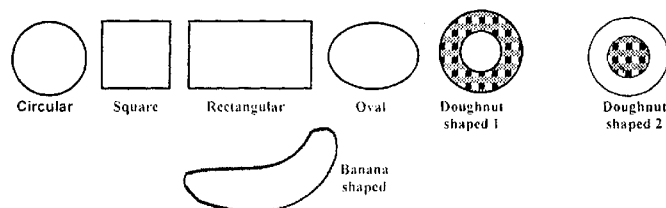


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CATALYST (CPCC OR CPCC²)Figure 2: Examples of the different shapes of Particulate Combustion Catalyst and Coated
Particulate Combustion Catalyst

(57) Abstract: Particulate Combustion Catalyst and Coated Particulate Combustion Catalyst that overcomes risks of failure due to continuous built up of trapped particulate matter by allowing an alternate open flow path in case of soot saturation, thereby confining backpressure under permissible limits. A three dimensional device for the catalytic treatment of exhaust gases of automotive vehicles comprising of a unique substrate.

PARTICULATE COMBUSTION CATALYST (PCC OR PCC²) AND COATED PARTICULATE COMBUSTION CATALYST (CPCC OR CPCC²)

FIELD OF INVENTION

The present invention is towards elimination or reducing particulate matter of exhaust from combustion engines.

The invention relates to Particulate Combustion Catalyst (PCC), particulate filter, and exhaust gas clean-up system. The invention more particularly relates to a composition and device designed to remove particulate matter or soot from the exhaust gas of diesel engines, Gasoline Direct Injection (GDI) engines etc. The present invention also relates to methods for manufacturing the said device.

BACKGROUND OF THE INVENTION:

The elimination or reduction of particulate matter emanating from the exhaust of combustion engines during its operation is always desired. Commonly known wall-flow particulate filters (DPF) can remove over 95% of the particulate matter (PM) from diesel engine exhausts. Some filters are designed for single-use, intended for disposal and replacement once full of accumulated soot. Others are designed to burn off the accumulated particulate either passively through the use of a catalyst or by an active means such as a fuel burner which heats the filter to soot combustion temperatures.

Filters require more maintenance than catalytic converters. Continuous built up of trapped particulate matter blocks the filter medium thereby leading to increase in the back pressure across such devices and adversely impacting engine performance and consequently emission compliance. The soot gets collected inside porous metallic medium and on the metallic screen due to principles of inertial impact. There is a continuous need to develop efficient particulate removal and the present invention provides for the same. The present invention provides for a device which produces less back pressure than a conventional DPF with more cross flows and utilization of the substrate.

SUMMARY OF INVENTION

The inventors have designed a PCC that overcomes risks of failure due to continuous built up of trapped particulate matter by allowing an alternate open flow path in case of soot saturation, thereby confining backpressure under permissible limits. Simulation based approach and field testing was used to study, design and develop new cross flow structures by evaluating the pressure drop and collection efficiency. The structure was optimized for efficient soot collection without blockage of the main flow paths.

The invention discloses a three dimensional device for the catalytic treatment of exhaust gases of automotive vehicles comprising of a substrate formed by connecting a plurality of honeycomb/substrate members, each having a structure in which a number of cells are arranged in parallel or in series or parallelly arranged in series with respect to each another.

Another aspect of the present invention is a substrate formed by a unique combination of Porous Metallic Medium (PMM) and metallic screen with different shape of its openings, and different mesh numbers with or without or corrugated or micro corrugated material to form a three dimensional (3D) structure.

Another aspect of the present invention is to combine a corrugated or micro corrugated PMM with the corrugated or micro corrugated metallic screen with different shape of its openings, and different mesh numbers with or without or corrugated or micro corrugated material to form a three dimensional (3D) structure.

Another aspect of the present invention is to combine a corrugated or micro corrugated PMM with the non-corrugated metallic screen with different shape of its openings, and different mesh numbers with or without or corrugated or micro corrugated material to form a three dimensional (3D) structure.

Yet another aspect of the present invention is a non-corrugated PMM can be uniquely combined with the corrugated or micro corrugated metallic screen with different shape of its openings and different mesh numbers with or without or corrugated or micro corrugated material to form a three dimensional (3D) structure.

Another aspect of the present invention is that every cell inside the substrate, is composed of metallic screen with different shape of its openings and different mesh numbers and/or corrugated or micro corrugated notched metallic material and / or inorganic material and PMM as its walls.

Yet another aspect of the present invention is that CPCC² is coated with a unique washcoat material that is capable of continuously producing in-situ nitrogen dioxide, which is essential for continuous oxidation of trapped soot particles leading to increase PM reduction efficiency.

BRIEF DESCRIPTION OF DRAWINGS

The features of the present invention will become apparent from the following description of the preferred embodiments given in conjunction with the accompanying drawings, in which:

Figure 1.1: PCC² combination of PMM & metallic screen – Schematic depiction

Figure 1.2: Improved mass and heat transfer in turbulent type corrugated channel

Figure 1.3: Straight channel corrugated substrate structure.

Figure 1.4: Straight channel corrugated porous metallic media with micro corrugated / notched metallic foil.

Figure 1.5: Straight channel corrugated foil with micro corrugation

Figure 1.6: Angle corrugated foil with higher cpsi & with micro corrugation

Figure 1.7: Angle corrugated foil with lower cpsi and with micro corrugation

Figure 1.8: Angle corrugated flat foil substrate and Angle + micro corrugated foil substrate

Figure 1.9: Angle + micro corrugated foil and Straight channel micro corrugated foil

Figure 1.10: Turbulent type corrugated porous metallic medium

5 Figure 1.11: Angle corrugated porous metallic medium

Figure 1.12: Flat / un-corrugated porous metallic medium

Figure 1.13: Metallic screen with single-knit structure and square mesh opening

Figure 1.14: Metallic screen with multi-knit structure and square mesh opening

Figure 1.15: Structure of rectangular screen

10 Figure 1.16: Structure of square screen

Figure 2: Examples of the different shapes of Particulate Combustion Catalyst and Coated Particulate Combustion Catalyst

Figure 3.1 – 3.13: ΔP variations of selected samples having different combinations and with corrugation.

Figure 4: Mass emission data of selected samples having different combinations and with corrugation.

15 Figure 5: Outline of Scheme 1 Process flow for Particulate Combustion Catalyst (PCC) and Coated Particulate Combustion Catalyst (CPCC);

Figure 6: Outline of Scheme 2 of Process flow for Particulate Combustion Catalyst (PCC) and Coated Particulate Combustion Catalyst (CPCC);

20 Figure 7: Outline of Scheme 3 Process flow for Particulate Combustion Catalyst (PCC) and Coated Particulate Combustion Catalyst (CPCC)

Figure 8: Outline of Process flow for preparation of washcoat for Coated Particulate Combustion Catalyst (CPCC)

25 Figures 9 – 22: Comparative Laboratory Simulation Plots of oxidation reactions of Carbon monoxide oxidation, Propylene oxidation & Nitrogen dioxide formation with temperature for different combinations of PCC² and CPCC² (henceforth called as catalytic activity), tested under different operating conditions.

Figures 9a & 9b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30,000 h⁻¹ for one and two layer VF-structures with flat porous metallic medium (PMM) and angle corrugated metallic screen with rectangular mesh with PGM-loadings 1, 2, 5, 10 and 20 g/ft³.

Figure 10 compares the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 h⁻¹ for one layer VF-structure with flat porous metallic medium (PMM) and angle corrugated metallic screen with rectangular mesh with PGM-loading 1 g/ft³ and for one layer Prior art VX-structure with PGM-loading 20 g/ft³.

Figures 11a & 11b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 and 60.000 h⁻¹ for one layer VF-structures with flat porous metallic medium (PMM) and angle corrugated metallic screen with rectangular mesh with PGM-loadings 1 and 5 g/ft³.

Figures 12a & 12b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 60.000 h⁻¹ for one and two layer VF- with flat porous metallic medium (PMM) and angle corrugated metallic screen with rectangular mesh with PGM-loadings 1, 5, 10 and 20 g/ft³.

Figures 13a & 13b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 h⁻¹ for uncoated structures with three different type of corrugations for porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with micro corrugated / notched foil (MF).

Figures 14a & 14b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 h⁻¹ for one layer structures with three different type of corrugations for porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with micro corrugated / notched foil (MF). PGM-loading is the same 1 g/ft³ in all cases.

Figures 15a & 15b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30,000 h⁻¹ for one layer structures with different type of corrugations for porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with Micro corrugated / notched foil (MF). PGM-loading is the same 5 g/ft³ in all cases.

Figures 16a & 16b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30,000 and 60.000 h⁻¹ for one layer structures with angle type of corrugation of porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with Micro corrugated / notched foil (MF). PGM-loading is 10 g/ft³.

Figures 17a & 17b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 60.000 h⁻¹ for one layer structures with with three different type of corrugations of porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with Micro corrugated / notched foil (MF). PGM-loading is 10 g/ft³.

Figures 18a & 18b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 h⁻¹ for one layer Prior art VX-structure with 330 cpsi, corrugated metallic screen having a PGM-loading of 1, 5, and 10 g/ft³.

Figure 19 compares the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 and 60.000 h⁻¹ for one layer structures with the three different type of corrugations for foil (CF) with flat porous metallic medium (PMM). PGM-loading is the same 1 g/ft³ in all cases.

Figure 20 compares the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 and 60.000 h⁻¹ for one layer structures with the three different type of corrugations for foil (CF) with flat porous metallic medium (PMM). PGM-loading is the same 5 g/ft³ in all cases.

Figure 21 compares CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 and 60.000 h⁻¹ for one layer structures with the three different type of corrugations for foil (CF) with flat porous metallic medium (PMM). PGM-loading is the same 10 g/ft³ in all cases.

Figures 22a & 22b compare the CO, HC conversion-% and NO₂ formation % as a function of temperature with Space Velocity 30.000 and 60.000 h⁻¹ for one layer structures with two different type of corrugations for porous metallic medium (PMM) with flat / uncorrugated foil (UF) or with micro corrugated / notched foil (MF). PGM-loading is the same 1 g/ft³ in all cases.

Figures 23.1 & 23.2 describe Soot loading behavior as a function of distance covered CPCC² samples having a different structural combination and different corrugations.

DETAILED DESCRIPTION OF THE INVENTION

Other objects and aspects of the invention will become apparent from the following description of the embodiments with reference to the accompanying drawings, which is set forth hereinafter. The embodiments of the present invention can be modified variously. Thus, the scope of the present invention should be construed not limited to the embodiments to be described herein. The embodiments are provided to better explain the present invention to those of ordinary skill in the art. Further, the elements and areas of the drawings are drawn roughly only, and the scope of the present invention is not limited to the relative sizes, shapes and gaps in the drawings.

The below list provides the full forms of abbreviations whenever used in the specification:

Abbreviation	
PCC	Particulate Combustion Catalyst
PCC ²	Particulate Combustion Catalyst
DOC	Diesel Oxidation Catalyst
CPCC	Coated Particulate Combustion Catalyst
PCC ²	Coated Particulate Combustion Catalyst
PMM	Porous Metallic Medium
MF	Micro-corrugated Foil
uc	Un coated

c	Coated
CC	Closely Coupled
UF	Under Floor

The device disclosed in the present invention is for catalytic treatment of exhaust gases which is comprised of a substrate formed by connecting a plurality of individual members wherein said individual member comprises of a plurality of cells. The individual member can have a honeycomb body. The plurality of cells are arranged in parallel or in series or in parallel series with respect to each another.

The invention discloses a substrate formed by a unique combination of Porous Metallic Medium (PMM) and metallic screen with different shape of its openings, and different mesh numbers with or without or corrugated or micro corrugated material to form a three dimensional (3D) structure. The invention allows for substantial trapping of particulate matter emanating from an engine.

A corrugated or micro corrugated PMM is combined with the corrugated or micro corrugated metallic screen with different shape of its openings and different mesh numbers and/or corrugated or micro corrugated notched metallic foil and/or inorganic fibrous woven matrix material to arrive at the three dimensional (3D) structure.

Alternative embodiment of the invention is to combine a corrugated or micro corrugated PMM with the non-corrugated metallic screen with different shape of its openings, preferably rectangular and different mesh numbers and/or corrugated or micro corrugated notched metallic foil and/or inorganic fibrous woven matrix material to arrive at this three dimensional (3D) structure. The PMM could be fleece.

Alternatively, a non-corrugated PMM can be uniquely combined with the corrugated or micro corrugated metallic screen with different shape of its openings, preferably rectangular and different mesh numbers and/or corrugated or micro corrugated notched metallic foil and/or inorganic fibrous woven matrix material to arrive at this three dimensional (3D) structure.

The invention further discloses that every cell inside the substrate, is composed of metallic screen with different shape of its openings, preferably rectangular and different mesh numbers and/or corrugated or micro corrugated notched metallic foil and / or inorganic fibrous woven matrix material and PMM as its walls. The cell density is preferred to be in the range from 20 to 1300 cells per square inch (cps), preferably from 50 – 600 cps. The inorganic fibrous woven matrix material has a fiber thickness in the range of 5 to 22 micrometers. The inorganic fibrous woven matrix material thickness is from 0.5 to 100 millimeter in a single layer, more preferably 0.5 – 10 millimeter and porosity is in the range of 70 to 95 %. The PMM has a preferred porosity in the range of 70 - 95% and used in varying thickness of 0.1mm to 1mm.

The members of the substrate are combined in unique ways to form different geometries such as circular, oval, square, rectangular, doughnut shaped, banana shaped, layered doughnut etc., each with or without a bypass and for different sizes and can either be solid fitted or can be partially open in radial and / or axial direction to give a variety of flow patterns.

5 The mesh numbers of the metallic screen of the substrate are preferred in the range of 120 - 20 meshes per inch, more preferably 90 - 30 meshes per inch. Metallic screen wire diameter is in the range of 0.08 - 0.3mm, preferably between 0.1 - 0.2 mm. whereas metallic foil has a thickness in the range of 20 - 110 micrometers, preferably between 40 - 80 micrometers. The height of micro-corrugation is in the range of 0.01 - 0.5 mm, preferably between 0.02 - 0.2 mm.

10 The substrate of the invention exhibits high thermal and mechanical durability at all engine loads.

The invention discloses that it is possible to produce PCC² /CPCC² with cell densities ranging from 20 to 1300 cells per square inch (cps), preferably between 50 and 600 cps, with or without micro corrugation. The corrugation is angular and corrugation angle is in the range of 10 to 60 degrees, preferably in the range of 32 - 40 degrees. The corrugation can also be straight or turbulent.

15 CPCC² which is the coated PCC² is capable of oxidizing the trapped soot particles leading to increase PM reduction efficiency. It is further disclosed that CPCC² & PCC² is capable of oxidizing the trapped soot particles with a volume substantially lower than that of prior art. A much lower back pressure is seen when compared to the existing devices when the substrate of the present invention is used in a device to increase the PM reduction efficiency.

20 The invention discloses that CPCC² is coated with a washcoat material that is capable of continuously producing in-situ nitrogen dioxide, which is essential for continuous oxidation of trapped soot particles leading to increase PM reduction efficiency. The invention discloses the unique washcoat material and method of preparing the same.

25 The unique coating of a washcoat is disclosed by the inventors. The washcoat comprises of a combination of catalytically inactive material and catalytically active material. The washcoat is to be applied before or after the substrate is formed.

The catalytically inactive material of the washcoat includes a combination of a variety of oxides, nitrates, and hydroxides of aluminum, silicon, titanium, zirconium, hafnium, calcium, barium, strontium and rare earth metal oxides. The catalytically inactive material has a specific surface area ranging between 100 to 260 sqm per g.

30 The washcoat comprises of fine particles having a median particle size distribution ranging between 0.5 - 3.5 microns.

The washcoat allows substantial in-situ generation of nitrogen dioxide in the range of 20% to 50% by volume, which continuously allows efficient oxidation of soot accumulated inside the body of the honeycomb

structure during the operation of the engine. The substrate provides same or lower backpressure than that before washcoat coating. It was surprisingly found that the washcoat coating provides catalytic performance at much lower volumes leading to cost and pollution reduction.

The catalytically active material used in the washcoat comprises but is not limited to a combination of a variety of salts of platinum, palladium, rhodium, ruthenium, osmium and iridium, preferably platinum, palladium and rhodium. The catalytically active material is contained in the honeycomb body of the substrate preferably in the range of 0.5 to 30 g/cubic feet, more preferably from 1 – 10 g/cubic feet.

The coating of the washcoat has a thickness in the range of 0.5 to 10 micrometers, preferably from 1 – 5 micrometers. The elements can be incorporated in pre-washcoated honeycomb body. The elements can be incorporated into the washcoat material directly, before carrying out the coating.

The washcoat is designed to have a high degree of adhesion to both the PMM and metallic screen as well as metallic foil and inorganic material and its combinations thereof. The washcoat exhibits high thermal and mechanical durability and resists poisoning due to sulfur present in the automotive exhaust gas, when the engine is in operation.

The substrate of the invention offers uniform flow distribution and has interacting three dimensional channel network, which allows quick dissipation of heat energy released during regeneration of such devices. There is improved heat and mass transfer efficiency leading to optimum internal diffusional and axial flows.

The substrate has interacting channels which effectively decelerates sticky and/or wet & dry particles alike, from the engine exhaust, on their surfaces that eventually are trapped inside the PMM and /or metallic mesh with different shape of its openings, preferably rectangular and different mesh numbers and/or within the inorganic fibrous woven matrix. The capturing of solid particles happens predominantly by impinging the collected particles from the engine exhaust, upon the interposed deflecting surface

In another embodiment of the invention the PMM and the metallic screen are also individually coated with a combination of catalytically inactive material and catalytically active material, before forming them into a substrate

The different features of the invention are further described by way of non-limiting examples to better understand the invention:

Figure 2.1 depicts schematically the PCC² combination of PMM & metallic screen of the present invention. Figure 1.2: explains the improved mass and heat transfer in turbulent type corrugated channel. Figure 1.3 – 1.16 reveal the different embodiments of the substrate structure and combinations including straight/corrugated/micro corrugated / notched metallic foil/ angle corrugation/Turbulent/porous /Flat /un-corrugated/Metallic screen/rectangular screen/square screen

Figure 2 depicts examples of the different shapes of Particulate Combustion Catalyst and Coated Particulate Combustion Catalyst

Evaluation of backpressure:

5 From Figure 3.1, it can be seen that substrate formed by the combination of flat PMM & angle corrugated 330 cpsi screen clearly exhibits highest ΔP (1448). The second highest is for flat PMM & angle corrugated 330 cpsi (1401/1).

This is followed by a substrate formed by the combination of flat PMM and 330 angle corrugated screen with having a lower volume (1461).

10 Both the prior art structures (1394/3 & 1405) show a little lower ΔP with 33 screen corrugation and with square & rectangular mesh.

From Figure 3.2, it can be seen that the substrate formed by the combination of flat PMM and 330 cpsi angular corrugated screen (1448) exhibits the highest ΔP , while the combination of flat PMM and 400 cpsi angular corrugated screen (1461) exhibits the lowest ΔP .

15 An another combination of prior art substrate structure (1405 +1407) and combination of flat PMM and 330 cpsi angle corrugated (1401 /1) lies in between.

From Figure 3.3, it can be seen that the substrate formed by the combination of 330 cpsi angle corrugated PMM and 330 cpsi angle corrugated screen gives the highest ΔP (1436/1). The second prior art substrate with 330 cpsi angle corrugated screen (1394/3) gives the same ΔP with both square and rectangular mesh (1405).

20 The lowest DP is exhibited by the substrate formed by the combination of 200 cpsi turbulent type corrugated screen and grooved PMM (1444)

From Figure 3.4, it can be seen that the prior art containing 330 cpsi corrugated screen evidently gives highest ΔP (1394/3). It is also observed that the structure formed by the combination of 100 cpsi angle corrugated PMM and flat screen (1401/4), exhibits a high DP, than the structure formed by the combination of flat PMM and 100 cpsi angle corrugated screen (1401/3).

25 From Figure 3.5, it can be seen that the prior art substrate (1583/1) with 400 cpsi screen gives the highest delta P and 1582/1 with 33p cpsi screen has the lowest delta P. Both flat PMM substrates, 1584/1 & 1585/1 with 330 & 400 cpsi respectively are in between.

30 From Figure 3.6, it can be seen that the prior art substrate with 400 cpsi screen (1581/1) exhibits the highest ΔP , The substrate formed by the combination of flat PMM and straight channel 300 cpsi corrugated screen gives lowest ΔP . The soot loading efficiency the prior art substrate with 330 cpsi screen (1580/1) lies between.

From Figure 3.7, it can be seen that substrate formed by the combination of flat PMM and straight channel 300 or 400 cpsi corrugated foil (1590/1 & 1591/1) exhibits a lower ΔP and a combination of flat PMM and straight channel 500 cpsi corrugated foil (1592/1), a combination of flat PMM and turbulent channel 350 cpsi corrugated foil (1597/1) exhibits the highest ΔP values.

From Figure 3.8, it can be seen that substrate formed by the combination of flat PMM and straight channel 100 cpsi corrugated foil (1588/1) exhibits a lower ΔP and a combination of flat PMM and turbulent type channel 200 cpsi corrugated foil (1596/1) exhibits the highest ΔP values. ΔP measured for a combination of flat PMM and turbulent channel 120 cpsi corrugated foil (1595/1) and a combination of flat PMM and straight channel 200 cpsi corrugated foil are about the same and lies in between.

Figure 3.9, describes the ΔP behaviour of two distinct substrate structure types, formed by the (1) combination of flat PMM and straight channel 300 cpsi corrugated foil (1590/1_uc & 1590/1_c) and (2) as well as that formed by another combination of flat PMM and turbulent type channel 350 cpsi corrugated foil (1597/1_uc & 1597/1_c).

In this plot, the combination of flat PMM and turbulent type corrugation exhibits higher DP. In the both structures, coating does not increase ΔP .

From Figure 3.10, it can be seen that substrate formed by the combination of flat PMM with straight channel 100 cpsi corrugated foil (1588/1_uc & 1588/1_c) exhibits much lower ΔP than a combination of flat PMM with turbulent type channel 120 cpsi corrugated foil (1595/1_uc & 1595/1_c).

In the both structures, coating does not increase ΔP .

