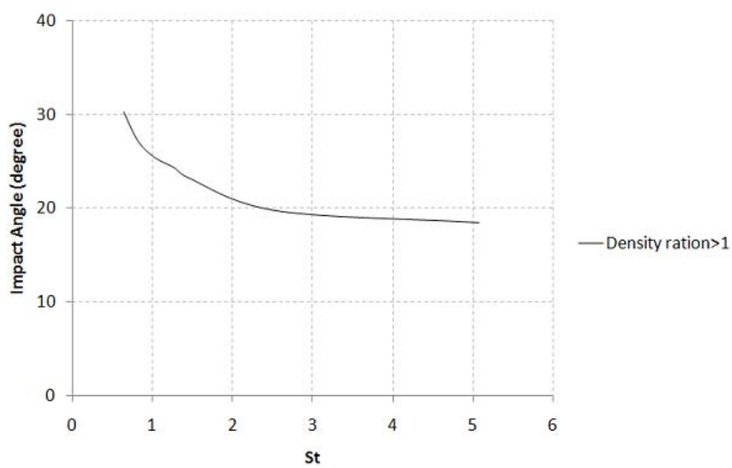

Fig. 10 : The angle between the particle impact direction and the tangent to surface at the bend wall during the particle impact for different Stokes number considering the density ratio is bigger than one

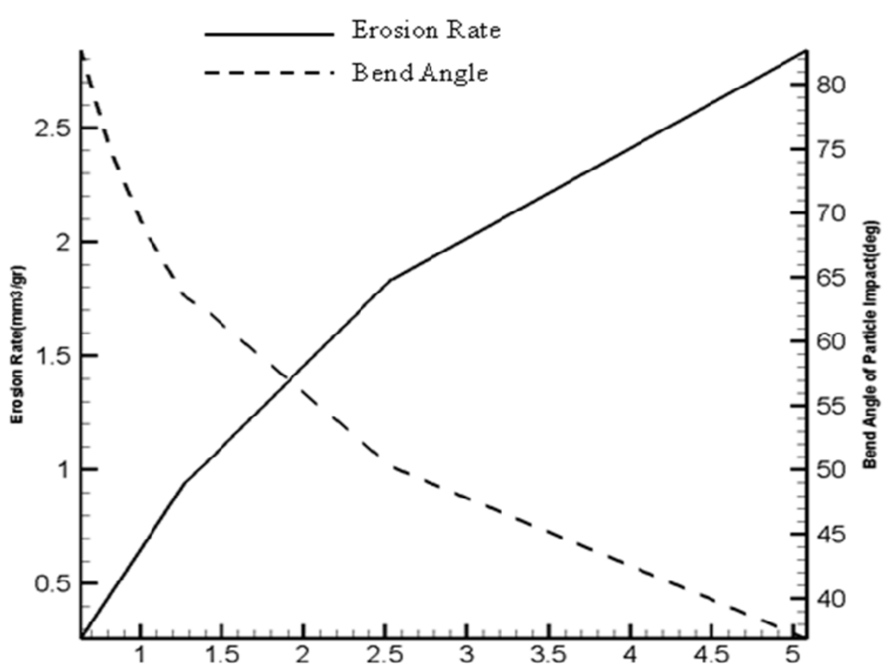

Fig11 : The particle impact angle and the erosion rate at the bend for different Stokes number

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Experimental and Analytical Modal Analysis of Welded Structure Used For Vibration Based Damage Identification

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Abstract - This paper presents a systematic procedure and details of the use of experimental and analytical modal analysis of a welded structure used for vibration based damage identification. First an experimental modal analysis was conducted on the undamaged welded structure model used for vibration based damage identification. Using impact hammer test, when the test structure is fitted to the multi-axis electro dynamic vibration shaker .In this experimental modal analysis frequency response functions are calculated from measured input force and output response of a structure using piezoelectric accelerometers from the frequency response function the peaks were identified. To compare the experimental modal analysis values finite element modal analysis was conducted using ANSYS software version 11.0. It has been observed from the results the natural frequencies obtained from the experimental modal analysis and ANSYS software version 11.0 shows a good consistency in comparison.

Keywords : Experimental Modal Analysis, Theoretical Modal Analysis, Finite Element Method, Impact Hammer, Vibration Based damage identification, Eigenvalues and Eigenvectors, frequency response function, Resonance condition.

GJRE-A Classification : FOR Code: 091304

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Putti Srinivasa Rao [α], Ch.Ratnam [Ω]

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I. Introduction

Our dependency on mechanical, aerospace, marine and civil engineering infrastructures is increasing day by day. These structures continue to be used, despite aging and the associated potential for damage accumulation. All these infrastructures are subjected to damage as a result of fatigue, overloading conditions, material degradation through environmental effects and unanticipated discrete events such as impacts or seismic events. Damage adversely affects the current or future performance of these infrastructures. Therefore, the interest in the ability to monitor the health of these infrastructures and damage identification at the earliest possible stage is very important to ensure performance standards, extend the operational lifespan, economical and maintain life-safety. Therefore the need for robust global damage identification methods that can be applied to complex structures has led to the development of methods that examine changes in the vibration parameter of the structure [1-6].

The actual implantation of vibration based damage identification using statistical process control for mechanical, aerospace, marine and civil engineering infrastructures starts with designing a proof of concept experiment. First, an excitation mechanism for vibration testing should be selected. The excitation methods fall into the two general categories of ambient and forced excitation methods. During ambient excitation, the input to a system is not generally measured. In contrast, excitation forces are usually applied in a controlled manner and measured when the forced excitation method is employed [7]. A resonance condition exists when the frequency of excitation due to any source coincides with a natural frequency of the structure. Therefore it is necessary to know the natural frequencies of the structure to be monitored prior to the experimentation. The modal analysis primarily concerns determination of natural frequencies and mode shapes of a dynamic structure. Once the modes are determined, they can be used in understanding the dynamic nature of the structure. Therefore Modal analysis is an important tool in vibration analysis, diagnosis, design, and control.

Vibration is a repetitive, periodic, or oscillatory response of an engineering structure. The rate of the vibration cycles is termed “frequency”. Vibrations can naturally occur in an engineering structure and may be representative of its free and natural dynamic behavior. Vibrations may also be forced onto a structure through some form of excitation [8]. The excitation forces may be either generated internally within the dynamic system, or transmitted to the structure through an external source. When the frequency of the forcing excitation coincides with that of the natural motion, the structure will respond more vigorously with increased amplitude. This condition is known as resonance, and the associated frequency is called the resonant frequency. Natural, free vibration is a manifestation of the oscillatory behavior in engineering structures, as a result of repetitive interchange of kinetic and potential energies among components in the structure.

