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Nano Gas Bubbles Dissolve in Gasoline Fuel and Its Influence on Engine Combustion Performance

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Abstract. Nowadays, the issues of air pollution and global warming have become serious as the atmosphere contaminated with harmful gases from human daily life use of vehicles and industrial manufacturing process, leading to global warming and greenhouse effect. These had emphasised the need for better engines with higher performance and less emission level towards non-harmful and friendly environmental vehicle axillary. There are various techniques and methods used for such purposes. For instance, the nano gas dissolve technique can be used for fuel enhancement through a better combustion reaction by adding more oxidant gases molecular into combustion reaction. Dissolved gases can improve engine combustion performance for reducing the levels of harmful gas emission. The property of small nano particles helps to join or mix or transport interfacial within large molecules of fuels to mix up together and form new combination, introducing different chemical properties. Thus, this paper introduces a pre-design concept for fuel enhancement technique by dissolving nano gases such as air or oxygen into the gasoline fuel, taking advantage of hammer shock phenomena in fluid flow. It presents a case study for understanding combustion influence through use of gas dissolve technique with theoretical calculation validating the condition. The validating results obtained from the theoretical calculation and chemical theoretical results reactions theoretically expressed significant development in combustion mixture. Such technology can provide better fuel improvement for future recommended work by direct integration of the nano bubble generator hardware mobile size device on the fuel supply line.

1. Introduction.

Today, the field of fuel enhancement for developing higher engine performance concerns with higher power, less emission and lower fuel consumption operations of a vehicle. The regulation of vehicle pollution control has become more strict and severe [1][2][3]. Efforts have been given by researchers for better optimisation methods of engine emission reduction enhancements technology for better engine performance and less pollutant. Understanding the challenges of introducing better methods for engine enhancements involves the optimisation of combustion reaction behaviour and its parameters' influence for required improvements. There are modification and design methods available such as mechanical developments, physical enhancement and chemical influence enhancement. The mechanical enhancement is on engine modifications, upgrades and add-ons technology [4]. The physical enhancement deals with the combustion gas physical properties such as the combustion air charge temperature control, air charge pressure and density enhancement [5]. Meanwhile, chemical enhancement is the upgrade or modification of fuel properties and new fuel production for less harmful emissions [6]. Engine modifications including piston material property upgrades are preferred for a better performance [7]. Physical property control of charge air cooling temperature [8]. Charge air pressure influence on combustion using turbocharged add-ons technology [9]. Compression ratio influence on emission and engine RPM speed [10]. Technology of alternative fuels becomes another best solution for emission reduction [11][12]. Even though most of these methods have significant emission reduction, there is still a need for much easier and faster productive technique that is cost effective with no physical influence on the engine system. Therefore, fuel enhancement technology can be the best-nominated technology for a better emission reduction. In addition, most vehicles owners do not prefer any modifications or upgrade on their engines due to cost influence. This is why fuel enhancement technology becomes reliable to be used for fuel enhancement. Nano technology makes a huge revolution in all technology fields, offers better quality and better production with more accuracy due to small size and flexibility of handling to mix and transport [13]. The engine combustion chamber operation depends on the amount of oxidant gas in air mix with the fuel for optimum combustion flame reaction, which leads to the expansion of gas inside the cylinder converting through the piston into mechanical energy [14] where complete combustion will prevent the emission of CO and harmful gases [15][16][17].

In this study, a new technology method for fuel enhancement concept is presented adopting the use of hammer shock phenomena in fluid flow [18]. This technique uses liquid flowing integrated with nano air or oxygen bubble mixed with the gasoline fuel. The idea behind this technique is focused on increasing the amount of oxygen molecules inside the combustion chamber for a better burn flame combustion as the amount of oxygen molecular will take part in combination, which will help to reduce the gas emission [19]. The objective of this case study is to show the reliability of nano gas dissolver technology in fuel taking the advantage from the phenomena of hammer shock in fluid flow and make the mechanical device familiar by researchers for future design enhancement of fuel refine technology.