From Figure 3.11, it can be seen that layered doughnut type substrate structures formed by the combination of flat PMM and angle corrugated screen with 263 cpsi (1674/1) and another combination of flat inorganic fibrous woven matrix with angle corrugated 263 cpsi screen gives the lowest ΔP value.

The double crossing layered doughnut structure (1675) exhibits a clearly higher ΔP compared to the single crossing layered doughnut structure (1674/1).

The prior art substrate structure with 292 cpsi angular corrugation (1687) & a combination of flat PMM with angle corrugated 263 cpsi screen (1676) exhibits the highest ΔP .

From Figure 3.12, it can be seen that layered doughnut type substrate structures formed by the combination of flat PMM with angle corrugated 263 cpsi screen (1669) exhibits the lowest DP.

Another combination of flat PMM with angular corrugation, 263 cpsi (1669) screen exhibits the highest DP and prior art substrate (1682) with 263 cpsi angle corrugated screen lies in between.

From Figure 3.13, it can be seen that layered doughnut type substrate structures formed by the combination of flat PMM with angle corrugated 263 cpsi screen (1673) exhibits the lowest ΔP .

Another combination of flat PMM with angular corrugation, 263 cpsi (1659) & 303 cpsi (1660) corrugated screen substrates exhibits about the same and the highest ΔP .

Performance evaluation studies on chassis dynamometer (mass emission):

The catalytic activity in terms of mass emission of various combination of CPCC² was evaluated on chassis dynamometer. The samples under study were assembled into the exhaust assembly of the test vehicle, which was then driven to on a driving cycle simulating a typical Indian city driving pattern. During this operation, major pollutants consisting of carbon monoxide, hydrocarbon, oxides of nitrogen & particulate matter, emanating from the engine, are continuously monitored and measured as grams of these pollutants emitted per kilometre travelled by the test vehicle

Figure 4 compares the mass emission data of the prior art substrate structure, with the substrate (CPCC²) formed by the various combinations of flat PMM & angle corrugated screen at different levels of volume viz. 1.817 L (prior art) & 0.374L (current invention) respectively.

The data shows that in spite of having a lower volume (4.85 times) than the prior art substrate, the substrate formed by the various combinations of flat PMM & angle corrugated screen exhibits lower mass emissions, specifically for particulate matter.

Performance evaluation studies on simulated gas test bench:

All the catalytic activity studies described in the examples were carried out on simulated exhaust gas test bench. The typical inlet gas composition gas comprises of (1) CO: 1000 – 1500 PMM, propylene propane: 500 – 800 ppm, O₂: 12 – 14 %, NO: 500 – 800 ppm, 6 – 10 % CO₂, 7 – 12% steam & balance nitrogen.

Regulated flow of preheated mixture of these gases are fed into a reactor containing the sample under evaluation. Space velocities are controlled by regulating the flow of the gas mixture entering the reactor. The output gases from the reactor are analyzed by a state of the art multi gas analyzer.

The output of the evaluation are the plots of oxidation reactions of Carbon monoxide oxidation, Propylene oxidation & Nitrogen dioxide formation with temperature.

PCC² and CPCC² formed by unique combinations of corrugated or micro corrugated PMM and/or corrugated or micro corrugated metallic screen with different shape of its openings, preferably rectangular and different mesh numbers and/or corrugated or micro corrugated notched metallic foil and/or inorganic fibrous woven matrix material, with different precious metal loadings, varied washcoat layers, were evaluated at different space velocities.

PCC² was formed by combining a flat PMM with an angle corrugated metallic screen with rectangular mesh. The so formed PCC² was converted to CPCC² by coating the former with a combination of catalytically inactive

material, in such a manner to achieve a coating thickness of 2 micrometers. Four samples of this said CPCC² were then each coated with 1 g/cft, 5g/cft, 10g/cft & 20 g/cft of PGM.

The above substrate was dried, calcined & evaluated for its catalytic activity. Figure 9 compares catalytic activity, specifically the light-off temperature curves of the CPCC² at space velocities of 30,000 /h.

5 The corrugation angle of 34° was selected for all the angle corrugated samples combinations.

From Figure 9a, it can be seen that at a space velocity of 30.000 h⁻¹ SV, CPCC² having 5 g/ft³ of PGM, exhibits the best CO and HC light-off curves for one layer VF structure (VF0, VF1, VF5, VF10, VF20. VF5) also exhibits the highest NO₂ formation among all the evaluated series.

10 From Figure 9b, it can be seen that at a space velocity of 60.000 h⁻¹ SV, CPCC² having 20 g/ft³ of PGM, exhibits the best light-off curves for two layer VF structure (VF0, VF1, VF5, VF10, VF20. VF5), specifically in the case of NO₂ formation of 38% at the temperature of 350 °C.

VF20 on two layer washcoat gives the best efficiencies and with 30.000 h⁻¹ SV since the whole washcoat layer is available for the catalytic reaction.

VF5 on one layer and VF20 on two layer have the best in situ NO₂ formations.

15 From the cost point of view the best solution is VF5 in one layer.

Blank (uncoated and PGM-free) samples, PCC² show only minor conversions.

From Figure 10, it can be seen that, CPCC² having 5 g/ft³ of PGM in one layer VF structure (VF1), exhibits better light-off behaviour than that having 20 g/ft³ of PGM in prior art VX honeycomb structure (VX20).

This implies a reduction of 95% in PGM-cost.

20 VF1 gives also better in-situ NO₂-formation efficiency.

From Figures 11a & 11b, it can be seen that, at a space velocity of 30,000 /h, CPCC² having 5 g/ft³ of PGM exhibits the best light-off behaviour (VF5, 30K).

However at a space velocity of 60.000 /h CPCC² having PGM-loading of 1 g/ft³ is about at the same level with this one layer VF-structure (VF5, 60K).

25 Cost wise VF5 is 80 % cheaper solution in PGM-cost.

From Figure 12a, it can be seen that CPCC² having PGM-loading of 1 g/ft³ gives the best light-off behaviour for one layer VF-structure.

It is also observed that CPCC² having PGM-loading of 20 g/ft³ exhibits a very poor light-off behaviour for one layer VF-structure, which can be explained by the fact that that PGM-density is too high for this one layer VF-structure.

From Figure 12b it can be seen that, at a space velocity of 60,000 /h, VF10 (CPCC² having PGM-loading of 10 g/ft³) on the 2 layer VF structure gives the best efficiencies because PGM-density is better than that with PGM-loading 20 g/ft³, when the whole washcoat layer is not in use for catalytic activity.

Cost wise best solution is VF1 in one layer.

Figure 13 shows the light-off curves for samples P-1661 to P1666 as following blank/uncoated structures (PCC²): Turbulent type of corrugated PMM with UF as flat (P-1661) and with MF as Micro corrugated (P-1662); Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664); Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated (P-1666).

From Figure 13 it can be clearly seen that, without coating or PGM-loading, structures with a combination of different corrugated PMM and flat (uncorrugated) or micro corrugated foil doesn't give any remarkable conversions.

Figure 14a shows the light-off curves for samples P-1661 to P1666 as following coated structures (CPCC²): Turbulent type of corrugated PMM with UF as flat (P-1661) and with MF as Micro corrugated (P-1662); Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664); Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated (P-1666).

In all the three types of corrugation, it is observed that the catalyst efficiency is superior for micro corrugated foil structures as compared to flat uncorrugated foil structures as evaluated at a space velocity of 30.000 h⁻¹ and with a PGM-loading 1 g/ft³. The light off curves show the advantage of micro corrugation, especially at temperatures greater than 300°C, where the mass and heat transfer phenomena begins to control catalytic reactions. With the use of micro corrugated substrate, the laminar type of flow at the catalyst surface (boundary layer) can be broken, thereby enhancing the mass transfer between the exhaust gas and the wall, which results in improved catalytic efficiency.

Figure 14b shows the light-off curves for samples for only Straight channel corrugated PMM with UF as flat (P-1663) and with MF as micro corrugated (P-1664). It is clear that the catalyst efficiency is better for micro corrugated foil structure compared to flat uncorrugated foil structures evaluated at a space velocity of 30.000 h⁻¹ SV and with PGM-loading 1 g/ft³. The results show how micro corrugation helps especially at over 300 °C temperatures where mass and heat transfer start to control catalytic reactions.

Figure 15a shows the light-off curves for samples for Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664). It is evident that the catalyst efficiency is superior for Micro

corrugated foil structure compared to flat uncorrugated foil structure evaluated at 30,000 h⁻¹ SV and with PGM-loading of 5 g/ft³.

Figure 15a shows the light-off curves for CPCC² samples with Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664). Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated (P-1666). The catalyst efficiencies are found better for micro corrugated foil structures compared to flat uncorrugated foil structures evaluated at 30,000 h⁻¹ SV and with PGM-loading of 1 g/ft³.

Figure 16a shows the light-off curves for CPCC² samples with Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated P-1666 evaluated at a space velocity of 30,000 h⁻¹ SV and 60,000 h⁻¹ SV is shown in Figure 16b. Results show that when the space velocity increases from 30,000h⁻¹ to 60,000 h⁻¹ the light-offs move to higher temperature regime but at both the space velocities, the micro corrugated foil structures show better catalytic efficiencies compared to flat uncorrugated foil structures with PGM-loading of 10 g/ft³.

It is also observed that NO₂ formation is at good level at the space velocity of 30,000 for (P-1666) with MF and with a PGM-loading 10 g/ft³. This kind of in situ NO₂ formation gives good basis to reach efficient soot regeneration for diesel exhaust PM starting from about temperatures of 230°C.

Figure 17a shows the light-off curves for CPCC² samples with Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664).

From this CPCC² with Straight channel corrugation test case, it can be seen that the catalyst CO and HC efficiency are slightly better and NO₂ clearly better for flat uncorrugated foil structure UF compared to Micro corrugated foil structure MF at a space velocity of 60,000 h⁻¹ SV and a PGM-loading 10 g/ft³.

Figure 17b shows the light-off curves for CPCC² samples with Turbulent type of corrugated PMM with UF as flat (P-1661) and with MF as Micro corrugated (P-1662); Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated (P-1666).

Results show that the micro corrugated foil structures MF show better efficiencies compared to flat uncorrugated foil structures UF in both turbulent type and angle corrugated PMM with PGM-loading 10 g/ft³ and at a space velocity of 60,000 h⁻¹. Also it can be seen that the angle corrugated PMM with MF gives the best efficiencies in all studied respects (CO, HC and NO₂).

Figure 18a shows the light-off curves for CPCC² samples with both VX and VL prior art structures with PGM-loadings of 1, 5 and 10 g/ft³ with one layer coating.

Figure 18a shows the light-off curves for CPCC² samples VX1 & VL10. As can be seen, the catalytic performance of the former is far poorer as compared to that for VL10, which is the best. Both the samples have one layer coating.

In both cases VX and VL the efficiencies improves as PGM-loading increases. VL10 and VL5 are the best in this set of comparison.

Figure 19 shows the light-off curves for CPCC² samples with Straight channel corrugated foil CF with flat PMM (P-1700); Turbulent type corrugated foil CF with flat PMM (P-1701); Angle corrugated foil CF with flat PMM (P-1702).

It is obvious from all the three corrugation cases, that the catalyst efficiency is better at a space velocity of 30.000 h⁻¹ SV than with that of 60.000 h⁻¹ and with a PGM-loading 1 g/ft³.

From the different corrugations examined, the turbulent channel corrugation exhibits superior catalytic efficiency, while the Straight channel corrugations is the second best, followed by the Angle corrugation, which is comparatively inferior or in this set of comparison.

NO₂ formation % are rather low for all cases, because higher PGM-loadings are needed to give higher efficiency in this respect. Turbulent corrugation P-1701 gives NO₂ formation-%.

Figure 20 shows the light-off curves for CPCC² samples with Straight channel corrugated foil CF with flat PMM (P-1700); Turbulent type corrugated foil CF with flat PMM (P-1701); Angle corrugated foil CF with flat PMM (P-1702).

From all the three corrugation cases it is observed that the catalyst efficiency is better at a space velocity of 30,000 h⁻¹ SV than with 60.000 h⁻¹ and with a PGM-loading 5 g/ft³.

Among the three different corrugations evaluated, the turbulent channel corrugation gives the best efficiencies, Straight channel corrugations is the second best and Angle corrugation the worst in this comparison with 30.000 h⁻¹ SV. However with 60.000 h⁻¹ SV Straight channel structure is the best.

NO₂ formation % are still rather low for all cases, because higher PGM-loadings are needed to give higher efficiency in this respect. Turbulent corrugation P-1701 gives the NO₂ formation-%.

Figure 21 shows the light-off curves for CPCC² samples with Straight channel corrugated foil CF with flat PMM (P-1700); Turbulent type corrugated foil CF with flat PMM (P-1701); Angle corrugated foil CF with flat PMM (P-1702).

From all the three corrugation cases we can see that the catalyst efficiency is better at a space velocity 30,000 h⁻¹ SV than with that of 60.000 h⁻¹ and with a PGM-loading 10 g/ft³.

Among the three different corrugations evaluated, the Straight channel corrugation gives the best efficiencies, Turbulent channel corrugations is the second best and Angle corrugation the worst in this comparison with 30.000 h⁻¹ SV. However at a space velocity of 60.000 h⁻¹, turbulent channel structure P-1701 exhibits the best performance.

NO₂ formation at 28 % max and Straight channel corrugation is the best with PGM-loading 10 g/ft³. For straight channel corrugation P-1700 NO₂ formation improves when PGM-loading increases from 1 to 5 and 10 g/ft³ but turbulent corrugation P-1701 gives best NO₂ formation-% with PGM-loading 5 g/ft³ and is at the same level than straight channel corrugation P-1700 with 10 g/ft³ loading.

5 Figure 22a & 22b shows the light-off curves for CPCC² samples with Straight channel corrugated PMM with UF as flat (P-1663) and with MF as Micro corrugated (P-1664); Angle corrugated PMM with UF as flat (P-1665) and with MF as Micro corrugated (P-1666) at space velocities of 30,000 h⁻¹ & 60,000 h⁻¹ respectively

Among both the types of corrugation, it can be seen that the catalyst efficiency is better for micro corrugated foil structures compared to flat uncorrugated foil structures with both SVs and PGM-loading 1 g/ft³.

10 The light off curves show the advantage of micro corrugation, especially at temperatures greater than 300°C, where the mass and heat transfer phenomena typically starts to control catalytic reactions.

In the case of Angle corrugated PMM with MF (P-1666) the effect of efficiency improvement is prominent with a space velocity 60.000 h⁻¹ than compared to 30.000 h⁻¹. With the use of micro corrugated substrate, the laminal type of flow at the catalyst surface (boundary layer) can be broken, thereby enhancing the mass transfer
15 between the exhaust gas and the wall, which results in improved catalytic efficiency.

Soot loading studies

Soot loading studies were carried out on some of the selected samples, as described in figures 23.1 & 23.2. The said samples were fitted into the exhaust assembly of the test vehicle, which was then driven to a distance of 200 km on a driving cycle simulating a typical Indian city driving pattern. During this operation, soot emanating
20 from the engine, enters the sample structure and gets collected therein. This process is termed as soot loading.

Figure 23.1 shows that, for catalysts placed in the close coupled position, flat PMM and angle corrugated screen yields the highest soot collection efficiency up to 150 Km. After that, the prior art substrate 1394/2 collects the most.

The under floor (UF) catalyst with prior art substrate 1395/2 exhibits lowest soot loadings.

25 Figure 23.2 shows that, flat PMM and straight channel corrugation screen (1586/1) shows the highest soot collection efficiency, followed by the substrate formed by the combination of Flat PMM and turbulent type of corrugation foil (1597/1). The next best soot loading efficiency is exhibited by the substrate formed by the combination of flat PMM and straight channel corrugated foil with 400 cpsi (1591/1).

30 The lowest soot loading efficiency is displayed by the substrate formed by the combination of flat PMM and straight channel corrugated foil with 200 cpsi.

Results of the experiments conducted on some samples are presented in below tables:

Table 1
Reference Figure 3.1

Sample Code	Sample No	Structure Description	Dimensions D*L(mm)	Corrugation (cps)	Coating/ PGM(g/cft)	Mesh shape
VX10	1394/3	Prior Art	D63L152	330	Prior art/10	Square
VX10	1405	Prior Art	D63L152	330	Prior art/10	Square
VF	1401/1	Flat PMM + Angle Corrugated Screen	D63L152	330	0	Square
VF	1448	Flat PMM + Angle Corrugated Screen	D63L152	330	0	Square
VF	1461	Flat PMM + Angle Corrugated Screen	D63L120	400	0	Square

Table 2
Reference Figure 3.2

Sample Code	Sample No	Structure Description	Dimensions D*L(mm)	Corrugation (cps)	Coating/ PGM(g/cft)	Mesh shape
VX10	1405	Prior art substrate structure	D63L152	330	Prior art/10	Rectangular
VX10	1407	Prior art substrate structure	D75L304	330	Prior art/10	Square
VF	1401/1	Flat PMM + Angle Corrugated Screen	D63L152	330	0	Square
VF	1448	Flat PMM + Angle Corrugated Screen	D63L152	330	0	Square
VF	1461	Flat PMM + Angle Corrugated Screen	D63L120	400	0	Square

5

Table 3
Reference Figure 3.3

Sample code	Sample No	Structure description	Dimensions D*L(mm)	Corrugation (cps)	Coating / PGM (g/ft ³)	Mesh shape
VX10	1394/3	Prior art substrate structure	D63L152	330	Prior art/10	Square; 1394/3 = 1404
VX10	1405	Prior art substrate structure	D63L152	330	Prior art/10	Rectangular
	1436/1	Angle corrugated PMM + Angle corrugated Screen	D63L150	330	0	Rectangular
	1444	Turbulent type corrugated screen + grooved PMM	D63L150	200	0	Turbulent type structure

Table 4

Reference Figure 3.4

Sample code	Sample No	Structure description	Dimensions D*L(mm)	Corrugation (cpsi)	Coating / PGM (g/ft ³)	Mesh shape
VX10	1394/3	Prior art substrate structure	D63L152	330	Prior art/10	Square
VF	1401/3_uc	Flat PMM + Angle Corrugated Screen	D63L152	100	0	Rectangular
VF0	1401/3_c	Flat PMM + Angle Corrugated Screen	D63L152	100	Current invention/ 0	Rectangular
	1401/4_uc	Angle corrugated PMM + Flat Screen	D63L152	100	0	Rectangular
	1401/4_c	Angle corrugated PMM + Flat Screen	D63L152	100	Current invention/ 0	Rectangular

Table 5

Reference Figure 3.5

Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cpsi)	Coating / PGM (g/ft ³)	Mesh shape
VL0	1582/1	Prior art substrate structure	D63L150	330	current invention / 0	Rectangular
VL0	1583/1	Prior art substrate structure	D63L150	400	current invention / 0	Rectangular
VF0	1584/1	Flat PMM + Angle Corrugated Screen	D63L150	330	current invention / 0	Rectangular
VF0	1585/1	Flat PMM + Angle Corrugated Screen	D63L150	400	current invention / 0	Rectangular

Table 6

Reference Figure 3.6

Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cpsi)	Coating / PGM (g/ft ³)	Mesh shape
VX0	1580/1	Prior art substrate structure	D63L150	330	current invention / 0	Rectangular
VX0	1581/1	Prior art substrate structure	D63L150	400	current invention / 0	Rectangular
VF0	1586/1	Flat PMM + Straight Channel Corrugated Screen	D63L150	300	current invention / 0	Rectangular

Table 7

Reference Figure 3.7					
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)
P1700	1590/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	300	current invention / 0
P1700	1591/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	400	current invention / 0
P1700	1592/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	500	current invention / 0
P1701	1597/1	Flat PMM + Turbulent Type Corrugated Foil	D63L150	350	current invention / 0

Table 8

Reference Figure 3.8					
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)
P1700	1588/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	100	current invention / 0
P1700	1589/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	200	current invention / 0
P1701	1595/1	Flat PMM + Turbulent Type Corrugated Foil	D63L150	120	current invention / 0
P1701	1596/1	Flat PMM + Turbulent Type Corrugated Foil	D63L150	200	current invention / 0

Table 9

Reference Figure 3.9					
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)
P1700	1590/1_uc	Flat PMM + Straight Channel Corrugated Foil	D63L150	300	no
P1700	1590/1_c	Flat PMM + Straight Channel Corrugated Foil	D63L150	300	current invention / 0
P1701	1597/1_uc	Flat PMM + Turbulent Type Corrugated Foil	D63L150	350	no
P1701	1597/1_c	Flat PMM + Turbulent Type Corrugated Foil	D63L150	350	current invention / 0

Table 10

Reference Figure 3.10					
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cpsi)	Coating / PGM (g/ft ³)
P1700	1588/1_uc	Flat PMM + Straight Channel Corrugated Foil	D63L150	100	no
P1700	1588/1_c	Flat PMM + Straight Channel Corrugated Foil	D63L150	100	current invention / 0
P1701	1595/1_uc	Flat PMM + Turbulent Type Corrugated Foil	D63L150	120	no
P1701	1595/1_c	Flat PMM + Turbulent Type Corrugated Foil	D63L150	120	current invention / 0

Table 11

Reference Figure 3.11						
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cpsi)	Coating / PGM (g/ft ³)	Comments
	1674/1	Flat PMM + Angle Corrugated Screen	D65L120	263	Current invention / 1	Layered doughnut structure / Rectangular mesh
	1674/2	Flat inorganic fibrous woven matrix + Angle Corrugated Screen	D65L120	263	Current invention / 1	Layered doughnut structure / Rectangular mesh
	1675	Flat PMM + Angle Corrugated Screen	D65L2x60	263	Current invention / 1	Layered doughnut structure / Rectangular mesh
VF1	1676	Flat PMM + Angle Corrugated Screen	D90L120	263	Current invention / 1	Rectangular mesh
VL1	1687	Prior art substrate structure	D90L120	292	Current invention / 1	Rectangular mesh

Table 12

Reference Figure 3.12						
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)	Comments
	1669	Flat PMM + Angle Corrugated Screen	D84L2x90	263	Current invention/ 1	Layered doughnut structure / Rectangular mesh
VL1	1682	Prior art substrate structure	D115L2x90	292	Current invention/ 1	Rectangular mesh
VF1	1683	Flat PMM + Angle Corrugated Screen	D115L2x90	263	Current invention/ 1	Rectangular mesh

