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Calibrated Catalytic Converter

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Abstract:
Due to increase in number of vehicles pollution has raised to its peak point. Exhaust emissions of much concern are Hydrocarbon (HC), Carbon Monoxide (CO) and Nitrogen Oxide (NOx) from the automotive vehicles. In order to reduce the emissions many different technologies are being used. One of them is the catalytic converter. Catalytic converter plays an important role in reducing the emissions from the exhaust gas which is being released by the engine of an automobile. Catalytic converter is made out of many precious metals like platinum, rhodium, palladium, etc. It is made out of ceramic material and it is brittle in nature. This research paper deals with how emission can be controlled by using different parameters on the catalytic convertor. It deals with how the gap between the case and the substrate can be controlled effectively to reduce the effect of the back pressure which is been acting on the substrate.

Keywords — **catalytic converter, canning, calibration, gap bulk density.**

Introduction

Air pollution generated from mobile sources such as automobiles contributes major air quality problems in rural as well as urban and industrialized areas in both developed and developing countries. About 50 million cars are produced every year and over 700 million cars are used worldwide. Vehicle population is projected to grow close to 1300 million by the year 2030[1].

Most vehicular transportation relies on combustion of gasoline, diesel and jet fuels with large amount of emission of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx) and particulates matter (PM) are especially concern. HC and CO occur because the combustion efficiency is less than 100%. The NO*x* is formed during the very high temperatures (>1500 0C) of the combustion process resulting in thermal fixation of the nitrogen in the air which forms NO*x*.

Typical exhaust gas composition at the normal engine operating conditions are: carbon monoxide (CO, 0.5 vol.%), unburned hydrocarbons (HC, 350 vppm), nitrogen oxides (NO*x*, 900 vppm) hydrogen (H2, 0.17 vol.%), water (H2O, 10 vol.%), carbon dioxide (CO2, 10 vol.%), oxygen (O2, 0.5 vol.%) [2]. Carbon monoxide is a noted poison that has an affinity for haemoglobin in the blood 210 times greater than the oxygen affinity prolonged exposure to levels above 9 ppm can lead to reduce mental acuity for some individuals. HC and NOx lead to photochemical smog in presences of sunlight give secondary [3].

The monolithic catalytic converter remains the main pollution control device for modern automobiles towards reaching the ever-increasing legislative demands for low emission standards. The catalytic converter is expected to attain conversion efficiencies of the order of 95% or above for the main exhaust gas pollutants, namely CO, hydrocarbons and NOx. The conversion efficiency is a function of numerous design and operating parameters
of the complete system, comprising the engine, the exhaust line and the catalytic converter.

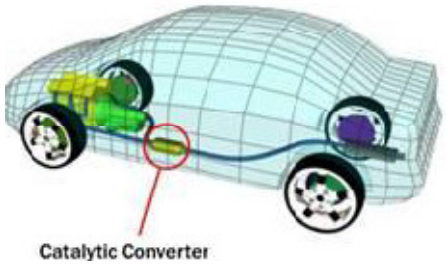

Figure 1: Catalytic Converter

1. Canning

Canning is the universal name for the installation of ceramic substrate in a metal housing. A number of different canning methods have been developed. The most used methods are shown in figure. There are called stuffing, tourniquet and clamshell [4].

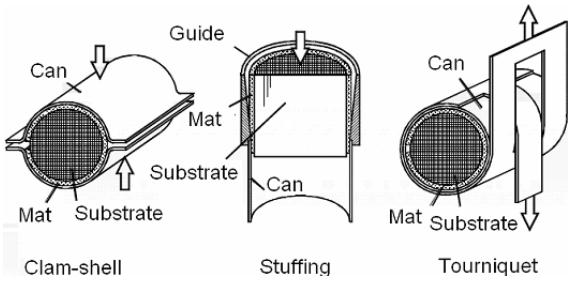

Figure 2: Canning Methods [4]

Before canning the substrate is sleeved in a support mat. Different support mat types exist, but all have the same objective to supply holding force to the substrate during operational lifetime.
Almost all support mats used today are made-up of ceramic fibres or alumina fibres.
The shape of the substrate influences the canning stability. The shape and size of the used substrate is usually determined by the design volume available for the catalyst or particulate filter. Figure 2 shows the canning stability for different substrate shapes. Low canning stability implies larger the risk of substrate breakage [4].

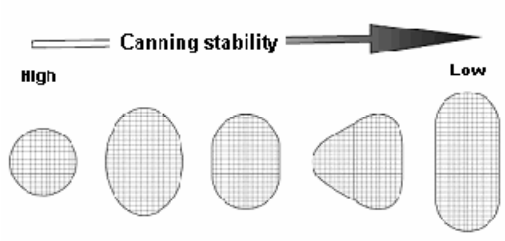

Figure 3: Canning Stability [4]

The most stable canning process can be achieved with round substrates. The reason is that a more uniform pressure field around the substrate can be achieved with round substrates. The long oval racetrack shape makes it difficult to obtain a uniform pressure field around the substrate which increase the risk of substrate breakage.

