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By

Maryam Khan[1], Abdullah Yasar[1]*, Abdul Sattar Nizami[1], Yusra Mehfooz[1]

Abstract

The automatic Jet Pulsing Dust Collector type bag house is studied which is installed on boiler of 06 ton capacity using heavy fuel oil at shoes manufacturing industry, Batapur, Lahore Pakistan. Bag house is a device that is used to collect dust and purify the flue gases released in the air. There are various technologies to control particulate matters like Gravity Settling Chambers, Centrifugal Separators, Particulate Wet Scrubbers and Electrostatic precipitators. The flue gas data of boiler before and after installation of bag house was monitored. The studied bag filter contained 30 bags made of imported glass fiber. The normal velocity at which the gas is passed through the bags is 0.4 to 1 m^3/minute. The results revealed that values of O_2 is 3.3%, CO_2 is 13.32%, CO is 388.68 mg/Nm^3, emission of NO is 192.72 mg/Nm^3, NO_2 is 30.45 mg/Nm^3, NO_x 223.17 mg/Nm^3, SO_x 2597.22 mg/Nm^3 with temperature value 196.9 ˚C before installation of bag house and values of O_2 (1.62%), CO_2 (6.48%), NO (121 mg/Nm3), NO_2 (14.21 mg/Nm3), NO_x (135.21 mg/Nm3), SO_x (1926.06 mg/Nm^3) and Temperature (135.7 ˚C) decreased after installation of bag house but there is no significant change in smoke and CO is observed. CO levels tend to be higher in older boilers compared to newer ones. Highest removal efficiency of SO_x is observed which is 74.16% followed by NO 62.79% and NO_x 60.59%.

Keywords: *Bag house Filter, Boiler emissions, Heavy Fuel Oil, Jet Pulsing Dust Collector*

1. Introduction

Numerous industrial activities result in the discharge of air pollutants, and among these, particulate matter stands out as a significant concern due to its detrimental impact on both the environment and human well-being. Effectively curtailing the release of dust into the atmosphere is of paramount importance. In recent decades, the drive for enhanced methods of dust reduction has been spurred by increasingly stringent regulations, as highlighted by Ginestet et al. 2022. Undoubtedly, the significance of industrial development in driving economic growth cannot be overstated. However, industries also stand as significant contributors to global air pollution (Liu et al., 2019). These emissions from industrial activities encompass a range of air pollutants, including particulate matter, carbon oxides, nitrogen oxides, volatile organic compounds (VOCs), and persistent organic pollutants. These pollutants pose substantial threats to both human health and the environment (Geng et al., 2019).

In recent times, there has been notable concern surrounding fine particulate matter primarily because of its substantial health hazards (I. Manisalidis et al., 2020). An efficient strategy for eliminating fine particles from the air involves the utilization of dust collection technology (C.H. Zheng et al., 2018), where bag filters have gained

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extensive adoption for industrial air purification due to their effectiveness in capturing a broad spectrum of particle sizes (R. Burnett, et al., 2018).

Electrostatic precipitators (ESPs) and bag filter systems are extensively employed for the elimination of solid particulates from manufacturing process gases. ESPs are recognized to exhibit collection efficiencies ranging from 99.5% to 99.9% for larger particles with diameters spanning between 2.5 and 10 micrometers (μm), designated as PM10. However, ESPs tend to exhibit diminished collection efficiency for finer particles (Y. Cuiping et al., 2013). In contrast, bag filters, constructed from fabric materials, not only exhibit exceptional separation efficiency (exceeding 99.99%) but also possess commendable capability for collecting fine. This technology finds widespread application in various industrial settings to capture solid particulate matter present in process gas streams (Y. Cuiping et al., 2013). For instance, fabric filters have emerged as a viable alternative for dust collection, effectively capturing fly ash from flue gas (Ortiz. F.J.G et al., 2007). Bag filters have demonstrated their utility in diverse scenarios, such as the removal of fly ash (Y. Cuiping et al., 2013), polychlorinated dibenzo-p-dioxins (dioxins) (Y.H. Wang et al., 2009), and carbon particles suspended in flue gas (D. Fino et al., 2009).