Table 13

Reference Figure 3.13						
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)	Comments
VF1	1659	Flat PMM + Angle Corrugated Screen	D80L74.5	263	Current invention/ 1	Rectangular mesh
VF1	1660	Flat PMM + Angle Corrugated Screen	D80L74.5	303	Current invention/ 1	Rectangular mesh
	1673	Flat PMM + Angle Corrugated Screen	D54L74.5	263	Current invention/ 1	Layered doughnut structure / Rectangular mesh

Table 14

Reference Figure 4

Sample Code	Sample No	Structure Description	Dimensions D*L(mm)	Volume (L)	Corrugation (cps)	Coating/ PGM(g/c ft)	Mesh shape
VX10	1404+1406	Prior art substrate structure	D63L152	1.817	330	Prior art/10	Square
VX10		Prior art substrate structure	D75L304		330	Prior art/10	Square
VF	1401/1	Flat PMM + Angle Corrugated Screen	D63L152	0.468	330	0	Square
VF	1448	Flat PMM + Angle Corrugated Screen	D63L152	0.468	330	0	Square
VF	1461	Flat PMM + Angle Corrugated Screen	D63L120	0.374	400	0	Square

Table 15

Reference Figure 23.1						
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)	Mesh shape
VX10	1394/2	Prior art substrate structure	D63L152	330	prior art / 10	Square
VL10	1558/6	Prior art substrate structure	D63L152	330	prior art / 10	Rectangular
VF0	1584/1	Flat PMM + Angle Corrugated Screen	D63L150	330	current invention / 0	Rectangular
VX10	1395/2	Prior art substrate structure	D75L304	330	prior art / 10	Square

Table 16

Reference Figure 23.2						
Sample code	Sample No	Structure description	Dimensions D*L (mm)	Corrugation (cps)	Coating / PGM (g/ft ³)	Mesh shape
P1700	1589/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	200	current invention / 0	
	1586/1	Flat PMM + Straight Channel Corrugated Screen	D63L150	300	current invention / 0	Rectangular
P1700	1591/1	Flat PMM + Straight Channel Corrugated Foil	D63L150	400	current invention / 0	
P1701	1597/1	Flat PMM + Turbulent Type Corrugated Foil	D63L150	350	current invention / 0	

Table 17 Structural information from Prior Art nominal (Ref. 1) and front DOC (1675) and Prior Art VL-substrate (1687) and Current invention Layered doughnut structures with Flat PMM + Layered doughnut Corrugated Screen (1674/1) and Flat inorganic fibrous woven matrix + Angle Corrugated Screen (1674/2)

Sample code	Sample No	Structure description	Dimensions D*L (mm)	Catalyzed Volume (dm ³)	Corrugation (Cpsi)	Coating / PGM (g/ft ³)	Position	Comments
DOC	Ref. 1	Prior art nominal DOC structure	D80L120	0.603	350	Prior art /6	CC	Turbulent with foils
DOC	1675	Prior art DOC / Front	D90L50.8	0.323	350	Prior art / 39	CC	Turbulent with foils
VL1	1687	Prior art substrate structure / Rear	D90L120	0.763	263	Prior art / 1	CC	Rectangular mesh
VF1	1674/1	Flat PMM + Angle Corrugated Screen / Rear	D65L2x60	0.103	263	Current invention / 1	CC	Layered doughnut structure / Rectangular mesh
VF1	1674/2	Flat inorganic fibrous woven matrix + Angle Corrugated Screen / Rear	D65L2x60	0.103	263	Current invention / 1	CC	Layered doughnut structure / Fibrous matrix

- 5 **Figure 17** shows the structural information of the prior art substrates and structures of the current invention. It is observed that for the substrates made of layered doughnut type of structures, the catalyst volume is only $(0.323 + 0.103) = 0.426 \text{ dm}^3$ compared to that for the angle corrugated prior art structure $(0.323 + 0.763) = 1.086 \text{ dm}^3$, which is only 39.2 %.

10

Table 18: Emission test results for the samples presented in Table 17.

Sample	Ref. 1 / DOC	Ref. 1 / DOC	1675 + 1687	1675 + 1687	1675 + 1674/1	1675 + 1674/2
Test condition	BSIII without EGR / IDC-Hot	BSIII with EGR / IDC-Hot	BS III with EGR / IDC-Hot	BS IV with EGR / IDC-Cold	BS IV with EGR / IDC-Cold	BS IV with EGR / IDC-Cold
CO (g/km)	0.104	0.18	0.048	0.097	0.096	0.105
THC (g/km)	0.031	0.064	0.013	0.023	0.038	0.04
NOx (g/km)	0.530	0.276	0.362	0.598	0.4	0.39
PM (g/km)	0.018	0.079	0.021	0.026	0.023	0.023

The mass emission tests were carried out on an Indian three wheeler test vehicle with BSIII and BSIV driving cycles with or without EGR system. The mass emission of the said vehicle were measured in hot condition on BSIII driving cycle and in cold condition on BSIV driving cycle. From Figure 18 it can be seen

15

that the current invention with Layered doughnut type of PMM or with inorganic Fibrous woven matrix gives competitive mass emissions, especially in the case of particulate matter, with only 39.2 % catalyzed volume as compared to the prior art structure, when tests are done with the same preceding DOC.

5 Various embodiments are possible of the invention other than those disclosed above and are easily comprehended by a person skilled in the art. The invention encompasses all such embodiments within its scope. While the present invention has been described with respect to certain preferred embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the scope of the invention as defined in the following claims.

We Claim:

1. A device for catalytic treatment of exhaust gases comprising of a substrate formed by connecting a plurality of individual members wherein said individual member comprises of a plurality of cells.
2. The device as claimed in claim 1, wherein said individual member of said substrate forms a honeycomb body.
3. The device as claimed in claim 1, wherein said plurality of cells are arranged in parallel or in series or in parallel series with respect to each another.
4. The device as claimed in claim 1-3, wherein said cell is composed of metallic screen and PMM as its walls.
5. The device as claimed in claim 1, wherein said cells have a cell density in the range from 20 to 1300 cells per square inch (cpsi), preferably from 50 – 600 cpsi
6. The device as claimed in claim 1, wherein said members of said substrate is combined in unique ways to form different geometries such as circular, oval, square, rectangular, doughnut shaped, banana shaped, layered doughnut etc., each with or without a bypass and for different sizes.
7. The device as claimed in claim 1, wherein said members of said substrate can either be solid fitted or can be partially open in radial and / or axial direction to give a variety of flow patterns.
8. The device as claimed in claim 1, wherein said substrate is a three dimensional (3D) structure combination of
 - a. Porous Metallic Medium (PMM) and
 - b. metallic screen with different shapes of openings and different mesh numbers, and
 - c. optionally corrugated or micro corrugated notched metallic foil, and
 - d. optionally inorganic fibrous woven matrix material.
9. The device as claimed in claim 8, wherein said PMM is fleece.
10. The device as claimed in claim 8, wherein said shapes of openings is square or rectangular, preferably rectangular.
11. The device as claimed in claim 8, wherein said corrugation is either straight or angular or turbulent.
12. The device as claimed in claim 8, wherein said angular corrugation has a corrugation angle in the range of 10 to 60 degrees, preferably in the range of 32 – 40 degrees.

13. The device as claimed in claim 8, wherein said inorganic fibrous woven matrix material has an overall thickness ranging from 0.5 to 100 millimeter in a single layer, preferably 0.5 – 10 millimeter.
14. The device as claimed in claim 8, wherein said inorganic fibrous woven matrix material has a porosity in the range of 70 to 95 %.
- 5 15. The device as claimed in claim 8, wherein said PMM has a porosity in the range of 70 - 95% and used in varying thickness of 0.1mm to 1mm.
16. The device as claimed in claim 8, wherein said mesh numbers of the metallic screen is in the range of 120 - 20 meshes per inch, preferably between 90 – 30 meshes per inch.
- 10 17. The device as claimed in claim 8, wherein said metallic screen has a wire diameter in the range of 0.08 – 0.3mm, preferably between 0.1 – 0.2 mm.
18. The device as claimed in claim 8, wherein said metallic foil has a thickness in the range of 20 - 110 micrometers, preferably between 40 - 80 micrometers.
19. The device as claimed in claim 8, wherein said wherein said micro-corrugation height is in the range of 0.01 – 0.5 mm, preferably between 0.02 – 0.2 mm.
- 15 20. The device as claimed in claim 8, wherein said substrate exhibits high thermal and mechanical durability at all engine loads.
21. The device as claimed in claim 8, wherein said inorganic fibrous woven matrix material has a fiber thickness in the range of 5 to 22 micrometers.
22. The device as claimed in claim 1-21, wherein said substrate further comprises of a coating of a washcoat, wherein said washcoat comprises of a combination of catalytically inactive material and catalytically active material.
- 20 23. The device as claimed in claim 22, wherein said washcoat is applied before or after the substrate is formed.
24. The device as claimed in claim 22, wherein said catalytically inactive material includes a combination of a variety of oxides, nitrates, and hydroxides of aluminum, silicon, titanium, zirconium, hafnium, calcium, barium, strontium and rare earth metal oxides.
- 25 25. The device as claimed in claim 22, wherein said washcoat comprises of fine particles having a median particle size distribution ranging between 0.5 – 3.5 microns.
26. The device as claimed in claim 22, wherein said catalytically inactive material has a specific surface area ranging between 100 to 260 sqm per g.
- 30

27. The device as claimed in claim 22, wherein said washcoat allows substantial in-situ generation of nitrogen dioxide in the range of 20% to 50% by volume, which continuously allows efficient oxidation of soot accumulated inside the body of the honeycomb structure during the operation of the engine.
28. The device as claimed in claim 22, wherein said washcoat on said substrate provides same or lower backpressure than that before coating.
29. The device as claimed in claim 22, wherein said washcoat coating provides catalytic performance at low volume.
30. The device as claimed in claim 22, wherein said catalytically active material includes a combination of a variety of salts of platinum, palladium, rhodium, ruthenium, osmium and iridium, preferably platinum, palladium and rhodium.
31. The device as claimed in claim 30, wherein said catalytically active material is contained in said honeycomb body in the range of 0.5 to 30 g/cubic feet, preferably from 1 – 10 g/cubic feet.
32. The device as claimed in claim 22, wherein said washcoat coating is in the range of 0.5 to 10 micrometers thickness, preferably from 1 – 5 micrometers.

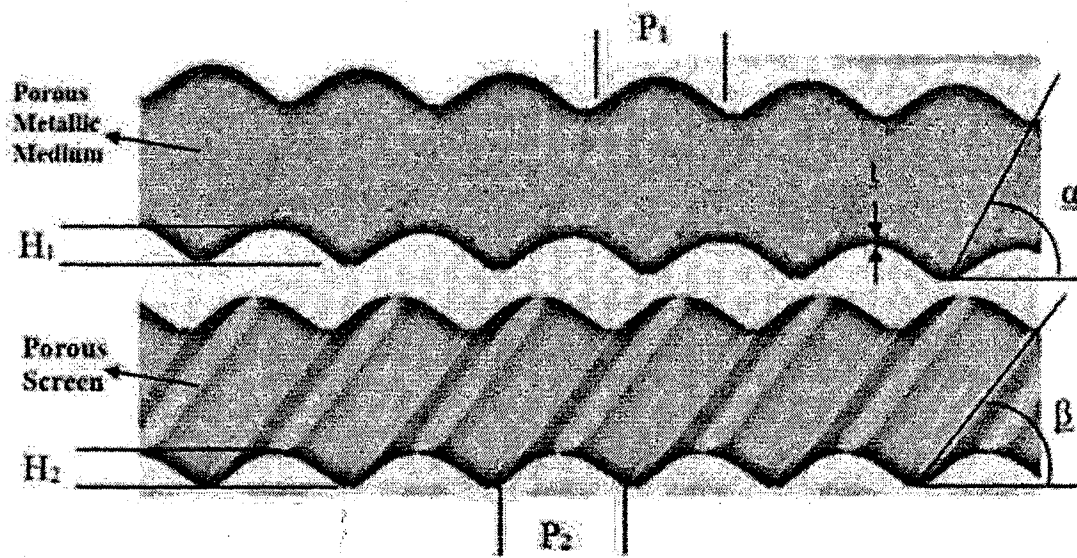


Figure 1.1: PCC^z combination of PMM & metallic screen – Schematic depiction

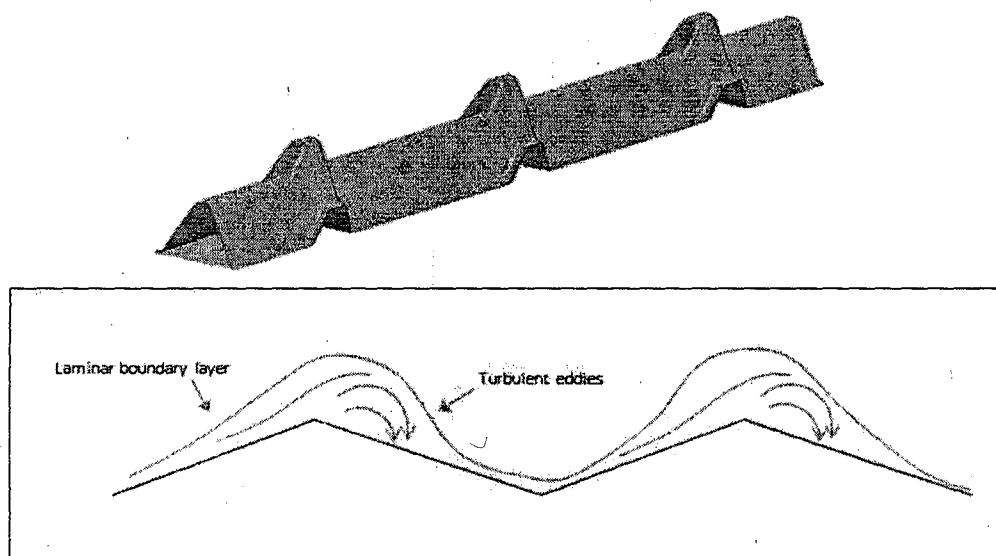


Figure 1.2: Improved mass and heat transfer in turbulent type corrugated channel

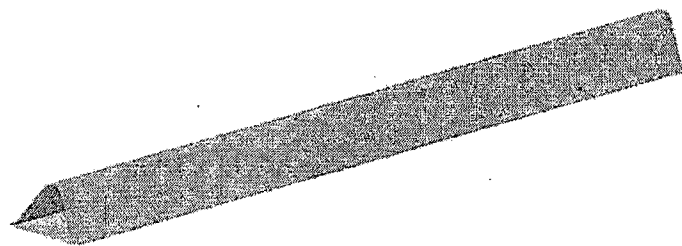


Figure 1.3: Straight channel corrugated substrate structure.

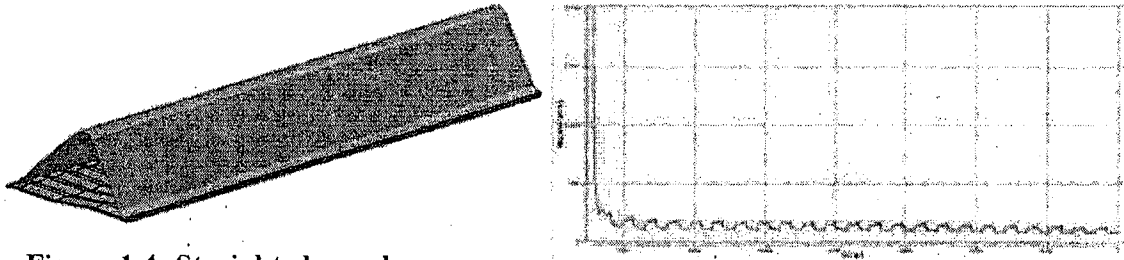


Figure 1.4: Straight channel corrugated porous metallic media with micro corrugated / notched metallic foil.

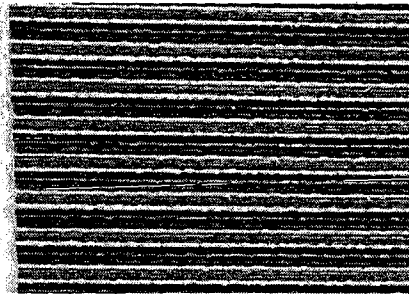


Figure 1.5: Straight channel corrugated foil with micro corrugation

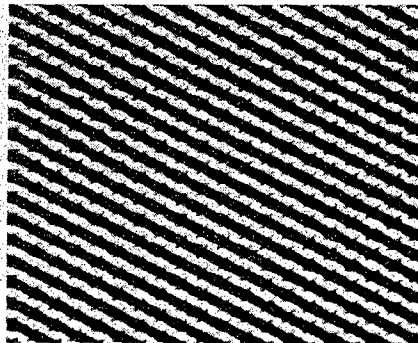


Figure 1.6: Angle corrugated foil with higher cpsi & with micro corrugation

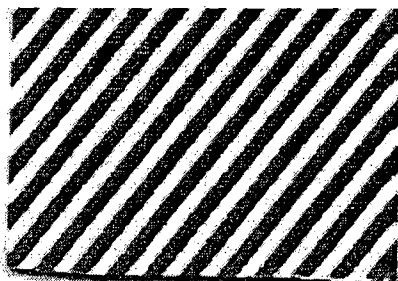


Figure 1.7: Angle corrugated foil with lower cpsi and, with micro corrugation

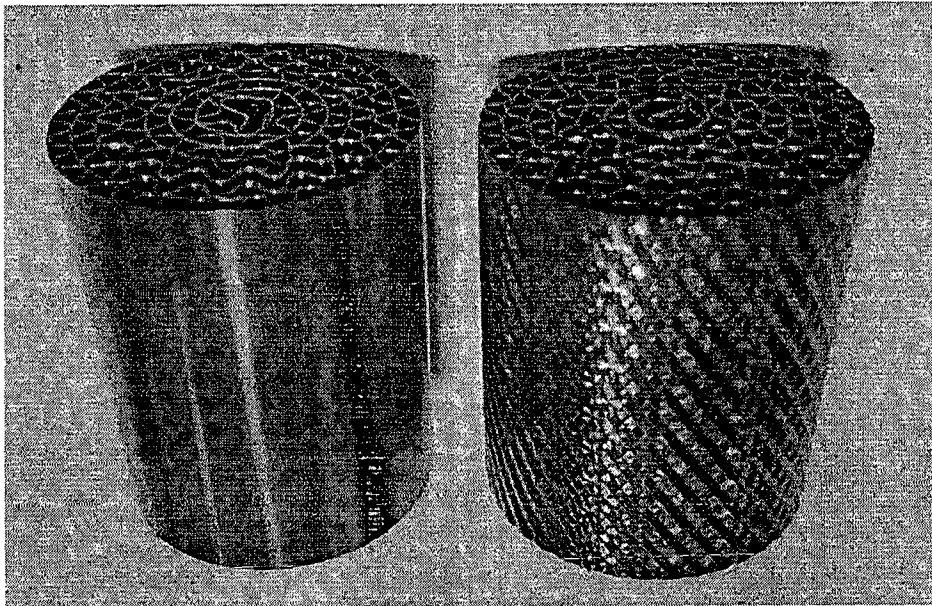


Figure 1.8: Angle corrugated flat foil substrate and Angle + micro corrugated foil substrate

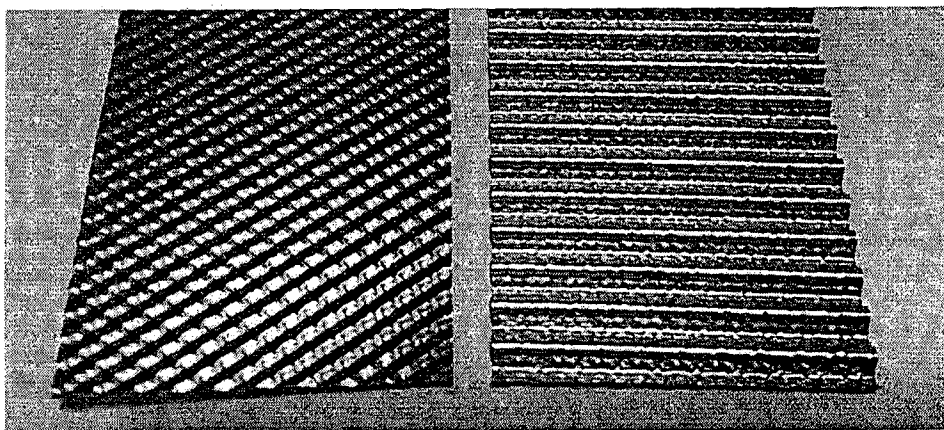


Figure 1.9: Angle + micro corrugated foil and Straight channel micro corrugated foil

