Catalytic Converters Operation & Automated Coating Process

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01___Executive Summary

Technological & Legal Evolution of Catalytic Converters

Air pollution causes an estimated 2.4 million deaths per year over the globe as per the World Health Organization (WHO) [1]. And, the transport sector is the number one source of air pollution in urban areas across the world [1]. This is not a new phenomenon. Air pollution and its disastrous effects go back a very long way.

It was as early as 1306 that English monarch Edward I prohibited burning of certain coal varieties to curb air pollution [2]. The advent of the Industrial Revolution saw air pollution assuming gigantic proportions. A smog killed 400 in London in the 1950s, pushing the British Parliament into enacting the Clean Air Act, 1956 [2].

Emissions from automobile exhaust and smoke stacks had spiked air pollution to dangerous levels across leading global cities in the 1940s and the 1950s. Bothered at this state of affairs, French engineer Eugene Houdry built the first catalytic converters around 1950 to deal with exhaust from smoke stacks [3].

Houdry thereafter made catalytic converters for forklift warehouse trucks. Somewhere in the mid-1950s, he commenced with research for making converters for car engines running on gasoline (petrol) [3]. The idea was far ahead of time.

Catalytic converters took material shape when deteriorating air quality prompted legislative and regulatory actions. United States Congress passed the Clean Air Act in 1970. Then, the Environment Protection Agency's (EPA's) 1973 directive made catalytic converters mandatory on all cars made post 1975 [4].

In 1973, Engelhard Corporation engineers

Carl Keith and John Mooney made the first production grade converter [3]. To start with, cars in the state of California were fitted with catalytic converters. Their use spread around the globe later [2].

Petrol engines work smoother with leaded gasoline [2]. However, lead interferes with the converter's functioning and seriously affects human health. Lead poisoning was a serious issue for early converters fitted onto engines burning leaded petrol. Gasoline stations in the US continued to sell leaded as well as unleaded petrol till 1995 when the amended Clean Air Act completely prohibited leaded gasoline [4].

Early converters on petrol engines that operate on the Spark Ignition (SI) principle were two way converters that only oxidized carbon monoxide (CO) and hydrocarbons (HC). They did not reduce nitrogen oxides (NO_x), which are a part of the emissions [5].

Three way converters evolved to meet this need. Rhodium and platinum reduced NO_x while palladium and platinum are involved with oxidizing carbon monoxide (CO) and hydrocarbons (HC) [6].

Initial three way converter models had the reduction and oxidation sections in series. To utilize these converters, the engine was tuned to operate on a rich air-to-fuel mixture (more fuel than necessary). Besides, air had to be added before the oxidation section [2].

Advances in exhaust oxygen sensors, fuel injection mechanisms, and control systems eliminated this complicated arrangement. Cerium oxide (CeO_2) addition to the catalyst extracted and supplied oxygen alternatively to maintain a balance [2].

In addition to carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x), diesel engines also emit particulate matter (PM) [1]. Diesel engines work on the Compression Ignition (CI) principle and use the two way Diesel Oxidation Converter (DOC) that oxidises CO and HC [5].

Selective Catalytic Reduction (SCR) employs urea to nullify NO_x in diesel exhaust. NO_x adsorbers or traps serve the same purpose but are expensive. Diesel Particulate Filters (DPF), also called Soot Traps, prevent the soot or particulate matter from escaping to the environment [5].

Now, catalytic converters oxidize carbon monoxide (CO) to carbon dioxide (CO_2), the latter being the main Greenhouse Gas (GHG) contributing to the dreaded phenomenon of Global Warming. It is worthwhile to ponder if they escalate global CO_2 levels. The answer is negative [7].

Catalysts do not actually take part in a reaction. They only speed it up. In theory, therefore, the catalyst should last forever. A host of practical working conditions ensure that this is never the case. Catalytic converters work best when the engine, spark plug, and oxygen sensor work properly [6].