Throughout the filtration procedure, particles progressively accumulate on the filter bag's surface, forming a layer of powdery cake. This accumulation results in an escalation of the pressure drop across the filtration process (D. Thomas et al., 2001). To circumvent a decline in the flow of dusty gas and a subsequent surge in energy consumption, periodic regeneration of the filter becomes necessary (X. Simon et al., 2010). Consequently, the swift buildup of a compact filter cake necessitates more frequent cleaning cycles, leading to increased instances of process downtime. Furthermore, frequent cleaning also contributes to the reduced longevity of the filter bag (S.J. Park et al., 2003). Hence, a primary objective in air filtration using bag filters remains the reduction of resistance imposed by the cake layer. Various factors influence the resistance exhibited by filter cakes, encompassing operational conditions like filtration velocity and dust concentration (T.C. Hsiao et al., 2018), as well as the characteristics of the dust, including particle size (M. Hennemann et al., 2021) and sphericity (R. Deshpande et al., 2020). The resistance attributed to the filter cake is primarily governed by factors such as the mass loading and cake porosity (Y.S. Chen et al., 2009). Enhancing particle deposition efficiency (Y. Fan et al., 2013) or fostering the formation of a less compact filter cake can aid in mitigating cake resistance (Guangyu Zhou, 2023).

The functioning principles of a pulse-jet cleaning system have been explored by various researchers (Morris, 1984; Sievert and Löffler, 1987). They've identified that certain parameters and equipment factors, such as compressed air pressure, injection duration, injection pipe geometry (hole type, hole diameter, nozzle), distance between injection pipe and filtering elements, and the use of a venturi, influence the cleaning process of filter elements. Achieving optimal performance for the pulse-jet baghouse necessitates ensuring uniform detachment of dust cake from filtering elements and uniform cleaning across all filter elements. The significance of hole diameter in injection pipes has been underscored by various studies (Simon et al., 2007; Andersen et al., 2016; Thumbe et al., 2017; Li et al., 2019). Empirical and computational investigations have been conducted to assess airflow within injection pipes and ascertain pressure, mass flow rate, and the angle of inclination of the air jet exiting the holes in injection pipes (Thumbe et al., 2017).

It is suggested by Thumbe et al., 2017 that achieving uniform cleaning of all filter bags within a pulse-jet bag house requires equal mass flows through the holes in the injection pipe. Findings reveal that at the outlet of holes with identical diameters, the mass flow rates exhibit non-uniformity, with the exit angle of air jets not aligning coaxially with the holes' axis. The mass flow rate and the angle of the air jet's inclination are contingent upon the hole's position. Holes situated closer to the tank exhibit lower mass flows and larger inclination angles. The variations in certain flow characteristics, such as mass flow rate and jet angle at the hole's outlet, likely contribute to disparities in the cleaning efficiency of filter bags positioned beneath nozzles of the same injection pipe.

To enhance filter bag cleaning, Simon et al. (2007) have identified an optimal nozzle diameter for pulse-jet cleaning. They observed that increasing the nozzle diameter can augment the pulse pressure up to a specific threshold, beyond which a larger diameter becomes detrimental. Fu and Ger (1999) introduced a model to attain uniform mass flow rate distribution from nozzles by adjusting nozzle sizes. Hemerka and Doubek (2002) formulated a guideline for achieving uniform compressed air distribution within the injection pipe, grounded on a constant flow momentum from the nozzles. They proposed a methodology to design hole diameters in the injection pipe, utilizing the inner diameter of the injection pipe, the number of cylindrical holes, and the nominal hole diameter.

An investigation conducted on an experimental pulse-jet baghouse that featured five parallel pleated cartridge filters Li et al. 2019. To characterize the influence of pulse-jet cleaning, the authors introduced the concept of "composite pressure," which factors in the peak static pressure distribution within the cartridges. The authors assert that an ideal scenario would involve equal composite pressure values across all cartridges belonging to the same injection pipe. In their study, the composite pressure demonstrates an ascending trend along the injection pipe, with the fifth cartridge exhibiting a value 1.73 times that of the first cartridge. He proposed a modification to the injection pipe's geometry, wherein the orifice diameter decreases from the inlet to the pipe's end. With this revised configuration, the composite pressure profile becomes notably more uniform, with the fifth cartridge's value being only 1.09 times that of the first cartridge. Consequently, this altered geometry has several effects on cartridge behavior: a reduction in residual pressure drop post-cleaning, an extension of the cleaning cycle duration, and a decrease in average dust emissions. This is despite the fact that the peak emission immediately after cleaning experiences an increase. The aim of this study is to monitor the flue gas data of boiler emissions and efficiency of bag house filter in controlling boiler air emissions.

