International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 10, Issue 6, pp 150-160, June-2026

https://doi.org/10.47001/IRJIET/2026.106017

Cyclone and Chimney Redesign for Particulate Emission Control in the Ploso Village Tofu Industry Cluster, Kudus, Indonesia

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***Abstract* - Small-scale tofu industries in Indonesia commonly use wood biomass for boiling soybeans. In the Ploso Village industrial center, 18 micro, small, and medium enterprises (MSMEs) burn firewood without air pollution control equipment. One major facility consumes 171 kg of firewood per hour to process ±700 kg of soybeans daily, resulting in emissions of PM2.5, PM10, and total suspended particulate (TSP). Calculations indicate a TSP concentration of 515.5 mg.m-³, which exceeds the biomass boiler limits established by Minister of Environment Regulation No. 07/2007. In response, an air pollution control system was developed using the Analytic Hierarchy Process (AHP), identifying a cyclone as the optimal solution. The engineered cyclone achieves removal efficiencies of 98.49% for TSP, 45.76% for PM10, and 3.26% for PM2.5, resulting in a total collection efficiency of 53.16%. The chimney was also redesigned according to technical standards to improve emission dispersion. Dispersion modeling shows that implementing these control devices in eight high-capacity MSMEs reduces ambient air TSP concentrations by 36.22%, thereby meeting the national ambient air quality standards specified in Government Regulation No. 22/2021.**

Keywords: Biomass, Chimney, Cyclone, Combustion, Particulate Matter, Tofu MSMEs.

I. INTRODUCTION

Micro, Small, and Medium Enterprises (MSMEs) constitute a cornerstone of the Indonesian economy, accounting for 60.5% of the national Gross Domestic Product (GDP) and employing 96.9% of the total workforce [1]. At the regional scale, data from the Kudus Regency Central Bureau of Statistics (2023) demonstrate that the manufacturing sector, which includes tofu processing plants, continues to drive economic activity and makes a significant contribution to the Gross Regional Domestic Product (GRDP). Tofu production units are distributed throughout sub-districts such as Kudus, Jati, and Undaan, collectively shaping the local economic landscape [2]. The Tofu Industrial Center in Ploso Village, in particular, displays a distinctive spatial arrangement, with production units predominantly concentrated in dense clusters rather than being dispersed. These facilities are frequently situated immediately adjacent to one another or directly across narrow roads. While such clustering enhances logistical efficiency and strengthens social networks, it also results in the accumulation of emissions within a confined area, thereby elevating pollutant exposure for workers and nearby residents.

The vast majority of these enterprises operate as traditional, cottage-scale industries that rely heavily on firewood to fuel their boiling processes and utilize rudimentary smokestacks. This continuous biomass combustion significantly compromises local air quality, particularly within these dense industrial clusters [3]. The resulting flue gas is visible as dense black smoke continuously discharged throughout production hours. This visible plume indicates a heavy release of hazardous particulates, primarily Total Suspended Particulates (TSP), Particulate Matter under 10 µm (PM_{10}), and fine Particulate Matter under 2.5 µm ($PM_{2.5}$), along with trace concentrations of gaseous pollutants such as sulfur oxides (SOx) and nitrogen oxides (NOx)[4]. Beyond localized air quality issues, this extensive wood burning releases substantial amounts of carbon monoxide (CO) and black carbon, which contribute to atmospheric warming [5]. From a public health standpoint, PM_{10} and $PM_{2.5}$ pose severe risks; their microscopic size allows them to penetrate deep into the lungs, triggering acute respiratory distress and long-term chronic illness among the exposed population [6].