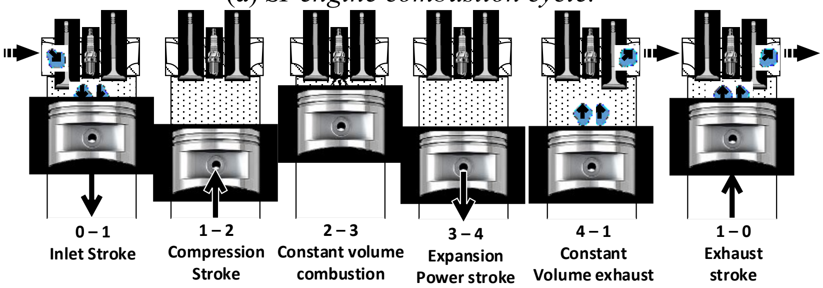
2. Combustion characteristics

2.1 Four stroke OTTE cycle

The basic geometry and engine operation principle in an internal combustion engine is to produce mechanical power from the chemical energy reaction stored in the fuel. Fuel burn in a combustion chamber results in high pressure due to mixture of temperature rise inside the cylinder, mixture expanded gas produce work by pushing a piston in displacement inside the combustion chamber. This linear movement is transformed into rotatory movement by a crankshaft. In a four-stroke engine, the thermodynamic cycle (Figure 1), which produces work, is completed during two revolutions of the crankshaft or four piston strokes:

- **Intake stroke**: Charge air stage where the piston goes from TDC (Top Dead Center) to BDC (Bottom Dead Center) entering fresh air into the combustion chamber from the intake manifold of the combustion chamber.
- **Compression stroke:** the piston compresses the mixture while going to TDC changing in volume ratio. During this stroke, the work done on the gas by the piston (negative work).
- **Power or Expansion stroke:** when the piston reaches the TDC the in cylinder pressure and temperature becomes higher the mixture is fully mixed and the spark plague ignition the flame. The high pressure forces the piston down towards BDC. During this stroke, the work done is by the gas mixture on the piston (positive work).
- **Exhaust stroke:** the piston due to momentum energy will try to reach the TDC with valves is open the after burning gases emission will be compressed out exhaust the cylinder.

(a) *SI-engine combustion cycle.*



(b) *SI-engine P-V cycle diagram.*

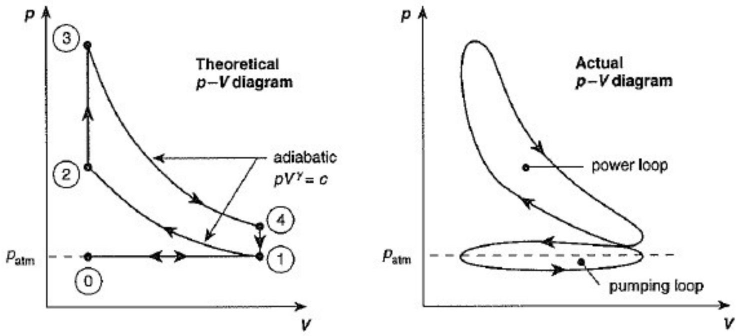
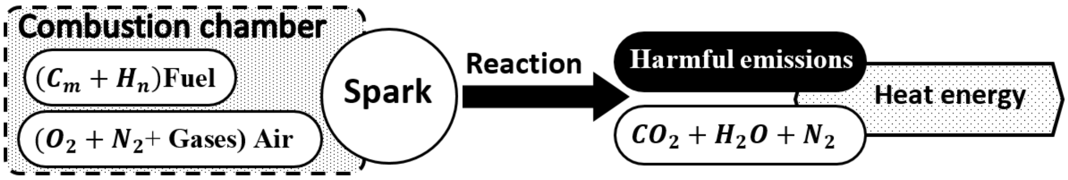


Figure 1. SI engine cycle, (a) SI-engine combustion cycle. (b) SI-engine P-V cycle diagram.