02___Vehicular Emissions: Need for Catalytic Converters

Internal Combustion (IC) engines burn fuels to produce mechanical work. The combustion process generates polluting gases. Automobiles utilize the IC engine and are a major source of pollution.

Carbon monoxide, nitrogen oxides, and hydrocarbon emissions are particularly lethal. Minimizing their discharge is a crucial design parameter for automobile engines [6]. Toxic vehicle exhaust emissions include [1]:

• **Carbon Monoxide (CO)**: Is the result of incomplete combustion of the fuel. Rich air-to-fuel mixtures that use surplus fuel are particularly prone to discharging this gas. Reacting with haemoglobin, the gas lowers the capacity of blood to transport oxygen. The resultant suffocation leads to slower reflexes, loss in focus, and confusion.

• **Nitrogen Oxides (NO_x)**: Elevated cylinder temperatures make nitrogen react with oxygen and generate NO_x viz. nitrogen oxide (NO) and nitrogen dioxide (NO_2). Since the diesel engine operates at higher temperatures, they emit more NO_x. Between 40% and 70% of urban NO_x originates from road transport.

Five times as toxic as NO, NO_2 causes lung disease and decreases immunity against respiratory ailments apart from lowering visibility by forming pollutant haze. Both these nitrogen oxides trigger acid rains, create smog, and form ozone.

• **Volatile Organic Compounds (VOCs) or Hydrocarbons**: Unburned fuels form hydrocarbon emissions. Fuel near the cylinder walls is often left unburned as temperature there is lower than at the centre of the cylinder. Typically, diesel engines discharge lesser hydrocarbons.

Cancer, uneasiness in the respiratory track, and ground-level ozone are some issues that hydrocarbons create.

• **Particulate Matter (PM)**: Diesel engines emit between 6 and 10 times higher PM than that of gasoline engines. Responsible for a host of cardiovascular ailments such as lung cancer and asthma, PM can cause early death, cut visibility and farming productivity, soil buildings, and contribute to climate change.

Incomplete burning of the hydrocarbon content in lubricating and fuel oil is the main source of PM. Factors influencing PM formation are the quality of fuel oil (ash and sulphur percentage) and lube oil, combustion process, cooling of exhaust gas, expansion process, and combustion temperatures.

Most PM is spherical with diameter of under 1 μm and majority of it is soot. Other components are the soluble organic fraction (SOF) as well as the inorganic fraction (IF).

Three way catalytic converters on gasoline engines operating in a narrow range around the stoichiometric (theoretically correct) air-to-fuel ratio cut CO, HC, and NO_x emissions by between 80% and 90% [8]. Diesel engines use two way converters for dealing with CO, HC, and a fraction of PM discharges. They also employ Selective Catalytic Reduction (SCR) for addressing NO_x releases [9]. Properly designed catalyst converter for the diesel engine slashes down the emissions of the following pollutants in the mentioned percentages [10]:

• Carbon monoxide by between 80% and 95%.

• Hydrocarbon by between 85% and 90%.

• Diesel Particulate Matter (DPM) by between 25% and 35%.

Selective Catalytic Reduction (SCR) technique employed in diesel engines cuts down [11]:

• Up to 90% of NO_x emissions.

• Between 50% and 90% of CO and HC discharges.

• Between 30% and 50% of PM releases.

Automobile transport is an inseparable part of our present day lifestyles, needed as it is for the movement of goods, people, and services. This makes the catalytic converter an essential device, a part and parcel of our life.

03___Global Catalytic Converter Market

Enforcement of increasingly stricter emission norms by regulators is the chief factor propelling the rise of the worldwide catalytic converter market [12]. Other drivers include the flourishing use of passenger cars, growing environmental awareness, positive research funding prospects, agreements and partnerships between major producers, and pressure on manufacturers to improve technology [12]. There is also a growing aftermarket for catalytic converters [13].