With the stricter vehicle emission legislation, the use of thin-walled and ultra-thin-walled substrate is a possibility to comply with regulations with smaller substrates, back pressures should also decrease.

2. Canning Methods

Canning methods are divided in different categories depending on how they obtain the required ceramic support mat pressure to keep the substrate in place. Different methods have been developed to fit different shapes of substrate. The classifications of methods are shown in table

	Fixed Gap	**Fixed Force**
Single Seam	Stuffing, Swagging	Tourniquet
Double Seam	Clamshell	Shoebox

The Shoebox and Tourniquet methods uses a fixed force to close the surrounding metal housing, while the Stuffing, Swaging and Clamshell methods uses a predetermined gap between the catalyst or particulate filter and the surrounding metal housing. Single seam implies that the surrounding metal is closed by welding one seam, Tourniquet method is one example described later in this chapter [5]. Double seam means that the metal is made up from two separate parts that are closed by welding on two seams

The major difficulty in canning with a fixed gap is the poor manufacturing tolerances of the components. To overcome this problem, the components are measured and the metal housing dimension is adjusted to obtain the right gap. This is known as “soft-canning”; consequently, in “hard-canning” components are not measured [5].

a. Stuffing

In this method mat is wrap around the substrate and is slide into the funnel. With the particular force it is been pushed inside the case [6].

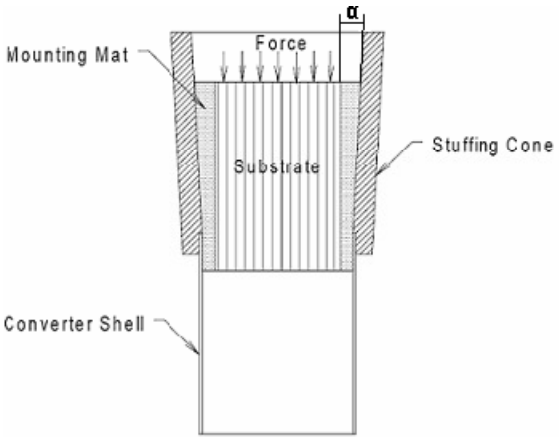

Figure 4: Stuffing Method

Stuffing cone is used to get the smooth compression of the mat and to reduce the pressure during insertion

b. Tourniquet

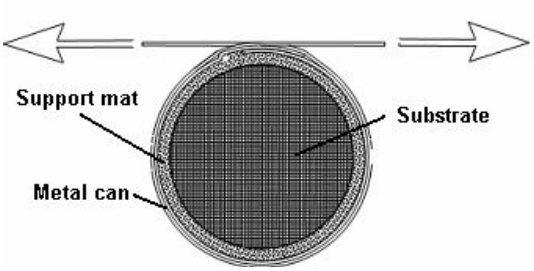

Figure 5: Tourniquet

The tourniquet method is a fixed force, single seam method. The substrate is sleeved with a support mat and then inserted into rolled steel sheet and the closed by pulling on the opposite sides of the steel sheet until the set force is met and welded shut [6].

The tourniquet method is restricted to round and close-to-round substrates. It is the most used method for packing of catalyst today and it is also used for particulate filter.

c. Clamshell

The clamshell method is a fixed gap, dual seam method [6]. The metal housing is usually made up from two prefabricated halves, stamped out of sheet metal.

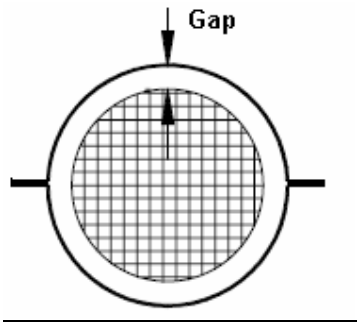

Figure 6: Clamshell Method

The clamshell method is mostly used for non-round and oval substrate which is used in underfloor placement of catalysts and particulate filters. To obtain the right gap around the substrate, the diameter of the substrate needs to be measured and the shell adjusted accordantly.

d. Shoebox

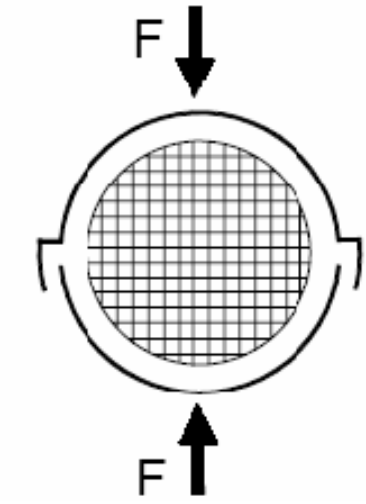

Figure 7: Shoebox

The shoebox canning method uses two prefabricated stamped out metal halves that are pressed with a fixed force to obtain the required GBD as in figure 5. The overlapped shell is then welded into place. Thedifference from the clamshell method is the overlapping of the halves.

e. Swaging

Swaging is a new method and not commonly used and is restricted to round substrates. The substrate is sleeved in a support mat and inserted into a tube. The shell is formed down to reach the desired diameter, inlets and outlets are also machined [6].