2.2 Stoichiometry of combustion

Stoichiometric or theoretical Combustion is the ideal combustion process where fuel is burned completely [14] which is shown in Figure 2.A complete combustion is a process burning all the carbon (C) to (CO_2), all the hydrogen (H) to (H_2O) and all the Sulphur (S) to (SO_2) with release of heat energy.



Where: C = Carbon, H = Hydrogen, O = Oxygen, N = Nitrogen

Figure 2. Theoretical Combustion reaction.

- **Harmful emission**

harmful emission produced due to several conditions in the combustion chamber that prevent a perfect combustion such as an incomplete burn or combustion temperatures which lead to creating unwanted chemical reactions combination.

a- **Carbon Monoxide (CO) Emission**: is a product of incomplete combustion, essentially partially burned fuel. , insufficient oxygen in the mixture existing to fully oxidize the carbon and convert into carbon dioxide (CO_2). Carbon atoms bond with only one oxygen atom forming carbon monoxide (CO).

b- **Hydrocarbon (HC) Emission**: It is created due to misfire or incomplete combustion or non-ignition sparked. When combustion does not take place large amounts of hydrocarbons are discharged from the combustion chamber.

c- **Oxides of Nitrogen (NO_x)** : When cylinder temperature and pressure during the combustion process become high, it cause nitrogen to react with oxygen at high temperatures conditions to form Oxides of Nitrogen (NOx).

d- **Particulate Matter (PM):** it is the remaining particles unburned or soled carbon formed in combustion due to fuel contain of ash in diesel fuel.

The combustion processes depend on oxidizer which mix with fuel to create the combustion charge, oxidizer could be oxygen, atmospheric air (21% O_2, 78% N_2, other gas 1%), air enriched with oxygen (O_2 > 21%) or air mixed with N_2O. The amount of combination mixture effect the combustion mixture quality as:

- Reach mixture: Excess of fuel
- Lean mixture: Excess of oxidizer and lack of fuel
- Stoichiometric mixture: both fuel and oxidizer are satisfaction

2.3 Stoichiometric air (λ)

It is the theoretical air amount required to complete combustion with fuel, results from the equation of stoichiometry of oxygen/fuel reaction [20]. It is the minimum air in the stoichiometric mixture can be present in air/fuel ratio (AFR) [32-33] which can be calculated from the reaction equation (g/g) or (m^3/m^3) for gas AFR. The actual combustion air depends also on the assumed air excess as shown in Equation 1.

$$\lambda = \frac{actual\ air}{Stoichiometric\ air} \tag{1}$$

- Reach mixture: $\lambda < 1$
- Lean mixture: $\lambda > 1$
- Stoichiometric mixture: $\lambda = 1$

From A/F ratio chart (Figure 3 and 4), which shows the resultant gasses from burning petrol at different A/F. it shows rich mixtures increased Hydrocarbon emissions, as the excess fuel is unburned. Nitrogen oxides are low at lower air charge temperature, but Carbon Monoxide becomes higher with the lack of oxygen to convert from CO to CO_2.

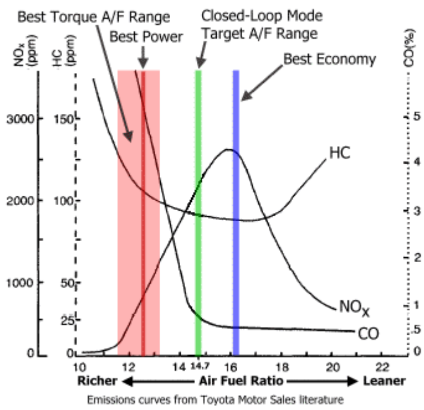


Figure 3. A/F ratio chart - – source by: by (www.toyota-4runner.org)