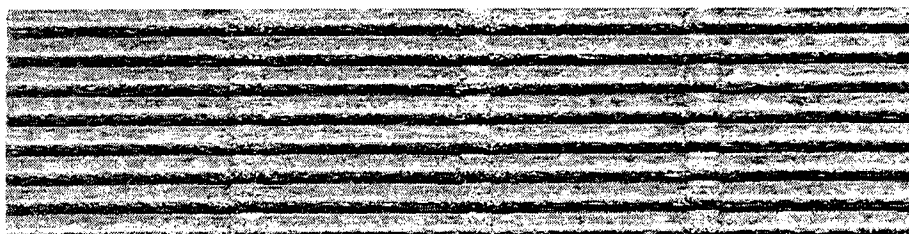


Figure 1.10: Turbulent type corrugated porous metallic medium

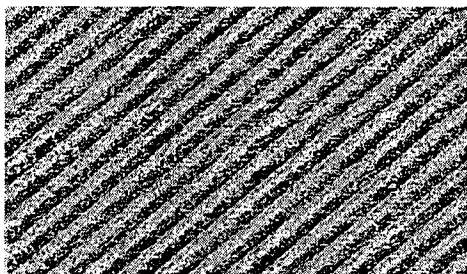


Figure 1.11: Angle corrugated porous metallic medium

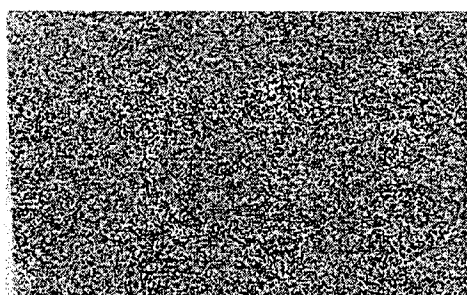


Figure 1.12: Flat / un-corrugated porous metallic medium

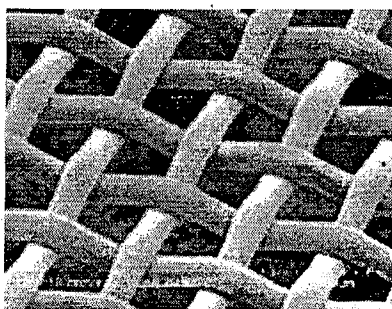


Figure 1.13: Metallic screen with single-knit structure and square mesh opening

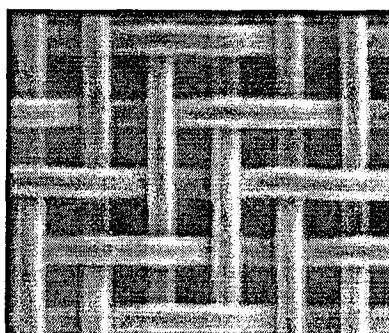


Figure 1.14: Metallic screen with multi-knit structure and square mesh opening

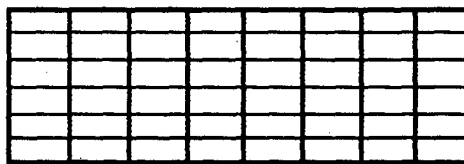


Figure 1.15: Structure of rectangular screen

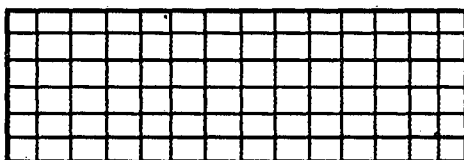


Figure 1.16: Structure of square screen

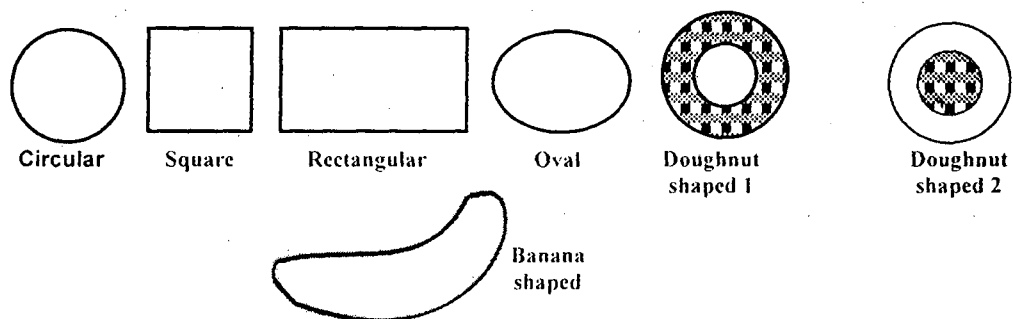


Figure 2: Examples of the different shapes of Particulate Combustion Catalyst and Coated Particulate Combustion Catalyst