This environmental and public health challenge is heavily compounded by the complete absence of emissions control technology. Field observations reveal that every tofu factory in the area relies solely on conventional, unmitigated chimneys. Furthermore, the height and diameter of these existing smokestacks vary arbitrarily and fall short of the technical thresholds required to lift and disperse emissions effectively away from adjacent residential zones. Consequently, the resulting air pollution not only leads to persistent respiratory illnesses among local communities but also threatens to diminish regional productivity and socioeconomic well-being over time [7]. Given this precarious balance between economic livelihood and environmental health, there is an urgent need for an actionable engineering solution. Designing an affordable, low-maintenance air pollution control device and optimizing chimney dimensions specifically for small-scale operations offers a viable path forward. This practical approach aims to drastically curb particulate emissions without overestimating the financial capacity of local producers, while directly supporting Kudus Regency's commitment to fostering eco-friendly manufacturing through its Green Industry program[8], [9].

II. METHODOLOGY

2.1 Study Area and Data Collection

The research was conducted at the Tofu Industrial Center in Ploso Village, Jati District, Kudus Regency, Central Java Province, Indonesia, with a focus on small-scale facilities that use firewood as the primary fuel for boiling. In this area, 18 active production units were identified. A representative facility processes approximately 700 kg of soybeans and consumes 1,534 kg of firewood per day. Primary data were collected through field observations, direct measurements, and structured interviews with facility owners to document production capacities, fuel consumption rates, operational hours, chimney dimensions, combustion characteristics, and surrounding structural conditions. Secondary data, including technical design manuals, institutional regulations, and published literature on biomass combustion, particulate emission factors, and cyclone criteria, were also obtained. Firewood proximate and ultimate analyses were specifically sourced from established literature to provide baseline inputs for combustion and emission calculations.

2.2 Emission Analysis and Technology Selection

Flue gas characteristics were quantified using a mass-balance framework based on combustion stoichiometry and fuel composition, using proximate (moisture, ash, volatile matter, and fixed carbon) and ultimate (carbon, hydrogen, oxygen, nitrogen, and sulfur) analysis data. This approach determined the mass flow rates of CO_2, CO, SO_2, NO_2, $PM_{2.5}$, PM_{10}, and TSP. Pollutant concentration (C, $mg.m^{-3}$) was calculated using Equation:

$$C = \frac{m}{Q_s}$$

where m is the pollutant mass flow rate ($mg.s^{-1}$), and Q is the flue gas volumetric flow rate ($m^3.s^{-1}$). The resulting concentrations were benchmarked against national biomass boiler emission standards stipulated in Appendix III of the Indonesian Ministry of Environment Regulation No. 07/2007.

To determine the optimal air pollution control strategy, an Analytical Hierarchy Process (AHP) was deployed to evaluate three competing alternatives: a cyclone, a baghouse filter, and an electrostatic precipitator (ESP). The selection matrix incorporated four core criteria: collection efficiency, technical feasibility, economic feasibility, and environmental performance. Pairwise comparison questionnaires were completed by a panel of environmental engineering academics, field practitioners, and tofu industry representatives. Expert judgments were validated using consistency ratios (CR) before computing the final priority weights for technology ranking.

2.3 Cyclone and Chimney Design

A standard 2D2D cyclone configuration was engineered based on the volumetric flue gas flow rate and recommended inlet velocity ranges. The specified geometric design parameters included the barrel diameter, inlet and outlet dimensions, cylinder and cone lengths, cut diameter, expected collection efficiency, and system pressure drop. Concurrently, the existing smokestack was redesigned to optimize downwind pollutant dispersion. This modification accounted for the exhaust gas volumetric flow rate, the height of surrounding structures, and standard engineering design criteria. Total pressure drop calculations were integrated into this phase to specify the required operational fan capacity.

2.4 Atmospheric Dispersion Modeling and OHS Assessment

The mitigation efficacy of the proposed engineering designs was evaluated through atmospheric dispersion modeling executed across multiple implementation scenarios using a Gaussian plume model for point sources. The resulting downwind ground-level particulate concentrations were simulated and systematically compared with applicable ambient air quality standards. Furthermore, an Occupational Health and Safety (OHS) assessment was conducted to address potential workplace hazards associated with the routine operation and maintenance of the newly designed cyclone and chimney systems.