2. Methodology

The automatic Jet Pulsing Dust Collector type bag house is studied which is installed on boiler of capacity 06 ton at shoes manufacturing industry, Batapur, Lahore. Process flow diagram of shoes manufacturing industry is shown in figure 1. The said industry used natural gas and furnace oil as a fuel in boiler. 06 to 07 months natural gas is used as a fuel or on its availability whereas furnace oil is used in winter. The bag filter contained 30 bags made of imported glass fiber. There are 05 lines and in one line there are 6 filters each. They are suspended with open ends attached to a manifold. The Bag Filter separates dust from the exhaust gas by collecting them with the filter media. The dust is accumulated on the surface of filter media he hopper at the bottom serves as a collector for the dust. The gas entering through the inlet duct strikes a

baffle plate, which causes the larger particles to fall due to gravity. The carrier gas then flows to the tubes and then outward through the fabric leaving the particulate matter as a cake on the bag surface. Efficiency during pre-coat formation is low but increases as the pre-coat (cake) is formed. Once formed, the pre-coat forms part of the filtering medium that helps in further removal of the particulate matter. The accumulation of dust increases the air resistance of the filter media and therefore filter bags have to be periodically cleaned. They are cleaned by pulse jet or reverse jet air flow, causing the filter cake to be loosened and to fall in the hopper. The normal velocity at which the gas is passed through the bags is 0.4 to 1 m3/minute. Bag house filter cannot operate if there is moisture in air. The schematic diagram of pulse jet bag filter to control air emissions is shown in figure 2 and 3. The equipment consists of bag filters, nozzles, fan and tube sheets. Design and physical properties of bag filter material are depicted in Table 1.

The latest technology of cleaning i.e high pressure cleaning with pulse jets is used. When dust laden gas enters the system and comes in contact with the filters, the dust is collected on the outside surface. To clean the filters, a blast of compressed air is directed into the top opening of the filter. The air is supplied through a blowpipe which feed into venturies (to increase the velocity) located above each filter. The air blast creates a shockwave that causes the fabric to flex down the length of the filter. As the filter flexes, the dust cake fractures and dust falls into the hopper below. The cleaning frequency and cycle for the pulse jet system is critical for maximum efficiency and is set by an adjustable timer to ensure proper cleaning. Pulse jet cleaning requires no moving parts, cleans on demand.