Complex vibrating structures usually consist of components that possess distributed energy storage

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and energy dissipative characteristics. An engineering structure, when given an initial disturbance and allowed to execute free vibrations without a subsequent forcing excitation, will tend to do so at a particular "preferred" frequency and maintaining a particular "preferred" geometric shape. This frequency is termed a "natural frequency" of the structure, and the corresponding shape (or motion ratio) of the moving parts of the structure is termed a "mode shape." Any arbitrary motion of a vibrating structure can be represented in terms of its natural frequencies and mode shapes.

The limitations of the human mind are such that it cannot grasp the behavior of its complex structures in one operation. Thus the process of subdividing all complex structures into their individual components or "Finite elements" whose behavior is understood very easily, then rebuilding the original complex structures from the individual components or "Finite elements" to study its behavior. The term finite element was first used by Clough in 1960 [9] and gives the basic idea of Finite element method. The finite element method is a numerical method but is more general and powerful in its application to real world problems that involves complicated physics, geometry and/or boundary conditions. Engineering application of the Finite element method may be used in the three major categories of boundary value problems, namely 1) Equilibrium problems 2) Eigenvalue problems 3) Propagation or Transient problem

The generalized problem in free vibration is that of evaluating an Eigenvalue which is a measure of the frequency of vibration together with the corresponding eigenvector indicating the mode shapes. Actually the Eigenvalue problem may be considered as extension of the equilibrium problem in which critical values of certain parameters are determined in addition to the steady state configurations. The Eigenvalue-eigenvector calculation procedure falls into the three basic categories namely characteristic polynomial technique, vector iteration method and transformation method.

Aiming to investigate the vibration phenomena occurring in test structure first an experimental modal analysis (EMA) was conducted. The rapid development of finite-element techniques accompanied by tremendous technological progress in the field of personal computers allowed structural designers to use software packages like ANSYS for accurate simulation of structural behavior. In this work the experimental modal analysis (EMA) values are compared with the results obtained from ANSYS software version 11.0.

The main purpose of this paper is to present our perspective concerning the evolution of modal analysis of the test structure used for vibration based damage identification, experimentally and compared the results obtained from ANSYS software package version 11.0.

II. Specifications of the Test Structure

The applicability of the proposed vibration based damage identification technique to structural health monitoring problems is implemented using the cantilever plate like structure. The geometry considered for this purpose is shown in Fig 1, where the two plates are welded to form a cantilever plate. The thicknesses of both the plates are 12 mm and are made up of carbon steel. The dimension of the first plate is 150 mm x 150 mm square plate and it is drilled with four 8 mm through holes at each corner of the plate. The centre of the drilled holes is at 18 mm from each corner of the plate. The dimension of the second plate is 150 mm x 100 mm and is welded to the plate one to form a cantilever plate like structure. The elastic module of the structure material (E) is 200×10^9 N/m^2, Poisson's ratio 0.3 and the mass density is 7850 kg/m^3. The test structure is fitted to the multi axis electro dynamic vibration shaker with the help of four bolts and nuts as shown in Fig. 1

Fig.1 : Test Structure fitted to the Multi Axis Electro Dynamic Vibration Shaker

III. Experimental Modal Analysis(EMA)

Modal analysis is vital to understand and optimize the inherent dynamic behavior of structures, leading to lighter, stronger, and safer structures with better performance. Experimental modal analysis is based on determining the modal parameters by testing, unlike analytical modal analysis, where the modal parameters are derived from finite element models (FEMs). There are two ways of doing experimental modal analysis [10-15]. They are 1) Classical modal analysis and 2) Operational modal analysis. In classical modal analysis frequency response functions (or impulse response functions) are calculated from measured input forces and output responses of a structure. Most of the analysis in modal testing is performed in the frequency domain inside the analyzer.

The task of the analyzer is to convert analog time domain signal into digital frequency domain information compatible with digital computing and then to perform the required computations with these signals. Operational Modal Analysis is based on measuring only the output of a structure and using the ambient and operating forces as unmeasured input. It is used instead of classical mobility-based modal analysis for accurate modal identification under actual operating conditions, and in situations where it is difficult or impossible to control an artificial excitation of the structure. Classical modal analysis is a more mature technique in comparison to operational modal analysis, and is extremely useful in the design of engineering structures. Enhanced computing power and advances in finite element analysis (FEA) techniques have increased the fidelity of analytical model and in several cases have reduced the need for classical modal analysis, especially with legacy structures. However, classical testing will continue to be required to give engineers the confidence they need to continue to bring new product into development in today's competitive market. Classical modal analysis relies heavily on adhering to the four primary assumptions: 1) observability, 2) linearity. 3) time invariant and 4) reciprocity.

When a modal test is performed on a test structure the objective is to measure data from which the modal parameters - modal frequencies can be estimated. The most typical data used for parameter estimation are frequency response functions (FRFs), which use excitation input and the corresponding output of the test structure. Transient excitation is an input of short duration relative to the measured time record in contrast to random or sine inputs. The versatility of transient excitation techniques allows for several advantages over typical vibration shaker input. Quick diagnostics of structures with short setup times are possible. The most commonly used method of transient excitation for modal testing is the impact hammer. The impact hammer used to excite the test structure during experimental modal analysis is shown in Fig. 2.

Fig. 2 : Impact Hammer

The idea of exciting a structure with an impact hammer actually involves striking the structure at a particular location and in particular direction with an impact hammer as shown in Fig. 3. Instrumented with a force transducer located behind the tip, the impact hammer measures the force used to excite the structure.

The force input and corresponding responses are then used to compute the FRFs. The FRFs obtained from the impact hammer test is shown in Fig.4. Testing with impact hammer has some very distinct advantages. The input spectrum from the impact is flat out to the roll-off frequency with no holes in the spectrum. The technique can be very efficient and portable compared to the aligning and moving of shakers and their associated control systems.

Fig. 3 : Experimental setup for Impact Hammer test

The natural frequencies of the test structure which were identified with the peaks in FRFs plot and the values up to five kHz are tabulated in table 1.