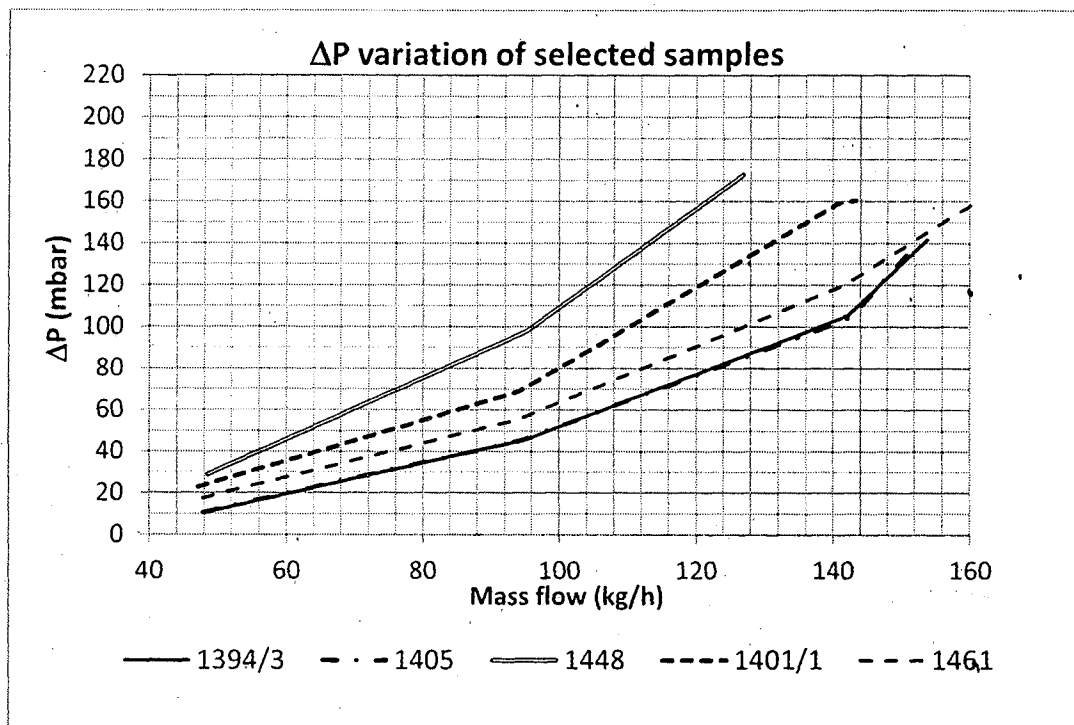


Figure 3.1

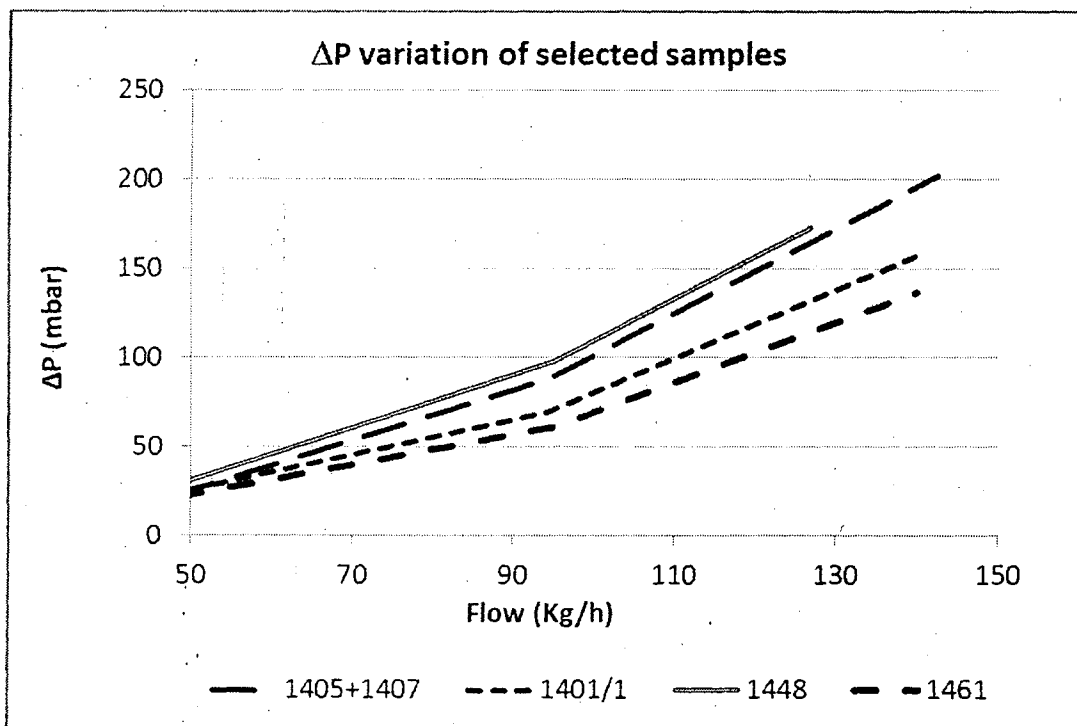


Figure 3.2

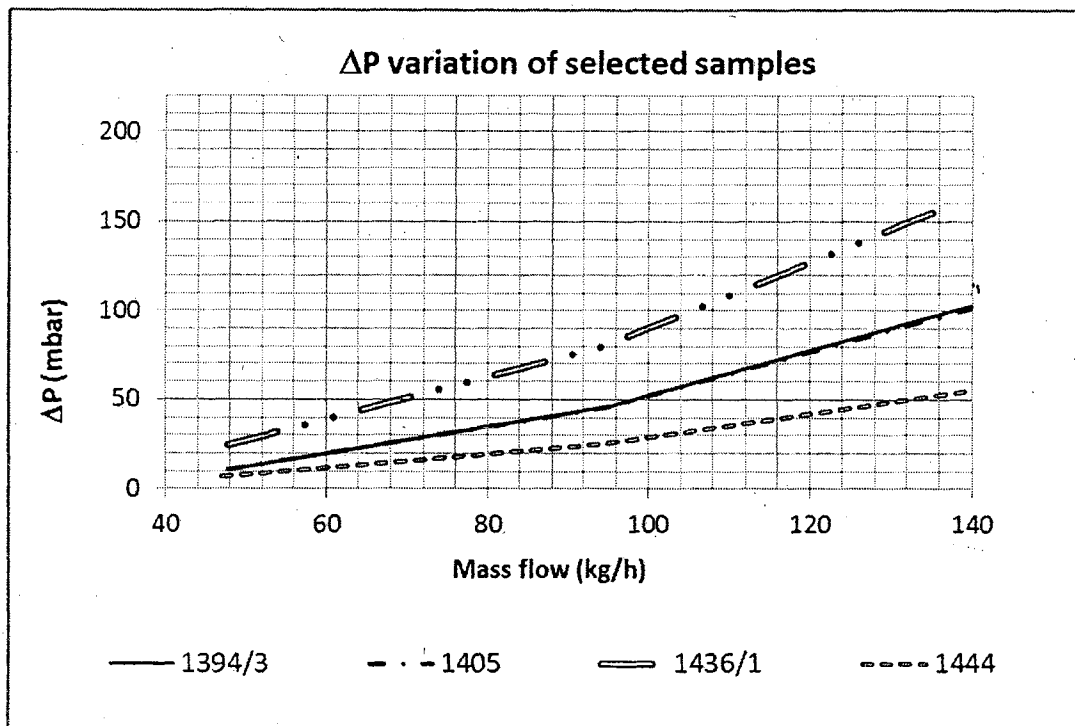


Figure 3.3

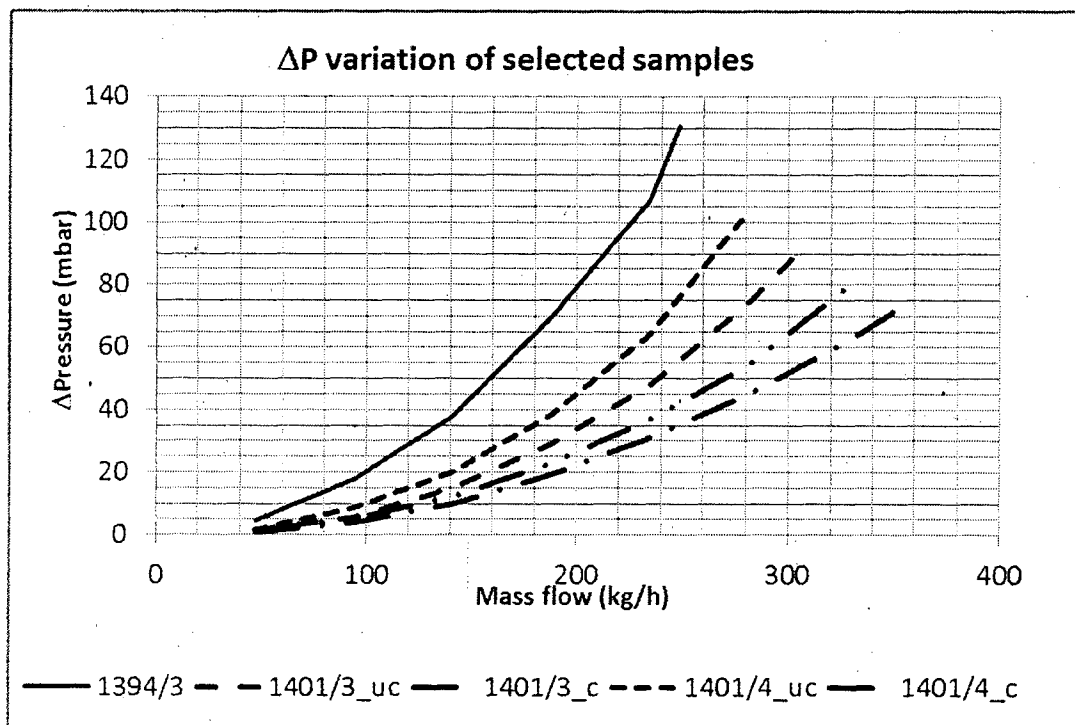


Figure 3.4

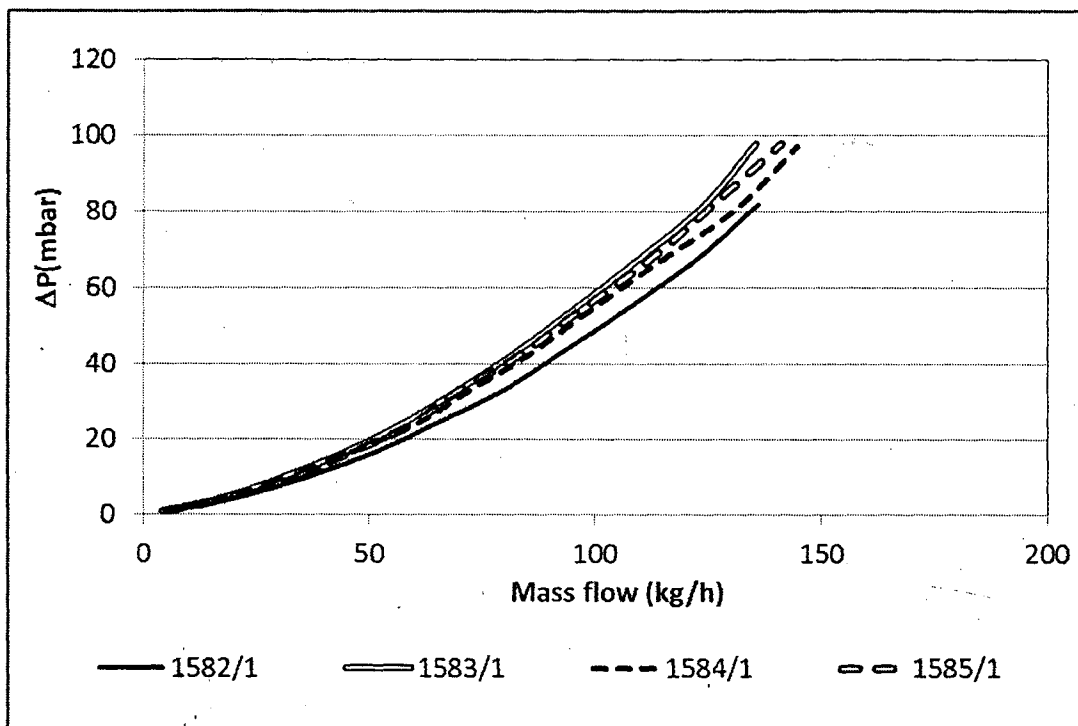


Figure 3.5

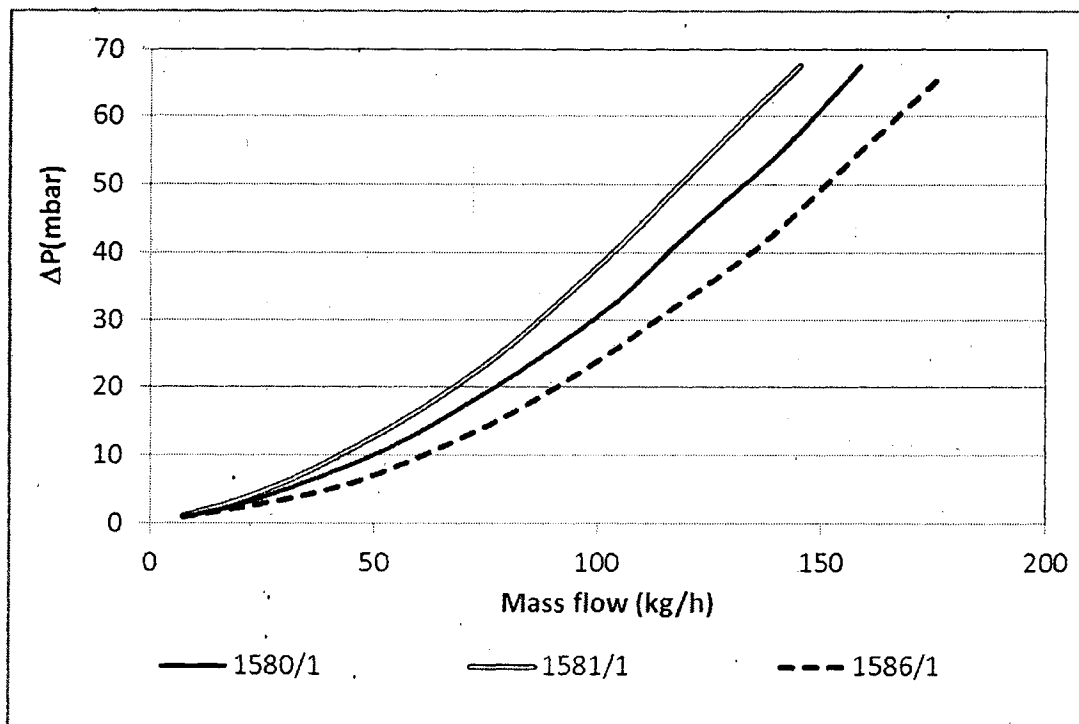


Figure 3.6

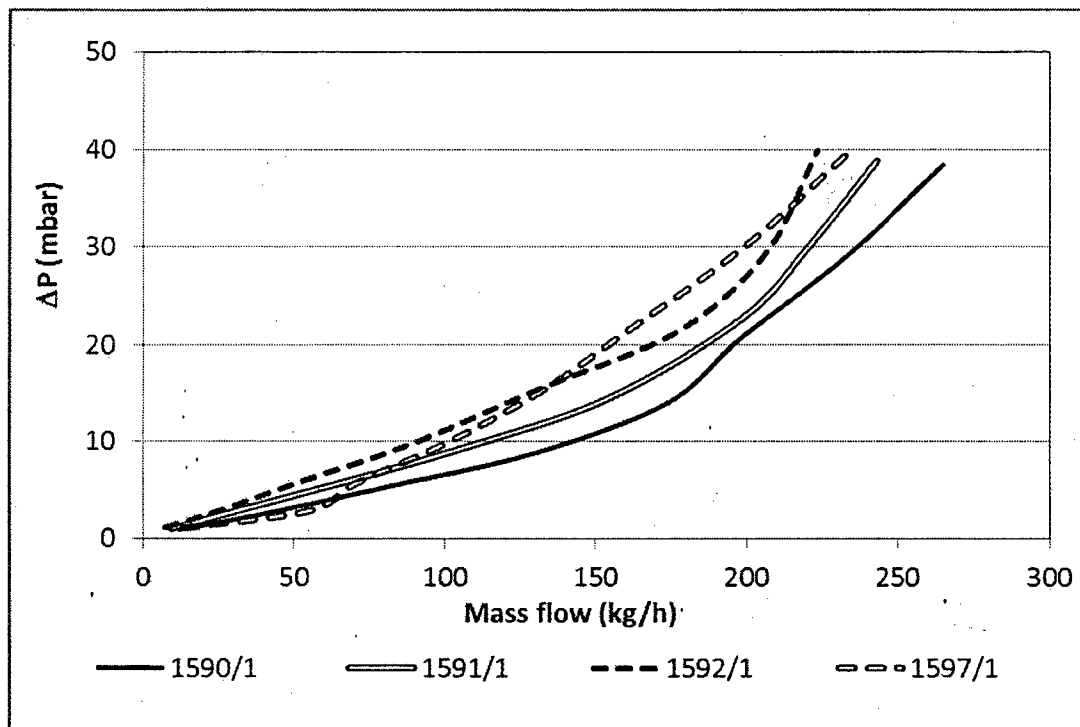


Figure 3.7

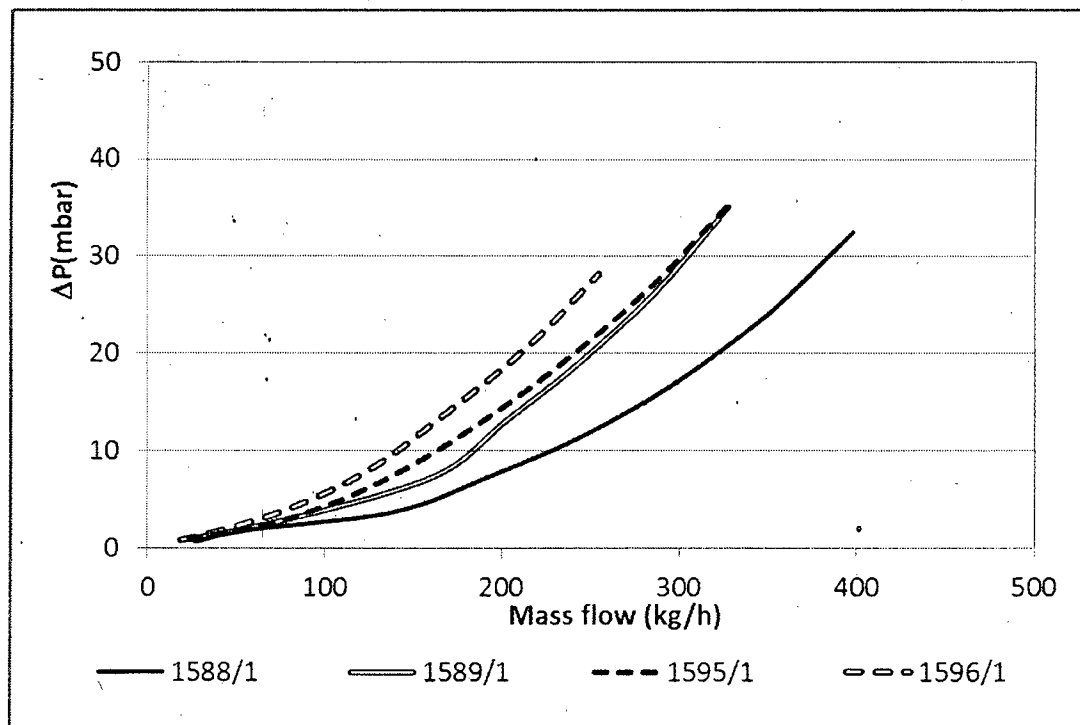


Figure 3.8

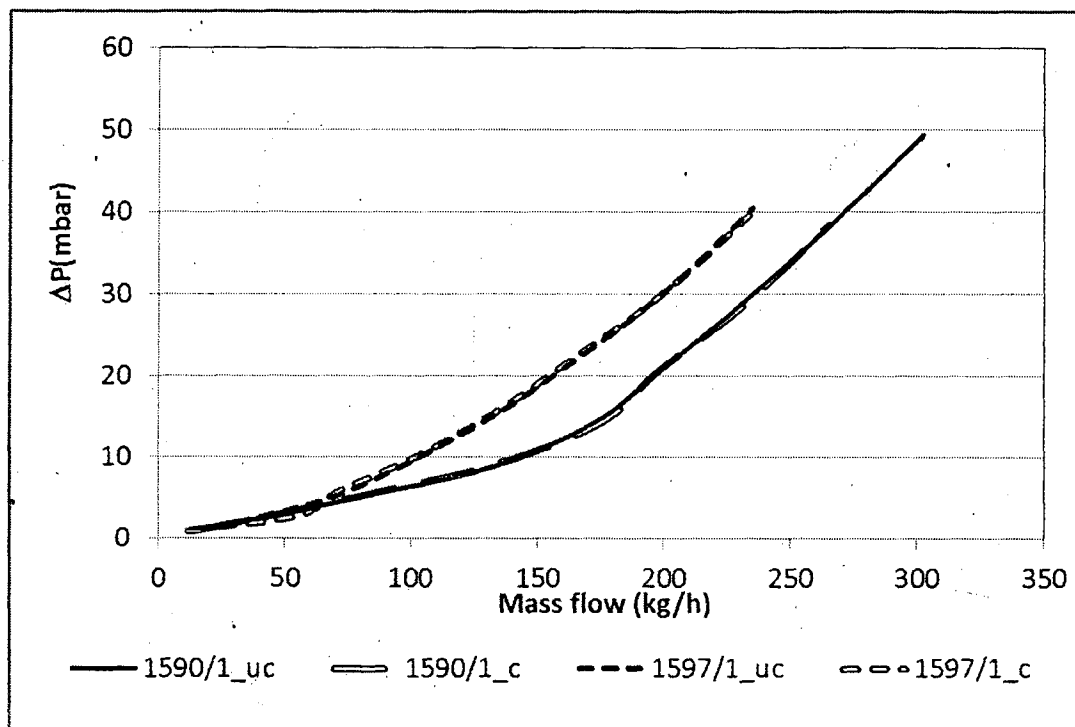


Figure 3.9

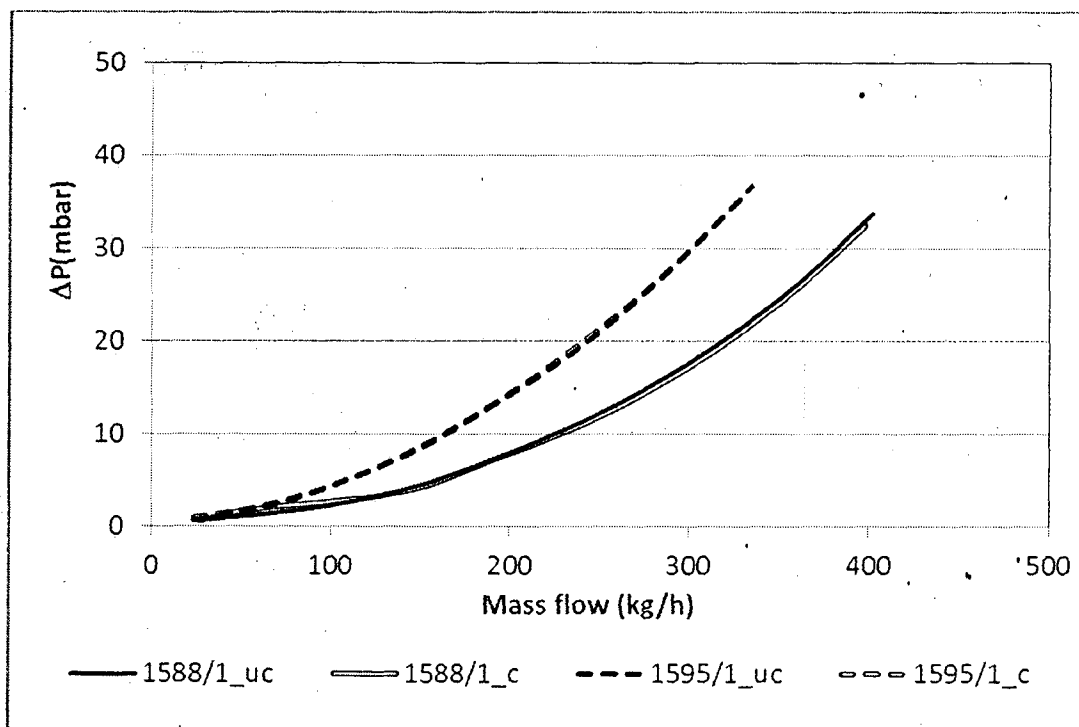


Figure 3.10

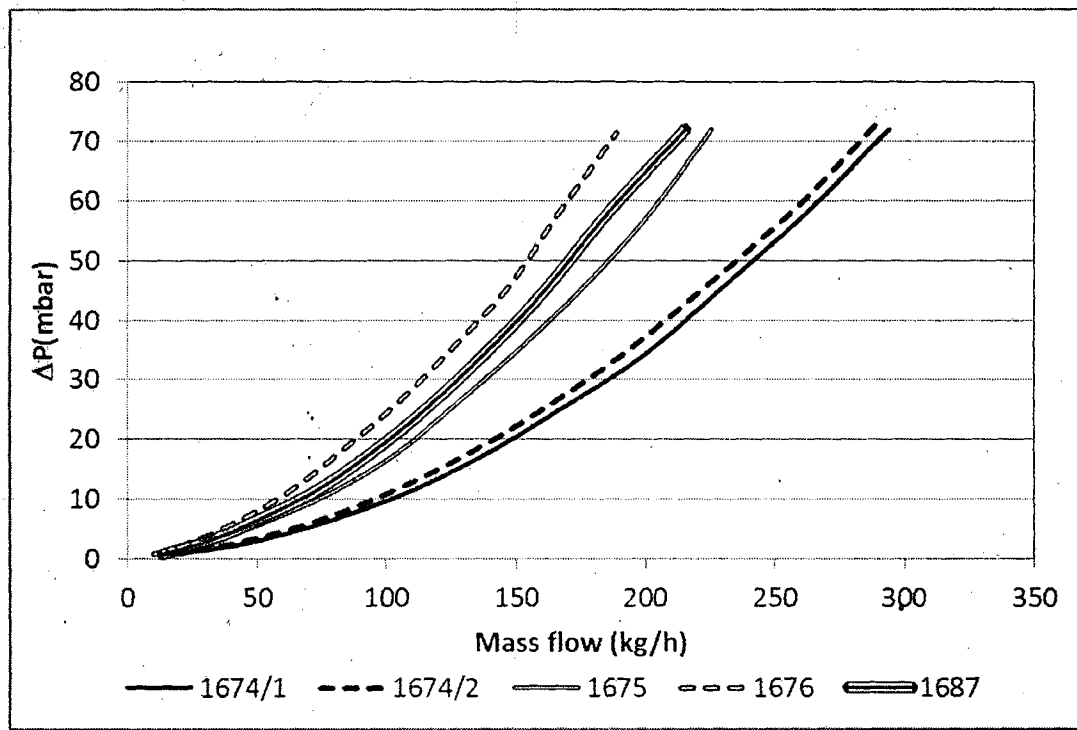


Figure 3.11

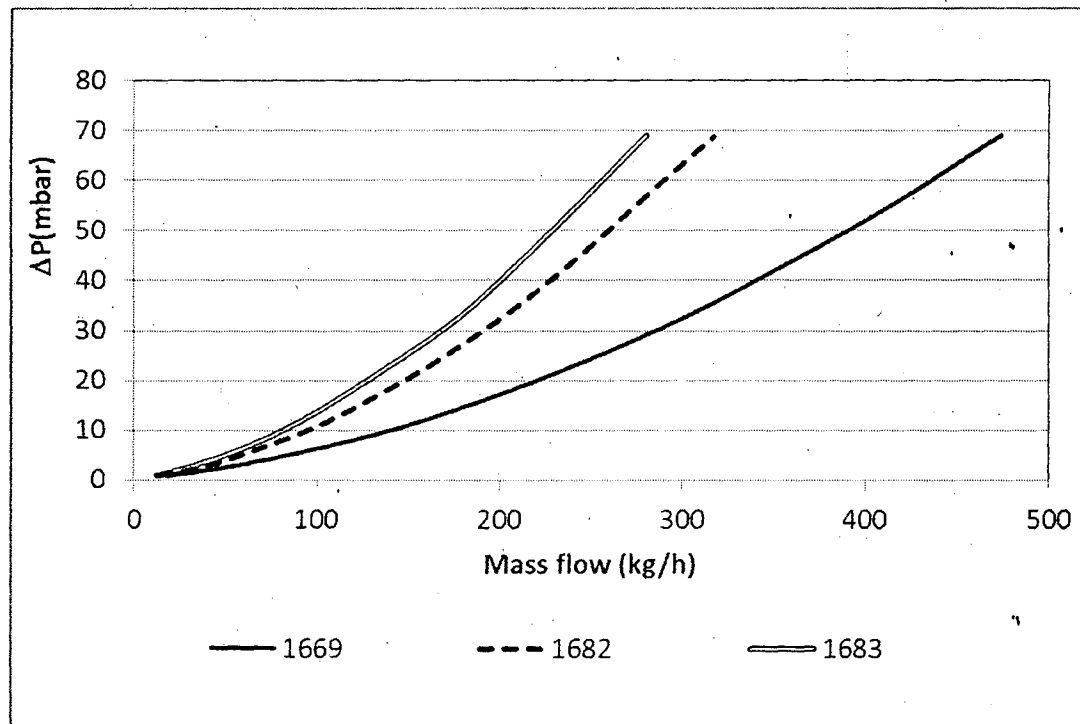


Figure 3.12

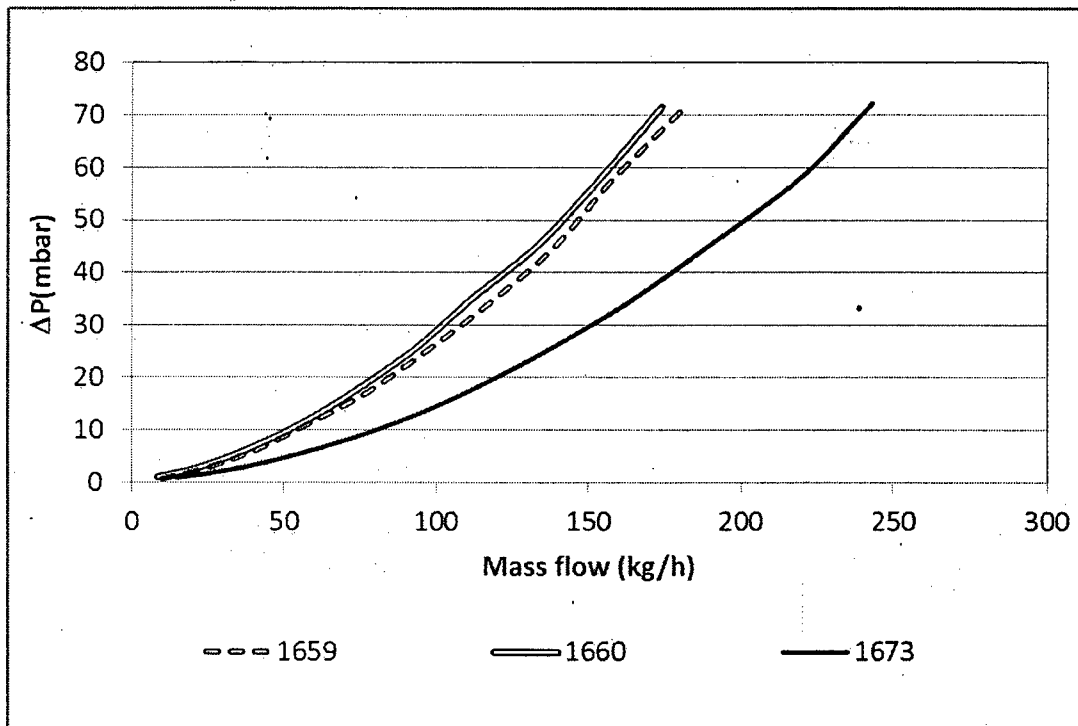


Figure 3.13

Figures 3.1 to 3.13 ΔP variations of selected samples having different combinations and with corrugation

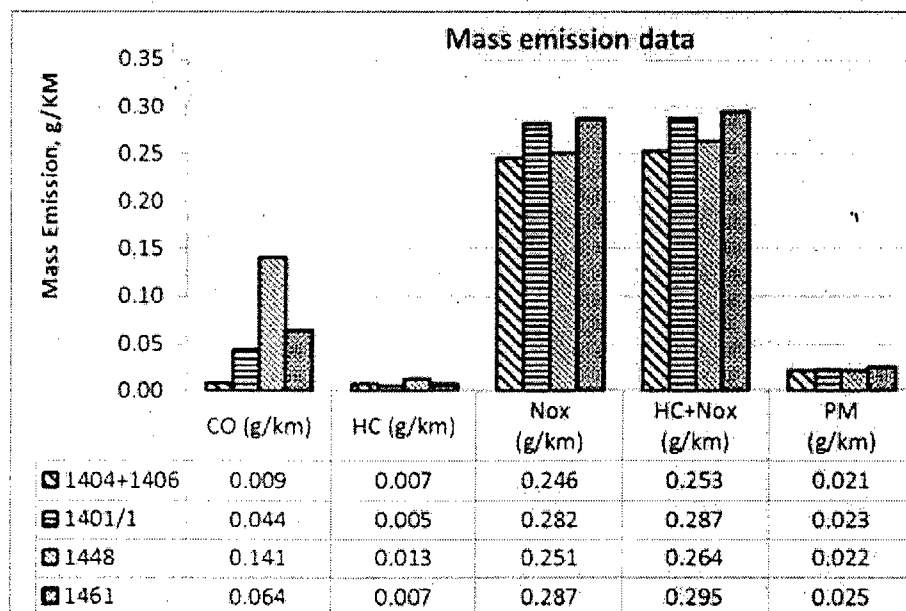


Figure 4: Mass emission data of selected samples having different combinations and with corrugation.