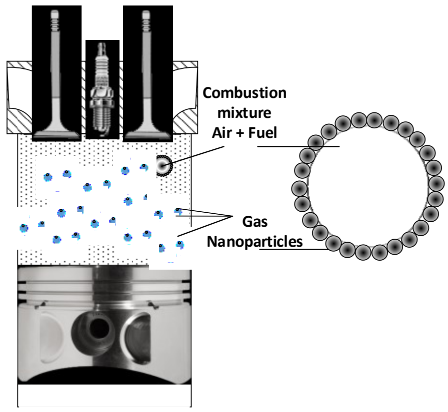


Figure 4. Nanoparticles in combustion chamber mixture (imaginary)

3. Water hammer shock phenomena

It is the phenomena that occurs in incompressible fluid flow under pressure and sudden change face impact in flow due to elbow turn or walls, creating vacuumed space bubbles due to speed increment at impact with the surface as well as noise and vibration in pipe flow like a hammer hit [21]. When the amount of shock created becomes higher, the thermal hydraulic effect causes the fluid bobble induced temperature to become higher [22]. The change in liquid pressure rate variation is more than its temperature, which causes the liquid molecular bonds to vibrate; this vibration leads to friction in combination with molecules in the fluid [23], which will cause fluid temperature to rise. In water, the effects of hammer shock can lead to boiling temperature without using any external heat source depending on molecular bond vibration by exposing the water to sudden shock with the high-speed flow, making the molecular bonds to be cracked or broken and creating exothermic heat energy due to broken bonds [24]. Continuous shocking can reduce the rebounding joint time, resulting in the conversion of water into O2 and H2 with the release of energy. At the same time, O2 molecular when impacted with H2 molecule due high-speed flow leads to explosive reaction that rises the temperature of water to boiling

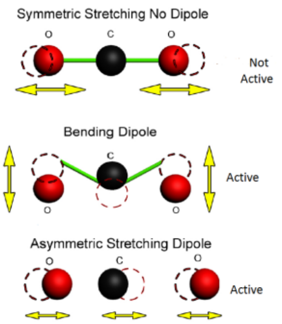


Figure 5. Molecular vibrations

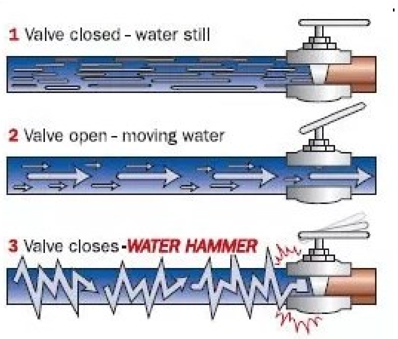


Figure 6. Hammer shock in water flow, by (www.theprocesspiping.com/water-hammer)

Scientists and engineers developed this phenomenon to design the non-heat source water boilers in which the water is boiled into steam without using fuel or any heat source; this phenomenon is used to create higher intensity shock in water with high-speed rotation. Steam generated in a short period with no use of a boiler or any fuel. This technique named Steam generator fuel-less heater.

This technology was then banded, or controlled by powerful companies in petroleum and power electric, preventing it from global use. This is because the decrement in use of fuel will influence fuel price and loss to petroleum companies in the market. It started in the USA by an engineer named (Steve) accidently [25], which was then adopted by Russian engineers to improve and design an operational production steam generator [26].

