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Design and Fabrication of the High Pressure EffervescentSpray Combustion System

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ABSTRACT

The purpose of the present work is to design and fabricate the high pressure effervescent spray combustion system for the study of high pressure spray effervescent combustion characteristics. In the present work, the high pressure effervescent spray cylindrical combustion chamber or system was developed by producing internal pressure and temperature due to combustion process approximately equal to 32 bar and 800 K respectively. It is found that curved surface thickness and closed end surface thickness of the cylindrical combustion chamber were 7.42 mm and 15.76 mm respectively.

Keywords: *Effervescent Combustion; Atomization; High Pressure; Cylindrical Chamber.*

1.0 Introduction

Most air blast and air-assist atomizers are of the external-mixing type in which the bulk liquid is first transformed into a jet or sheet before being exposed to atomizing gas flowing at high velocity. Where internal mixing is employed, the impact between the high-velocity atomizing gas and the liquid takes place within the atomizer body. The effervescent atomizer falls into the category of „internal-mixing‟ but, in marked contrast to all other types of twin-fluid atomizers, the atomizing gas is injected into the liquid at very low velocity to form a bubbly two-phase mixture upstream of the discharge orifice. Owing to its relatively low density, the gas occupies a significant proportion of the total cross-sectional flow area. This improves atomization by reducing the characteristic liquid dimensions within the discharge orifice. The atomization process is further enhanced by the rapid expansion of bubbles at the nozzle exit that shatters the issuing liquid stream into ligaments and drops. One incentive to the development of effervescent atomization was the drawbacks associated with flash atomization and dissolved gas atomization. Flash atomization depends on the rapid evaporation (flashing) of a small portion of the liquid. Dissolved gas atomization relies on a dissolved gas coming out of solution to form bubbles. As a result, these techniques apply only to a limited range of liquids that are either highly volatile or which can hold a significant quantity of dissolved gas. During the past decade, many detailed experimental studies have been carried out to determine the performance and spray characteristics of effervescent atomizers over wide ranges of operating conditions. The results of these experiments indicate that effervescent atomizers exhibit the following advantages over conventional pressure, rotary, and twin-fluid atomizers:

- Good atomization can be achieved at injection pressures that are several times lower than those required by other types of atomizers.
- For any given injection pressure, smaller drop sizes are obtained than those produced by more conventional methods of atomization.
- Gas flow-rates are much smaller than those employed in most other forms of twin-fluid atomization.
- Exit orifice diameters are larger than those of other atomizer types having a comparable flow rate. This alleviates clogging problems and facilitates atomizer fabrication.
- In combustion applications, effervescent atomizer-produced sprays are conducive to lower pollutant emissions due to the presence of air (atomizing gas) in the spray core.
- Mean drop size is relatively insensitive to liquid viscosity. This means that a single atomizer can handle a variety of liquids without compromising

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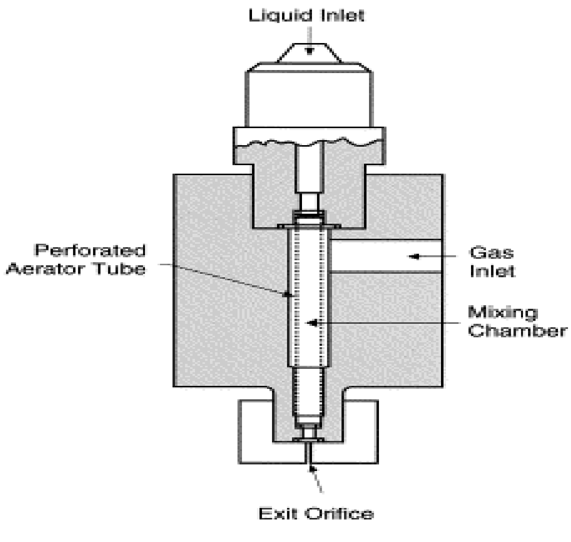
- performance.
- Flow velocities in the discharge orifices of effervescent atomizers are much lower than those encountered in conventional atomizers because two-phase flows choke at significantly lower velocities than single-phase flows. This reduces orifice erosion when handling liquids with solid suspensions.
- The device is simple, rugged, and reliable. It requires little or no maintenance and can be operated at low cost.

