RESEARCH ARTICLE

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Design and Fabrication of Economical Industrial Air Filter

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ABSTRACT

The design and fabrication of an economical air filter is for an industrial cupola furnace in MIDC, Hingna. The purpose of an industrial filter is to remove unburned coal particles' hazardous fumes and reduce NOX in the environment. The filtration system consists of a filter box that comprises four filter media which are placed vertically like a cartridge. The first media is manufactured like a frame containing a steel wool scrubber. This frame traps hot gases and large particles of smoke. The second frame contains a layer of blue silica gel that absorbs moisture present in polluted air. The third filter frame consists of activated carbon which has chemical properties for the adsorption of Carbon dioxide and Nitrogen dioxide gases. The last filter is HEPA (high-efficiency particulate air) filter, which is made from element paper. It can filter 0.3µm diameter of dust particles. Finally, we get the filtered air through the exhaust. This filtration system is effective in terms of cost, cleaning, and maintenance. The filters are easy to remove when the dust gets chocked in it, also clean easily with the help of a pneumatic gun or some dust cleaning system. This will be economical and easy to maintain.

Keywords: adsorption, blue silica gel, interwoven fiberglass fibers, ultra-low particulate air, HEPA – (high-efficiency particulate air)

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INTRODUCTION

In air pollution in India or the world, there are several fine particles which are harmful to human. These fine particles enter in human body and may cause damage to parts like the nose, throat, and be captivated inside the human body part, which is dangerous and more harmful. The effect of fine particle may cause health problems such as eye irritation, nose irritation, irritation throat, and lung irritation, also others types of problems may arise like coughing, sneezing, runny nose, and asthma [1]. These types of ultra-fine particles are also called airborne particles having diameter of 2.5 µm or less. These fine dust particles can be carried by air/wind from one place to another easily in the environment. There are so many technologies are used to minimize and removal of fine particles from the environment, like cold plasma, cyclonic air filtration (venture), wet scrubbing, electrostatic precipitate and physical filters. Though, most of the technologies are not energy-efficient as well as not able to provide cost-effective filtration.

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Air quality index is one of the main parameter to study of air pollution. It is consist of different suspended and repairable particulate matter. The Repairable particulate matter in-short RPM is divided in to two sizes, one is PM10-whose size is less than 10 microns and other is PM2.5 whose size is less than 2.5 microns [2]. If Air Quality Index value is above 100 in air, then those types of air is unhealthy and dangerous for people.

The filtration system designed has multiple filtering compartments which are efficient, effective, and economical. The special filter removes carbon, dust, debris. Filter size, porosity, are the most important features for the classification and selection of filters.

METHODOLOGY AND DESIGN

Product Design

The product design and development process is one of continues improvement cycle over time period with iterative feedback and inputs from customers, executives, team members, sales and marketing departments, and production teams in an organization. The Recent trends in PDD (Product Design & Development) are increases the involvement of customer directly into product development to get advantages, and also have short improvement processes time, as well as involvement of other departments in the design of new products or new concepts [3]. On the other hand, there are unusual strategies to convert the customer need or market need into the product for sales companies can obtained. These types of strategies depend on company policies, product type, place of company, type of company etc.

Product Development

The product development is conceptualized as the number of activities needed for the formation and design to manufacturing the product, from the identification of a market opportunity to its delivery to the client. In short product development is the conversion of a market opportunity and set of assumptions about product technology into a product available for sale [3]. A product concept is generally brought to life through decisions about the physical from and appearance of the product. The product development process is mainly driver by the rapid absorption of technology, increasing consumer demands, and increasing completion in the market. Evolving product platform that can form the basis of multiple products and developing solution along with products can manage cost and complexity during product growth.

The process of product design and development together mainly includes seven step as shown in figure 1.