Table 1 : Result Obtained From Experimental Modal Analysis (Impact Hammer Test)

Mode Number	Natural Frequency in Hz
1	862.5
2	1737.5
3	2159.4
4	2631.3
5	4050.0

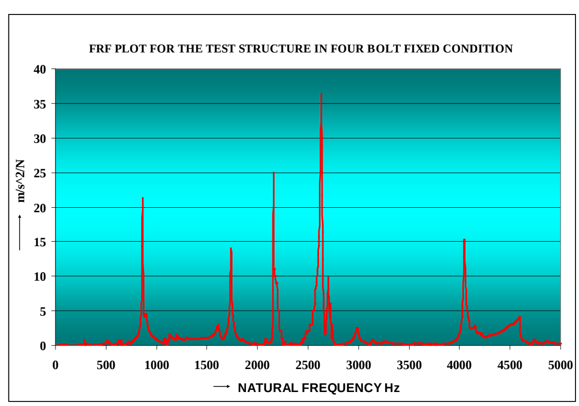


Fig.4 : Impact Hammer FRFs Measured from the Test Structure

IV. Modal Analysis Using Ansys

In this application the plate is subjected to transverse loads and in-plane loads and at any point inside the plate experiences both in-plane and lateral displacements. The natural frequencies for the test structure are calculated using SHELL63 element in ANSYS software version 11.0. SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted for the SHELL63 element. The element has six degrees of freedom at each node i.e., translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

The geometry, node locations, and the coordinate system for SHELL63 element are shown in Fig.5. The SHELL63 element is defined by four nodes, four thicknesses, elastic foundation stiffness, and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. In this application the thickness of the element is constant. The elastic foundation stiffness (EFS) is defined as the pressure required to produce a unit normal deflection of the foundation. The elastic foundation capability is bypassed if EFS is less than, or equal to, zero.

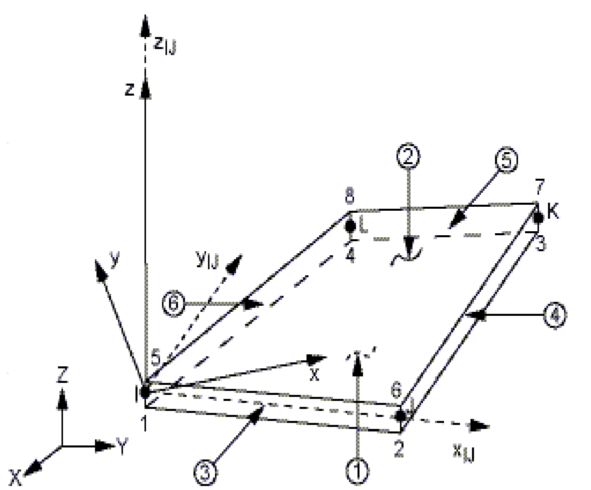
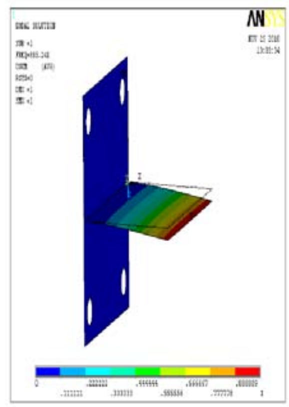


Fig.5 : SHELL63 Element Geometry

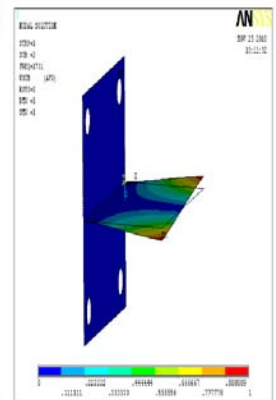
Table 2 : Results Obtained From Ansys Software Package Version 11.0

Mode Number	Natural Frequency in Hz
1	885.2
2	1731.0
3	2164.0
4	2626.0
5	4053.0
6	5454.0
7	6752.0
8	6859.0
9	6957.0

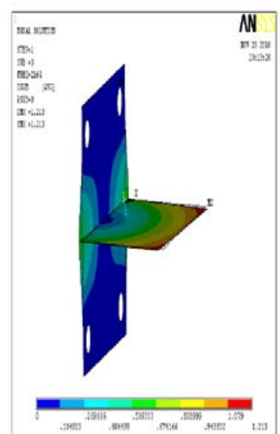
The total number of nodes generated in the meshing of the test structure is 1289, and the total number of elements is found to be 1164. The first nine natural frequencies for the test structure are then calculated and the values are tabulated in table 2. The resultant deformation at each natural frequency and corresponding figures are given in Fig 6.