III. RESULTS AND DISCUSSIONS

3.1 Flue Gas and Emission Characteristics

The fuel required for a single cooking cycle (12 kg of soybeans) is 2 sacks of wood, each weighing approximately 13 kg. Therefore, for one day of production, there are 59 cooking cycles, totaling 700 kg of soybeans, requiring 1,534 kg per day of firewood. Consequently, for a single day of production, the fuel input for the 9-hour process is 1,534 kg per day, equivalent to 171 $kg.h^{-1}$ of firewood for the combustion furnace.In this design, pollutant concentrations from combustion were obtained from the proximate and ultimate analyses of the wood used, sourced from the literature. The proximate and ultimate analysis data of the firewood used, based on the literature, are presented in Table 1 and 2.

Table 1: Proximate Analysis Data

No	Parameter Analysis	Value	Unit
1	Moisture Content	6.97	%
2	Ash Content	1.67	%
3	Volatile Matter	76.01	%
4	Fixed Carbon	15.35	%

Source: Wibowo, 2022

Table 2: Ultimate Analysis Data

No	Parameter Analysis	Value	Unit
1	Sulfur	0.03	%
2	Carbon	45.72	%
3	Hydrogen	6.41	%
4	Nitrogen	0.34	%
5	Oxygen	45.84	%

Source: Wibowo, 2022

Based on the stoichiometric calculation results, the mass balance for wood combustion is summarized as follows.

Table 3: Mass Balance Recapitulation

Input		Output	
Component	**Mass Flow Rate ($kg.h^{-1}$)**	**Component**	**Mass Flow Rate ($kg.h^{-1}$)**
N	0.58	N_2	941.12
C	78.18	O_2	38.82
H	10.96	H_2O	15.6
S	0.05	SO_2	0.10
O	78.39	CO_2	286.66
O_2 in air	359.4	CO	182.42
$N_{2\ in}$ air	940.5	NO_2	0.49
		Ash	2.86
Total	**1,468**	**Total**	**1,468**

The next step after obtaining the emission load for each parameter is calculating the emission concentration from wood combustion using Equation.

$$concentration\ (mg/m^3) = \frac{mass\ flow\ rate\ (mg/s)}{volume\ flow\ rate\ (m^3/s)}$$

Table 4: Emission Concentrations from Wood Combustion

Parameter	Mass Flow Rate ($kg.h^{-1}$)	Mass Flow Rate ($mg.s^{-1}$)	Concentration ($mg.m^{-3}$)
CO_2	286.66	79,629.06	241,300.19
SO_2	0.103	28.50	86.36
NO_2	0.49	136.91	414.87
CO	182.42	50,673.04	153,554.67
$PM_{2.5}$	0.475	131.94	399.51
PM_{10}	0.551	153.10	463.95
TSP	0.612	170.11	515.5

After obtaining the emission concentration calculation results, a comparison was made with the emission standards according to Appendix III of the Ministry of Environment Regulation Number 07 of 2007. The comparison results are presented in Table 5.

Table 5: Comparison of Emission Concentrations with Emission Standards

Parameter	Concentration ($mg.m^{-3}$)	Emission Standard ($mg.m^{-3}$) (*)
CO_2	241,300.19	-
SO_2	86.36	800
NO_2	414.87	1000
CO	153,554.67	-
$PM_{2.5}$	399.51	-
PM_{10}	463.95	-
TSP	515.49	350

Source: (*) Appendix III of Ministry of Environment Regulation No. 07/2007[11]

Based on the table above, the emission concentration for the TSP parameter exceeds the emission standard for stationary sources, in accordance with Appendix III of the Ministry of Environment Regulation Number 07 of 2007. Therefore, an air pollution control device with a minimum removal efficiency of 32.1% is required so that the TSP emission concentration does not exceed the emission standard.