(a) (b)

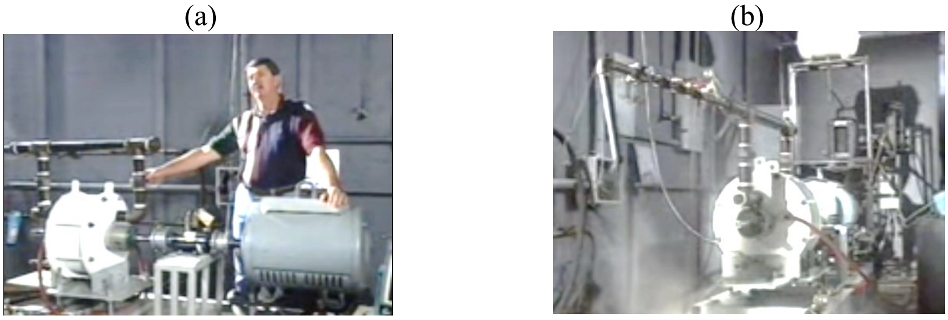


Figure 7. (a) The USA engineer (Steve) (b) The Heater at operation for steam generate – (photos are related to video of the designer user at https://youtu.be/yh_-DUKQ4Uw)

(a) (b)

Figure 8. (a) The non-heat source water boilers Russian version (b) The Heater at operation generate steam (photos are related to video)

3.1 Nano-bubble technology

Nanotechnology describes the design, production, and usage of substances at the nanometer (nm) level [27]. Micro-bubbles regularly decrease in volume size due to the dissolution of interior gases by the surrounding liquid and eventually disappear, leaving some Nano-Bubbles. The micro bubble generator can used to generate bubbles resizing, applying high speed rotating flung blades to splash and broke the liquid molecular size to micro or minimum size, depending on speed rotation and gas supplied to dissolve with the liquid. The technique was adopted from water hammer shock idea.

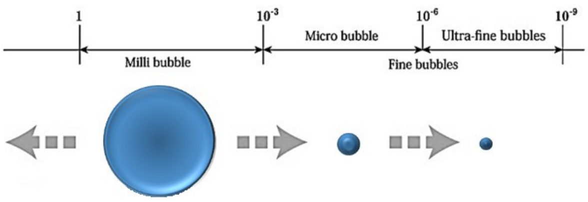


Figure 9. Liquid bubble resizing compare smaller size

Figure 10. Micro bubble generator device designed by (www.ktmbubblegenerator.com)

3.2 Gas solubility in liquid

It is the use of compressed gas under high pressure induced dissolving into the liquid including solubility of CO_2 in water to make soda carbonised [28]. This forces the gas molecular to interfere with water molecular through size reduction over high pressure. After removing the pressure force, the gas changes size due to difference in pressure leading to the release of gas and water.

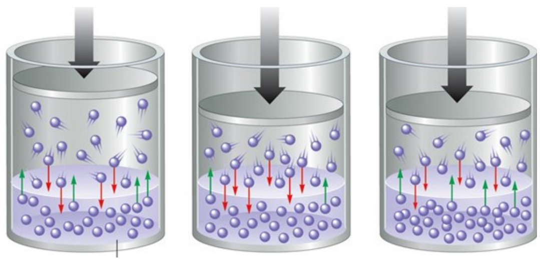


Figure 11. Gas solubility in water using pressure force

4. Proposed study

From the combustion analysis performance, the engine combustion emission influenced by the variation of air-fuel ratio, fuel quality and physical property of fuel and air charge. Reduction in emission depends on complete combustion. Complete combustion requires qualified air and fuel for best mixture in combustion chamber [29]. Complete combustion helps to reduce harmful emissions creation. Combustion enhancement requires the development of fuel or air physical property enhancement; the fuel enhancement method showed a better chance in lowering the cost and easy production handling than mechanical engine developments. From the previous review of engine combustion and hammer shock phenomena, nano-bubble technology with gas solubility or dissolving in liquid becomes effective fuel enhancement technique adopted for design. Besides, it is economically cheaper and chemically efficient. The nano gas bubbles dissolved in fuel device will be the cheapest and advanced technique for fast fuel enhancement as fuel quality leads to better combustion.