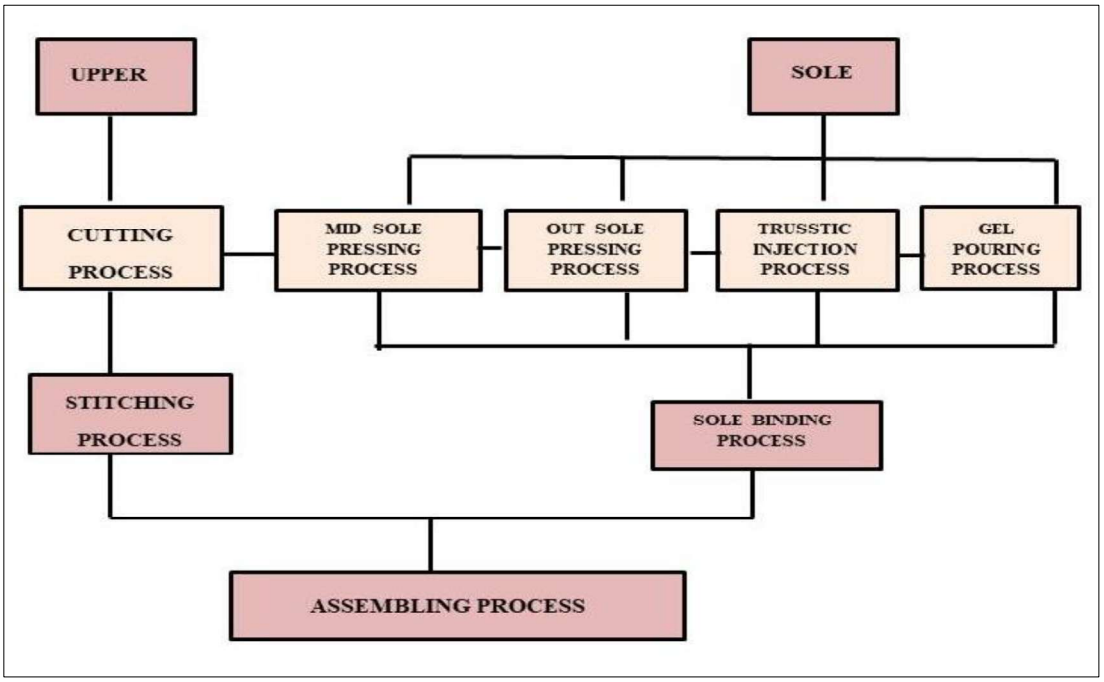


Fig-1: Process flow diagram of shoes manufacturing industry

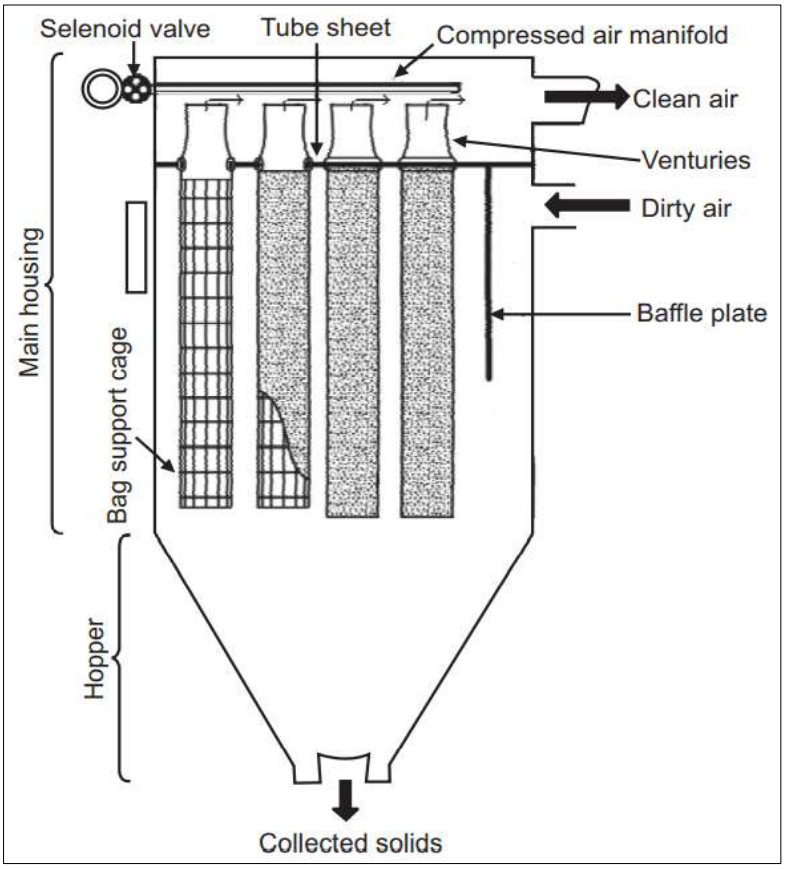


Fig-2. Schematic diagram of the pulse jet bag house

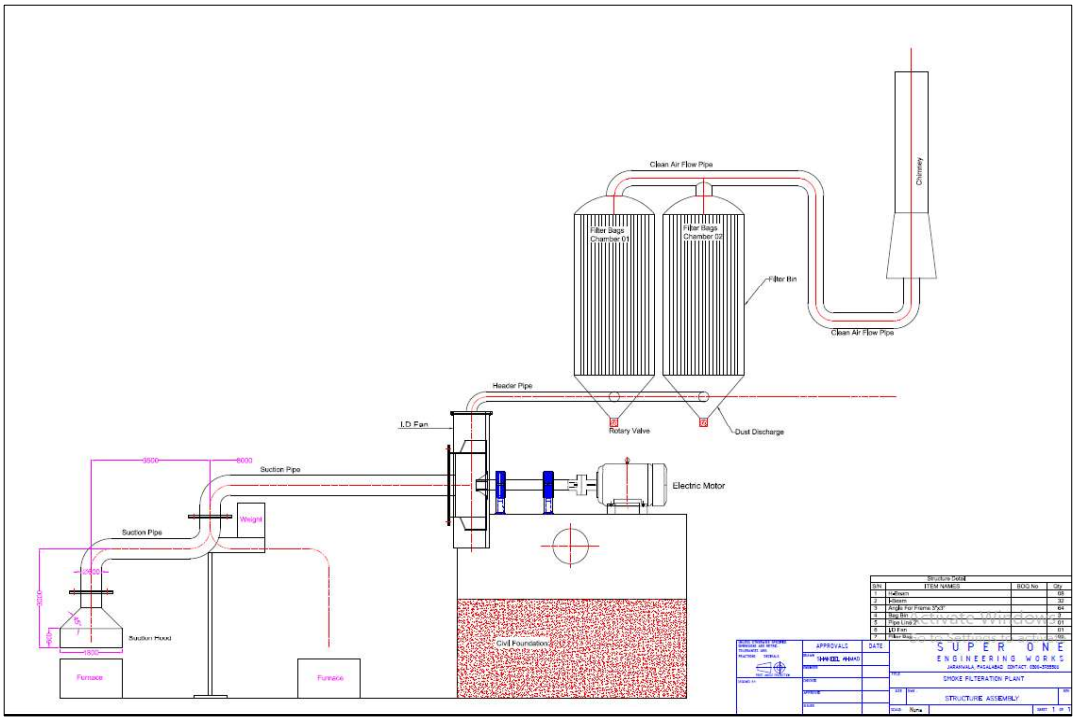


Fig-3. Layout diagram of the pulse jet baghouse installed at shoes manufacturing industry