3.2 Alternative Fuels for Energy Substitution

a) Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG) was selected as an alternative fuel due to its widespread availability and high calorific value of 87.92 MJ/kg (Chiang & Gao, 2022). Furthermore, it exhibits a combustion efficiency of 80%–90%. The selection of LPG is also justified by its lower combustion emissions than those of fuel wood.The calculation for the required LPG relative to fuelwood is detailed below.

Given:

Calorific value of wood = 20.809 MJ/kg[12]
Calorific value of LPG = 87.92 MJ/kg [13]

$$LPG\ Requirement = \frac{Q_{initial\ \ material} \times Calor\ wood \times Efficiency\ wood}{Calor\ LPG \times Efficiency\ LPG}$$

$$LPG\ Requirement = \frac{1.534\ \text{kg/day} \times 20{,}809\ MJ/kg \times 20\%}{87{,}92\ MJ/kg \times 85\%}$$

$$LPG\ Requirement = 85{,}43\ kg\ LPG/day\ \approx 86\ kg\ LPG/day$$

$$LPG\ Cylinder\ Requirement = \frac{86\ kg}{12\ kg} = 7{,}16 \approx 8\ cylinders$$

Given that 12 kg LPG cylinders are currently available on the market at IDR 500,000.00 per cylinder, the daily requirement is 8 cylinders, resulting in a daily fuel expenditure of IDR 4,000,000.00.

b) Other Biomass Fuels

In addition to wood, several other types of biomass fuels can be used as thermal energy sources in the production process. This biomass generally originates from agricultural and forestry waste, such as rice husks, sawdust, straw, and corn cobs. Utilizing biomass as an alternative fuel is considered advantageous due to its relative ease of sourcing and lower cost compared to LPG.

However, compared to LPG and wood, biomass fuels such as rice husks or sawdust still exhibit lower combustion efficiency and produce higher air pollutant emissions. Biomass combustion tends to produce higher particulate matter and ash levels, thereby requiring higher-efficiency emission control systems. The calculated requirements for alternative biomass fuels relative to the existing baseline condition are presented in the Table below.

Table 6: Fuel Requirements for Alternative Biomass

Biomass Type	Calorific Value (MJ.Kg^{-1})*	Requirement (Kg.day^{-1})
Wood (existing condition)	20.809	1,534
Rice Husk	12.34	2,587
Straw	14	2,280
Sawdust	24.85	1,168
Corn Cob	10.85	2,354

Source: Telmo & Lousada, 2011[12]; Wahyudi, 2006[14]; Jenkins *et al.*, 1998[15]; Primandanu & Krishna Putra, 2022[16]

3.3 Technology Selection Results

The selection of the control technology was conducted using the AHP method based on criteria of removal efficiency, technical, economic, and environmental feasibility, with three alternatives: cyclone, baghouse filter, and electrostatic precipitator. The weighting results show that the cyclone has the highest priority value (±0.61), followed by the baghouse filter (±0.25) and the ESP (±0.14). The cyclone was selected because its construction is simple, capital and maintenance costs are lower, it does not require filter media, and it is the most suitable for the operational capacity of MSMEs.

3.4 Cyclone Design

In this planning, a conventional cyclone was selected based on a moderate pressure drop and a sufficient removal efficiency to meet the TSP parameter. The conventional cyclone is classified as a 2D2D cyclone, meaning the cone and the cylindrical body each have a length equal to twice the diameter. The optimal inlet velocity for a 2D2D cyclone is 914 ± 120 m/min (15 ± 2 m.s^{-1}), and in this planning, an inlet velocity of 15 m.s^{-1} was selected[17]. Additionally, determining the cyclone dimensions requires the flue gas flow rate (Q).

The cyclone's removal efficiency is very high for TSP (98.49%), moderate for PM_{10} (45.76%), and low for $PM_{2.5}$ (3.26%). The total efficiency of the designed cyclone is 53.16%. The concentration of each particle size in the flue gas after passing through the cyclone is presented in Table 7.