The main drawback of effervescent atomization, which it shares with many other forms of twin-fluid atomization, is the necessity of having a supply of pressurized gas. However, since the gas flow-rates needed are small, this requirement can often be met with relative ease. [1]

1.1. Description of effervescent atomization

Fig 1: A Typical Effervescent Atomizer [1]



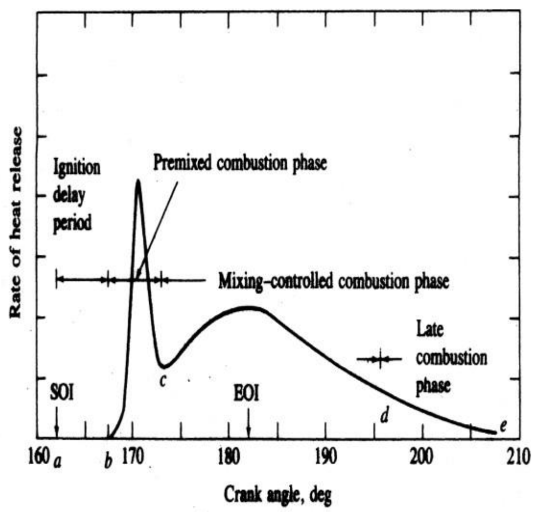
A typical steady-state effervescent atomizer is illustrated in Fig.1.1. It consists of four main components: liquid and gas supply ports, a mixing chamber where the gas is bubbled into the liquid stream, and an exit orifice. In the geometry shown in Fig.1.1, liquid is supplied to the atomizer through a port at the top and flows down inside a perforated central tube to the exit orifice. The gas — referred to as „atomizing gases — is supplied to an annular chamber surrounding the perforated central tube. The gas supply pressure is slightly higher than that of the liquid. Being at a higher pressure, the gas flows through the perforations in the central tube into the liquid stream, and forms bubbles. The internal cavity of the central tube serves as the mixing section. The bubbly two-phase mixture formed flows downward and is ejected through the exit orifice.

12 Diesel engine combustion

Diesel engines have high thermodynamic efficiency therefore they have been the first choice for heavy duty vehicles. However, future emissions regulations pose a challenge for upcoming diesel engine combustion systems. Future emissions regulations are becoming more restrictive, forcing engine designers towards lower exhaust values. With this perspective, knowledge of the injection and the combustion process is currently being considered as a major research objective. Particularly, the analysis is focused on direct injection diesel engines, where the fuel-air mixing process plays a dominant role. Only with the good understanding of these phenomenons"s it will be possible to reduce the emissions levels without impairing the engine performance and efficiency. **[2]**

The following stages of the overall compression- ignition diesel combustion process can be defined. They are defined on the heat release rate diagram for aDI engine in Fig. 1.2 given below:

Fig 2: ROHR Curve for Diesel Engine [3]



Ignition delay is affected by the various factors such as Injection Pressure, Injection timing advance, Compression Ratio, Intake Temperature and pressure, Fuel Temperature, load, A/F ratio etc. [4]

2.0 Experiment and Its Components

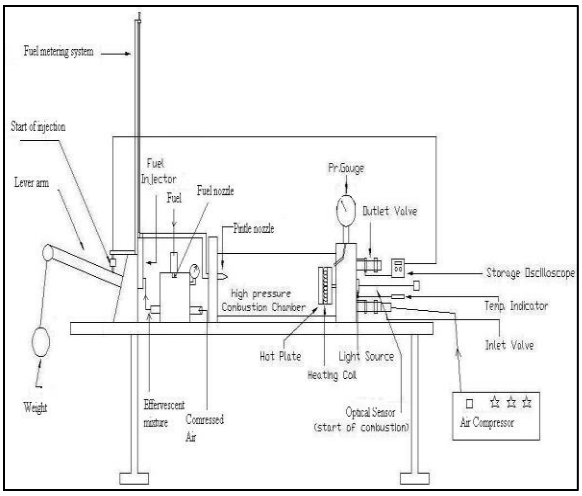
2.1 Experiment

The purpose of the present work is to develop the high pressure effervescent spray combustion system.