Speaking of tightening emission regulations, the EURO 6 norms of 2015 for light European vehicles mandated a 50%-plus cut in NO_x discharges vis-à-vis EURO 5 provisions. Similarly, petrol engines under the SULEV III or California LEV III norms demanded an over-70% lowering of CO emissions over the US federal regulations under Bin 5 of Tier 2 [14].

Various sources provide differing estimates on the size of the global market for catalytic converters:

• Markets and Markets expects this segment to expand from $42.4 billion in 2018 to $73.1 billion in 2025 after clocking an 8.1% CAGR [13].

• Allied Markets Research places the market at $183.4 billion in 2022 after growing at 7.7% CAGR between 2016 and 2022 [15].

• Reports & Data placed the 2019 market size at $43.68 and projected 8.2% CAGR will take it to $82.66 billion by 2027 [12].

• Grand View Research forecasts a $273 billion value for the industry by 2024 [16].

What can create serious roadblocks in the forward march of the market is the customer preference shifting towards hybrid and electric vehicles [15]. Catalytic converters use precious metals viz. Platinum, Rhodium, and Palladium. Already expensive, their prices keep changing with the swelling demand for converters [13].

Another limiting factor is the exorbitant cost of research and development [15]. However, if research is successful, low-cost converters will be a reality and further expand the market [12]. Important efforts in this regard are the experiments with metals other than the costly platinum, rhodium, and palladium [12].

04___Catalytic Converters: Construction, Operation, & Types

4.1. Construction of Catalytic Converters

Located downstream of the engine and upstream of the muffler, the catalytic converter consists of an outer shell that supports a metal or ceramic substrate [17]. A blend of precious metals such as Platinum, Rhodium, and Palladium along with oxides such as Ceria and Alumina is coated on the substrate [18].

Parts of catalytic converter:

- **Monolith or Substrate** is supported by the outer shell. Its honeycomb structure maximizes the surface area over which exhaust gases interact with the catalyst [7]. Material for substrate is ceramic or metal [6].

- **Washcoat** is a thin coating of ceramic applied over the substrate [6].

- **Catalyst** is deposited on the washcoat and is generally rhodium and platinum. Palladium is sometimes used [6].

Despite modest dimensions, the substrate has an active surface area of two football grounds thanks to its honeycomb structure. Early converters utilized palletized catalysts. Large surface area also limits the precious metals used in a single converter to between 1 and 2 grams [6].

4.2. Types of Catalytic Converters

Till 1981, Canadian and American automobiles employed two way convertors in both gasoline (petrol) engines working on the Spark Ignition (SI) principle and diesel engines operating on the Compression Ignition (CI) principle. These converters cannot neutralize nitrogen oxide emissions and were replaced by their three way variants [5].

- **Three Way Convertors**: Simultaneously carry out three reactions viz. one reduction (oxygen removal) and two oxidation reactions (oxygen addition) [18]. Details are:

  - **Reduction**: Rhodium and Platinum break down nitrogen oxide (NO_x) molecules into nitrogen atoms (N) and oxygen (O_2). The catalyst holds the nitrogen atoms which react to produce nitrogen (N_2) gas [6]. Nitrogen and oxygen are both non-toxic [7].

◦ **Oxidation**: Palladium and Platinum are involved in these reactions. First oxidation reaction converts carbon monoxide (CO) into carbon dioxide (CO_2) while the second one brings hydrocarbons (C_nH_x) and oxygen (O_2) together to produce carbon dioxide (CO_2) and water (H_2O) [6].

• **Two Way Convertors**: Execute only the two oxidation reactions and are used in diesel engines.

4.3. Operation of Catalytic Converters

Catalysts speed up a reaction without actually participating in it. Catalytic converters employ precious metals that transform the poisonous gases into safer, non-toxic gases but do not take part in the reaction.

For example, the convertor oxidises carbon monoxide into carbon dioxide. Carbon monoxide causes suffocation by compromising the capacity of blood to carry oxygen, thus lowering oxygen supply to vital internal organs [19].