Table 7: Particle Concentration After Passing Through Cyclone

Particle Size (µm)	η_J (%)	C_{in} (mg.m^{-3})	C_{remov} (mg.m^{-3})	C_{out} (mg.m^{-3})	Emission Standard* (mg.m^{-3})
0 – 2.5	3.26	399.51	13.04	386.47	-
2.5 – 10	45.76	463.95	212.28	251.66	-
10 – 100	98.49	515.49	507.72	7.77	350
Total		2,989.90	733.04	645.90	-

Source: (*) Appendix III of Ministry of Environment Regulation No. 07/2007[11]

Based on the emission standards for stationary sources in accordance with Appendix III of the Ministry of Environment Regulation Number 07 of 2007, the parameter that exceeds the standard at MSME 1 is TSP with a concentration of 515.49 mg.m^{-3}. After passing through the cyclone, the TSP concentration is 7.77 mg.m^{-3}, which meets the applicable emission standard. However, for $PM_{2.5}$, the concentration remains quite high due to the cyclone's limitations, which are ineffective at removing fine particulates. The following is a recap of the cyclone design, which is equipped with a dust hopper and an induced-draft fan to maintain the stability of the flue gas flow.

Table 8: Cyclone Design Recapitulation

Design Criteria	Design Results	Unit
Cyclone diameter (D_c)	41.95	cm
Inlet height (H_c)	20.98	cm
Inlet width (B_c)	10.49	cm
Outlet length (S_c)	26.22	cm
Outlet diameter (D_e)	20.98	cm
Cylinder length (L_c)	83.90	cm
Cone length (Z_c)	83.90	cm
Inlet velocity (v_i)	15.00	m.s^{-1}
Tangential velocity (v_{tan})	7.908	m.s^{-1}
Gas revolutions (N_e)	6	-
Cut diameter (d_{pc})	6.805	µm
Total efficiency	53.16	%

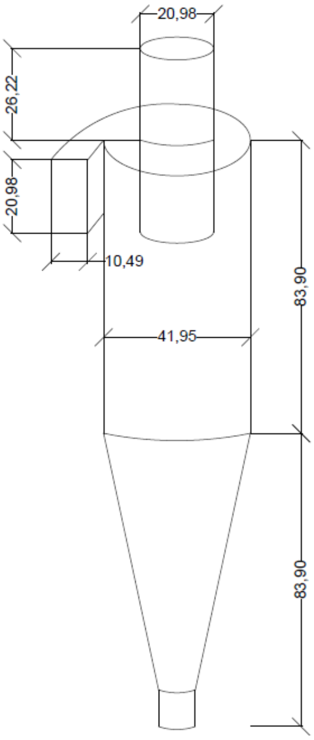

Figure 1: Cyclone

3.5 Chimney Redesign

The chimney design was carried out to minimize air pollution to the surrounding environment. Based on the chimney design criteria according to Kepdal Number 205 of 1996[18], the chimney height ranges between 2 and 2.5 times the height of the surrounding buildings, whereas according to the book Air Pollution Control and Design, the chimney height ranges around 2.5 times the height of the surrounding buildings or 1.5 times the height of the surrounding buildings for flat areas.

ISSN (online): 2581-3048
Volume 10, Issue 6, pp 150-160, June-2026
https://doi.org/10.47001/IRJIET/2026.106017

The existing chimney is approximately 5 m high and does not yet meet the dispersion criteria. The redesign was carried out using a chimney height approach of 2 times the height of the surrounding buildings in a flat area, resulting in a designated height of 10 m and a diameter of 0.3 m, with a sampling port located 7.2 meters from the gas inlet to the chimney. Increasing the chimney height improves plume release and reduces pollutant concentrations at ground level.