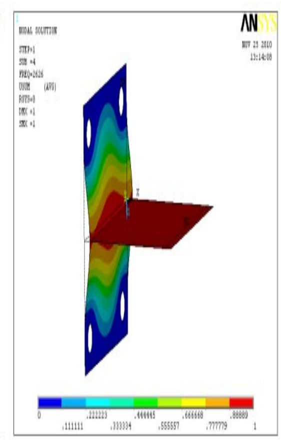
First Natural Frequency



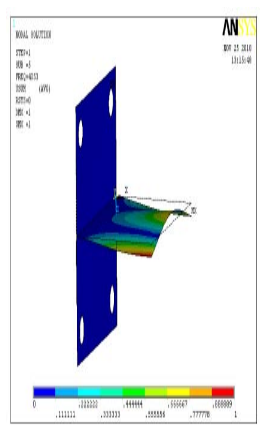
Second Natural Frequency



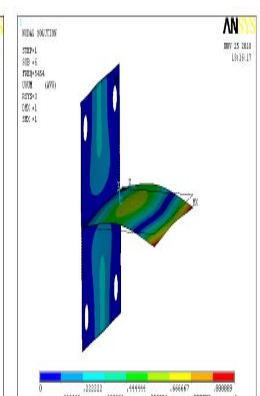
Third Natural frequency



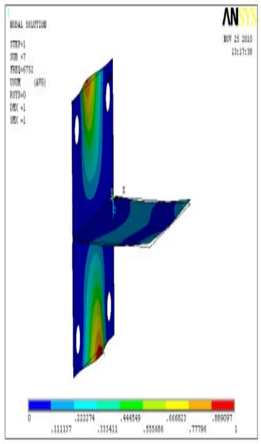
Fourth Natural Frequency

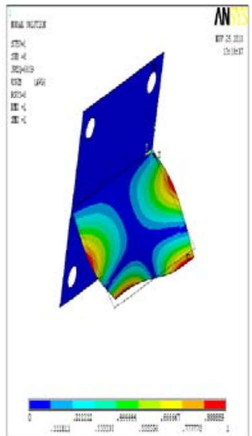


Fifth Natural Frequency

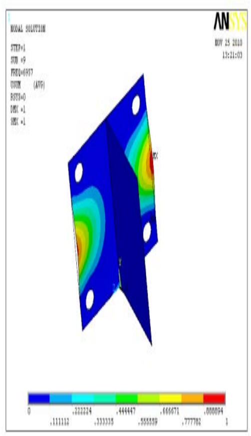


Sixth Natural frequency





Seventh Natural Frequency Eighth Natural Frequency



Ninth Natural frequency

Fig.6 : First Nine Natural Frequencies of the Test Structure

V. Results and Discussions

The actual implantation of vibration based damage identification using statistical process control for mechanical, aerospace, marine and civil engineering infrastructures starts with designing a proof of concept experiment. First, an excitation mechanism for vibration testing should be selected. The excitation methods fall into the two general categories of ambient and forced excitation methods. A resonance condition exists when the frequency of excitation due to any source coincides with a natural frequency of the structure. Therefore it is necessary to know the natural frequencies of the structure to be monitored prior to the experimentation. Experimental and analytical modal analysis of a welded structure used for vibration based damage identification was conducted.

The natural frequencies obtained from the experimental modal analysis using impact hammer test and finite element modal analysis using ANSYS version 11.0 software package were compared. It has been observed that the natural frequencies obtained from the experiment are almost coinciding with the ANSYS results. The table 3 shows the comparison of natural frequencies obtained from the experiment and ANSYS; and it shows a quite satisfactory correlation.

Table 3 : Comparisons Of Natural Frequencies

Mode Number	Natural Frequencies of the test structure in Hz	
	Experimentally	ANSYS
1	862.5	885.2
2	1737.5	1731.0
3	2159.4	2164.0
4	2631.3	2626.0
5	4050.0	4053.0
6	--	5454.0
7	--	6752.0
8	--	6859.0
9	--	6957.0

VI. Conclusions

This paper presents a systematic procedure and details of the use of experimental and analytical modal analysis of a welded structure used for vibration based damage identification. It has been concluded from the results that the natural frequencies obtained from the experimental modal analysis and ANSYS software version 11.0 shows a good consistency in comparison.

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Lean Sigma A Road to Success: A Perspective of the Indian Automobile Industry

By Saif Imam, Ashok Tripathi, Sudipto Sarkar
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Keywords : Lean manufacturing, Six sigma, Value-stream mapping, SMED, DMAIC.

GJRE-A Classification : FOR Code: 090299

LEAN SIGMA A ROAD TO SUCCESS A PERSPECTIVE OF THE INDIAN AUTOMOBILE INDUSTRY

Strictly as per the compliance and regulations of:

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Saif Imam [α], Ashok Tripathi [Ω], Sudipto Sarkar [β]

Abstract - The globalization of the auto industry increasingly fosters the formation of new alliances. As a resultant of this the automobile Industry in India is now working in terms of the dynamics of an open market. In order to achieve a breakthrough profit performance in a tight competitive environment and with the shadow of a never ending recession looming over, it is necessary to have a single heuristic approach to fight against the adversities of the market. In order to capitalize on the opportunities, the industry needs to develop or acquire technologies and capabilities to produce vehicles that meet future market needs. Thus, with respect to these factors this paper aims to develop lean sigma model for automobile industry and reveal the different processes involved in the manufacture of automobile. This paper also gives a brief review of the history of Indian Automobile Industry and summarizes the developments in the course.

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I. Introduction

Automotive industry is the key driver of any growing economy. It plays a pivotal role in country's rapid economic and industrial development. It caters to the requirement of equipment for basic industries like steel, non-ferrous metals, fertilizers, refineries, petro-chemicals, shipping, textiles, plastics, glass, rubber, capital equipments, logistics, paper, cement, sugar, etc. It facilitates the improvement in various infrastructure facilities like power, rail and road transport. Due to its deep forward and backward linkages with almost every segment of the economy, the industry has a strong and positive multiplier effect and thus propels progress of a nation.

The Indian automobile industry at present is experiencing an unprecedented boom in the demand for vehicles of all types. This boom has been primarily stemmed from two major factors; firstly, because of the rise in the disposable incomes and the standard of living of the middle class Indian families and secondly due to the Indian government's liberalization measures such as relaxation of the foreign exchange and equity regulations, reduction of tariffs on imports, and banking liberalizations. Industry watchers have predicted that the passenger vehicle sales will triple in the next five years to about one million, and as the market grows and the customer's purchasing abilities rise, there will be greater demand for high-end luxurious models also which currently constitute only a tiny fraction of the market. These trends have encouraged many giant multinational automakers to enter the Indian market. This is just one face of the coin. To get a better idea let us take a brief history of the Indian Automobile Industry.

a) *History of the Indian Automobile Industry*

For several years after India's independence from the British in 1947, the Indian car market was dominated by two localized versions of ancient European designs -- the Morris Oxford, popularly also known as the Ambassador, and an old Fiat. This was mainly due to the Indian government's complex regulatory system that effectively banned foreign-owned operations. Within this system, any Indian firm that wanted to import either technology or products needed a license from the government. The tedious process of obtaining these licenses stifled automobile and component imports. As a result of this, the Indian automobile industry had become a low volume and high cost car industry that was not only inefficient and unprofitable, but also technologically obsolete. Pingle (2000) reviews the policy framework of India's automobile industry in which he stated that the Indian Government was characterized by socialist ideology resulting in protection to the domestic auto industry and entry barriers for foreign firm between 1940's and 50's. During the next phase of rules, regulations and politics, the Indian auto industry was affected by many political developments and economic problems especially for passenger car segment. This is the period between in 1960' and 70's. In the early 1980's considering it as a third phase it was characterized by delicensing, liberalization and opening up of FDI in the auto sector. Narayanan (1998) analyses the effects of deregulation policy on technology acquisition and competitiveness in the Indian automobile industry during the 1980s and finds that competitiveness has depended on the ability to build technological advantages, even in an era of capacity-licensing. These policies resulted in the establishment of new LCV manufacturers. In the early

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1980's, the Indian government made a few efforts, all though limited, at reforming the automotive industry and thus initiated a joint venture with Suzuki of Japan. This landmark joint-venture called Maruti Udyog Limited launched a small but fuel efficient model priced at about $5,500.This new product perfectly caught the fancy of the Indian people and became an instant rage. In 1991, the government further initiated a series of economic liberalization measures designed make the Indian economy porous to foreign investment and trade. In 1993, the Indian government brought a wave of FDI to India's vehicle industry. Import barriers have been progressively relaxed. Today, almost all of the major global players are present in India. The automotive industry is today a key sector of the Indian economy and a major foreign exchange earner for the country. The government further followed up its earlier liberalization measures with significant reductions in the import duty on automobile components. As a results of these measures, the automotive industry experienced growth rates of above 25% which have been increasing since.

b) Present Scenario and scope for future

Based on the data available at Business portal of India, India is the world's second largest manufacturer of two wheelers, fifth largest manufacturer of commercial vehicles as well as largest manufacturer of tractors. It is the fourth largest passenger car market in Asia as well as a home to the largest motor cycle manufacturer. The installed capacity of the automobile sector has been 9,540,000 vehicles, comprising 1,590,000 four wheelers (including passenger cars) and 7,950,000 two and three wheelers. The sector has shown great advances in terms of development, spread, absorption of newer technologies and flexibility in the wake of changing business scenario. In the past two years, a number of multi-national firms have announced plans to enter the Indian market.