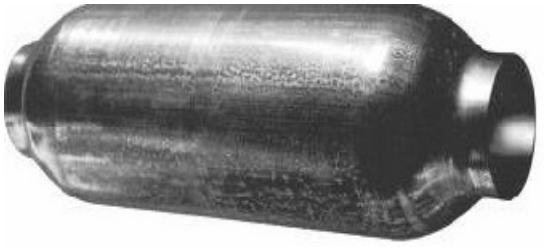

Figure 8: Swagging

The process is fully automated with the use of CNC machines. The investment costs are high which demands large volume production. Due to the spring-back of the tube the gap is machined less than the final gap, this will give higher pressures.

3. Wrapping Mat

The mat is the component that supplies mechanical support to the substrate to keep it in place during operation. It also acts as a thermal insulator between the substrate and the outer shell and as a seal to prevent exhaust gas flow going around the substrate. Three types of support mats are commercially available.

- Intumescent
- Non-intumescent
- Hybrid

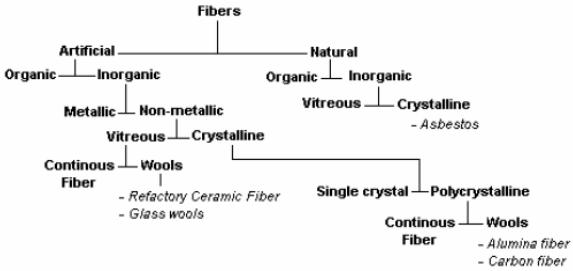

Figure 9: Classification of fibres

All support mat used for substrate support are made from artificially non-metallic fibres. The polycrystalline fibres are manufactured using the SOL-GEL technology [7], vitreous fibres are manufactured using a melt-spun technology that are becoming more infrequently used. The SOL-GEL method in fibre mat production is shown as Mixing and Fiberization.

4. Gap Bulk Density

GBD or Gap Bulk Density is the density of the mat within the gap between the case and the substrate. Every mat has certain amount of density according to the weight. When the substrate is wrapped with the mat and inserted in the case, it holds the substrate at the particular position [5]. The distance between the substrate and the case occupied by the mat to hold the substrate at right position is the gap. It is the thickness of the mat which possess some mass and the density. This Gap Bulk Density can be calculated by –

$$GBD = \frac{mat\ weight \times 1000}{gap}\left[\frac{g}{cm^3}\right] \qquad (1)$$

Where the mat weight is mass per area (g/m^2) of the support mat.
The support mats are also hydroscopic and can contain a couple of weight percent of moister. When fixed gap methods are used, the GBD will be overestimated. Therefore, the support mat should be stored in a room with a desiccant a couple of days

before installation to remove the moisture from the support mats [5].

Gap is calculated using equation 2. It is the distance between the substrate diameter and the innerdiameter of the shell housing.

$$Gap = \frac{Shell\ ID - Substrate\ OD}{2}\ (mm) \qquad (2)$$

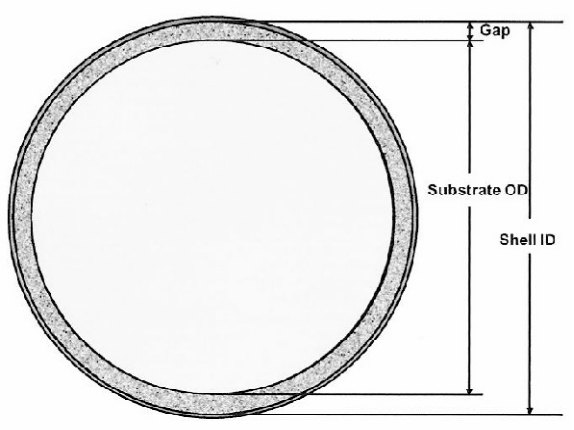

Figure 10: Intersection of Canned Substrate

Firstly, we need to weight the mat before stuffing it into the case. That will be the mass weight of the mat. Once the wrapped substrate is stuffed inside the case, its gap bulk density can be found out by the gap between the case and the substrate.