What intensifies the hazard of carbon monoxide is its odourless and non-irritating nature, which makes it tough for the potential victim to sense it early. On the other hand, carbon dioxide is not harmful to humans in open spaces [20].

A look at the Occupational Safety and Health Administration's (OSHA)'s Permissible Exposure Limit (PEL) for the two gases will illustrate the point [20]:

• For Carbon dioxide: 5000 parts per million (ppm) across 8 hour duration and 30,000 ppm across a 10-minute duration.

• For Carbon monoxide: 50 ppm across 8 hours. At 1500 ppm, the gas is Immediately Dangerous to Life and Health (IDLH).

4.3.1. Three Way Converters

Early gasoline engine converters only had a section to oxidize carbon monoxide and hydrocarbons. Added later was a section for reducing nitrogen oxides. A ponderous arrangement, this also required setting the engine to run on a rich mixture so as to facilitate NO_x reduction [2].

Three way converters evolved with the following technology breakthroughs [2]:

• **Oxygen Sensors** to accurately measure the amount of oxygen in the exhaust.

• **Fuel Injection via Electronic Mechanisms** that replaced Carburettors enabling better control over the air-to-fuel ratio.

• **Microprocessor Control Systems** to precisely transmit data on exhaust oxygen levels captured by the oxygen sensor to the fuel injection mechanism.

Control systems are a must for three way catalytic convertors in order to maintain a fine balance of oxygen availability. Air-fuel mixtures can be [5]:

• Lean mixtures (more than necessary air) leave excess oxygen in the exhaust entering the convertor and obstruct the reduction (removal of oxygen) from nitrogen oxides (NO_x).

• Rich mixtures (more than necessary fuel) leave deficient oxygen in the exhaust, which fails to oxidise carbon monoxide (CO) and hydrocarbons (HC).

Therefore, control systems are designed to maintain the air to gasoline (petrol) mixture ratio between 14.6:1 and 14.8:1 [5]. This range is around the stoichiometric or theoretically correct air-to-fuel ratio of 14.7:1 [6].

Within these limits, three way catalysts operate with high efficacy. They store the oxygen obtained from reduction of NO_x and supply the same for oxidation of carbon monoxide and hydrocarbons.

Certain actions such as rapid acceleration require a rich mixture, and seriously hamper the efficacy of the three way convertor. The extra rich mixture consumes all the available oxygen and precludes the convertor from supplying oxygen [5].

Then again, the air-fuel ratio keeps fluctuating between rich and lean. Addition of cerium oxide makes it possible to adjust the varying air-to-fuel ratios, for it supplies oxygen to rich mixture exhausts and removes oxygen from lean mixture exhausts [2].

Adding manganese or nickel to the convertor washcoat reduces hydrogen sulphide formation. Low sulphur fuels eliminate hydrogen sulphide formation entirely. Ammonia formation is similarly prevented by making alterations in the precious metals and washcoat [5].

Three way catalytic convertors cannot use leaded gasoline. Lead residue covers the metals in the convertor [21]. Without contact with exhaust gases, converter metals cannot neutralize them. Moreover, lead is a serious hazard to human health [22]. Lead poisoning was a serious issue for early petrol engine converters. Growing awareness on the negative effects of lead culminated in the banning of lead additives in gasoline [2].

4.3.2. Two Way Converters

Surplus oxygen exists in diesel engine exhaust as they use a lean mixture [1]. This disallows the reduction reaction as any reducing agent will react with NO_x only after reacting with the existing oxygen. With only oxidation possible, three way convertors cannot be used for dealing with diesel exhaust [18].

Four pollutants in diesel exhaust are carbon monoxide, hydrocarbons, particulate matter, and nitrogen oxides [1]. Diesel engines typically use Diesel Oxidation Catalyst (DOC) to oxidize carbon monoxide, hydrocarbons, and the organic part in diesel particulate matter [9]. Two elements that DOCs cannot neutralize are NO_x emissions and the inorganic part of particulate matter.