Besides, the announcement of 'Automotive Mission Plan' for the period of 2006-2016 is a major step taken to make India a global automotive hub. The Mission Plan aims to make India emerge as the destination of choice in the world for design and manufacture of automobiles and auto components, with output reaching a level of US$ 145 billion (accounting for more than 10% of the GDP) and providing additional employment to 25 million people by 2016. It envisages increase in production of automotive industry from the current level of Rs. 169000 crore to reach Rs. 600000 crore by 2016. McKinsey (2005) predicts the growth potential of India-based automotive component manufacturing at around 500 per cent, from 2005 to 2015.The Mission seeks to oversee the development of the automotive industry, that is, the present scenario of the sector, its broad role in the growth of national economy, its linkages with other key facets of the economy as well as its future growth prospects. This is involved in improving the automobiles in the Indian domestic market, providing world class facilities of automotive testing and certification as well as ensuring a healthy competition among the manufacturers at a level playing field.

The future challenges for the Indian auto industry in achieving the targets defined in the Automotive Mission Plan would primarily consist of developing a supply base in terms of technical and human capabilities, achieving economies of scale and lowering manufacturing costs, as well as overcoming infrastructural bottlenecks. While, the role of industry is primarily of designing and manufacturing products of world-class quality standards, establishing cost competitiveness, improving productivity of both labour and capital, achieving scale and R & D enhancing capabilities as well as showcasing India's products in potential markets.

As can be inferred from the literature, the emergence of foreign companies into the Indian market will lead to a tough competition amongst the indigenous companies to remain in the market. The need of the hour in today's highly competitive global economy requires even the most well established manufacturers to continuously improve their quality while reducing costs. This has become an essential for their survival. With the tight budget constraints and cost cuts, producing more with less has become the key to market leadership and sustainable competitive advantage. Changing production methods from mass production with high inventory to a leaner operation with low inventory has become an essential for successful manufacturers. As the concept of Lean six sigma satisfies both cost and quality constraints related to both products and services, many organizations would want to adapt the same.

II. Literature Review: Lean Sigma

The concept of mass production was established in the early 19^{th} century by Henry Ford (1913). This formed the building block for systemization of Lean production. Later in the century, at the end of the Second World War, the scarcity of resources coupled with intense domestic competition in the Japanese market for automobiles led to further innovations. Taiichi Ohno (1988) a former executive vice president of Toyota furthered the concept of Henry Ford and focused on the elimination of waste and tailored a more efficient production system according to the need of the Japanese market. Initially during the 1950's, this work was applied basically to car engine manufacturing followed by vehicle assembly in the 1960's and then to wider supply chain. This production philosophy was widely known as the Toyota production system in Japan. It was only in 1986 that Womack and Jones (1990) labeled it as "Lean Production and Lean thinking". The term Lean was used by John Krafick (1988) to describe the new production techniques that were used at Toyota.

The five key principles of Lean as identified of Lean Thinking given by Womack and Jones (1996) include:

1. Elimination of waste (or muda in Japanese);
2. The identification of the value stream;
3. The achievement of flow through the process;
4. Pacing by pull (or kanban, a Japanese term) signal;
5. The continuous pursuit of perfection.

According to Womack and Jones (1990) Lean refers to the total enterprise, from the shop-floor to the executive suite and from the supplier to customer value chain. It optimizes the skills of the workforce by encouraging continuous improvement activities and aims at achieving perfect value by the elimination of waste. By the application of Lean processes, an organization basically aims at being able to manufacture a large variety of products of high quality at a lower cost within a lesser time and with less investment. Between late eighties and early 90's lean concentrates on the shop floor. Later in the 1990's, Lean had moved away from a "shop floor focus" on waste and cost reduction to a more customer centric approach, where it tried to increase value to customers by adding product features and eliminating wasteful activities linked to customer requirement. Lean is defined by Womack and Jones (1994) as the systematic removal of waste by all members of the organization from all areas of the values stream. Kannan and Tan (2005) have referred Lean as a cost-reduction mechanism, which strives to make organizations more competitive in the market by increasing efficiency, decreasing costs incurred due to elimination of non value-adding (VA) steps and inefficiencies in the processes, at the same time simultaneously reduces cycle times and increases profit for the organization. This is achieved by identifying and removing wasteful activities with the help of the tool known as value stream mapping in lean terminology. With the help of this, analysis can also be done on the activities in the process. Value stream represents the "flow of value" to these organizations. Worley and Doolen (2006) made an analysis primarily based on identifying activities that add value to the product or activities. They classified this as muda- the Japanese word for waste. Kannan and Tan (2005) also found that waste can be found in all activities in the value stream, especially where the product moves from one department to another. Taj and Berro (2005) claimed that many manufacturing companies waste over 70 percent of their resources. Jones et al (1997) examined that for many organizations, less than 10 percent of activities often are value adding and as much as 60 percent do not add any value at all. Similarly, Bhasin and Burcher (2006) identified that implementing Lean can reduce waste by 40 percent and recognized seven typical forms of waste as overproduction, waiting, transportation, inappropriate processing, excess inventory, unnecessary motion, and defects. According to Claycomb et.al. (1999) the lean system promotes conditions necessary to manufacture high quality products to meet market demand with relatively small levels of inventory. Here, holding costs can be diminished by ordering the materials whenever needed and producing the items as per the forecasted demand. As a result, "companies have substantially cut lead times, drastically reduced raw material, work-in-process and finished goods inventories, and effectively increased asset turnover".