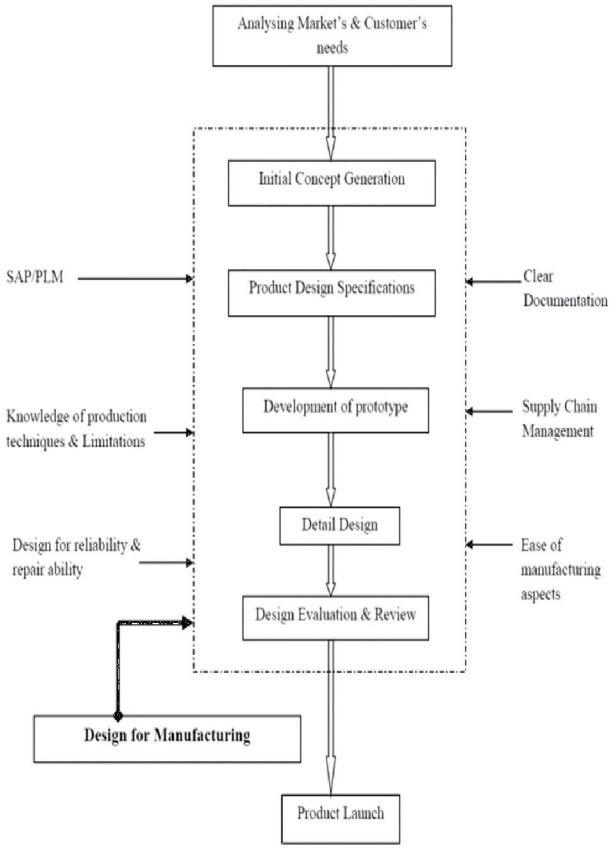

Figure 1: Design Process

The design process flowchart is shown in fig.2 for this project; there are seven stages of the design process which includes

- Research on pollution
- Study of different filters
- Selection of materials
- Design and calculations
- CAD modeling
- Fabrication
- Testing

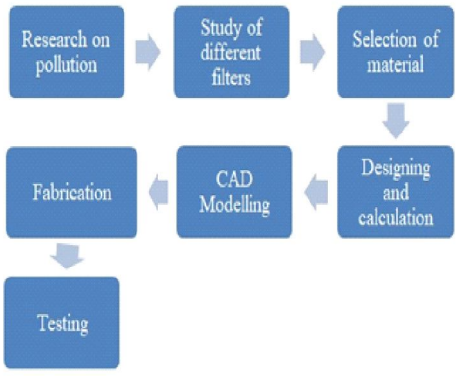

Figure 2: Design Process Flowchart

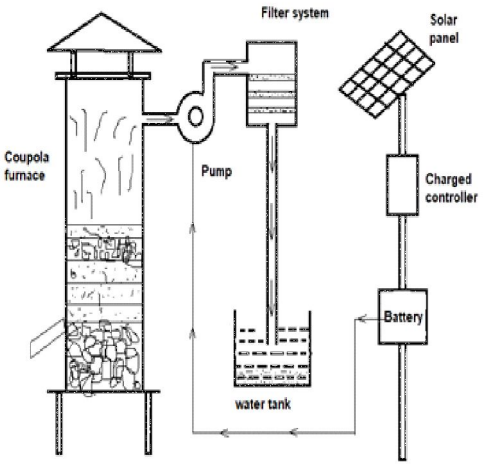

Figure 3: First Conceptual Design

Optimum Design Solution for Filter

The optimum design solution is shown in figure 4. The design consists of a furnace to which a horizontal pipe of 2.5 inch diameter is attached. This pipe is passed through the small box in which fan is installed. The pipe is then passed through the box of AISI 1030 [4]. In this design four filters are placed vertically at a distance of 3 inches each and the exhaust pipe is of 2inch. The first frame of filter is made up of steel wool scrubber, second frame is made up of Silica gel, and third frame is made up of Activated carbon, and fourth is made up of HEPA Filter. The filter box is covered with air tight cap using sealing.