4.1 Methodology

Identifying the design concept geometry required understanding the parameters influence the engine combustion performance, understand the combustion behaviour and identifying the modification ability and enhancement capability in combustion parts. From the combustion reaction inputs of fuel and air, there are two variable relabel for modifications, the fuel and air property. The (figure 12) is the flow chart of variable enhancement available for both air and fuel

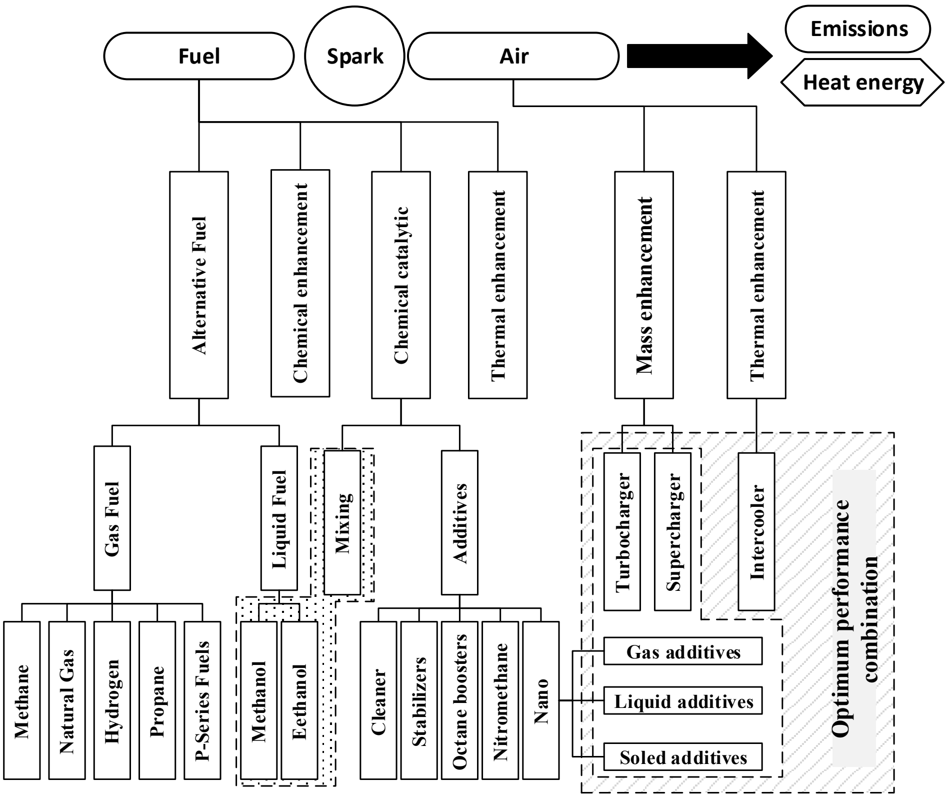


Figure 12. Combustion parameters enhancement chart.

- **Enhancement flow chart**

The flow chart in Figure 12 shows the most available methods of combustion enhancement; nevertheless, there are many methods available as there are a lot of techniques used nowadays. The fuel development is more popular [30] due to economic cost, scalability and performance influence. Thus, finding a new method for combustion enhancement influencing both variables for better combustion is a challenge. Nano technology becomes the best choice to influence both fuel and air enhancements to produce better combustion and reduction of harmful emissions. These include using nano O2 dissolve in fuel to add more oxidation molecular to combustion, reducing the creation of carbon monoxide CO, while at the same time cooling the charge air using Intercooler heat exchanger that helps to prevent the high temperature in combustion chamber, which helps to reduce the nitrogen reaction with oxygen reducing the (NO) emission.