Brady and Allen (2006) reviewed that Six Sigma concepts were developed at Motorola through the efforts of Bill Smith, a reliability engineer, in the 1980s. This method was adopted by many US Companies, including GE and Allied Signal. It was in fact through the work of Jack Welch, the CEO of GE in 1995, that Six Sigma found its popularity amongst companies. The term "Six Sigma" refers to a statistical measure of defect rate within a system. This typically presents a structured and systematic approach to process improvement, aiming for a reduced defect rate to 3.4 defects for every million opportunities. Pande et.al. (2000) stated six sigma is a strategic, company-wide approach which helps in reducing costs of a project and increasing customer satisfaction by focusing on reducing variations. George (2002) reviewed that six sigma uses tollgate at the end of each phase. These five tollgate or phases are: define, measure, analyze, improve, and control (DMAIC). This DMAIC methodology is designed specifically for improvement of existing processes which helps in reducing costs of a project and increasing customer satisfaction by focusing on reducing variations. Pojasek (2003) mentioned using statistical methods, organizations are able to understand fluctuations in a process, which allows them to pinpoint the cause of the problem and subsequently help in improving the process by eliminating root causes, and controlling the process to make sure that the defects do not reappear. According to Sower et.al. (1999) the root of six sigma lies in the concept of total quality management where everyone in an organization is responsible for the quality of goods and services produced by the organization. Apart from this, the other components of Six Sigma that can be traced to Total Quality Management (TQM) include the focus on customer satisfaction when making management decisions, and a significant investment in education and training in statistics, root cause analysis, and other problem solving methodologies.

Lean Six Sigma is a widely applied program for company wide quality improvement. It is the synthesis of Six Sigma and Lean. Using one of these tools has limitations. Since lean eliminates the use of Six Sigma's DMAIC cycle on the other hand, Six Sigma eliminates defects but does not address how to optimize the process flow. Hence, applying both Six Sigma and Lean tools sets results in far better improvements than could be achieved with either one method alone.

III. Methods and Meth

Based on an extensive research of the available data 5 major automobile industries in and around the Indian capital were shortlisted. After obtaining due permission from the concerned authority a survey was conducted. This survey was based on the individual visits to the shop-floor in order to understand the manufacturing processes involved in each industry. Along with this a detailed subjective interview of the employees of these industries was conducted. The employees interviewed belong to different levels of the industrial hierarchy from shop floor technicians to the production managers. Further details about the operating processes was obtained from the officially available data in the form of magazines and the other brochure of the companies. From the information collected on the basis of aforesaid sources the following details were collected.

a) Major Components of Production Division

Major Components of Production Division in the Automobile Industry are; Press Shop and Blanking Line, Weld Shop, Paint Shop, Engine Assembly, Assembly Shop, Machine Shop Materials, Casting, Engine, Vehicle Inspection.

Press shop : Press shop can be regarded as the starting point of the car manufacturing process. The weld shop as per the requirements picks the finished body parts from the press shop. These may be sub divided as according to size of blanks. Like 'A' components are large outer components as for example roof, door panels etc. Press Shop produce sheet metal components for different models.

Press shop has Press machines it can be according to the capacity of the press shop ranging from 4000 ton to 22000 ton in terms of total capacity i.e. draw, trim, pierce, bend, re-strike & 1 Tandem line. Coil processing lines (ROSL – Shear line & Blanking line). Capacity can be of 55,000 strokes / day from 400 tons of steel coils. Mass production presses are continuous flow transfer presses. Set of 4 to 5 dies are mounted on single press & complete panel comes out from press after going through stamping, trimming & piercing. Steel coil which are CRS coils made up of mild steel is a raw material used to make body sheet metal parts. Its thickness ranges from 0.65 mm to 0.8 mm & weight from 1 ton to 4 tons. Steel coils are received in bulk quantities & stored at a centralized storage & supplied to blank cutting areas as per plan. Steel coils are fed to Blanking & ROSL lines by overhead EOT cranes. Sheet is first de-coiled, cleaned, oiled & fed to cutting or shearing areas of blanking or ROSL lines. Coils are fed to blanking line & continuous supply of sheet to cutting dies result in shaping of coils to plan blanks. Blanks are cut by stamping or shearing process & are stacked one by one to form large mass of blanks. The stacks of blanks are further sent to press machines for forming into shape of body panels. Blanks are supplied to press lines for pressing. Blanks are converted to body panels by this process. Panels are stored in pallets which are supplied to Weld Shops for making White Bodies.

Fig.1 : Shows the cutout panels are stacked properly together in a trolley in order to maintain 5-S culture.

Types of Panels

1. External (skin) panels, such as fenders, bonnet, decklid, roof, side panels, doors, etc. Some of these are two panels in a set as left hand and right hand
2. Internal mating panels, such as bonnet inner, decklid inner or door inner deciding subassembly quality
3. Dimensionally critical inner panels that are complicated either because of their complex shape or severe draw condition, such as, floor pans, dash panel, etc.

Fig.2 : A completed panel after press work

The body panels produced in the press shop and the other small components are joined here to give the "white body" or "shell". In a typical car body 1400 different components are welded together. The weld shops should have the following facilities; Welding jigs, Spot welding guns, welding robots, hemming machines, punching machines. The weld shop has different lines for different models, each of, which is further divided into three parts:

1. Under Body: Here different underbody panels are welded together. These comprise of rear underbody, central underbody and front engine room panel. These underbodies are put on the conveyor and welded together to give the underbody.
2. Main Body: As the body moves on, the conveyor roof and side body panels (prepared on the sub lines) are welded to it to give the main body. The chassis number is punched on the cowl top and it is welded to the front engine room panel.
3. White Body: The doors, hood and back door are attached on the main body with the help of bolts and screws to make it a “white body”. The body is checked for dent, burr and spatter and these defects are repaired. It is sent to the paint shop thereafter.

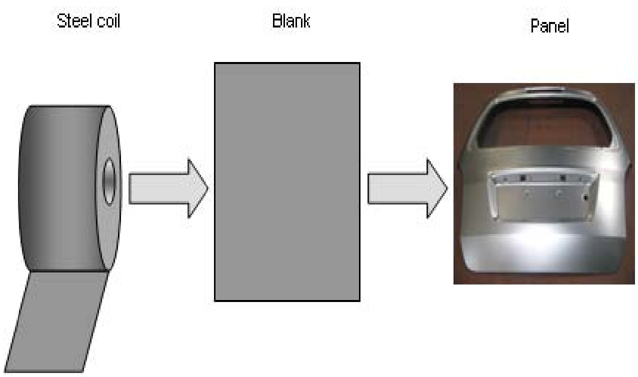

Fig.3 : Shows how steel coils are being cut before converting it into the panel

Paint Shop:

In the paint shops following processes are carried out; there are five plants/units that provide a uniform painting over the white body coming from the weld shop. In paint shop all the models are painted on the same line. Inside portion of vehicle is painted manually and outside is by Robots. After inspection and touch up the ready body is sent to the assembly shop.

