

# MINIATURIZED GAS SENSING ASSEMBLY FOR AUTOMOBILE EXHAUST

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**Abstract**— Vehicle emissions are composed of a plethora of toxic, non-toxic and greenhouse gases. These consist of Nitrogen Oxides (NO<sub>x</sub>), Sulphur Oxides (SO<sub>x</sub>), Carbon Monoxide (CO) and carbon dioxide (CO<sub>2</sub>). The detection and analysis of these gases is vital in the fight against climate change. With the advent of MEMS technology, solid state sensors have become more and more common in sensor modules used to detect various gases. These sensors used to detect the aforementioned gases are highly delicate and must be placed in protected, safe and suitable environments to perform accurately. This mechanical investigation has lead into the designing and analysis of a miniaturised chamber that is mounted in proximity to the exhaust gases emanating from the tail pipes of automobiles. The chamber protects the sensors from high temperatures, humidity, prevents back pressure or back flow and allows the sensors a sampling time, all while being economical, compact and easy to use. Data from the sensors may be used to actively monitor emissions from the internal combustion engines and hence allow authorities to take off the roads, vehicles that do not meet the emission standards if they exceed them or send the vehicle for servicing. This would mean an overall improvement in the quality of automobiles.

**Keywords**— Automobile Exhaust, Exhaust Gases, Sampling Chamber, Solid State Sensor.

## I. INTRODUCTION

The detection and analysing the level of various gases like Nitrogen Oxides (NO<sub>x</sub>), Sulphur Oxides (SO<sub>x</sub>), Carbon Monoxide (CO), carbon dioxide (CO<sub>2</sub>) and other hydrocarbons (HCs) in vehicular emissions [1] from automobile exhaust has been vital to compete with climatic change. Solid state sensors have become more common in detecting these toxic, non-toxic and greenhouse gases [2] [3]. However, these sensors are highly delicate and must be placed in a protected, safe and suitable environment while performing accurately and taking less place. For this purpose, a miniaturized chamber was designed. The various aspects considered in the design of the chamber were sampling of the exhaust gas, efficient removal of this sampled gas and intake of fresh air while removing the measurand gas to bring the sensors back to the normal state if solid state sensors with high response time are used. Since the sensors operate at lower temperatures, the hot exhaust gases are cooled in the miniaturized sensing chamber to avoid erroneous readings. To check humidity a suitable filter was provided. The chamber was designed such that there was no backflow or backpressure [4]. The dimensions were such that it occupied less space and could be easily mounted in proximity to the exhaust gases emanating from the tail pipes of automobiles while inducing negligible drag. The sensing chamber provides these advantages all while being economical and safe. The data from this assembly can be actively used to monitor emissions from the internal combustion engine and allow authorities to keep a check on the quality of automobiles.

## II. SELECTION OF MATERIAL

The miniature sensor chamber was made up of Alumina as it can be easily fabricated and has a

comparatively low density. Alumina is chemically inert to most of the chemicals as shown in Table 2. Material used for non-return valve was Brass. Since Brass and Alumina have high operating temperatures, it does not get damaged in normal use. Properties of brass are shown in Table 3.

Table 1. Mechanical and Thermal Properties of Alumina Ceramic Oxide [5]

PROPERTY	VALUE	UNIT
Density	3.98	g/cm <sup>3</sup>
Bulk Modulus	324	GPa
Compressive Strength	5500	MPa
Elastic Limit	665	MPa
Endurance Limit	488	MPa
Fracture Toughness	5	MPa.m <sup>1/2</sup>
Hardness	22050	MPa
Modulus of Rupture	800	MPa
Poisson's Ratio	0.33	-
Shear Modulus	165	GPa
Tensile Strength	665	MPa
Young's Modulus	413	GPa
Maximum Service Temperature	2114	K
Thermal Expansion	10.0 × 10 <sup>-6</sup>	/°C

Table 2. Chemical Properties of Alumina [5]

ENVIRONMENTAL PROPERTIES	
<i>Resistance Factors: 1=Poor 5=Excellent</i>	
Flammability	5
Fresh Water	5
Organic Solvents	5
Oxidation	5
Sea Water	5
Strong Acids	5
Strong Alkalis	5
Ultraviolet Rays (UV)	5
Wear	5
Weak Acid	5
Weak Alkali	5

Table 3. Thermal Properties of Brass [6]

PROPERTY	VALUE	UNIT
Thermal Conductivity	121	W/m.K
Specific Heat	0.402	KJ/kgK
Melting Point	940	°C
Thermal Expansion	20.2 × 10 <sup>-5</sup>	/°C