4.2 Combustion Theory

The use of enhancement fuel lead to better combustion ignition in the chamber. The air molecular will react with the Benzene (Benzol) C6H6 fuel. The hydrocarbon theoretical complete reaction with air is shown in Equation (2), (3) and (4):

$$C_mH_n + a\,(O_2 + 3.76\,N_2) --\rightarrow b\,CO_2 + c\,H_2O + d\,N_2 \quad (2)$$

Balance:
C : m = n
H: m= 2*c => C= m/2
O: 2a=2b+c => a= m+ n/4
N: 2*d= 2*(3.67)* a
d=3.67 * (m + n/4)

$$C_mH_n + \left(m + \frac{n}{4}\right)(O_2 + 3.76\,N_2) --\rightarrow n\,CO_2 + \left(\frac{n}{2}\right)H_2O + 3.76 * \left(m + \frac{n}{4}\right)\,N_2 \quad (3)$$

For the value of Air/Fuel stoichiometric

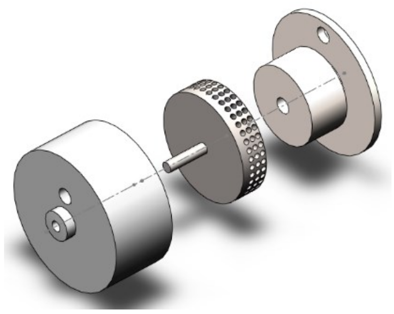
$$A/F = \frac{m_{air}}{m_{fuel}} = \frac{(\sum n_i\ \bar{M}_i)_{air}}{(\sum n_i\ \bar{M}_i)_{fuel}} = \frac{\left(m + \frac{n}{4}\right) * \bar{M}_{O2} + 3.67 * \left(m + \frac{n}{4}\right)\bar{M}_{N2}}{m * \bar{M}_C + n * \bar{M}_H} \quad (4)$$

5. Design Approach

Theoretical investigation analysis helps researchers to understand the combustion behaviour of parameter relations and contribute a pre-concept geometry design with dimension to fulfil the enhancement required with size-optimised for reliable in capacity production and quantity load to be used in engine fuel enhancement system. The device operates by use of an electric motor for core blade rotation.

Table 1: device concept dimensions in (mm)

Shaft	Flay well			Flay well holes		Hoot Soled body		Housing body	
D	Di	Do	L	D	L	D	L	D	L
30	300	400	100	10	50	290	200	410	250



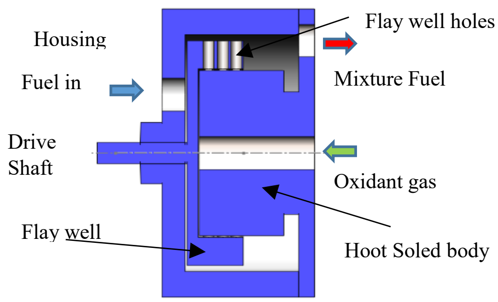


Figure 13. Device concept design layout

6. Results and Discussions

Theoretical case study investigation has led to the understanding of nano oxidant dissolved in fuel and its influence on combustion behaviours, which aided the designers to find an efficient suitable design of fuel enhancers. The nano bubbles dissolve can also help to add an extra percentage of oxygen oxidant gas. The estimated holding bubble to fuel capacity in litre is ranged from 5% to 10% of volume size optimised capacity depending on device size and rotation speed [31]. In this theoretical study, the fuel type Benzene C_6H_6 was selected for theory calculation assuming a complete combustion as (NO_X) created from (Equation 2).

$$C_6H_6 + (6 + \frac{6}{4})\,(O_2 + 3.76\,N_2) -\!\!-\!\!\rightarrow\ 6\,CO_2 + (\frac{6}{2})\,H_2O + 3.76 * (6 + \frac{6}{4})\ N_2$$
$$C_6H_6 + (7.5)\,(O_2 + 3.76\,N_2) -\!\!-\!\!\rightarrow\ 6\,CO_2 + (\,3\,)\,H_2O + 3.76 * (7.5\,)\ N_2 \tag{5}$$

Total mol emission produced = 6 + 3+ (3.76*7.5) = 37.2 mol
The percentage of each emission is:
CO_2: 6*100/37.2 = 16.13 %
H_2O: 3*100/ 37.2 = 8.1 %
N_2 : (3.76*7.5)*100/37.2 = 75.80 %