Two types of GBD are commonly used. When the binder, used to keep the support mat togetherduring transportation and encapsulation, is included theterm Bonded-GBD or B-GBD is used.The other Fibre-GBD is the F-GBD where the binder weight issubtracted and only the fibreweight is included.Manufacturers use the different definitions and therefore cautions have to be taken when doingcalculations [5].

When GBD is used it generallyimplies that the binder isincluded.The combinationof the hydroscopic properties, the poor manufacturertolerances of the components makes it difficult toreach consistent GBD. To regain some control of theGBD, components can be measured and pairedtogether. The metal housing dimensions can also beadjusted.The general manufacturing tolerances of the components are seen in table.

Substrate Ø (mm)	Mat Weight (gm)	Housing Ø (mm)
±2	±10	±0.5

With the proper dimension of the substrate, mat and the housing case can give an acceptable theoretical GBD. Possible GBD of the canning is seen in the table.

GBD_{low}	GBD_{nom}	GBD_{high}
0.25	0.4	0.75

Manufacturers set this tolerance high in reality in order to avoid the sorting of the components. GBD variation can cause both cracking and slippage of the substrate due to variation in the mat pressure.

During operation this catalytic convertor experience lot of back pressure due to emission. With the low GBD it can cause slippage of the substrate. For that reason, mat should have more density to apply the pressure from all sides on the substrate. Mass weight of the mat should be high to meet the required GBD. That can increase the cost of the mat, as it is made up of glass wool or the alumina fibre. To minimise the cost of the mat, case squeezing is used to reduce the diameter of the case.

5. Case Squeezing

Case squeezing is the technique used to reduce the diameter of the case to increase the pressure on the mat to hold the substrate properly. Case can be compressed on only the portion of the mat wrapped on the substrate to generalise equal force from all sides. This process is called calibration [8].

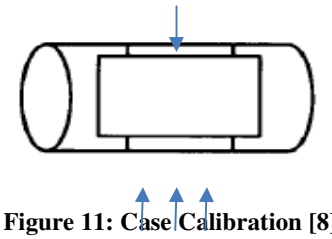

Figure 11: Case Calibration [8]

a. Post Calibration

In this process squeezing of the case is done after the canning [8]. Firstly, mat is being weighed and substrate's diameter is measured. Also, the case diameter and the thickness are measured. Gap is measured by the equation 2 with the parameters which is been measured earlier.

$$Gap = \frac{Shell\ ID - Substrate\ OD}{2}\ (mm)$$

As we know the that nominal GBD is 0.4 (g/cm^3), canning can be compressed to limit to get the desired GBD.

If the case is compressed more the GBD increases but it can damage the substrate as it is brittle and fragile. And if the case is compressed less the GBD decreases and can cause slippage of substrate.

b. Pre-Calibration

In this process case is first squeezed and then the substrate is stuffed with the mat. Firstly, mat is weighed and the diameter of substrate is measured. And then the squeezing of the case is decided. This process is difficult as it can damage the substrate at stuffing.

6. Closing speed

Canning closing speed is the rate of mat compression in the canning process [9]. Closing speed is important because of the viscoelastic properties of the mat. Figure shows the general behaviour of the mat pressure during compression.

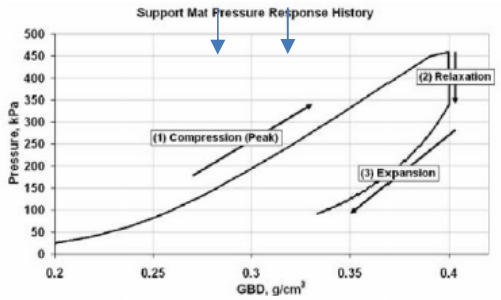

Figure 12: Mat pressure during compression [9]

A high closing speed will give a high peak pressure leading to an increased risk of substrate brakeage. For that reason, the mat compression speed should be kept low enough to prevent mat pressure rising above the strength of the substrate.

The most of the relaxation of the support mat occurs during the first minutes after canning. Relaxation can still occur 60 minutes after canning, but at a lower rate. The higher the closing speed the longer time is needed for relaxation [9]. The closing speed most commonly used is around 25 millimetres per minute, but speeds of 1-100 millimetres per minute are used [9].

7. Conclusion

Environmental, ecological and health concern result in increasingly stringent emissions regulations of pollutant emissions from vehicle engines. Among all the types of technologies developed so far, use of catalytic converters is the best way to control auto exhaust emission. Industries need to reduce the emission but at low manufacturing cost in order to earn more profit. Rather than investing more money on good density mat, squeezing of the case can be done to get good holding capacity to the mat. Use of calibration process is the best way to keep the substrate at the correct position as it provides nearly equal forces in all direction on substrate. In Europe many vehicles have calibrated canning, which obeys the emission norms.

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