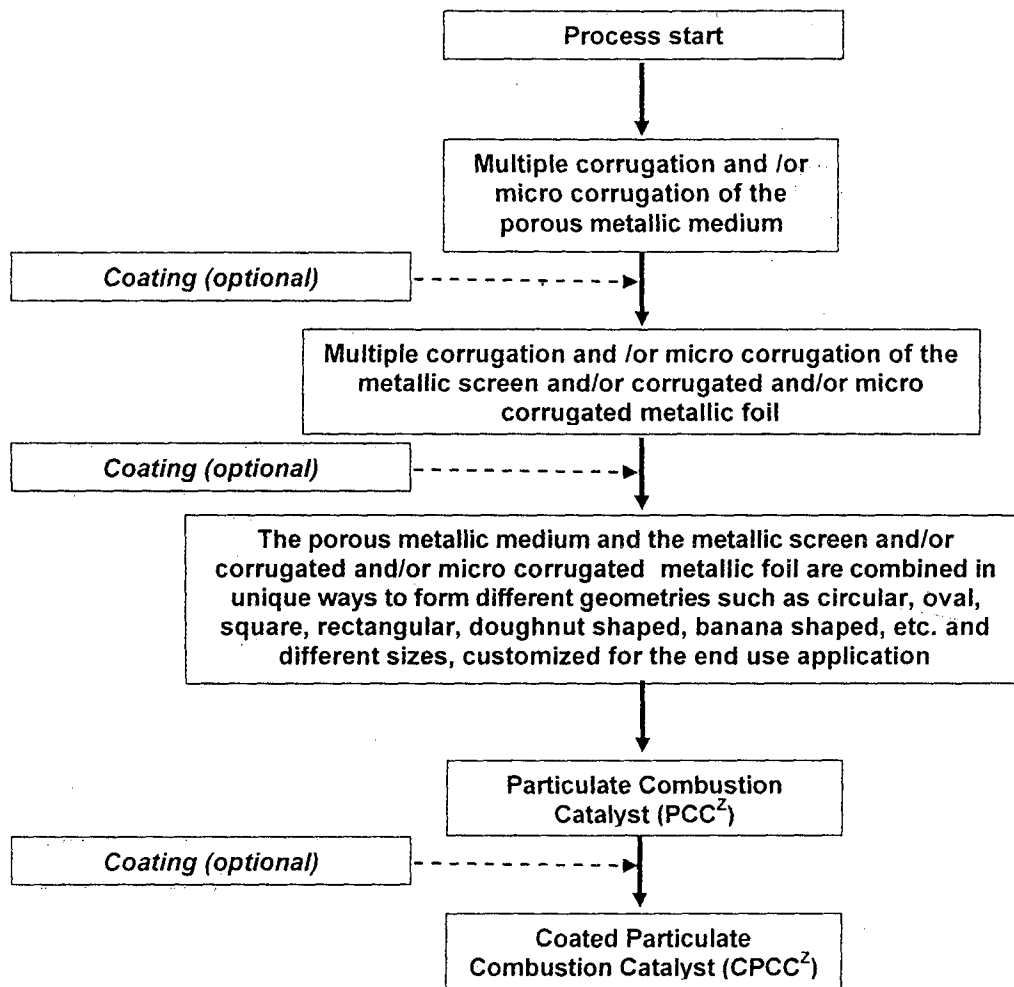


Figure 5

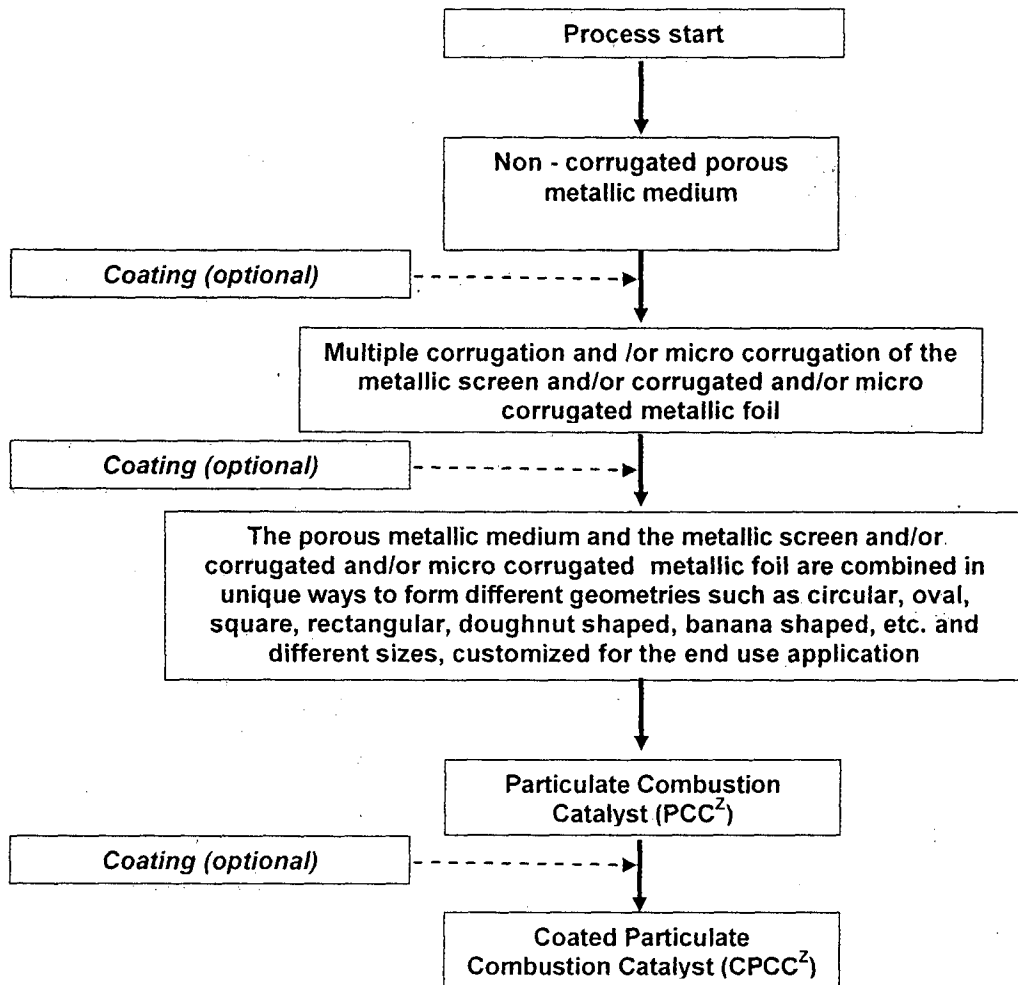


Figure 6

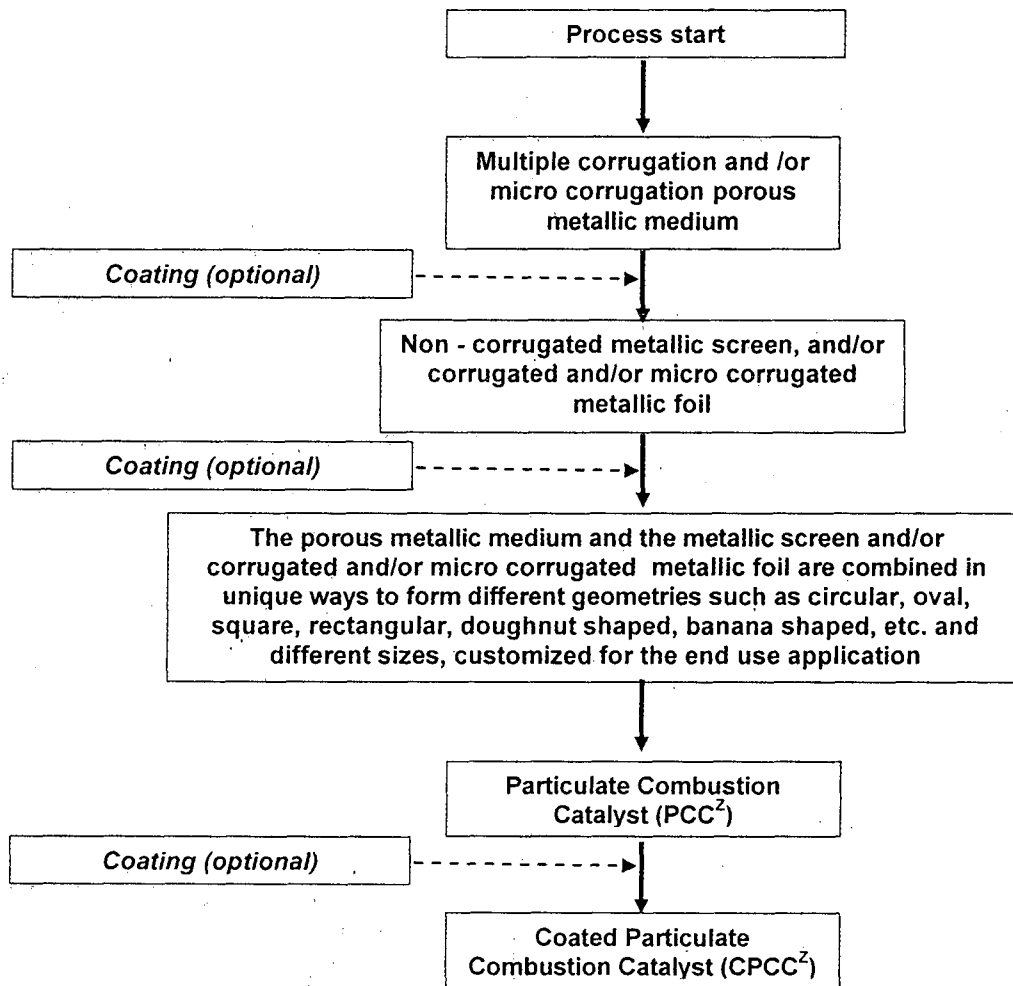


Figure 7

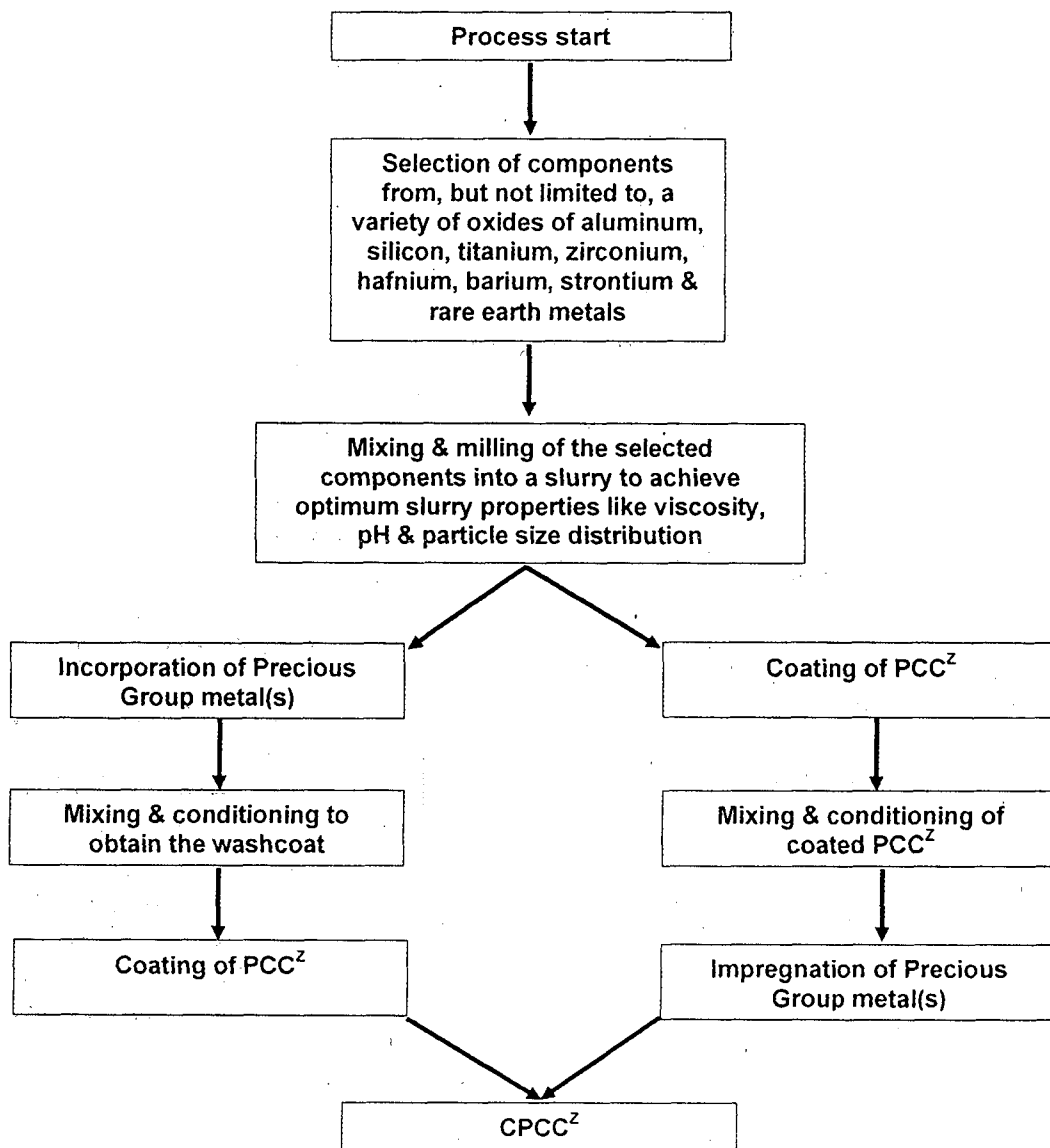


Figure 8

Figure 9

VF0	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, uncoated
VF1	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 1 g/cft
VF5	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 5 g/cft
VF10	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 10 g/cft
VF20	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 20 g/cft

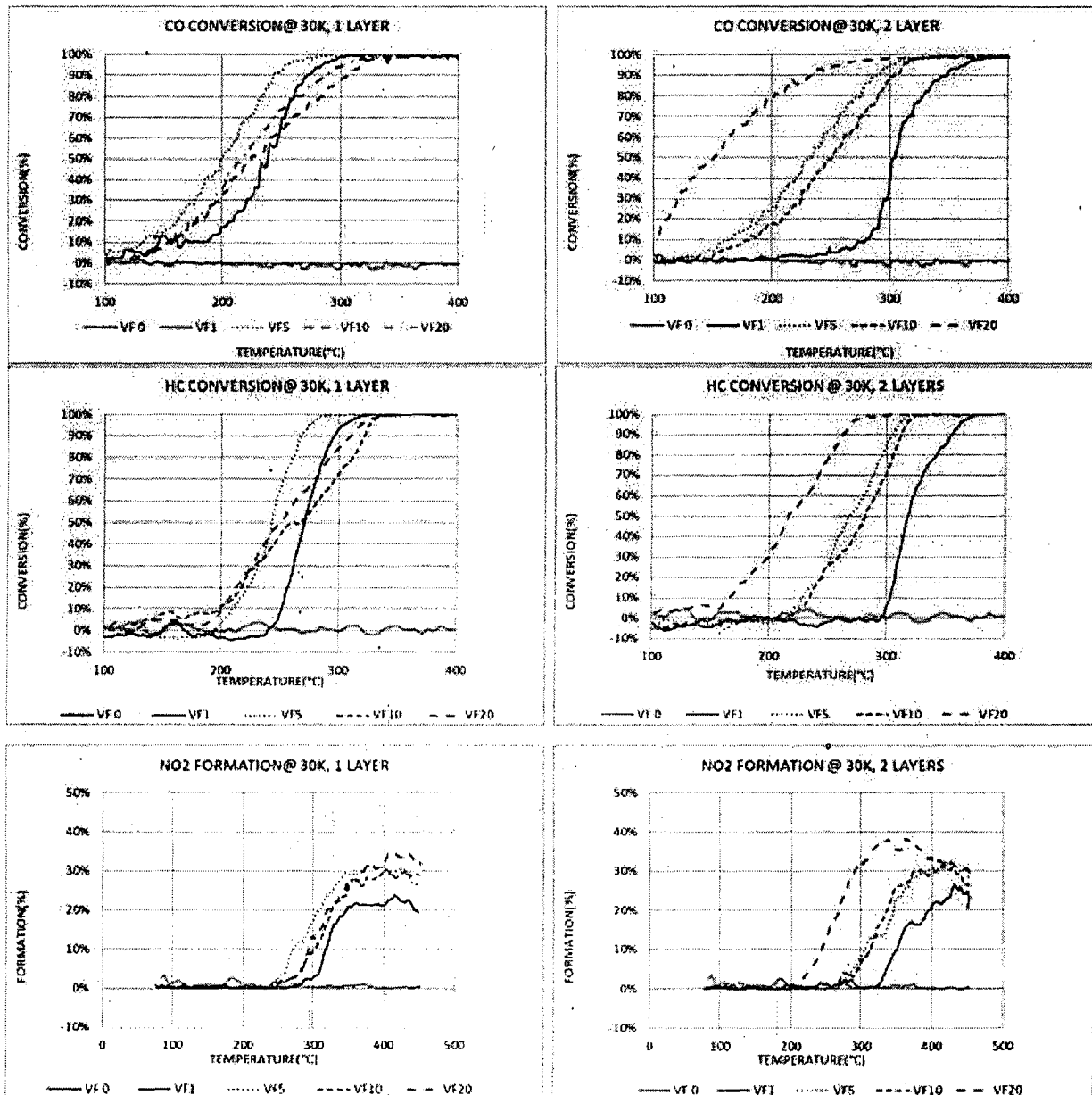


Figure 10

VF1	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 1 g/cft
VX20	Prior art honeycomb structure, 330 cpsi, Angle corrugated metallic screen PGM loading of 20 g/cft

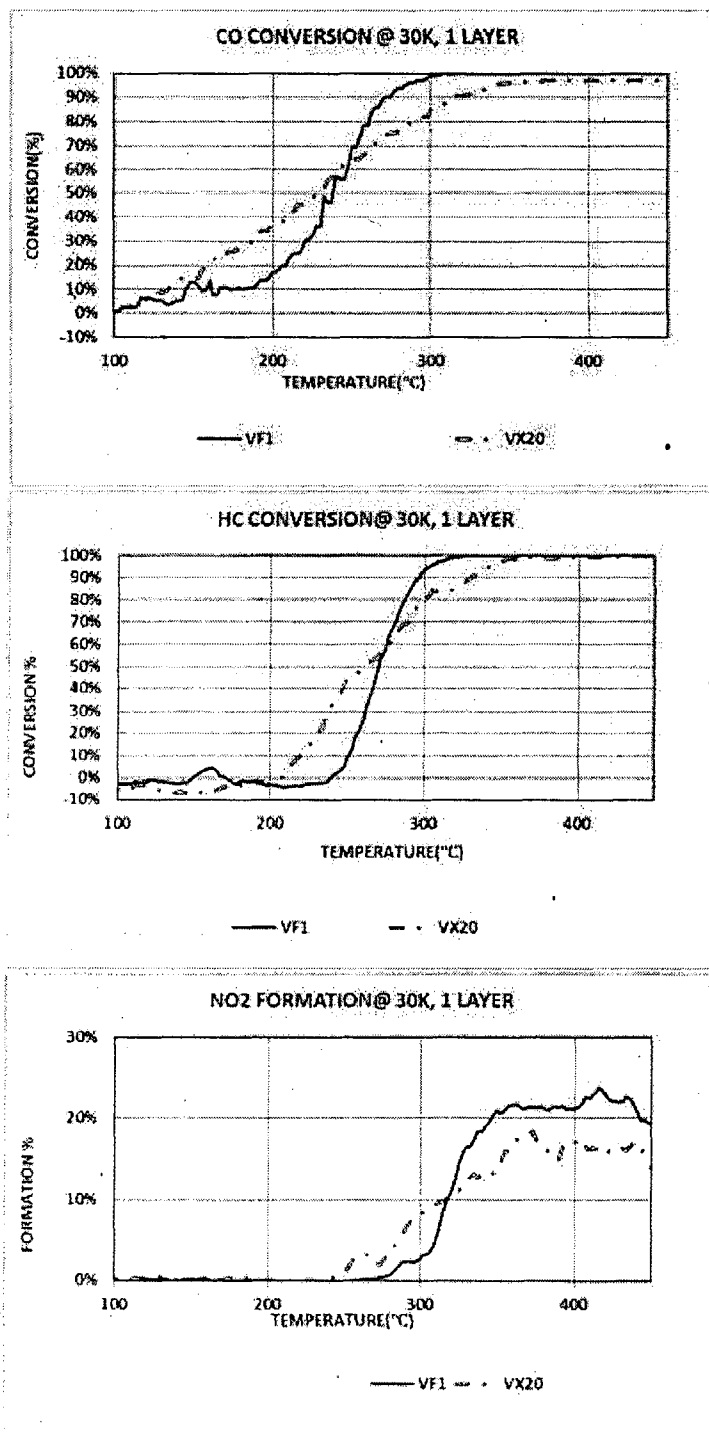


Figure 11

VF5, 30K	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 5 g/cft at space velocity of 30,000 /h
VF5, 60K	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 5 g/cft at space velocity of 60,000 /h

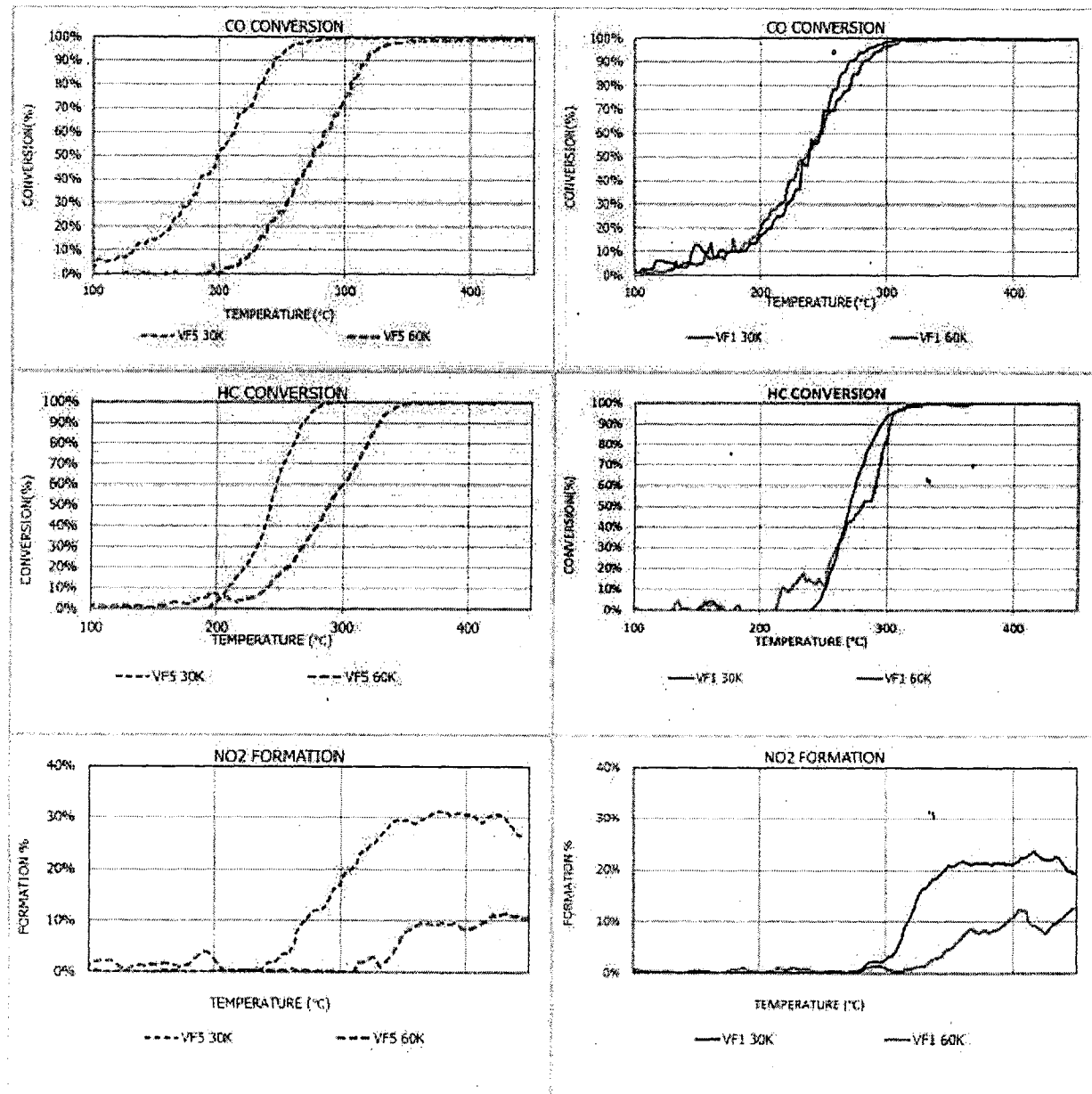


Figure 12

VF1	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 1 g/cft
VF5	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 5 g/cft
VF10	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 10 g/cft
VF20	Flat porous metallic medium + 330 cpsi Angle corrugated metallic screen with rectangular mesh, PGM loading of 20 g/cft

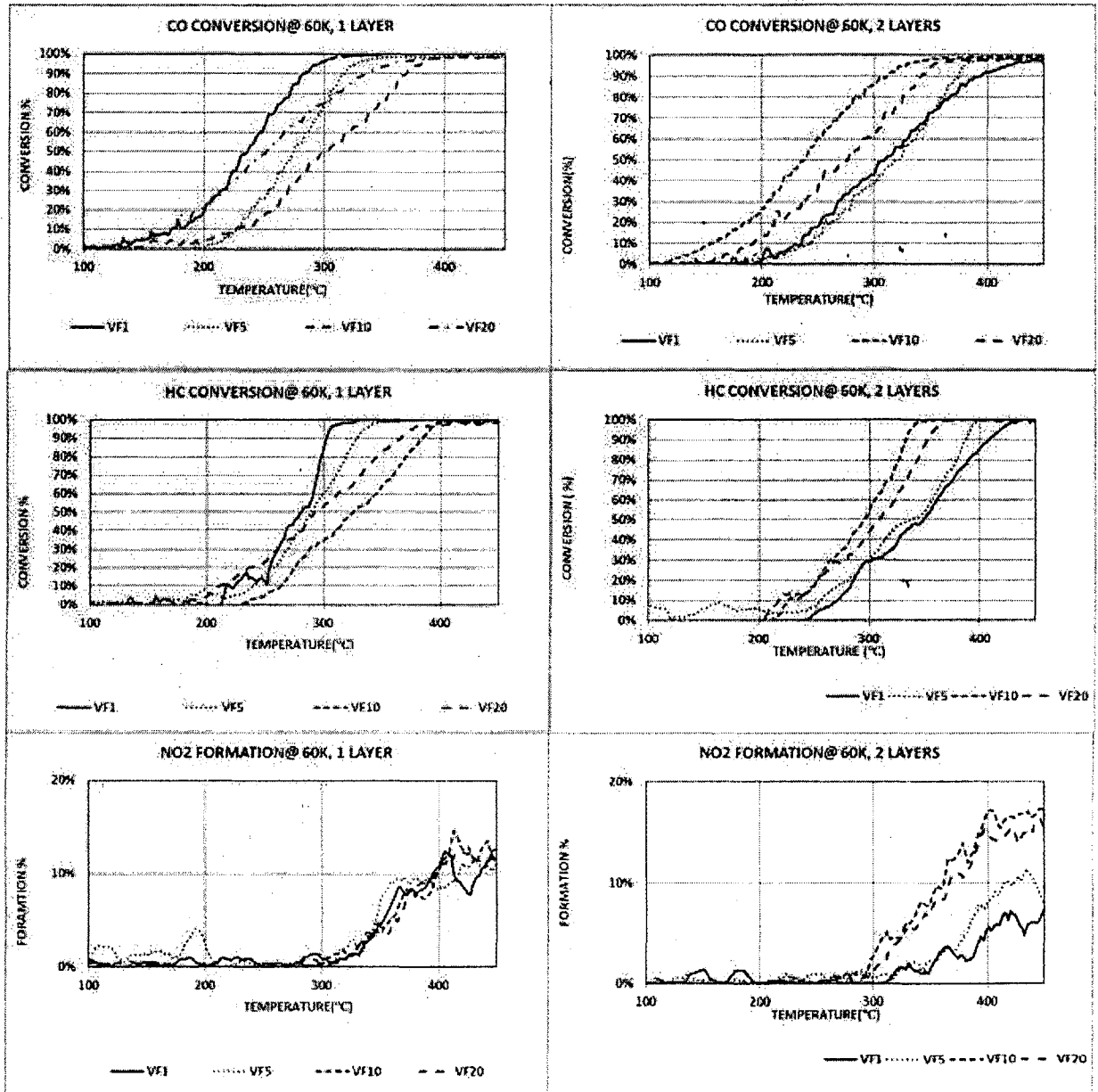


Figure 13

P 1661	200 cpsi Turbulent type corrugated porous metallic medium + Flat or uncorrugated Foil
P 1662	200 cpsi Turbulent type corrugated porous metallic medium + Micro corrugated / notched metallic foil
P1663	200 cpsi Straight channel corrugated porous metallic medium + Flat or uncorrugated Foil
P 1664	200 cpsi Straight channel corrugated porous metallic medium + Micro corrugated / notched Foil
P 1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P 1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil

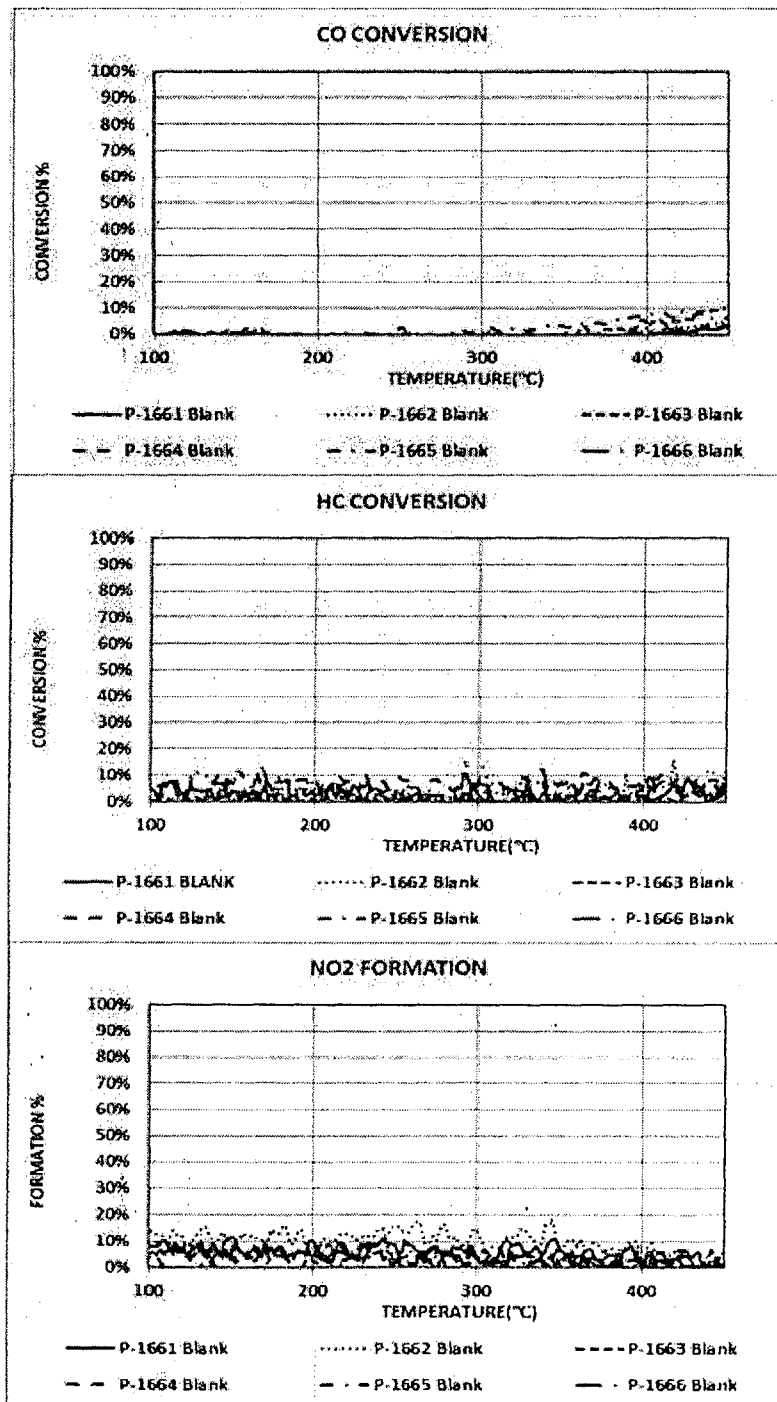


Figure 14

P 1661	200 cpsi Turbulent type corrugated porous metallic medium + Flat or uncorrugated Foil
P 1662	200 cpsi Turbulent type corrugated porous metallic medium + Micro corrugated / notched metallic foil
P1663	200 cpsi Straight channel corrugated porous metallic medium + Flat or uncorrugated Foil
P 1664	200 cpsi Straight channel corrugated porous metallic medium + Micro corrugated / notched Foil
P 1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P 1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil

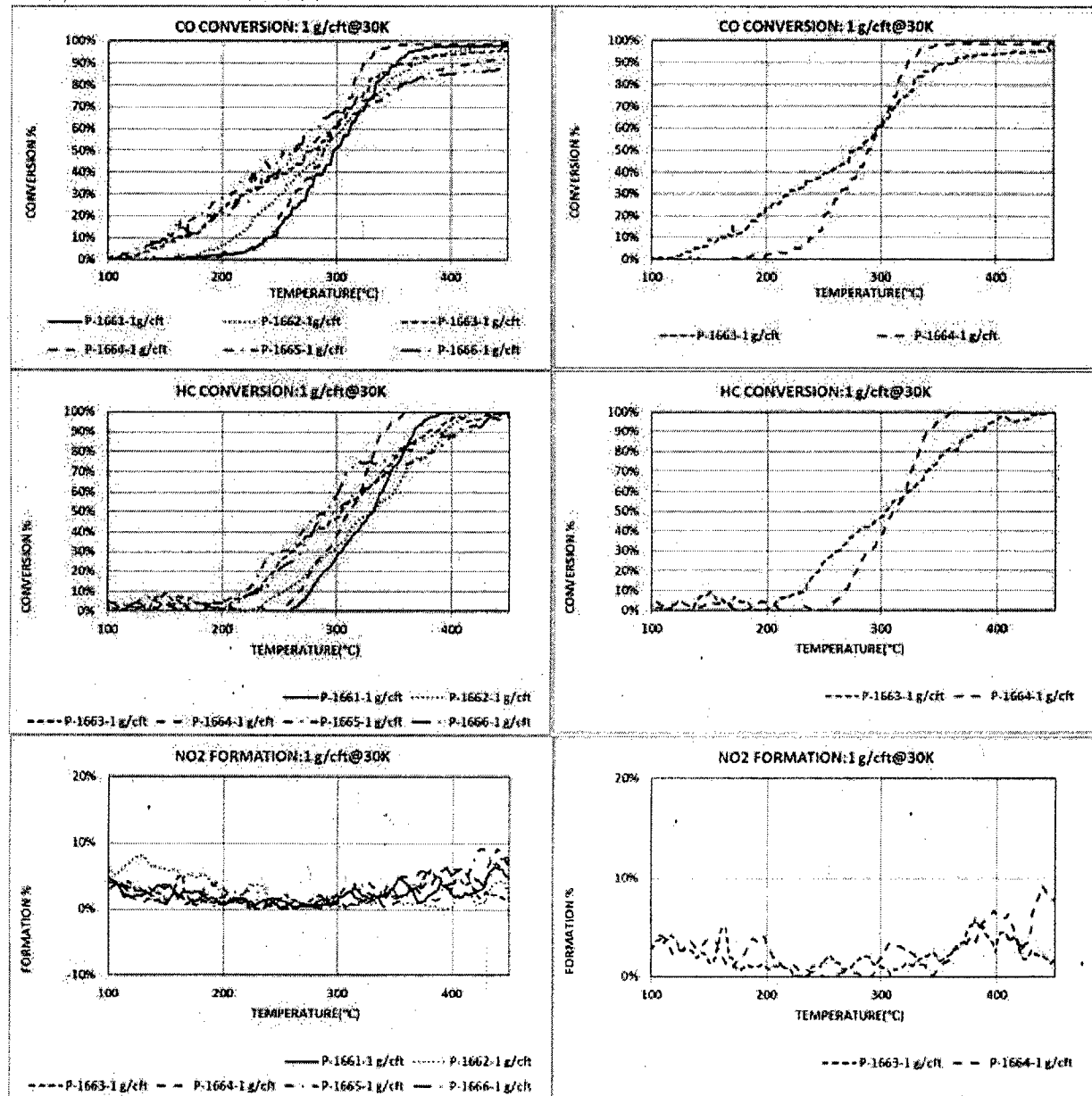


Figure 15

P1663	200 cpsi Straight channel corrugated porous metallic medium + Flat or uncorrugated Foil
P 1664	200 cpsi Straight channel corrugated porous metallic medium + Micro corrugated / notched Foil
P 1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P 1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil

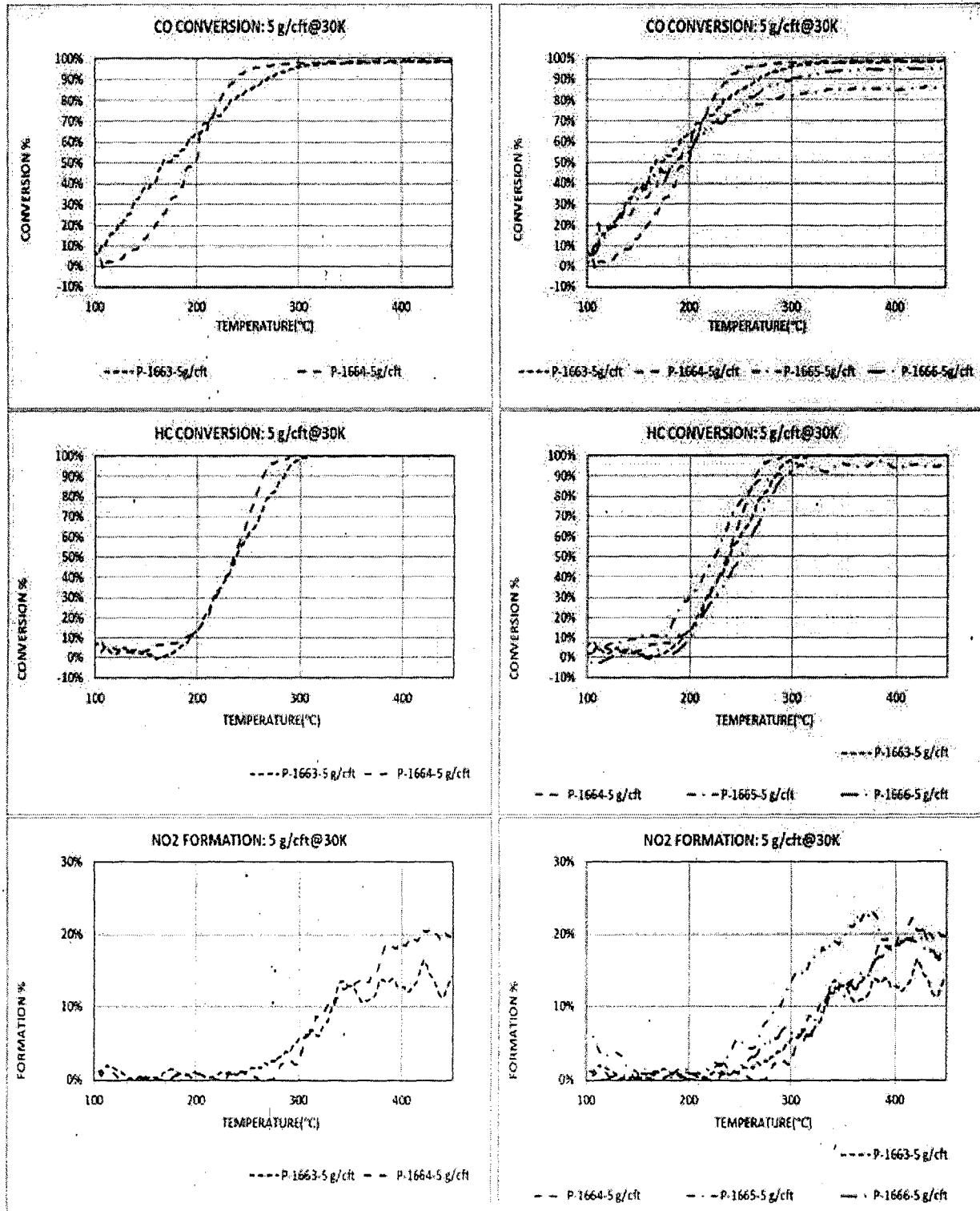


Figure 16

P 1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P 1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil

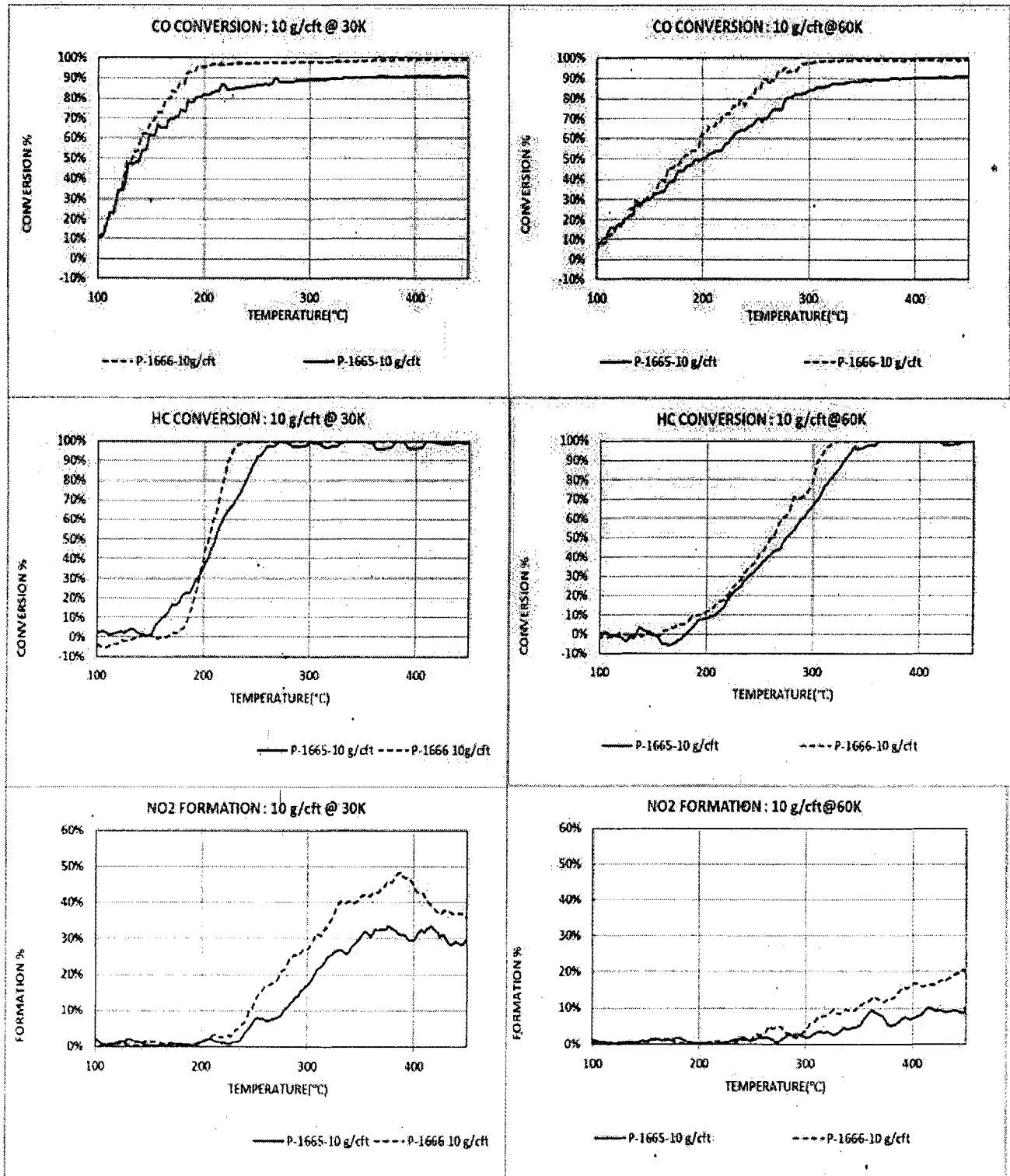


Figure 17

P 1661	200 cpsi Turbulent type corrugated porous metallic medium + Flat or uncorrugated Foil
P 1662	200 cpsi Turbulent type corrugated porous metallic medium + Micro corrugated / notched metallic foil
P1663	200 cpsi Straight channel corrugated porous metallic medium + Flat or uncorrugated Foil
P 1664	200 cpsi Straight channel corrugated porous metallic medium + Micro corrugated / notched Foil
P 1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P 1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil

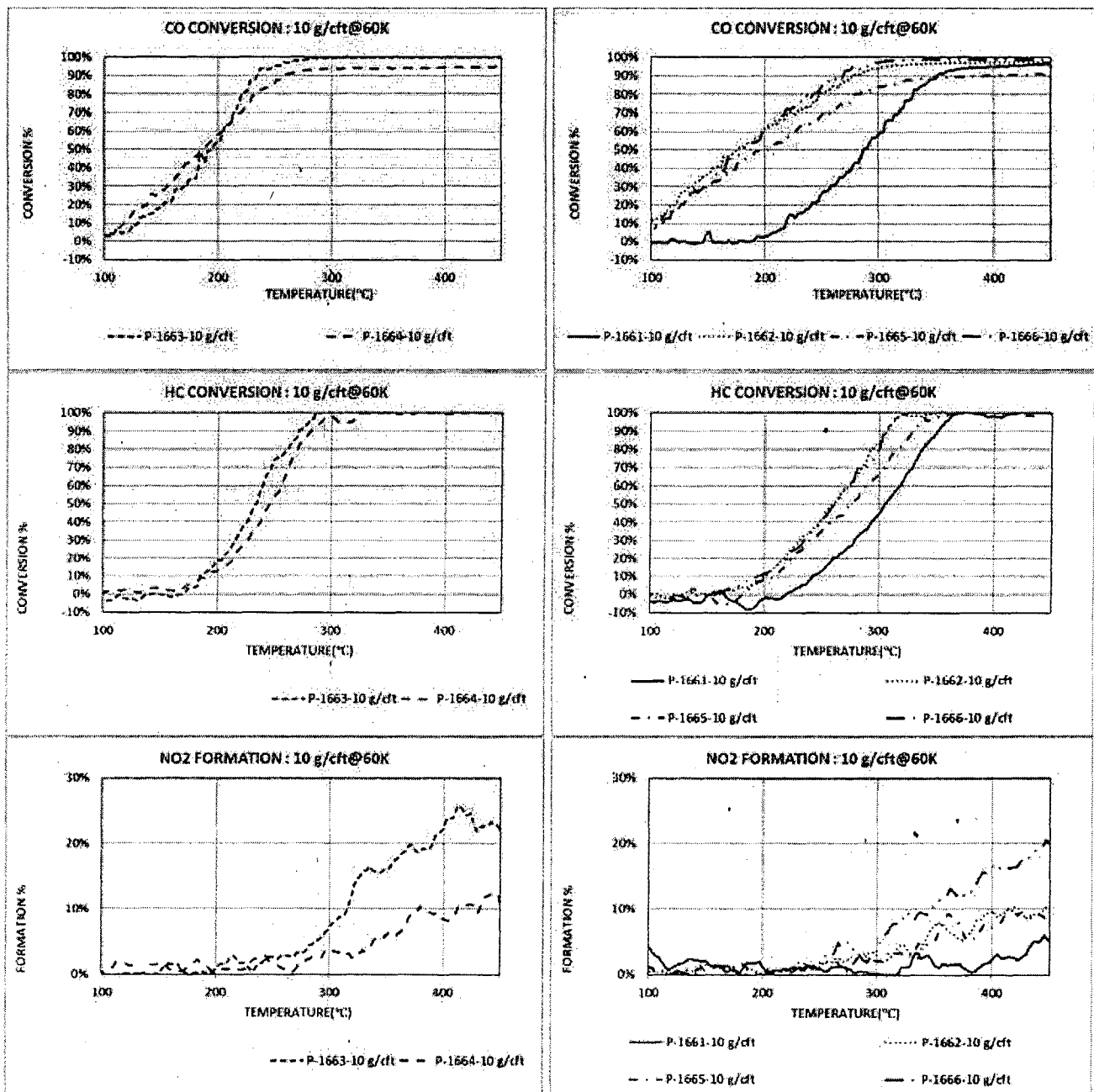


Figure 18

VX1	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 1 g/cft
VX5	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 5 g/cft
VX10	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 10 g/cft
VL1	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 1 g/cft
VL5	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 5 g/cft
VL10	Prior art honeycomb structure, with 330 cpsi, corrugated metallic screen PGM loading of 10 g/cft

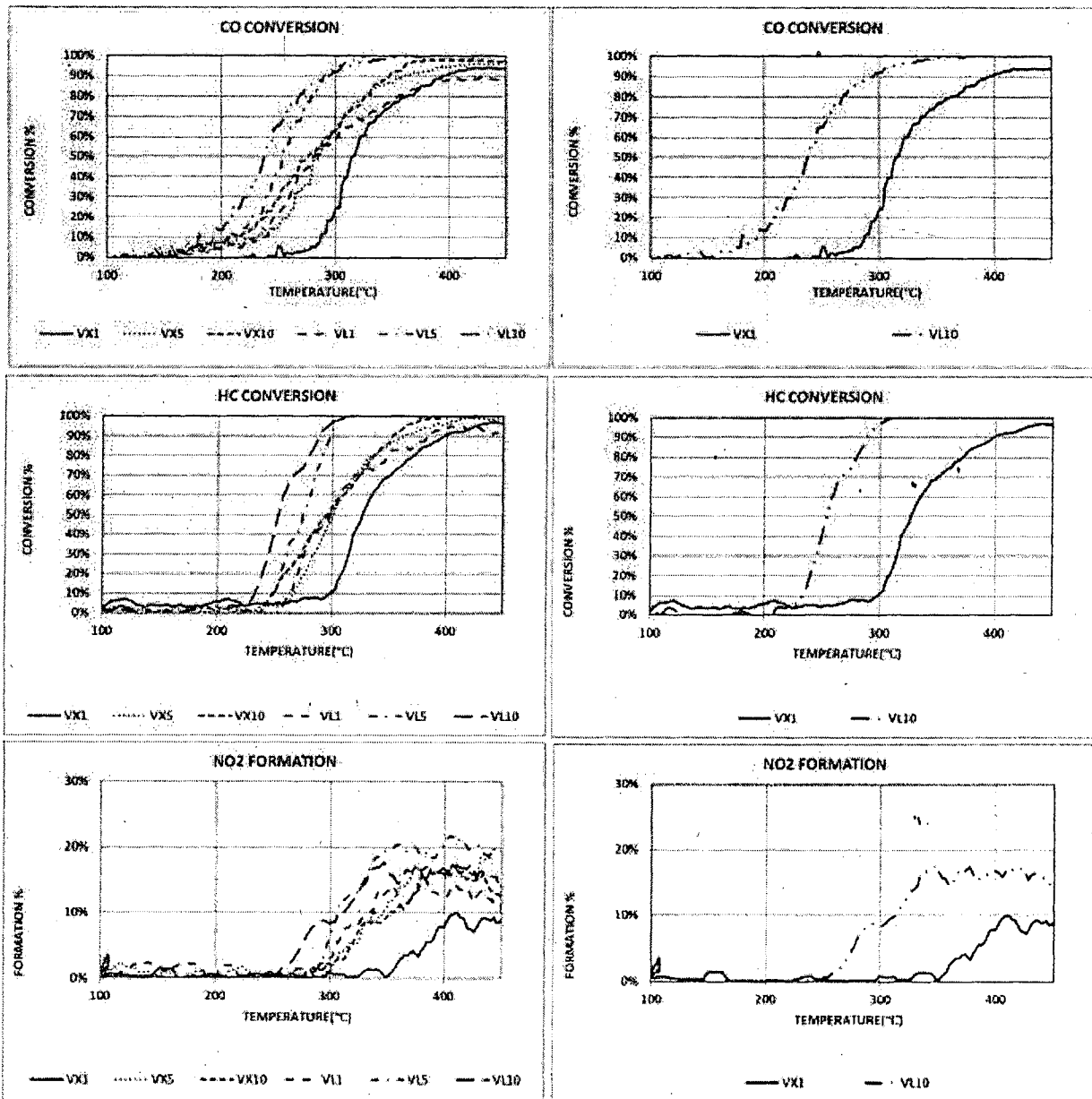


Figure 19

P 1700	Flat porous metallic medium + 200 cpsi Straight Channel Corrugated Foil
P 1701	Flat porous metallic medium + 200 cpsi Turbulent type Corrugated Foil
P 1702	Flat porous metallic medium + 330 cpsi Angular type Corrugated Foil