The five units of the paint shop are;

1. Pre-treatment (PT): The body is thoroughly washed to remove the dirt and oil scales. Then the body is phosphate treated to prevent corroding of the body.
2. ED coat: This is done by electric deposition method, at 240V-DC supply. After applying the ED coat the body is baked in oven.
3. Sol-sealer and under coat: Here the holes left in the body (due to welding) are filled with sol-sealer to provide water proofing. Under coat is done on the surface above wheels to prevent damage of body in that portion.
4. Intermediate coat: This is done by spray-painting method using Robots. Here also inside painting is done manually. After applying the coat, the body is dried in the oven. Painting done is basically an intermediate coating to provide base for the final coat. Paint thickness is taken care, after that vehicle is sent to IC oven. Oven temperature is 198+/-5’C.
5. Top coat: This is done by spray-painting method using Robots. For metallic coating, double coats are applied and aluminum flakes are provided to shine the metallic paints. Top coating is done after inspecting dry sanding. After this the vehicle will move to final inspection and will be sent to assembly shop.

Assembly Shop:

In the assembly shop the body is loaded on an overhead conveyor. As the conveyor moves the body, fitments are made at various stations. There must be separate assembly lines for separate models. The assembly shop has a continuous production system. The assembly line can be subdivided into the followings;

1. Trim line

The vehicle proceeds through a series of Trim workstations where team members begin by installing weather stripping, moldings and pads. Then they put in wiring, vents and lights. After an instrument panel, windows, steering column and bumper supports are added, it starts to look less like a shell and more like a car.

2. Chassis Line

This is where many safety-related items are installed. Things like brake lines, torque, gas tanks and power steering are double-checked. The engine is installed, along with the starter and alternator and then comes suspension and exhaust systems. After that wheel is mounted with the help of wheel nut fastening machine.

3. Final Line

From there the vehicle enters Final 1, which covers many interior items such as the console, seats, carpet, glove box and steering wheel. This is also where bumpers, tires and the battery are added, as well as finishing touches like covers and vents. Then, Coolant, Brake oil, Power steering oil are filled and also the A/C gas are charged.

3. Separate door Assembling Line

Doors are taken out from the vehicle at the first station of the trim line. Doors fitted in the final line make working easier.

Machine Shop:

The machine shop is the source of all major components for the engine assembly shop. It has the following lines; Transmission case line, Cylinder head line, Cylinder block line, Crankshaft line, Camshaft line. The un-machined crankshaft and camshaft forgings, transmission case cylinder head and cylinder block castings are brought in the form of raw materials from the vendors. The cylinder heads and transmission case are aluminum castings while crankshaft and camshaft are steel forgings.

Engine Assembly:

There can be many different types of engines which are assembled in the Engine Plant for petrol and diesel engines. FC Engine, aluminium engine, KB engines etc are the different engines.

Generalize Process Flow Chart

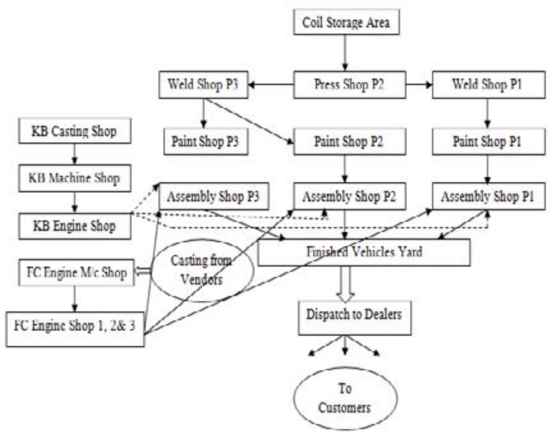

Fig.4 : Indicates the generalize process flow chart based on the survey showing the flow of material from one process to other

The results of the survey also shows that in the press shop the main challenge of any automobile manufacturer is reducing the scrap rate of sheet metal or increasing the utilization ratio. In this shop the aim is to save the sheet metal to go into the scrap so that money can be saved. One of the method that most of the company do not adopts is to use blank cutout of large panels as raw material for making small parts that has to be used in press machine otherwise it will go into scrap. Wastage control can also be done in the following manner:

Wastage Control

1. Residual flat parts (scrap) utilization
2. Die Face Modification
3. Reducing the Blank Size by Gauge Adjustment
4. Changing the Blank Shape
5. Modification of the Punch Profile
6. Modifying the Bead Design

Table 1 depicts the different tools pertaining to cost quality issues and their application areas within the automobile production and assembly lines. The survey of automobile manufacturing units in the research generalises the facts about the tools used in the manufacturing premises at different automobile industries.The different tools that are used in automobile industry is an important factor to cost and quality issues.

Based on the visits to manufacturing premises and interviewing at different levels from the shop floor technicians to managerial representatives the common defects that come into the picture that lead to rework are shown in Table 2. In context with the processes involved in the automobile line the following defects may occur in the processes listed below;

Table1

Tools	Category/ Belongs to	Application Area
5S (Sort, Set in order, Shine, Standardize, Sustain)	Lean	Everywhere in the organization
Quick Change over/ SMED	Lean	Press Shop
Fishbone Analysis	Lean	Press , paint, weld & machine shop
Value Stream Mapping	Lean	All processes starting from raw material to finished product
Mistake Proofing	Lean	
Waste identification and elimination	Lean	All the shops
Setup time reduction	Lean	Press Shop, machine shop
Inventory reduction	Lean	Store, in process, stock at last
Yield improvement	Six sigma	Blanking operation
Wastage Control	Six sigma	Scrap utilization at press shop
Avoiding any type of rework	Six sigma	All the shops
Mistake proofing	Lean/Six sigma	All the shops