1. Design the high pressure effervescent spray combustion system.
2. Fabrications of the high pressure effervescent spray combustion system.

The experimental set up for the high pressure effervescent spray combustion system is shown in the following figure 2.1-

Fig 3: Line Diagram For The Experimental Set Up

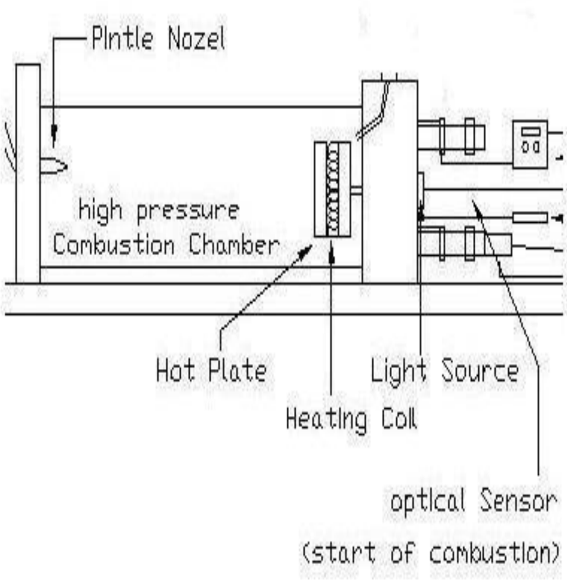


2.2 Combustion chamber

Combustion chamber for our experimental set-up is a stainless steel cylindrical tank as shown in Fig.

A pintle type nozzle is fitted on the head of the combustion chamber. The combustion chamber used in our study is a closed type chamber so the pressure inside the chamber is high as we want in our experiment. A heating coil (1000 watt) is fitted inside the combustion chamber between two stainless steel plates for increasing the temperature of surface. A stainless steel plate is fitted horizontally at opposite side from fuel injector for the providing hot surface. The heating coil is connected to the secondary coil of a step down transformer (output current 100 ampere) on one end of the tube a light source is fitted. On the end of the second tube a photo sensor is placed. We are using a high capacity compressor for maintain the high pressure inside the combustion chamber during the experiment, which is varying from 1 atmosphere to 25 bar pressure.

Fig 4: Combustion Chamber



2 3 Effervescent mixture formation cylinder

Fig 5: Cylinder for Effervescent Mixture Formation

Effervescent mixture of fuel and air is formed inside cylinder as shown in Fig. 2.3 given below. Compressed air is introduced inside the cylinder and fuel is injected with the help of fuel injection nozzle inside the cylinder. Pressure indicator is mounted on the cylinder for the measurement of pressure inside cylinder.

3.0 Design of Combustion Chamber

3.1 Combustion analysis

For combustion process, heat release from combustion of fuel is equal to the increase in internal energy of the fluid in the combustion chamber. From first law of thermodynamics

$$dQ = dU \qquad (1)$$

Also

$$dQ = m_f\, LCV$$

$$dU = (m_a + m_f\}(T_2 - T_1\}C_v$$

Hence from equation (1}, we have

$$m_f\, LCV = (m_a + m_f\}(T_2 - T_1\}C_v \qquad (2)$$

Let T2 is the temperature at the end of combustion process and T1 is the temperature at the start of combustion process. Since the combustion takes place at constant volume, then from ideal gas law, we have

$$\frac{P_2}{T_2} = \frac{P_1}{T_1} \qquad (3)$$

Forair,

$$C_v = \frac{R}{\gamma - 1} \qquad (4)$$

Combining all above equations, we get

$$m_f\, LCV = (m_a + m_f)\frac{R}{\gamma - 1}\left(\frac{T_2}{T_1} - 1\right)T_1$$

$$= (m_a + m_f)\frac{RT_1}{\gamma - 1}\left(\frac{P_2}{P_1} - 1\right)$$

Or

$$LCV = \left(\frac{m_a}{m_f} + 1\right)\frac{RT_1}{\gamma - 1}\left(\frac{P_2}{P_1} - 1\right)$$