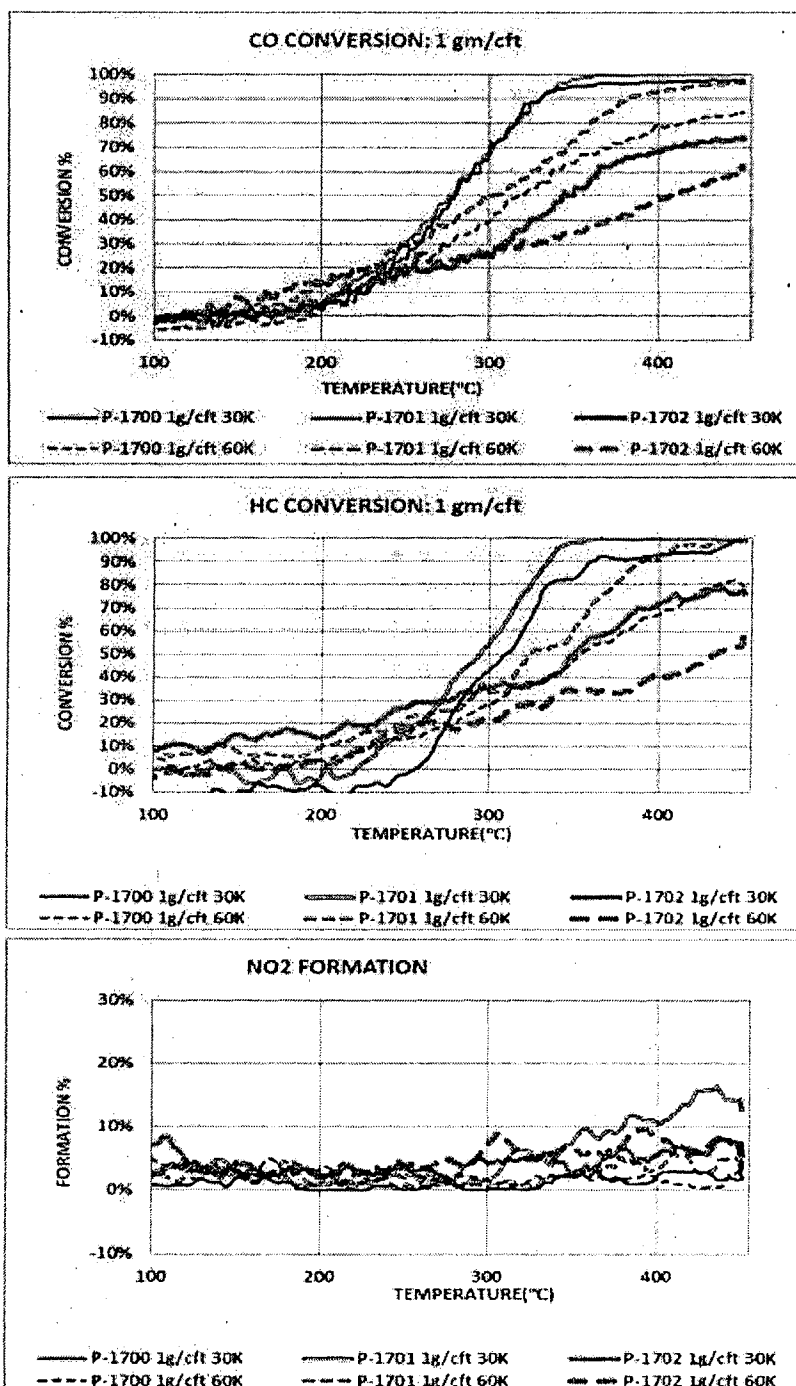


Figure 20

P 1700	Flat porous metallic medium + 200 cpsi Straight Channel Corrugated Foil
P 1701	Flat porous metallic medium + 200 cpsi Turbulent type Corrugated Foil
P 1702	Flat porous metallic medium + 330 cpsi Angular type Corrugated Foil

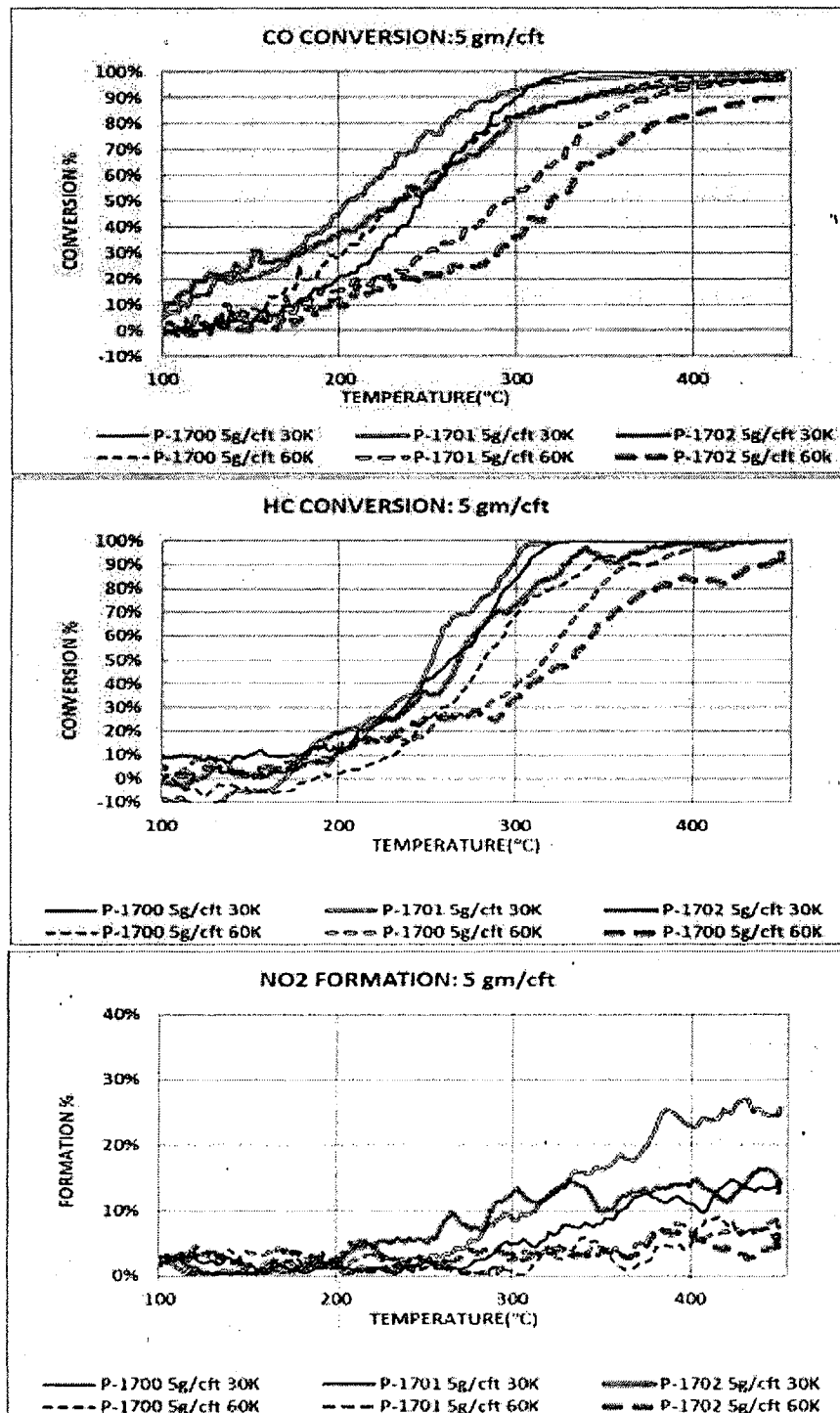


Figure 21

P 1700	Flat porous metallic medium + 200 cpsi Straight Channel Corrugated Foil
P 1701	Flat porous metallic medium + 200 cpsi Turbulent type Corrugated Foil
P 1702	Flat porous metallic medium + 330 cpsi Angular type Corrugated Foil

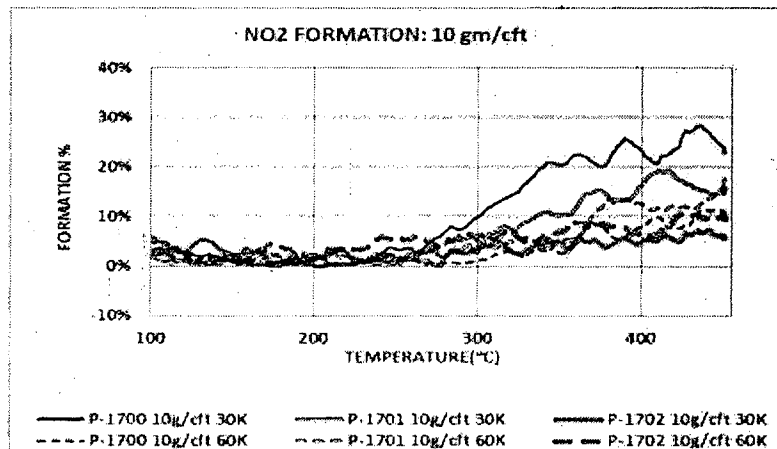
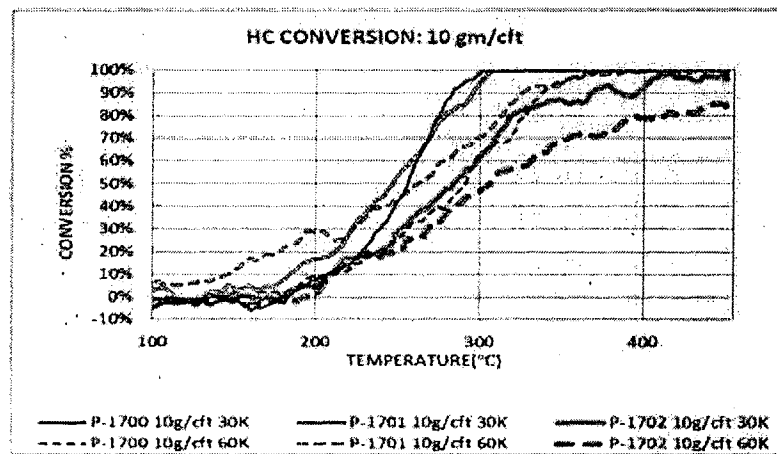
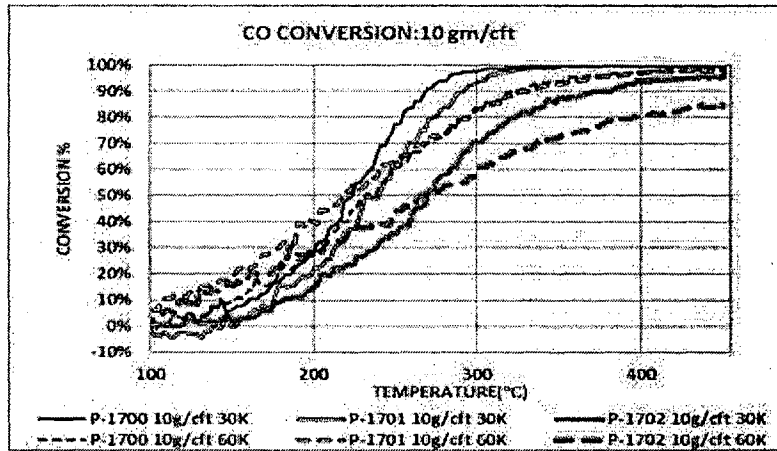
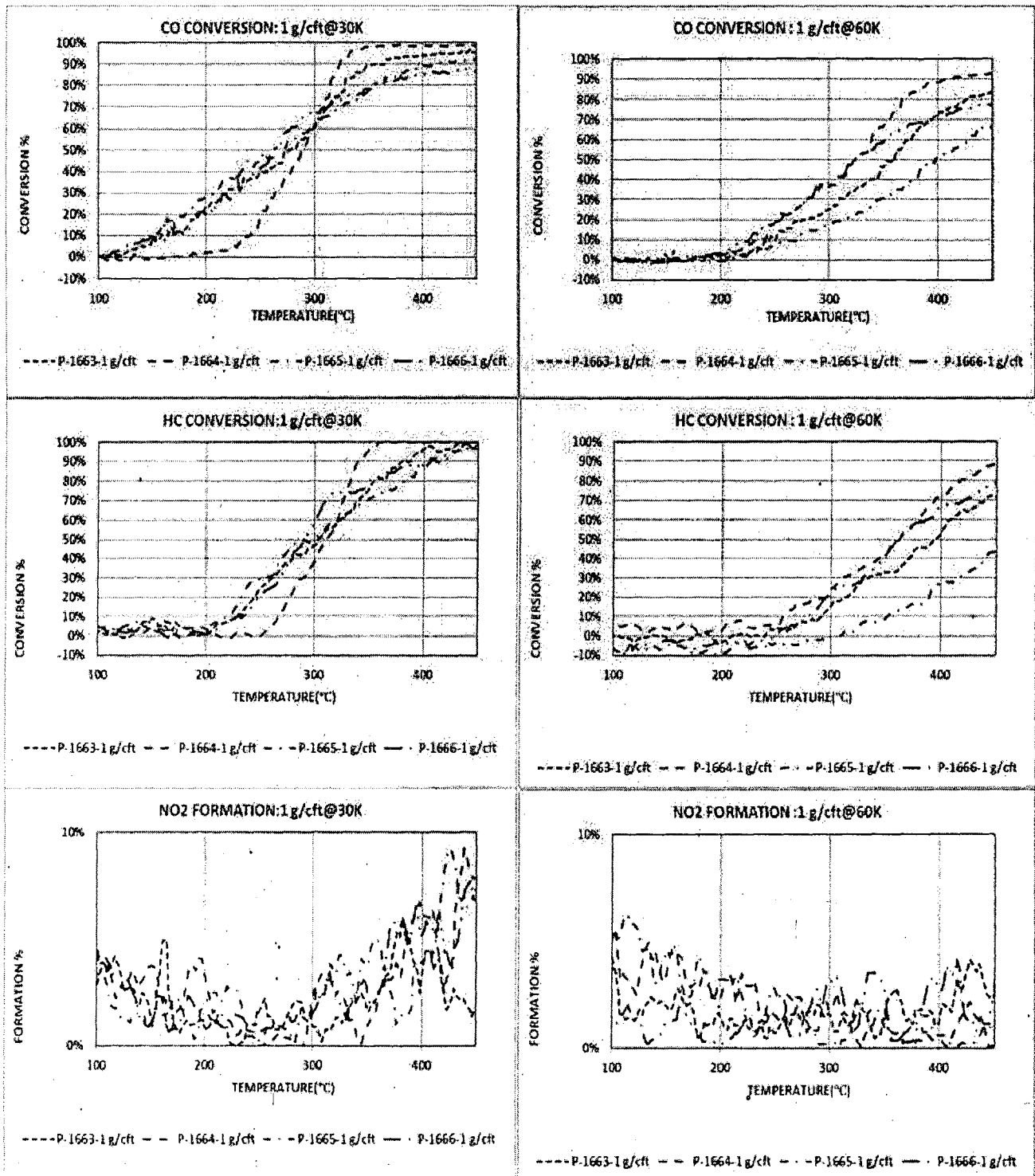


Figure 22

P1663	200 cpsi Straight channel corrugated porous metallic medium + Flat or uncorrugated Foil
P1664	200 cpsi Straight channel corrugated porous metallic medium + Micro corrugated / notched Foil
P1665	330 cpsi Angle corrugated porous metallic medium + Flat or uncorrugated Foil
P1666	330 cpsi Angle corrugated porous metallic medium + Micro corrugated / notched Flat Foil



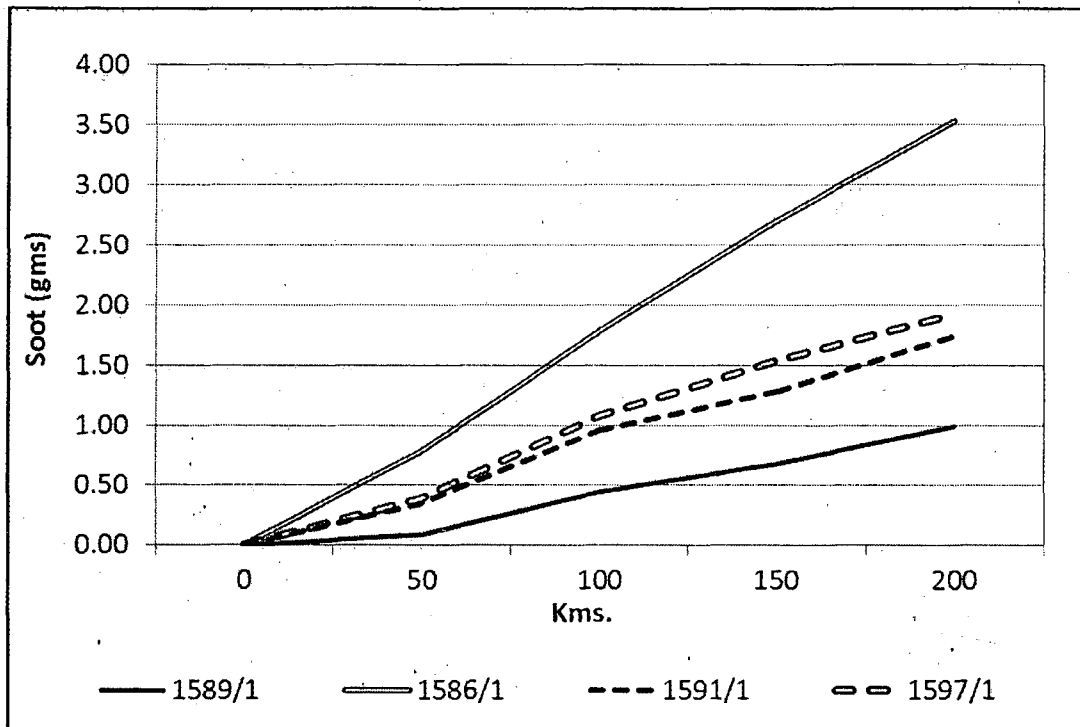


Figure 23.1

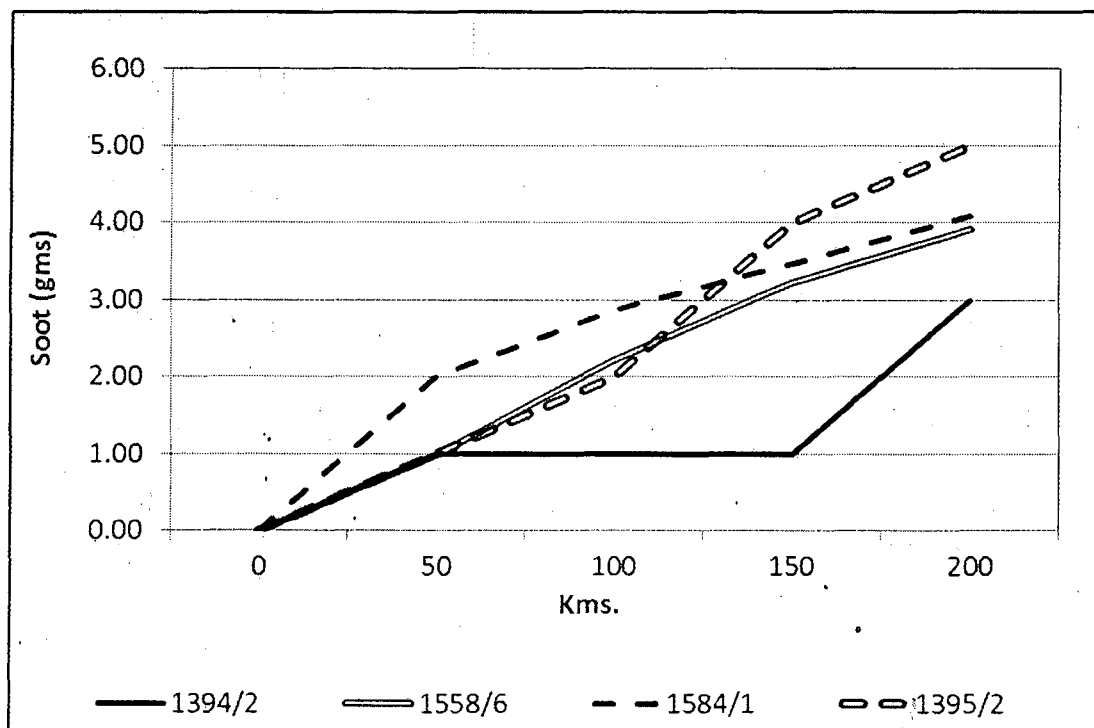


Figure 23.2

Figures 23.1 & 23.2: Soot loading pattern as a function of distance covered CPCC^z samples having a different structural combination and different corrugations.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2016/000027

A. CLASSIFICATION OF SUBJECT MATTER
F01N3/022 Version=2016.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F01N3/022

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Patseer, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 7625538 B2 (GURLI MOGENSEN) 1 December 2009 WHOLE DOCUMENT , ABSTRACT, FIGURES.-01-03	1-32
Y	EP0341832 A2 (COOPER BARRY JOHN; JUNG HYUN JONG; THOSS JAMES EDMUND) 15 November 1989 WHOLE DOCUMENT , ABSTRACT, FIGURES.-01-04	1-32

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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