Table 2

S.No	Process	Defects	Precautions
1.	Blanking operation	Excessive deformation *Surface defects*: cracks and necking *Form Defects*: wrinkling and marking lines	(i) Too much clearance
2.	Weld shop	Spot Welding: Improper squeezing, splashing , burnt surface conditions, electrode pick up, copper deposits in the weld area and excessive electrode wear, in-sufficient energy, over energy	(i) Proper setting squeeze time, proper setting of weld time, forge time, forge force, peak force
		Metal Inert Gas Welding: Porosity	(i) Gas flow too low or too high (ii) Blocked nozzle (iii) Leaking gas lines (iv) Nozzles distance from work is too great (v) Wet or rusty electrode/wire
		Lack of penetration	(i) Current too low (ii) Worn contact tip causing irregular arc (iii) Incorrect alignment of plates
		Lack of fusion	(i) Voltage too low (ii) Current too low or too high (iii) Irregular surface
3.	Paint Shops	Runs: (i) Incorrect spraying viscosity, spraying technique, flash-off times between coats, and film thicknesses (ii) Incorrect spraying pressure (iii) Temperature of paint, substrate or spray booth too low (iv) Incorrect choice of hardeners and Thinners	(i) Follow application recomm-enddation on technical data sheets (ii) Warm object and material up to room temperature of 20 °C/68 °F (iii) Use correct combination of hardeners and thinners
		Adhesion problems between base and clear coats: (i) Excessive coat thickness of basecoat (ii) Intermediate and final flash-off times of the basecoat too short (iii) Wrong mixing ratio of clearcoat/ hardener (iv) Incorrect hardener/thinner combination; system too fast	(i) Use the intermediate and final flash off times from the technical data sheet (ii) Choose and mix clear coat, hardener and thinner according to technical data sheet
		Lifting and Wrinkling: (i) Occurs when chemical reaction takes place between two incompatible substrates (ii) High film builds (iii) Overcoating an uncured substrate (iv) Wet-on-wet system combined with incorrect hardener/thinner	(i) Avoid working on high film thicknesses (ii) Ensure all products used are part of are finish system (iii) Allow materials to flash off and dry in accordance to technical data sheets (iv) Use recommended hardener/thinner combination

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IV. Proposed Lean Sigma Model: An Outline for Lean Sigma Execution

An outline is proposed to implement to Lean Sigma in the organization as shown in figure 5.The framework is developed, after a number of meetings with top and middle level management and the facilitators are carefully considered in the whole process. This helped to develop the Lean Sigma outline for implementation on the shop floor. In the proposed framework, Lean tools are used within the Six Sigma (DMAIC) problem-solving methodology to reduce the defects occurring in the ending product.

Define

Establishment of the rationale for a Lean Sigma project. Define the problem to be solved, including customer impact and potential benefits.

Measure

Identify the critical-to-quality characteristics (CTQs) of the product or service. Verify measurement capability. Baseline the current defect rate and set goals for improvement. This phase is concerned with selecting one or more product characteristics; i.e. dependent variables, mapping the respective process, making the necessary measurements, recording the results on process "control cards," and estimating the short- and long-term process capability

Analyze

Understand root causes of why defects occur; identify key process variables that cause defects. Benchmarking the key product performance metrics. Following this, a gap analysis is often undertaken to identify the common factors of successful performance; i.e. what factors explain best-in-class performance. Analyze the preliminary data collected in the Measure phase to document current performance (baseline process capability), and to begin identifying root causes of defects and their impact, and act accordingly.

Improve

Determine how to intervene in the process to significantly reduce the defect levels. Generating, selecting, and implementing solutions.

Control

Implement ongoing measures and actions to sustain improvement. Once the desired improvements have been made, put a system into place to ensure the improvements are sustained, even though significant resources may no longer be focused on the problem.

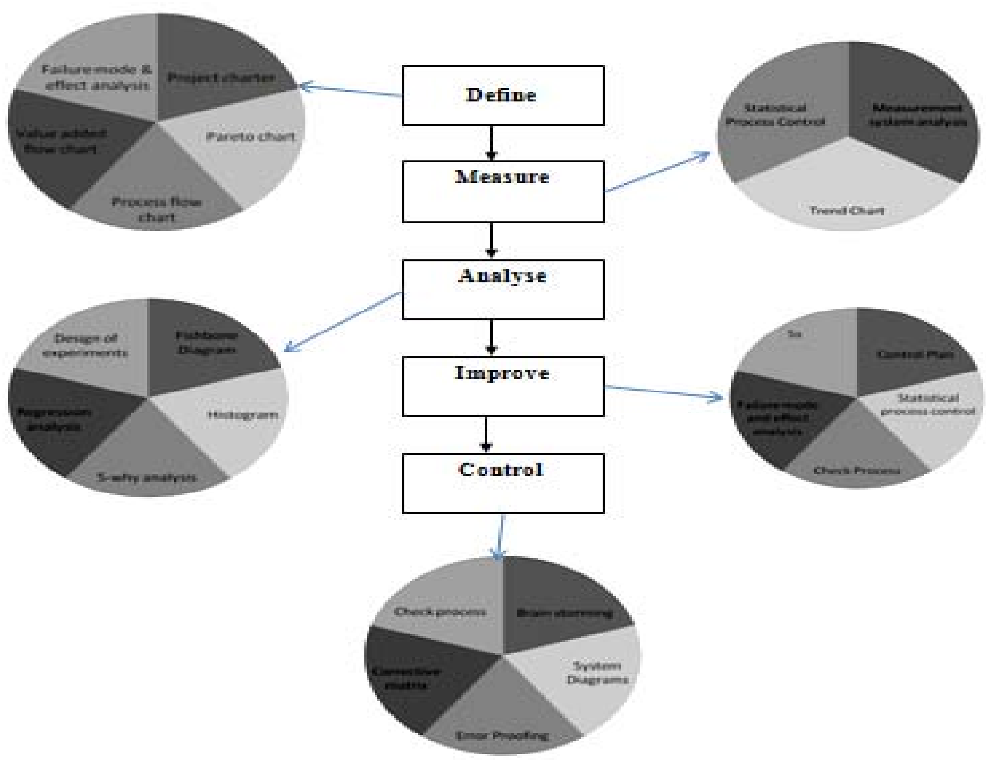

Fig.5 : Shows the proposed model for lean six sigma implementation

V. Conclusion

After a brief review of the history and a detailed analysis of the current state of the Indian automobile industry, it can be concluded that in order to stay ahead of competition and as well as meet the ever growing demands of the consumers, the industry needs to adapt newer measures for increasing productivity by eliminating waste and avoiding rework . This paper aims at doing so by introducing the concept of lean six sigma as an effective cost cutting tool. It also proposes a lean six sigma model for the effective lean sigma execution in the automobile industry. The author wishes to conclude by stating that the lean sigma model holds significance not only in the Indian context but can also be considered to be a global solution for the problems related to cost, quality, waste elimination, rework and productivity as a whole.

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- To the point depiction of the research
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Approach:

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The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

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	A-B	**C-D**	**E-F**
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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
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