### III. MECHANICAL DESIGN

The various aspects that affected the design of the chamber are minimum backflow, cooling capacity, heat transfer rate, gas sampling mechanism, drawing in of fresh air during exhaust post sampling. The design of the interior of the sensing chamber was made so as to maintain zero or negligible backflow or back pressure of inlet gas to maintain laminar flow to the furthest extent possible. The sensing chamber is 40mm x 90mm and walls made up of Aluminium are of thickness 3-4mm that conducts the heat to the Peltier plate which acts as a heat sink by maintaining one of its sides cooler than the other by applying a DC voltage across the plate (*Peltier effect*) [7]. The cooler side is placed in perfect contact with the sensing chamber and the other side is exposed to ambient conditions through fins and a fan. This arrangement cools the incoming gas and avoids erroneous readings or damage of sensor or PCB. The Peltier cooling region of the chamber was designed such that it decreases in area thus increasing the velocity which increases the heat transfer coefficient [8] of the inner wall of the chamber. A 2-way 2-position valve is placed at the inlet and the exhaust. The inlet valve should have a higher heat resistant rating to withstand high exhaust temperature. A brass non-return valve (NRV) is placed in the fresh air inlet pipe and the gas inlet pipe. The NRV stops the charge to flow out through it and only allows fresh charge to enter when needed. The sensing chamber is connected to a frame to take all the vibrations and provide dynamic stability. Before entering the chamber the gas passes through a thermoelectric generator. The gas is filtered out before entering the sensing unit. The filter membrane is made up of materials like *Polytetrafluoroethylene (PTFE)* and the filter substrate is made up of materials like *Polyethylene Terephthalate (PET)*. This filter can be placed either in the chamber or on the sensor packaging material according to convenience. It is preferred to place the filter on the sensing cap for ease of design. The exhaust suction can be provided by 3 processes: a vacuum servo assembly, a vacuum pump or a diaphragm pump.

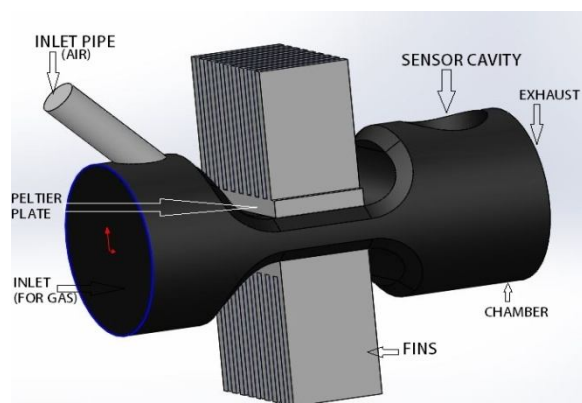


Figure 1. Sensing Chamber Design with Peltier Cooling System

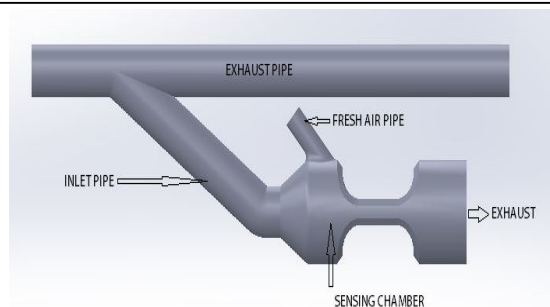


Figure 2. Sensing chamber assembly with exhaust pipe

### IV. OPERATION OF THE SENSING CHAMBER

The schematic diagram of the sensing unit assembly is shown in Fig 4. A part of the exhaust gas is taken into the sensing chamber through the inlet pipe. This exhaust gas is considered to be uniform due to high turbulence [9]. This gas passes through a thermoelectric generator and converts heat of the exhaust gas to electricity which charges a battery thus reducing the power required to supply across the Peltier plates. The measurand gas passes through the 2-way valve and the filter and enters the sensing chamber. The Peltier cooler cools the gas and the analysis is shown in Fig. The backpressure at the fresh air non-return valve increases and fresh air is prevented from entering in the sensing chamber and the gas is sampled when the inlet valve is closed. The sampling time depends on the solid state sensor's response. When the output of the sensor is obtained, the exhaust valve opens and the gas is removed in a way depending on the exhaust mechanism used. If a vacuum pump (already present in the automobile) or a diaphragm pump [10] is used, the sampled gas is removed by suction and during this the backpressure at the inlet pipe non return valve reduces and the valve opens and fresh air is drawn in due to suction. If a vacuum servo mechanism is used as shown in Fig. the fresh air is pumped in which drives the sampled gas out. In the vacuum servo mechanism, similar to the vehicle braking system [11], when the valve is pushed in the upward position, one side of the piston is exposed to atmosphere and the other side is exposed to vacuum from the inlet manifold [12] through a vacuum reservoir and non-return valve mechanism and the piston moves due to pressure difference thus providing the driving force to pump fresh air into the sensing unit and bring the sensors back to the initial normal condition. If the solid state sensors have a quick response time then a continuous flow of exhaust gas can be maintained and the 2-way 2-position valves, fresh air inlet pipe assembly and the exhaust assembly can be avoided in the design and the chamber consists only of the thermoelectric generator, filter, sensing chamber and frame connection. Thus, the response time of the sensor plays a crucial role in the chamber design, cost involved and the size of the chamber.