Table-1: Design of Bag House and Physical Properties of Bag Filter Material

Specifications of installed Bag House (Dust Collector)	
Total Height	18 feet
Plant height without collection system	12 feet
Hopper length	06 feet
Width x Depth	6x6 feet
Electricity consumption	11KW/hour
Height of main duct	25 feet
Bag Filter Material	Glass Fibre
Diameter of Bag	6 inches
Bag length	3.3 meter
Height of Bag	10 feet
No. of Bags	30
Physical properties of Glass Fibre (Bag Fabric)	
Maximum Continuous Operating Temperature	290 ^oC
Acid Resistance	Good
Alkali Resistance	Good
Alkali Resistance	Good
Flex abrasion resistance	Fair
Tensile Strength (kg/cm^2)	14,060

3. Results

Table 2 shows emission data of boilers having capacity of 06 tons with heavy furnace oil used as a fuel, the monitoring parameters are CO, NO, NO_x, SO_x and Temperature, O_2, CO_2, NO_2 and Smoke. Values depict that O_2 is 3.3%, CO_2 is 13.32%, CO is 388.68 mg/Nm^3, emission of NO is 192.72 mg/Nm^3, NO_2 is 30.45 mg/Nm^3, NO_x 223.17 mg/Nm^3, SOx 2597.22 mg/Nm^3, Smoke 20% and Temperature is 196.9 ˚C. The normal velocity at which the gas is passed through the bags is 0.4 to 1 m^3/minute. When these values are compared with Punjab Environmental Quality Standards (PEQS), it has been observed that no guideline value set for industrial gaseous emission is available for O_2, CO_2, NO, NO_2 and temperature whereas PEQS limit for CO is 800mg/Nm^3, NOx 600 mg/Nm^3, 1.62m^3, SOx is 1700 mg/Nm^3 and smoke is 40% and monitoring values are below these limits.

After installation of bag house filter results show that values of O_2 (1.62%), CO_2 (6.48%), NO (121 $mg/Nm^{3)}$, NO_2 (14.21 mg/Nm^3), NO_x (135.21 mg/Nm^3), SO_x (1926.06 mg/Nm^3)and Temperature (135.7 ˚C)decreases but there is no significant change in smoke and CO is observed after installation as shown in Table 3. Percentage removal efficiency of pollutants after installation of bag house filter is calculated in Table 4. It shows that NO removal efficiency is 62.79%, NO_x 60.59% whereas highest removal efficiency of SO_x is observed which is 74.16%. Removal efficiency of O_2, CO_2 and NO_2 is less than 50%.Figure 5 also shows that maximum peak of CO and Smoke because value of smoke remain same and there is less difference in CO value before and after installation of bag house filter. Comparison between before and after installation of bag house filter is shown in Figure 4(a) and (b) which shows that after installation of bag house filter there is significant reduction in SO_x and NO_2 emissions.

Table-2. Boiler emissions before installation of Bag House Filter

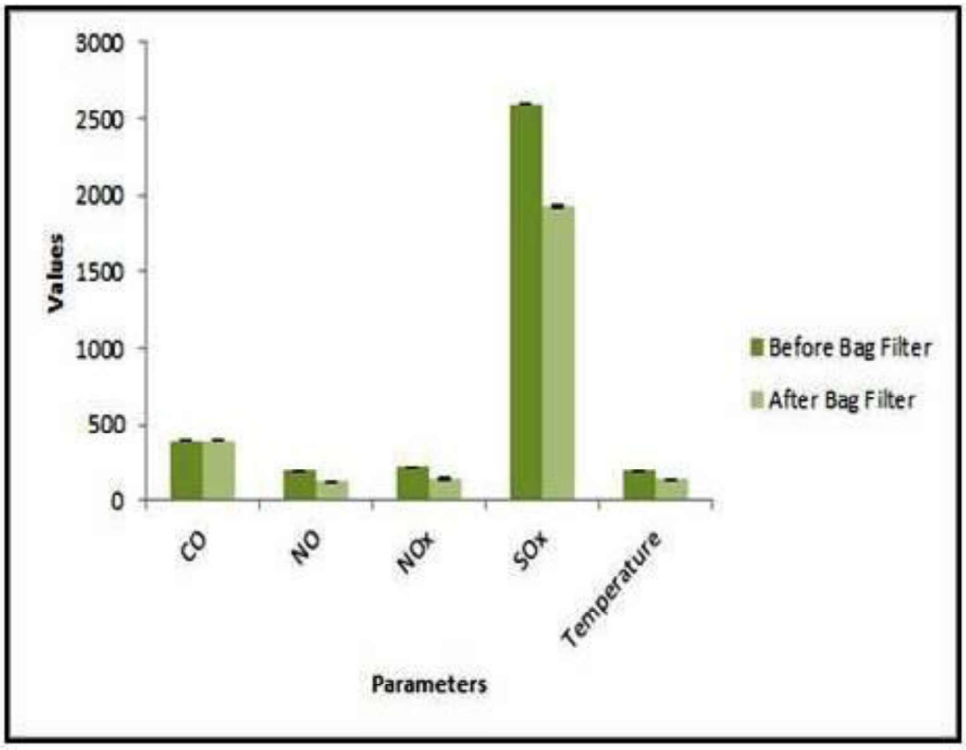
Sr. No	Parameters	Units	Methods	Reading 1	Reading 2	Reading 3	Average	Standard Deviation
1.	O_2	%	Electrochemical	3.3	3.31	3.3	3.3	0.01
2.	CO_2	%	NDIR Method 10	13.32	13.32	13.31	13.32	0.01
3.	CO	mg/Nm^3	OTM-39	391.1	391.1	391.21	391.14	0.06
4.	NO	mg/Nm^3	OTM-39	192.72	191.4	194.04	192.72	1.32
5.	NO_2	mg/Nm^3	OTM-39	30.45	32.48	28.42	30.45	2.03
6.	NOx	mg/Nm^3	OTM-39	223.17	223.88	222.46	223.17	0.71
7.	SOx	mg/Nm^3	USEPA Method 8	2597.22	2600.04	2594.40	2597.22	2.82
8.	Smoke	%	Ringelmann Scale	20	20	20	20	0.00
9.	Temperature	°C	-	197.6	196.2	196.8	196.9	0.70