1) Mechanical Components used
   a) AISI 1030 sheet
   b) AISI bars (15 bars of 3inch in length)
   c) Square pipe of 2.5 inch diameter
   d) Round Pipe (2 inch)
2) Electronic Component used
   a) Fan (24v, 1600rpm)
   b) Adapter (12v)

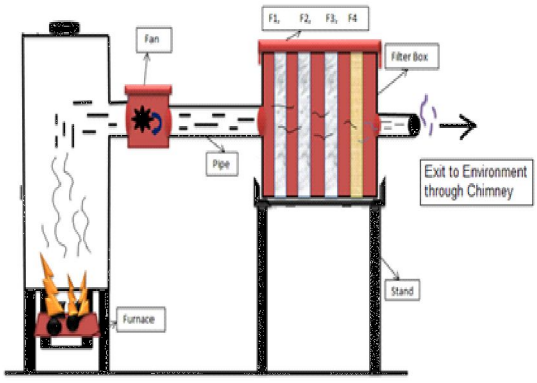

Figure 4: Design Model for Filtration System

CAD Modeling

To do the CAD (computer-aided design) modeling, we need some CAD software. The CATIA software is one of the leading multi-platform software suite CAD/CAM/CAE i.e. computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE). It is also used for PLM (Product life Management) and 3D. The CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault to provide 3D surface modeling and NC functions for the CADAM software they used at that time to develop the Mirage fighter jet[5].

The full form of CATIA is a computer-aided three-dimensional interactive application. The CATIA software can be applied to a wide variety of industries like automobile, aerospace and defense, industrial equipment, shipbuilding, plant design, architecture, and construction, etc.

The CAD modeling of optimum design for the filter system is shown in figure 5. In CAD modeling the filter system is designed such a way that the four filters are placed at an appropriate distance and right place.

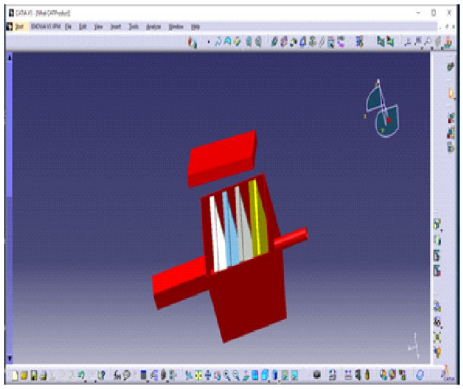

Figure 5: CAD Model of Filtration System

DESIGN CALCULATIONS

Calculations for Volume flow rate and Air velocity

Initial assumption and Dimension of the system Total length of the furnace: 4.5 ft.

- Diameter of furnace: 270mm
- Dimension of small box: 105×105×105mm
- Length of Inlet pipe: 275mm
- Diameter of inlet pipe: 72mm
- Length of filter box: 12×12×12 inch = 300×300×300 mm
- Length of metal strips = 80 mm
- Thickness of strips = 4 mm

- Length of filter cartridge = 11.5 inch = 290mm
- Breadth of Cartridge = 20 mm
- Length of outlet pipe = 6 In = 150 mm
- Diameter of outlet Pipe = 1.5 Ih= 40mm
- The volume flow rate or air-flow rate in a duct in measured in cubic feet per minute (CFM) [6]
- The Air velocity or the distance traveled by air per unit time measured in Feet per minute (FPM)

Air Flow Rate and Air Velocity at Inlet

Diameter of inlet pipe = 72 mm = 0.236 ft

Radius of inlet pipe = 0.118 ft

$$Air\ velocity = \frac{1}{60} 2 \times 3.14 \times radius\ of\ inlet \times rpm$$

$$Air\ velocity = \frac{12 \times 3.14 \times 0.118 \times 1600}{60}$$

Air velocity= 19.78ft/min

Area of inlet pipe= A= πr^2

= 3.14 * $(0.118)^2$

= 0.437 ft^2

Air flow rate at inlet = Air velocity × (area of inlet pipe)

= 19.78 × 0.0437

=8.64 ft^3/min (FPM)

Air Flow Rate and Air Velocity at Outlet

Diameter of outlet pipe = 1.5in

Radius of outlet pipe = 0.75 in = 0.0625ft

$$Air\ velocity = \frac{1}{60} 2 \times 3.14 \times radius\ of\ oulet \times rpm$$

$$Air\ Velocity = \frac{2 \times 3.14}{60} \times 0.0625 \times 1600$$

Air velocity= 10.47 ft/min(FPM)

Area of outlet pipe = A=pr^2

=3.14×$(0.0625)^2$

= 0.0122 ft^2

Air flow rate in outlet = Air velocity ×(area of duct)