Exhaust Gas Recirculation (EGR) was employed earlier to check NO_x emissions from diesel engines. A fraction of exhaust gases routed back to the combustion chamber lower the maximum combustion temperature, thereby cutting down NO_x generation [23]. EGR offers additional benefits such as [24]:

• For Diesel Engines: Hiking the temperature of exhaust gas for diesel particulate filter (DPF) regeneration.

• For Petrol Engines: Dilute the necessity of fuel enrichment, lower pumping losses, hike knock tolerance, and boost combustion efficiency.

Selective Catalytic Reduction (SCR) or lean NO_x Adsorber / Trap is used for controlling NO_x emissions from diesel engines. SCR is more popular as it uses base metals vis-à-vis NO_x adsorbers that employ precious metals. SCRs introduce urea in the exhaust stream and generate ammonia, which reduces NO_x [5].

Diesel exhaust contains large quantities of particulate matter. DOCs nullify only the organic element of particulate matter. The inorganic component of particulate matter is dealt with by Diesel Particulate Filter (DPF) or Soot Trap. Made of Silicon Carbide or Cordierite substrate, DPFs trap these soot particles.

Low density of diesel particulates (under 1 gm/cm^3) means large volumes accumulate at the DPF and escalate back pressure in the exhaust system. Thermal DPF regeneration oxidizes (burns) the trapped soot, and is the cleanest regeneration technique. EGR assists with thermal DPF regeneration as we have noted earlier [25].

4.3.3. Light Off

Light-off is the temperature that the monolith has to reach before it starts functioning. This temperature is between 250^0C and 270^0C. Automobiles attain light-off in some seconds from a cold start. Typical converter operating temperatures are between 400^0C and 600^0C [6].

Short journeys are an issue because the converter may not reach the light-off. The warm up phase before the converter attains light-off is when the engine pollutes the most. Pre-converters are smaller and positioned closer to the engine than the main converter. This enables them to start operating sooner. They also allow the main converter to attain light-off earlier by preheating exhaust [6].

4.3.4. Converter Failure

Catalysts coated on the monolith do not take part in the oxidation-reduction process, they only fast track it. Besides, the converter does not have any moving parts. Ideally, therefore, the converter should have unlimited life. Or, at least work for the lifetime of the automobile operating at typical working conditions.

Practical working conditions are vastly different, and cause converter failure:

• **Un-tuned Engine**: Results from a faulty air-to-fuel ratio, spark plug misfiring, or improper timing [6]. Three way converters work best when the air-to-fuel ratio is between 14.6:1 and 14.8:1 [5]. Outside this range, there is either deficient or surplus oxygen in the exhaust that seriously interferes with the converter function as noted in section 4.3.1.

When the spark plug misfires, the air-fuel mixture is not ignited in the cylinder. This leaves a large amount of unburned fuel in the exhaust which can partly or wholly melt the ceramic substrate [6].

Trials on a 1.0 litre spark ignition (SI) engine running at 1500-4000 rpm indicated:

◦ Misfire of 20% spikes catalyst temperatures by 250^{0}C [26].

◦ Ignition retard of more than 20^0 crank angle after top dead centre (TDC) as compared to normal timing escalated the exhaust temperature to over 1050^{0}C creating serious risk of thermal deactivation of the catalyst [26].

Ignition retard is the delaying of ignition of fuel in the combustion chamber so that it occurs nearer the top dead centre (TDC) i.e. when the piston is closer to TDC [27]. It can also mean ignition after TDC [28].

• **Dysfunctional Oxygen Sensor**: Does not correctly sense the amount of oxygen in exhaust. The flawed feedback it generates causes the mixture to be either rich or lean, both of which can damage the converter [6].

• **Run Down Spark Plug**: Misfiring or non-functioning spark plug leaves excessive and unburned fuel in the exhaust which can even melt down the ceramic monolith [6].