Table-3. Monitoring of boiler emissions after installation of Bag House Filter

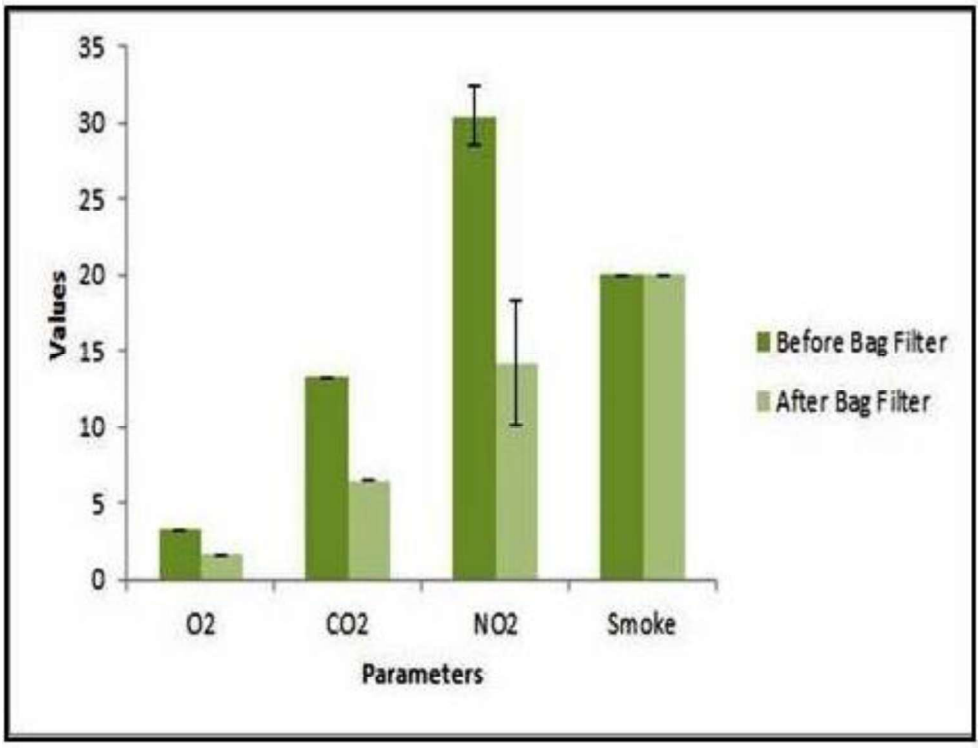
Sr. No	Parameters	Units	Methods	Reading 1	Reading 2	Reading 3	Average	Standard Deviation
1.	O2	%	Electrochemical	1.61	1.615	1.616	1.62	0.00
2.	CO2	%	NDIR Method 10	6.45	6.49	6.5	6.48	0.03
3.	CO	mg/Nm3	OTM-39	386.22	388.68	391.14	388.68	2.46
4.	NO	mg/Nm3	OTM-39	117.48	121.44	124.08	121	3.32
5.	NO2	mg/Nm3	OTM-39	10.15	14.21	18.27	14.21	4.06
6.	NOx	mg/Nm3	OTM-39	127.63	135.65	142.35	135.21	7.37
7.	SOx	mg/Nm3	USEPA Method 8	1917.6	1928.88	1931.7	1926.06	7.46
8.	Smoke	%	Ringelmann Scale	20	20	20	20	0.00
9.	Temperature	°C	-	135.4	135.8	135.9	135.7	0.26