= 10.47× 0.0122

= 0.127734 ft^3/min (FPM)

Pressure Drop in Square Duct

Mean hydraulic depth, $M = \frac{A}{P} = \frac{(l \times b)}{2(l+b)} = \frac{0.072 \times 0.072}{2(0.072+0.072)}$

M= 0.018m

$$V = \frac{\Delta d}{\Delta t} = \frac{0.4774}{60 \times 5.184 \times 10^{-3}} = 1.5348\ m/sec$$

$$P = \frac{\delta \times flv2}{2m} = f \times l \times \frac{Pv}{m}$$

PV (velocity pressure) $= (\frac{v}{60 \times 4.04})2$

$= (\frac{1.5348}{60 \times 4.04})2$

= 0.1443 mm of H_2O

P_f(frictional pressure) $= \frac{frictional factor \times l}{M} \times pv$

$= \frac{0.01 \times 0.275}{0.018} \times 0.1443$

P_f = 0.0220 mm of H_2O

Total pressure near inlet to the duct in order to maintain the air flow

$P_t = P_f + P_v$

= 0.0220 + 0.1443

= 0.1663 mm of H_2O

Total pressure in meter of air $= \frac{Pt}{1000} \times \frac{\delta water}{\delta air}$

$= \frac{PT}{1000} \times \frac{1000}{1.2}$

$= \frac{PT}{1.2} = \frac{0.1663}{1.2}$

= 0.1385 m of air

Air power = $\frac{1.2 \times g \times Pt}{1.2}$ = Q δ Pt watts

$= \frac{9.81 \times 0.4774}{60} \times 0.1663$

Air Power to maintain the flow = 0.01298 Watts

= 12.98 x 10^{-6} *kW*

DESCRIPTION OF THE COMPONENTS USED

Brushless DC Fan

The brushless DC fan is used to apply the external air supply. The purpose of using a fan is to supply sir forcefully or in other words forced convection of air [7]. The brushless 24V DC fan is shown in the figure. 6, which is used for external or forced convection of exhaust gases.

Figure 6: 24V Dc Brushless Fan

Stainless Steel Scrubber

The second filter median is made-up of Stainless Steel wool, ii is also known as iron wool, wire wool. The wire wool is a bundle of very fine and flexible sharp-edged steel filaments [8]. The main function of using this material is to avoid course dust particle. The Filter made with the use of stainless Scrubber is shown in figure.7, with the help of supporting mesh Stainless Steel wool is fitted in the frame.

Figure 7: Filter made with the use of stainless Scrubber

Silica Gel

The silica Get is a Blue semi-transparent glass substance containing an indicator as "Cobalt Chloride" a heavy metal salt. When free from moisture the Granules or beads are dark blue in color [9]. As shown in the figure 8, the filter is made from silica gel granules or beads. As the beads takes up moisture, they turns to light blue gradually & then they turn pink. When the gel has absorbed approximately 9% of its weight in water the colour crystals will turn from blue to pink making an easy visual indicator of whether the gel has become saturated with moisture. The technical specification of the silica gel granules are listed in table 1.

Figure 8: Filter made with use of silica gel

Table-1: Technical Specification of Silica Gel

TECHNICAL SPECIFICATION As per IS-3401-1979/1992/2003	
DESCRIPTIONS	**SILIC GET BLUE**
Type	Indicating Types
ASSAY (as SiO_2)	95-97%
pH	6-8
Bulk Density	0.65 – 0.75 gm/cc
Loss on Drying %	< 5.5-6.5%
Loss on Attrition %	2.8%
Adsorption Capacity at 100% humidity	30-42%
Friability	98.92
Chloride (as NACl)	0.42 ppm
Sulphates (Na_2SO_4)	0.51 ppm
Ammonium (NH_3)	NIL
Particle size (Mesh)	1-2, 3-4, 3-8, 5-8, 9-16, 16-30
Chemical Formula	SiO2 + H2O + CoC12

Activated Charcoal Granule

The Activated carbon is also called activated charcoal. It is a form of carbon processed, which have small and low-volume pores inside that increase the surface area available for adsorption or chemical reactions [10]. Due to its high degree of micro porosity, one gram of activated carbon has a surface area in excess of 3,000 m² (32,000 sq.ft) as determined by gas adsorption. The third filter is made of activated carbon as shown in figure 9, which is supported by mesh material with frame.