• **Physical Damage**: Can result from off the road driving, bad roads, debris on road hitting the converter, or damaged exhaust supports. The catalyst is applied as a thin layer on the wash coat, and its breakage sets off a chain reaction of further breakages. Broken pieces block the exhaust system and build up back pressure while also intensifying heat and engine power loss [6].

05___Do Catalytic Converters Escalate Global Carbon dioxide Levels?

Air pollution causes an estimated 2.4 million deaths per year on Planet Earth as per the World Health Organization (WHO). Transport sector is the number one source of air pollution in urban areas across the world. The sector also emits the second-highest amount of carbon dioxide (CO_2) [1].

Global Warming is escalating the intensity and frequency of extreme weather events such as tropical storms, heat waves, rains, and droughts. Soaring earth temperatures will further spur sea level rise and flood coastal cities, unleash new pathogens and pests, trigger stronger wildfires, disrupt habitats, and cause extinctions [29].

Greenhouse gases (GHGs) are a widely discussed topic today for they are responsible for Global Warming, a phenomenon with exceptionally destructive potential. Main GHGs are [1]:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Sulphur hexafluoride (SF_6)
- Nitrous oxide (N_2O)
- Perfluorocarbons (PFCs)
- Hydrofluorocarbons (HFCs)

Emitted in massive quantities, carbon dioxide is the primary GHG [30]. Annual global CO_2 discharges are at 35 billion tons [1]. The 2015 Paris Agreement guideline is to limit average global temperature rise to way under 2^0C vis-à-vis pre-industrial levels, preferably below 1.5^0C [31].

Complying with the 2^0C cap will necessitate restricting average atmospheric CO_2 levels to under 450 parts per million (ppm). The corresponding statistic for the 1.5^0C limit is 430 ppm [31]. In May 2020, the Mauna Lao Observatory recorded a monthly maximum 417 ppm of CO_2 [32].

Because catalytic converters oxidize carbon monoxide to carbon dioxide, a question that spontaneously arises is: **Do catalytic converters escalate global carbon dioxide levels? The answer is no.** This is because even without the converter, the CO from automobile exhaust will eventually convert to carbon dioxide [7].

What the converter does is speed up the process and minimize local air pollution [7], the effects of which can be lethal as noted under section 2.

06___Cybernetik

Cybernetik has provided customized and turnkey automation solutions to the automobile, food, and pharmaceutical industries since 1989. Starting from definition and design, our technicians proceed to deployment and support for a seamless and professional experience.

In the catalytic converter arena, CTPL has successfully designed and deployed Washcoat Automation, Coating Automation, and Substrate Handling cum Thermal Processing Automation for the manufacture of:

- Heavy Duty Truck Catalytic Converters
- Passenger Car Catalytic Converters
- Motorcycle Catalytic Converters

Custom designed to specific requirements, our automation solutions deliver best in class traceability, productivity, efficiency, safety, and quality via seamless and thoroughly planned-executed operations.

Scanners are built into the process solution to ensure automated quality checks at various stages. User-friendly HMI simplifies operational control and troubleshooting. SCADA / IoT enables customization.

6.1. Automated Coating Process for Catalytic Converter

In the context of the following discussion, **part means the Catalytic Convertor Body** that is being coated. All robots in the process utilize Servo Gripper with Camera for precision positioning and gripping.

Complete traceability is the foremost advantage of Cybernetik's process solution. Each operation on every part is checked and the relevant data recorded for real time access, monitoring, and control. Other benefits are:

- **High Productivity**
- **Customized Design**
- **Automated Quality Assurance**
- **Inbuilt Systems for Safety and Seamless Operations**

Process elements:

- **Washcoat Automation**
  - **Premix Tanks**: For accurate ingredient addition, uniform slurry premixing, and correct storage.
  - **Brewing Tanks**: Are movable and used for mixing ingredients. The blend is then pumped to premix tanks.
  - **Activation Tanks**: Are mobile and utilized for precision blending to final wash coat parameters.
  - **Portable Tanks**: Mix chemicals and acids using mobile agitators.
- **Coating Automation** deposits the coating solution onto catalytic converters installed on Heavy Duty Trucks, Passenger Cars, and Motorcycles.
  - **Coating Machine**: Deposits the coat.
  - **Air Stripper**: Facilitates the desired weight gain.
- **Substrate Handling and Thermal Processing Automation**
  - **Dryer**: Uses high temperature to evaporate water from the slurry that is wash coated onto the part.
  - **Calciner**: Boosts the catalyst layer's strength by gradually heating the part to a pre-set temperature, holding it at the temperature for a specified duration, and cooling the part slowly.
  - **Robotic Pick and Place**: Includes multiple robots integrated with the tracing system. All robots are equipped with vision system for accurate positioning and servo grippers for a smooth yet firm grip.
  - **Track and Trace**: Comprises of Height Sensor, Pad Printer, Laser Printer, Bar Code Scanner, and other scanning devices.

- **Quality Checks**

  - **Back Pressure Checking Station**: Operates after calcining. It utilizes a vacuum pump to check for blockages in the substrate.

  - **Weighing Station**: Gradually loads part on a sensitive scale. Three points for weight checking are:

    - Before coating.

    - After coating.

    - After calcining.

Flow of process is as follows:

1. Washcoat Automation prepares the required coating blend that is loaded into the system.

2. Operator loads part on Belt Conveyor.

3. Pad Printer marks a white square on the part.

4. Laser Printer marks barcode on the white square stamped on the part.

5. Barcode Scanner, also called Vision Sensor or Scanner, is a camera-like device which verifies if barcode is correctly printed on the part. If barcode is:

   i. Correctly Printed: Robot places part on Coating Machine.

   ii. Incorrectly Printed: Robot places part on Reject Conveyor.

6. Scanner near Coating Machine examines if the part is to be coated for the first layer or second.

7. During coating, the part gets rotated 360^0 in stages in the horizontal plane on the Coating Machine.

8. Robot picks up the part from the Coating Machine exit and places it on the:

   i. Pallet / Tray located on the Servo Slide if the part is properly coated.

   ii. Reject Conveyor if the part is incorrectly coated.

9. Servo Slide pushes the loaded Pallet on to the Pusher Slide.

10. Pusher Slide moves through a Drying Tunnel in which air at 150-200^{0}C enters the part from above and exits from below.

11. Accumulation Conveyor transports the part from the Drying Tunnel exit to a Flip Over.

12. Flip Over turns the part upside down.

13. Robot picks up the part and positions it on the Coating Machine and the process steps 6 to 10 are repeated to coat both sides of the part.

14. Robot picks up the part (that has been coated and dried twice) from the tray section

at the exit of the Drying Tunnel and places it on the slow moving Calciner Conveyor.

15. Calciner dries the part by subjecting it to high temperatures of 600-650^{0}C.

16. Robot picks up the part from Calciner exit and places it on the Weigher.

17. Back Pressure Station after the Weigher pulls air in through the Honeycomb structure which forms the internal section of the part. This action evaluates if some segments of the part are excessively coated.

18. Robot places the:

i. Properly coated parts on the Accept / Output Conveyor.

ii. Improperly coated parts on the Reject Conveyor.

07___Final Comments

Vehicular pollution is very much ingrained into our present day lifestyles. By extension, so are catalytic converters. Although their approach is to lower pollution at the local levels, they do not produce any global side effects i.e. they do not escalate atmospheric CO_2 levels which contribute to Global Warming, as we have categorically outlined in section 5.

Different types of electric vehicles have zero or minimal tailpipe pollutants. But it will be a while before sufficient charging infrastructure is available to thrust electrical vehicles in the mainstream of transportation. Until then, catalytic converters will continue to be integrated into the fabric of our existence. Technological advances will further boost their utility.

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