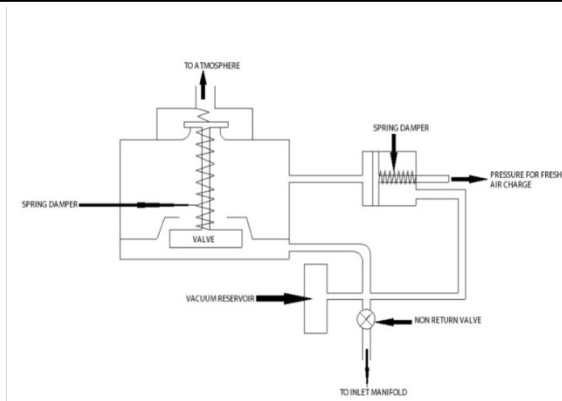


Figure 3. Schematic diagram of vacuum servo mechanism to pump in fresh air

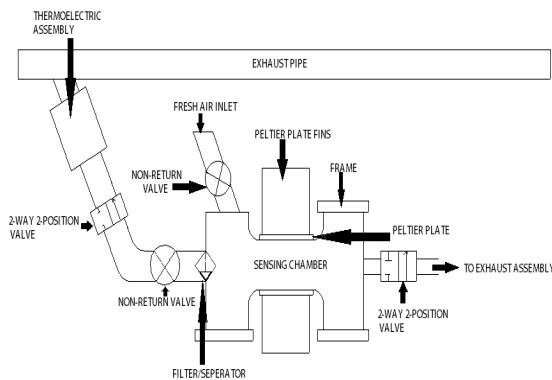


Figure 4. Schematic Diagram of Sensing Chamber Assembly

V. MECHANICAL ANALYSIS

Analysis for the miniature chamber was carried out by using the Fluid Flow (CFX) and Transient Thermal Analysis systems. Boundary conditions are set to extreme conditions to ensure that a level of design safety is maintained. The model that was used in the analysis was built in such a way that it represents the inner wall of the miniature sensing chamber throughout. Thermal and flow analysis were done to check the temperature distribution over the sensing chamber and the flow of exhaust gas into the sensing chamber.

To perform the thermal fluid flow analysis the inlet gas temperature was maintained at 120°C and the inlet, outlet and walls are defined. The inlet gas velocity was kept at 60 m/s which was acquired by measuring the exhaust gas velocity of a single cylinder petrol engine. The medium was chosen as atmospheric air. The pressure difference across the chamber was maintained zero. For the transient thermal analysis, the Peltier plates were maintained at -10°C, internal convection was assigned to the domain with the inlet temperature 120 °C. The modes of heat transfer that are being simulated are conduction (stainless steel), convection (stagnant air, thermal conductive coefficient = 5W/m<sup>2</sup>K), as well as radiation (emissivity = 0.5) with an ambient air temperature of 22 °C. The number of time steps is 5.