Figure 9: Filter made with the use of activated charcoal

Testing of NO_2 Adsorption with the help of Activated Charcoal Granule

The testing of adsorption of NO_2 by activated carbon was done in chemistry lab. The 2gm of copper wire was placed in beaker in which 20ml of nitric acid was poured. The cork was placed on the mouth of the beaker to prevent the loss of gases. In a few minutes the NO_2 gas started forming in large amount. The brown colored NO_2 gas is very harmful for humans. With the help of tube this gas was passed to the empty

beaker. The figure 10 shows the Beaker containing activated charcoal granules which has adsorbed NO_2.

Now, in the beaker containing NO_2 gas 5gm of activated charcoal was poured. After 5min all the gas was adsorbed and the color of brown gas faded.

Figure 10: Beaker containing activated charcoal granules which has adsorbed NO_2

Below is the reaction:

$4HNO_3(l) + Cu\ (s) \rightarrow Cu(NO_3)(S\ and\ Aq) + 2NO_2(g) + 2H_2O(l)$ [11]

High Efficiency Particulate air (HEPA) FILTER

The High efficiency particulate air (HEPA) also known as high-efficiency particulate absorbing and high-efficiency particulate air-resistance is an efficiency standard of air filter. Common standards require that a HEPA air filter must remove from the air that passes through – at least 99.94% (European standard) or 99.96% (ASME, U.S. DOE) of particles whose diameter is equal 0.3 mm [12]. HEPA filters are designed to target much smaller pollutants and particles. The HEPA filter is shown in a the figure 11, which are available in standard sizes.

Figure 11: High-efficiency particulate air (HEPA) Filter

Air Pollution Monitoring System (Testing Device)

Air control monitoring system shown in figure 12, is the system made for testing the amount of gases liberate from the source like chimney, exhaust etc. The purpose of this device is to monitor the quality of air using different sensors in embedded electronics have enabled the usage of wireless network technologies in monitoring the different real- time sensor data like temperature, humidity and air pollution.

Figure 12: Air pollution monitoring system

In the figure 13, the actual fabricated product model is shown, which includes a cupola furnace and filter system.

Figure 13: Actual Fabricated Product

RESULTS

The result of the filter system is noted by the use of air pollution monitoring system device.

The results are taken in two cases:

1) Initial liberation of smoke from the chimney and final filtration of gases with the filters are shown in the table.2. It is found that in case 1, that the smoke, dust, CO percentage, temperature and humidity are less as compared with the same passing through the chimney directly in environment.

Table-2 : Result of Case -I

Sr.no	Gases	Chimney	Filter box
1	Smoke	50%	45%
2	Dust	0.42 ppm	0.39
3	CO	1%	0.0%
4	Temperature	59ºc	40%
5	Humidity	50%	48%

Result using one by one filter

The test result for each filter one by one is shown in the table no. 3. Initially the tests are taken without filter, after that each filter is assembled and results are taken.

Table-3 : Result of Case-II

Sr. No	Gases	Chimney	F_1	F_1+F_2	$F_1+F_2+F_3$	$F_1+F_2+F_3+F_4$
1	Smoke (%)	77	71	55	56	47
2	Dust (ppm)	0.42	0.40	0.37	0.35	0.33
3	CO (%)	3	2	1	0	0
4	Temp (^{0}c)	50	47	45	46	44
5	Humidity (%)	60	56	56	55	54

Hence, the results were positive and approximate to some extent. The filter system was also able to reduce the smoke, dust, CO, temperature to some extent.

CONCLUSION

The proposed product of Industrial and Economical Air Filter is a very simple product in design. This is designed in consideration with the design of casting industry to remove gases from the chimney.

The design is made in consideration with the AQI and it is kept simple so that gases can easily pass through the filters. The filter system contains Chimney, furnace, fan, Filtration system containing four filters. These filters trap the particles on the basis of their material size.

This filter is low in cost and every time when filters are needed to be cleaned they can be easily removed and cleaned with the help of Pneumatic gun.

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