Or

$$\left(\frac{P_2}{P_1} - 1\right) = \frac{LCV(\gamma - 1)}{RT_1(1 + {}^{A}/_{F})}$$

Where

$$\frac{m_a}{m_f} = {}^{A}/_{F}$$

Or

$$\frac{P_2}{P_1} = 1 + \frac{LCV(\gamma - 1)}{RT_1(1 + {}^{A}/_{F})} \qquad (5)$$

let LCV = $42.2*10^6$ J/Kg

$\gamma_{air} = 1.28$

$R_{air} = 287.7$ J/Kg

Putting these values in equation (5)

$$\frac{P_2}{P_1} = 1 + \frac{42.2 * 10^6(1.28 - 1)}{(1 + {}^{A}/_{F})287.7T_1}$$

$$\frac{P_2}{P_1} = 1 + \frac{41070}{(1 + {}^{A}/_{F})T_1} \qquad (6)$$

Now from equation (3)

$$\frac{T_2}{T_1} = 1 + \frac{41070}{(1 + {}^{A}/_{F})T_1}$$

$$T_2 = T_1 + \frac{41070}{(1 + {}^{A}/_{F})}$$

Or

$$T_2 - T_1 = \frac{41070}{(1 + {}^{A}/_{F})} \qquad (7)$$

3.2 Calculations for pressure and temperature after combustion

Given data:

Thermal efficiency = 35%

Brake horse power = 5hp

Speed N = 1500 rpm = 25rps, 4-stroke cycle

Diameter of cylindrical combustion chamber = 200 mm.

Length of combustion chamber = 200 mm.

$$\pi/4 * (200mm)^3$$

$$= 6283.185cc.$$

$$= 6.283 * 10^{-3} m^3.$$

$$\text{Thermal efficiency} = \frac{BP}{\dot{m}_f * LCV}$$

Using above given values and put in this equation, we get

$$35\% = \frac{5 * 0.746}{\dot{m}_f * 42.2 * 10^3}$$

Or we get

$$\dot{m}_f = 2.525 * 10^{-4}\ kg/sec$$
$$= 0.2525\ gm/sec$$
$$= 252.5\ mg/sec$$

Mass of air in the combustion chamber = $density \times$ volume

$$m_{air} = \rho \times V$$
$$= 1.12 * 6.283 * 10^{-3}\ kg$$
$$= 7.03696 * 10^{-3}\ kg$$
$$= 7036.96mg$$

Fuel injected per revolution = $\frac{252.5}{25}$

= 10.1 mg per revolution

Now fuel injected per stroke =10.1/2 = 5.05 mg.

Air-fuel ratio = $\frac{7.03696 * 10^{-3} * 10^6}{5.05}$

$$= \frac{7036.96}{5.05}$$

A/F $= 1393.457$

Also, we have

$P_1 = 30$ bar

$T_1 = 500°C = 773$ K

From equation(6), we have

$$\frac{P_2}{P_1} = 1 + \frac{41070}{(1 + A/F)T_1}$$

$$\frac{P_2}{P_1} = 1 + \frac{41070}{(1 + 1393.457)(500 + 273)}$$

$$P_2 = 30\ bar\left(1 + \frac{41070}{(1 + 1393.457) * 773}\right)$$

$$\boldsymbol{P_2 = 31.143\ bar}.$$

Also from equation(7), we have

$$T_2 - T_1 = \frac{41070}{(1 + A/F)}$$

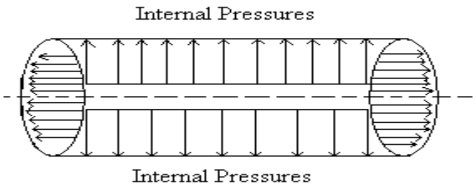
$$T_2 = 773 + \frac{41070}{1 + 1393.457}$$