Table-4. Removal Efficiency calculation of Bag House Filter

S. No	Parameters	Units	Before Installation	After Installation	%age efficiency
1.	O_2	%	3.3	1.62	49.09
2.	CO_2	%	13.32	6.48	48.65
3.	CO	mg/Nm^3	388.68	388.68	99.37
4.	NO	mg/Nm^3	192.72	121	62.79
5.	NO_2	mg/Nm^3	30.45	14.21	46.67
6.	NO_x	mg/Nm^3	223.17	135.21	60.59
7.	SO_x	mg/Nm^3	2597.22	1926.06	74.16
8.	Smoke	%	20	20	100.00
9.	Temperature	°C	196.9	135.7	68.92



(a)



(b)

Fig-4 (a) Calculated values of CO, NO, NO_x, SO_x and Temperature (b) O_2, CO_2, NO_2 and Smoke before and after installation of Bag House Filter

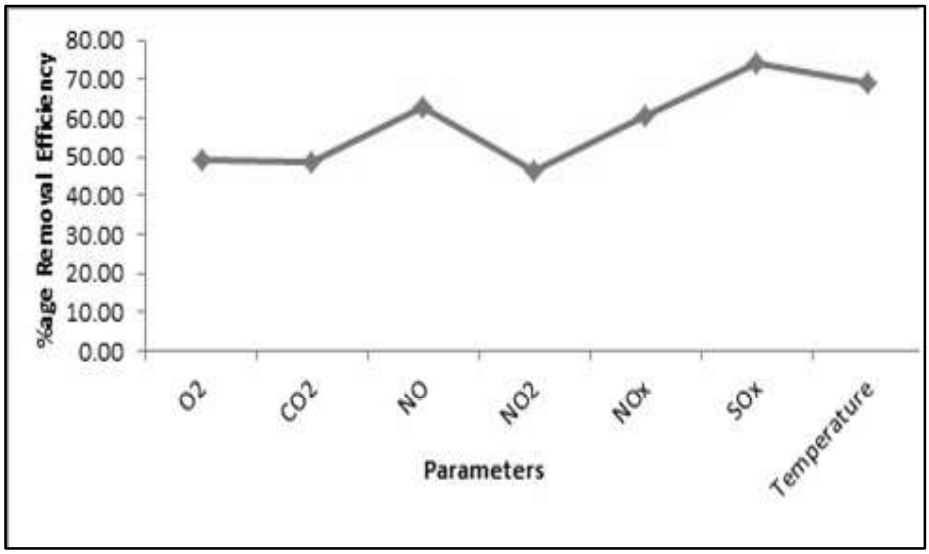


Fig-5. Percentage Removal Efficiency of parameters O_2, CO_2,, NO, NO_2, NO_x SO_x and Temperature of Bag House Filter

4. Discussion

In a study conducted by S. R. Malik et al. in 2009, it was observed that opting for natural gas as a fuel source could substantially reduce emissions. Natural gas primarily consists of methane, resulting in carbon dioxide and water vapor as the main byproducts during combustion similar to what we exhale when we breathe. In contrast, coal and oil are composed of more intricate molecules with higher carbon ratios, as well as elevated levels of nitrogen and sulfur. Consequently, the combustion of coal and oil leads to heightened emission levels of pollutants, including increased carbon emissions, nitrogen oxides (NOx), and sulfur dioxide (SO_2). Furthermore, coal and fuel oil release ash particles into the atmosphere, which are not combustible and contribute to environmental pollution. In contrast, using natural gas as a fuel produce less amount of sulfur dioxide and nitrogen oxide emissions negligible amount of ash or particulate matter and less quantities of carbon dioxide, carbon monoxide and other reactive hydrocarbons.

The most efficient approach for diminishing CO_2 levels involves a fuel transition. When utilizing natural gas for combustion, carbon dioxide emissions are notably reduced, with nearly a 30% decrease compared to oil and just under 45% decrease compared to coal (S.R.Malik et al. in 2009).

During the process of combustion, the carbon present in the fuel undergoes a series of reactions to ultimately form carbon dioxide (CO2). However, achieving complete conversion of carbon to CO2 is seldom accomplished in real-world scenarios, often resulting in partial oxidation to an intermediary stage, namely carbon monoxide.