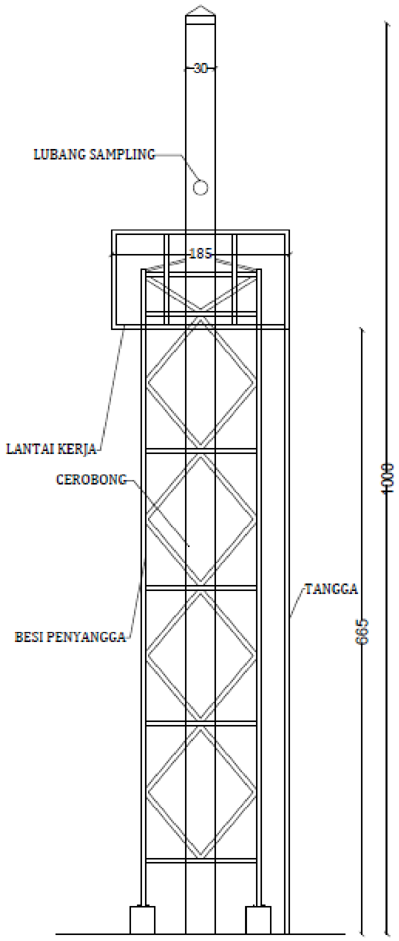

Figure 2: Chimney

3.6 Pressure Drop

Pressure drop is an important aspect of the design process because it relates directly to particle separation efficiency, operational energy requirements, and the overall performance of the cyclone system. Generally, a larger pressure drop results in a higher particle collection efficiency of the cyclone. According to Theodore (2008), a conventional cyclone has a diameter of 4 to 12 feet (1.2 to 3.6 m) and a pressure drop of 2 to 5 inches (5 to 13 cm) of water column. The recapitulation of the pressure drop calculations in this planning is presented in Table 9.

Table 9: Pressure Drop Calculation Recapitulation

Position	Pressure Drop (Pa)
Cyclone Pressure Drop	**506.25**
Furnace Pressure	
0.44 m Pipe	2.636
Gate valve	9.930
90° Elbow	19.861
0.6 m Pipe to cyclone inlet	3.595
Total	*36.023*

Position	Pressure Drop (Pa)
Cyclone Inlet Pressure Drop	
Round to rectangular transition	5.031
Total	*5.031*
Cyclone Outlet Pressure Drop	
Round to round transition	1.040
90° Elbow	19.861
0.3 m Pipe	1.804
90° Elbow	19.861
3.05 m Pipe	18.39
90° Elbow	19.861
0.3 m Pipe	1.804
Total	*82.626*
Fan Connection Pressure Drop	
Fan inlet	1.358
Fan outlet	117.34
Total	*118.707*
Chimney Connection Pressure Drop	
90° Elbow	144.462
0.8 m Pipe	310.689
10 m Chimney	51.2