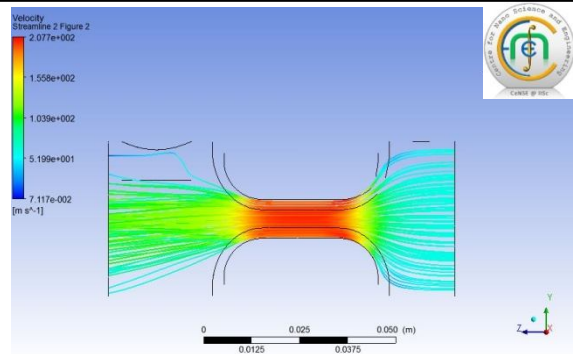


Figure 5. Flow analysis for miniature sensing chamber

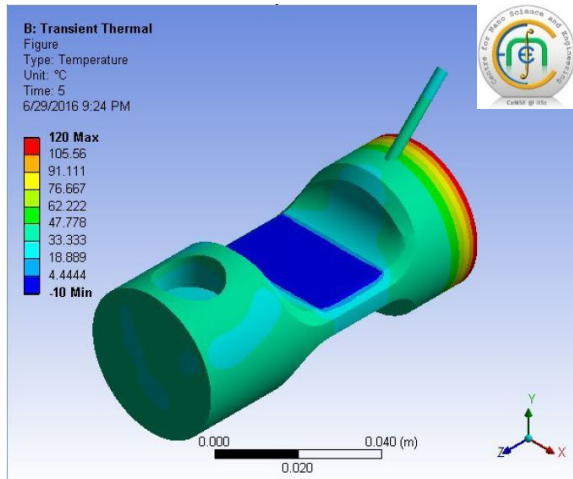


Figure 6. Thermal flow analysis for miniature chamber

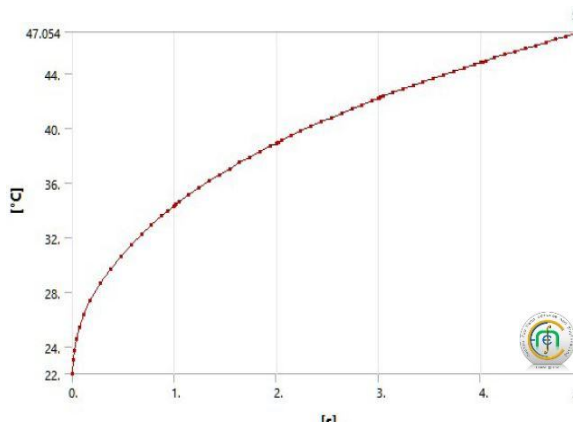


Figure 7. Outlet temperature versus time plot

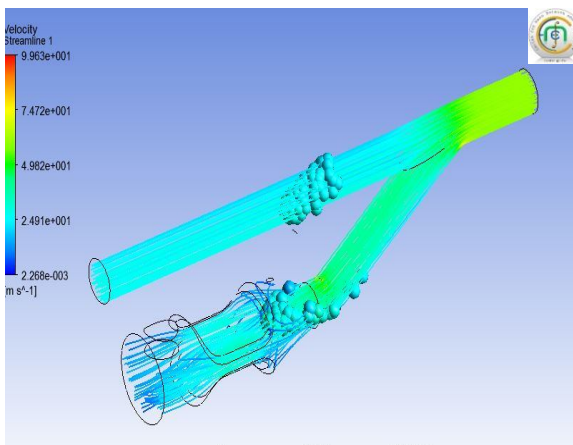


Figure 8. Flow analysis with exhaust pipe of an automobile

## VI. RESULTS AND CONCLUSION

For the fluid flow analysis, a major determining factor for the miniature chamber was the absence of any back flow. This was a major factor as the use of this chamber must not affect the performance and operation of the source of the measurand gas. As seen in Fig. 5, the streamlines seen all flow generally in the forward direction, thus resulting in negligible backflow.

For the thermal fluid flow analysis, we look at reducing the temperature of the hot inlet gas as far as possible for the aforementioned reasons. As seen in Fig. 6, we see that the temperature of the gas falls substantially in a rather small span. The graph shown in Fig. 7 gives us the outlet temperature as the exit, which after 5 seconds of flow at 60m/s of air at 120 °C is around 47 °C, which is well below the operating temperature of most of the solid state sensors. This proves that the sensor packaging material and the sensor itself is safe from the harmful effects of excessive temperatures. Fig. 8 shows the laminar flow of the exhaust gases from the exhaust pipe to the sensing chamber.

*Other applications* where such a sensing chamber can be used is:

*Automobile:* The sensor and sensing chamber assembly can be used in automobiles not only for exhaust gases but to check oxygen level in other parts of the engine too.

*Health and medicine:* A simple sensing chamber can be used in a breath analyser to detect diseases like CO poisoning and asthma. It could also act like a diet monitor while also checking alcohol intoxication level by using few solid state sensors. Such a Breathalyzer uses an NRV (non-return valve) at the inlet and a diaphragm pump cum valve at the exhaust to regulate the flow of the breath and fresh air.

*Agricultural robot:* The sensor and sensing chamber assembly can be used in an agricultural robot which could in turn be used to inspect whether the plant has a particular disease. Plants release a particular gas at a certain level which can be drawn in the sensing chamber of the robot and measured thus informing the user about the plant's condition. This chamber could be used in grading of various agricultural products like coffee and spices too.

*Air pollution sensing drone:* An environment monitor or air pollution sensing drone could adopt this

assembly of the miniaturized chamber and sensor to detect the level of particular pollutants in air.

*Safety:* Carbon Monoxide and other harmful gas detection devices could adopt the same assembly. These can be either used in homes or in mines.

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