CO levels tend to be higher in older boilers compared to newer ones, mainly due to the relatively recent recognition of CO as a significant issue. Older burner designs were not initially aimed at achieving low CO emissions. In this study, elevated carbon monoxide emissions largely stem from incomplete combustion, which can be attributed to inadequate burner design, suboptimal firing conditions (such as improper air-to-fuel ratio), or even potential furnace leaks. By adhering to proper burner upkeep, conducting regular inspections, appropriate operational procedures, and considering equipment upgrades or the incorporation of oxygen control mechanisms, it is possible

to manage and maintain carbon monoxide emissions at an acceptable threshold. (Energy Solution Centre Organization) .

Numerous experiments were undertaken to assess the impact of baghouse temperature on the removal of NOx. The baghouse temperature was adjusted within the range of 675°F to 850°F (357°C to 454°C) to identify the optimal operating conditions for effective NOx removal. The outcomes of the conducted tests indicated that, in conjunction with the employed catalyst, higher baghouse temperatures led to improved NOx removal it was deduced that achieving the project's objective of 90% NOx removal required a baghouse temperature within the range of 800°F to 850°F (425°C to 454°C). (Kudlac, G. A., 1992)

Sangras, R., et al in 2005 discovered that elevating temperatures within fuel-rich environments and prolonging the duration during which fuel-bound nitrogen is present can lead to a decrease in NOx emissions. This process involves the conversion of nitrogen into a molecule resembling CN, which subsequently transforms into N2, all occurring within fuel-rich conditions.

The group of nitrogen oxides, known as NOx, encompasses nitrous oxide (N2O), nitric oxide (NO), nitrogen dioxide (NO2), nitrogen trioxide (N2O3), and nitrogen pentoxide (N2O5). Among these, the main focus in relation to air pollution revolves around nitric oxide (NO) and nitrogen dioxide (NO2). Nitric oxide (NO), a colorless gas, acts as a precursor to NO2 and plays an active role in photochemical reactions that lead to the formation of smog. Nitrogen dioxide (NO2), which has a reddish-brown appearance, imparts the color to smog and can contribute to the visibility obstruction of flue gas plumes emitted from stacks.

Boilers are operated with an extra supply of air, known as excess air, to ensure complete combustion and safety. Among the factors impacting the generation of nitrogen oxides (NOx) within a boiler, the level of excess air is noteworthy. Elevated excess air levels can lead to heightened NOx production because the surplus nitrogen and oxygen from the combustion air combine within the flame, forming thermal NOx. The control of excess air intake is achieved through burner design and can be optimized using oxygen trim controls. For most boilers, adopting a strategy of firing with lower excess air is feasible and typically brings about a reduction of 5-10% in overall NOx emissions when natural gas is the chosen fuel (S.R.Malik et al. in 2009)

For industrial boiler operators, the most economically efficient approach to reducing SOx emissions involves the use of low sulfur fuels. Given that the levels of SOx emissions are predominantly tied to the sulfur content within the fuel, opting for fuels with lower sulfur concentrations (such as distillate oil) can lead to diminished SOx output. This reduction can be achieved without the necessity of installing and upkeeping costly equipment. The burning of sulfur-containing fuels, mainly oils and coals, produces pollutants in the forms of sulfur dioxide (SO2) and sulfur trioxide (SO3), collectively known as sulfur oxides (SOx). The quantity of SOx released is directly influenced by the sulfur content in the fuel. The emission levels of SOx are unrelated to the size of the boiler or the design of the burner. Typically, around 95% of the fuel's sulfur content is emitted as SO2, with 1-5% as SO3, and 1-3% as sulfate particulate. It's important to note that sulfate particulate is not considered within the overall assessment of total SOx emissions.

In contrast to NOx, SOx, and CO2, which exhibit reactivity and acidity, carbon monoxide is inert in nature. It possesses minimal dipole and quadrupole moments.

Standard adsorbents like activated charcoal, zeolites, and earth materials fail to comprehensively adsorb carbon monoxide due to its rapid desorption rate. When coexisting with other constituents of flue gas, the adsorption of carbon monoxide on these conventional adsorbents is insignificant. (Puranik and Puranik, 2019).

5. Conclusion

Air pollution is exerting detrimental effects on both human health and the environment. The emissions data obtained from boilers at shoes manufacturing industry underscores that notable amount of air emissions released when heavy furnace oil is used in boilers. The primary focus regarding air pollution revolves around primary pollutants i.e SO_X, NO_X, CO_2 and CO which pose risks not only individually but also contribute to the development of hazardous secondary pollutants such as ozone and acid rain. The simplest approach to mitigate pollution involves adopting eco-friendly fuels like natural gas and installation of air pollution control devices like bag house. The study shows that bag house plays an important role in highest removal efficiency of SO_x i.e 74.16% followed by NO 62.79% and NO_x 60.59%.

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