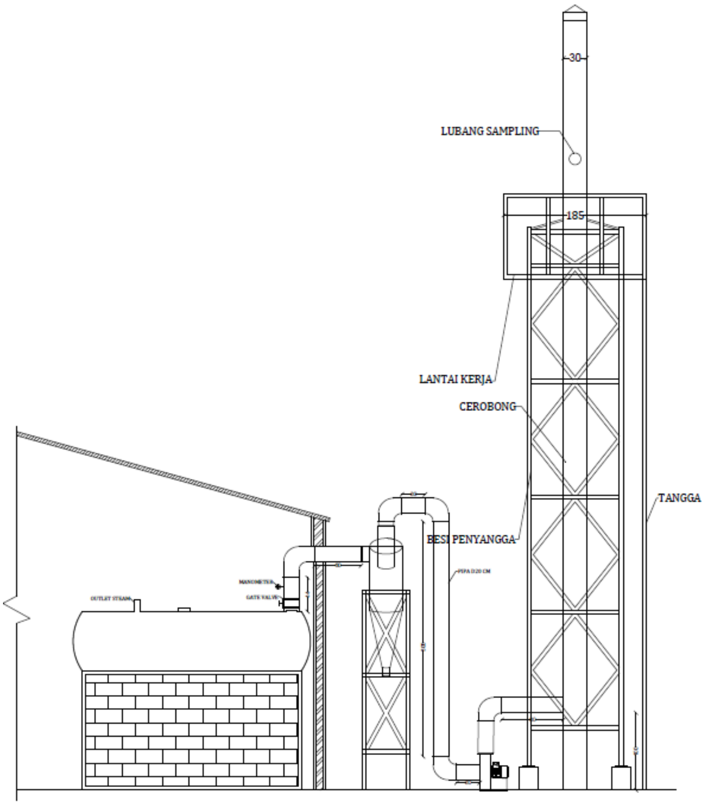

Figure 3: Integrated Control Device Setup

3.7 Occupational Health and Safety (OHS) Aspects in Cyclone and Chimney Operation and Maintenance

Various potential risks and OHS considerations to be considered during operational and maintenance activities for both the cyclone and the chimney are presented in Table 10.

Table 10: OHS Aspects in Cyclone and Chimney Operation and Maintenance

No	Activity	Potential Hazards and Risks	OHS Control Measures
1	Initial operation of cyclone and chimney	Gas flow instability during the initial operating phase, which can trigger sudden pressure surges and reduce system stability.	Perform start-up gradually, ensure the fan and damper operate normally, and monitor pressure and flow rate parameters before the system is fully run.
2	Daily operation	Exposure to dust and fine particulates from the cyclone system and chimney.	Use complete PPE (respirator, earplugs/earmuffs, heat-resistant gloves).
		Risk of pressure leaks or unstable pressure drop.	Perform routine pressure drop inspections to prevent system failure.
		Potential noise from the cyclone equipment.	Ensure work room ventilation is adequate.
		Potential contact with hot surfaces.	Maintain a safe distance from hot surfaces and install warning signs.
3	Flow damper adjustment and regulation	Incorrect damper adjustment, which can cause an increase in pressure drop, reduce particulate collection efficiency, and overload the fan.	Establish documented damper adjustment procedures, restrict adjustments to trained personnel only, and monitor system pressure changes after adjustment.
4	Operation at maximum load	Risk of overheating on the cyclone and chimney walls due to high flue gas temperatures, which can cause burns upon accidental contact.	Apply heat insulation coatings on equipment surfaces, install high-temperature warning signs, and restrict direct access to hot areas during operation.
5	Chimney operation under extreme environmental conditions	Chimney draft disruption due to strong winds or heavy rain, which potentially causes backflow of flue gas into the work area.	Evaluate weather conditions before operation, ensure the chimney design complies with standards, and temporarily suspend operations if conditions are deemed unsafe.
6	Cyclone cleaning	Exposure to accumulated dust during hopper or internal cleaning.	Perform lockout-tagout (LOTO) before cleaning.
		Risk of falling from heights if cleaning is performed on the upper part of the cyclone.	Use safety helmets and full-body harnesses.
		Danger of getting caught in cyclone parts if the machine is not turned off.	Clean using appropriate tools to minimize direct contact.
7	Mechanical repair (fan/blower)	Risk of injury due to cyclone parts or getting caught in mechanical components.	Implement lockout-tagout (LOTO) before repairs.
		Potential electric shock during repairs.	Ensure electrical measurements are safe before touching panels.
		Excessive vibration that can affect component balance.	Perform vibration checks after repairs are conducted.
8	Emergency procedures	Exposure to smoke or hazardous gases if a chimney operational failure occurs.	Stop all activities, evacuate workers out of the production area, and open all available ventilation.
		Risk of fire due to dust accumulation or short circuits.	Provide light fire extinguishers (APAR) in strategic areas.
		Potential injuries during evacuation if the area is dark or narrow.	Provide clear and unobstructed evacuation routes.
9	Operational, maintenance, and sampling at the chimney	Risk of exposure to hot gases and particulates when opening or cleaning.	Use protective masks (light respirators) and heat-resistant gloves.
		Potential falling from heights when climbing to the chimney platform.	Use safety helmets and full-body harnesses.