If the Nano oxygen dissolved in C_6H_6 with 10% then the change will be:

$$C_6H_6 + (7.5\,)((1 + 10\%)O_2 + 3.76\,N_2)\quad -\!\!\rightarrow\quad 6\,CO_2 + 3\,H_2O + 55.2\,N_2 + 1.5\,O \tag{6}$$

Total mol emission produced = 6 + 3+ (3.76*7.5) +1.1= 38.3 mol
CO_2: 6*100/38.3 = 15.66 %
H_2O: 3*100/ 38.3 = 7.83 %
N_2 : (3.76*7.5)*100/38.3 = 71.86 %

The extra oxygen produced during dissolving in fuel served as an oxidant burn in the flame combustion. The emission amount of CO_2 was reduced from 16.13% to 15.66 % when just 10% oxygen was dissolved in the liquid fuel. This theatrical process is not realistic as 100% in real life; thus, experimental processes are required for investigation using a variable type of fuel and variable air property with variable nano dissolving gases, creating a study chart that can be used as a baseline reference for future experimental studies.

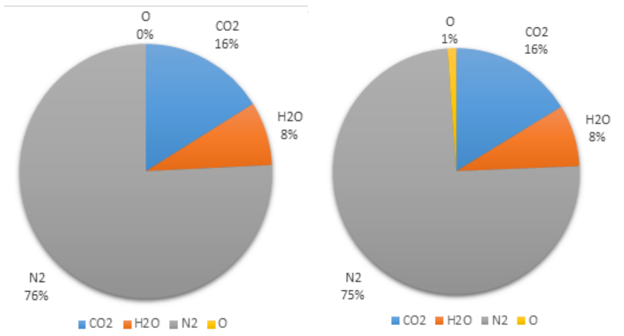


Figure 14. Combustion emission percentage of C_6H_6 with and without the use of Nano oxygen in the fuel

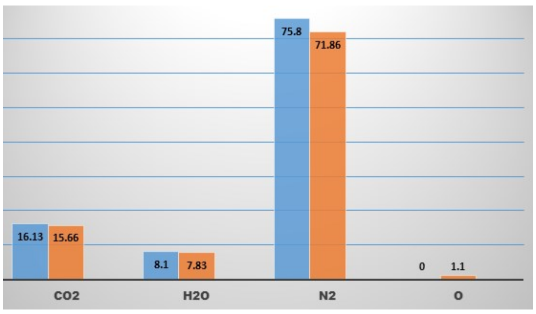


Figure 15. Relation combustion percentage without and with use Nano oxygen in fuel

7. Conclusions

The investigation of the nano gas bubble dissolve in gasoline fuel through theoretical analysis showed significant effects of oxidant dissolve in fuel. Pre-design concept device was contributed for the general use of researchers on nano dissolve mixture device, with optimised capacity suitable to be used with other industrial purposes besides fuel nano bubble dissolving. Helpful in improving the combustion in gasoline engines, considerations required for using thermal effect with this technology will reach the optimum combustion performance. Other boundary conditions controlling the designs are the rotation speed limit and space gap in dissolve generator. The geometry theatrically showed significant enhancement in fuel performance. Limitations of the device include the speed control of rotation as higher speed rotation makes the fuel face the hammer shock property, leading to heating and loss of dissolved gas. Oxidation dissolving is not chemically stable. Thus, it should be used in enforced fuel tank container made of plate or high-pressure resistance material using safety valves and gas return system to reserve tank. However, adding an intercooler cooling in the output fuel will prevent oxidant bubble loss; while low-speed rotation leads to splash the fuel and reduce the percentage of dissolved oxidant. Thus, speed rotation needs to be optimized experimentally until reach its optimum correct speed for the design combining with fuel used.

Acknowledgement

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