$$\boldsymbol{T_2 = 802.45}\ \text{K}.$$

3.3 Calculation for the thickness of the walls of the combustion chamber employed

A circular combustion chamber is employed for the combustion of effervescent mixture of fuel and air as shown in Fig. 3.1 given below.

Fig 6: Combustion Chamber



3.4. Circular plates

The thickness "t" of the circular plates at the two ends of the cylinder of diameter D supported at the circumference and subjected to a uniformly loaded pressure over the entire surface is calculated by using the formula: **[6]**

$$t = c_1 D\sqrt{p/f}$$

Where, c_1 = constant = 0.42. D = Diameter = 200mm.

P = internal pressure after combustion in MN/m^2 =3.1143 MN/m^2

f = allowable stress value in MN/m^2 = 84.3 MN/m^2 (Material Specification: IS: 1570-1961, Grade-15CrMo55)

Therefore,

$$t = 0.42 * 200 * \sqrt{3.1/84.3}$$

$$\boldsymbol{t = 15.376mm = 1.5376cm}.$$

3.4 Rectangular plates

Rectangular plates for the rectangular cylinder, the two ends of the cylinder will be rectangular plates therefore for the rectangular combustion chamber; the thickness of the rectangular plates is given by: **[6]**

$$t = abc_3\left[\sqrt{\frac{p}{f(a^2 + b^2)}}\right]$$

Where,

A = length of the plate = 200mm b = width of the plate =200mm

p = internal pressure = 3.1143 MN/m^2

f = allowable stress value = 84.3 MN/m^2

c_3 = constant = 0.6

Therefore,

$$t = 200 * 200 * 0.6 * \sqrt{\left[\frac{3.1143}{84.3(200^2 + 200^2)}\right]}$$

$$t = \mathbf{16.31mm = 1.631cm}.$$

3.6 Curved surface of the combustionchamber

The maximum shear stress is used for the ductile material and according to the maximum shear stress theory; the maximum shear stress is equated to the yield stress in tension test. i.e, **[7]**

$\tau_{max} = \sigma_y/2$

And $\tau_{max} = (\sigma_H - \sigma_r)/2$

For mild steel $\sigma_y = 280MN/m^2$

$$\sigma_H = A + \frac{B}{r^2}$$

$$\sigma_r = A - \frac{B}{r^2}$$

Then, $\tau_{max} = \left(A + \frac{B}{r^2}\right) - \left(A - \frac{B}{r^2}\right) = 2B/r^2$

Now $\tau_{max} = 280/2 = 140\ MN/m^2$

Let Factor of Safety = 3 then,

Allowable stress, $\sigma = \tau_{max}/F.S = 140/3$ =

Now, allowable stress = $2B/r^2$

Where,

$$B = lame's\ constant = \frac{p * R_2^2 * R_1^2}{(R_2^2 - R_1^2)}$$

R_2 = Outer radius, R_1 = Inner radius

p = Internal pressure

Also, the shear stress will be maximum at the inner radius R_1, i.e,

Allowable stress = $\sigma = 2B/{R_1}^2$

Hence, $\sigma = 2B/{R_1}^2 = (2 * R_2^2 * p)/(R_2^2 - R_1^2)$

Given: inner radius = 100 mm = 0.1m

Or $46.667 = (2 * 3.1143 * R_2^2)/(R_2^2 - 0.1^2)$

R_2 = 0.10742 m = 107.42 mm

Hence, the thickness of the curved wall of CC is given by "t" = R_2-R_1 = 107.42-100 = **7.42 mm.**

4.0 Conclusions

The purpose of the present work is to design and fabricate the high pressure effervescent spray

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