3.8 Dispersion Modeling

The recapitulation of the modeling scenarios was conducted to compare emission dispersion under existing conditions and with the control devices at the tofu MSMEs in Ploso Village. The number of MSMEs utilizing the control device is influenced by the amount of fuel consumed. If an MSME consumes ≥ 100 kg.h^{-1} of fuel, the MSME should implement a control device so that the ambient air quality meets the ambient standards. The recapitulation of the several modeling scenarios is shown in Table 11.

Table 11: Recapitulation of Dispersion Modeling Scenarios

Condition	Modeled TSP Concentration	Ambient Air TSP Standard	Description
Before implementation of control devices	558 µg/m^3	230 µg/m^3	Non-compliant
3 MSMEs utilizing control devices	400.3 µg/m^3	230 µg/m^3	Non-compliant
8 MSMEs utilizing control devices	213 µg/m^3	230 µg/m^3	Compliant

Figure 4: Modeling Scenario without Control Devices

Figure 5: Modeling Scenario with Control Devices for 3 MSMEs

Figure 6: Modeling Scenario with Control Devices for 8 MSMEs

3.9 Cost Budget Plan

The total construction cost calculation for the cyclone and the chimney is presented below.

Table 12: Cost Budget Plan (RAB) for Cyclone and Chimney Construction

Cyclone Construction Budget		
A	Earthworks and Footplate Foundation	Rp7,478,416.59
B	Steelworks	Rp3,496,496.17
C	Electrical Works	Rp205,508.38
D	Equipment Procurement	Rp17,758,317.00
Total Cyclone Construction		**Rp28,938,738.14**
Chimney Construction Budget		
A	Earthworks and Footplate Foundation	Rp7,478,416.59
B	Chimney Fabrication	Rp15,022,509.01
Total Chimney Construction		**Rp22,500,925.60**
TOTAL CYCLONE AND CHIMNEY CONSTRUCTION		**Rp49,841,364.74**

Based on the Cost Budget Plan (RAB) calculations, the design and engineering of one cyclone unit and one chimney unit require a total cost of Rp49,841,364.74.

IV. CONCLUSION

Based on the analysis and design of the emission control system at the tofu industrial center, it can be concluded that the wood combustion process at the Ploso Village Tofu Industrial Center generates various gaseous and particulate emissions, where the particulate emissions from the existing 4 meter unequipped square galvanized chimneys disperse into the surrounding ambient air at a level that exceeds the applicable environmental quality standards. To address these findings and achieve the emission reduction objectives, an air pollution control system consisting of an integrated cyclone and a redesigned 10 meter chimney was engineered, which successfully reduces the particulate emission concentration from 515.49 mg.m^{-3} to 7.77 mg.m^{-3} through a 98.49% cyclone removal efficiency and decreases the ambient particulate concentration from 558 µg.m^{-3} to 213 µg.m^{-3} to comply with regulatory thresholds, thereby significantly improving local air quality. To further develop this system and enhance environmental sustainability, it is recommended that future initiatives focus on field testing and dispersion modeling to advance air pollution control science for small-scale industries, while ensuring that local MSMEs implement the cyclone system and chimney redesign, local governments provide technical and policy support, and the community participates in collaborative awareness efforts to mitigate pollution impacts.

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Citation of this Article:

Adinda Bella Dhea Phitaloka, Adinda Khansa Anintya, Nurandani Hardyanti, & Haryono Setiyo Huboyo. (2026). Cyclone and Chimney Redesign for Particulate Emission Control in the Ploso Village Tofu Industry Cluster, Kudus, Indonesia. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 10(6), 150-160. Article DOI https://doi.org/10.47001/IRJIET/2026.106017

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