

FABRICATION, TESTING AND EVALUATION OF A DUST FILTRATION SYSTEM FOR SMALL-SCALE SPICE GRINDING MILLS

D. A. N. Dharmasena¹, D. N. Jayatissa¹, N. G. V. C. M. Kumara¹ and D. T. N. Wijesinghe¹.

ABSTRACT

The generation of excessive levels of spicy aroma and the airborne dust in spice grinding mills is one of the main ergonomic problems of the workers and sometimes create social problems due to environmental pollution. Although the fine dust as well as the aromatic chemicals has an economic value, collection of them is fairly a difficult task under small-scale processing plants. A technically and economically feasible low-cost dust filtration system was designed to filter and maintain the concentration of airborne dust level below the recommended level of 10 mg/m³ for 8-hour exposure time, in a spice grinding plant. The dust filtration system was designed based on a similar principle as in the existing spray tower filter. However, the method does not require very high pressure for fluid atomization as in that system and the unit can be fabricated using locally available materials with a very high lifetime. Dust measurements were carried out using a special cloth bag-collecting device with a fixed airflow rate. Dust removal rates were determined with different concentrations of a foaming shampoo (Lifebuoy shampoo) and a non-foaming detergent ('Rinso' automatic washing machine powder). Results showed that the filtration unit is capable of filtering airborne dust with an efficiency of 91% with the foaming detergent while an efficiency of 78% with the non-foaming detergent. An initial dust load of 108-150mg/m³ in the air was reduced to 9.6mg/m³ with the foaming detergent and 32mg/m³ with the non-foaming detergent or tap water without any detergent. Therefore, the dust filtration system is effective only with the foaming detergent. The cost of the system is about Rs.11000.00 (US \$ 110) and the estimated additional cost for dust filtration per one kg of processed chilli powder is about 52 Cents (US \$ 0.005).

Key Words: *Spice, Grinding Mills, Small Scale, Dust Filtration*

INTRODUCTION

Drying, size reduction and extraction are the most common processing operations in the spice industry in Sri Lanka. Grinding is a popular small-scale self-employment and well-established enterprise as there is an increasing demand for powdered spice for cooking purpose. Most of the small-scale spice grinders do not use dust and emission control measures since the environmental regulations in the country are not properly implemented at present. Spice grinding operation releases a fair

amount of dust, aromatic odors, bacteria, fungi and pesticide residues, which are hazardous to health and nuisance to the neighbors (Shen, 1995). However, some industrial supporting agencies have recently made it compulsory to take air pollution control measures to provide their services. In Sri Lanka, most of the small-scale, family owned entrepreneurs usually pay a low attention on environmental issues as they have limitations of additional capital investment. They cannot afford expensive equipment with relatively high running costs. However, the

¹Department of Agricultural Engineering, University of Peradeniya, Sri Lanka

government and non-government micro-industries based on primary and secondary processing of agricultural produce. This air pollution control unit was developed to assist the local spice grinders to assure their sustainability in business in terms of environmental agencies are working hard to develop regulations and obtaining uninterrupted services from their workers. Most of the workers are unable to provide continuous services and therefore reluctant to work in these places due to health problems.

Table 01: Commercially available particulate control devices

Device	Minimum particle size μm	Efficiency %	Advantages	Disadvantages
Gravitational Settler	> 50	< 50	Low pressure loss, simplicity of design and maintenance.	Much space required and low collection efficiency.
Centrifugal collector	5 – 25	50-90	Simplicity of design and maintenance. Little floor space required. Dry continuous disposal of collected dusts, low to moderate pressure loss. Handles large particles and high dust loadings. Temperature independent.	Much head room required and low collection efficiency of small particles. Sensitive to variable dust loadings and flow rates.
Wet collector				
Spray tower	> 10	< 80	Simultaneous gas absorption and particle removal.	Corrosion and erosion problems.
Cyclone				
Cyclonic Impingement Venturi	>25	< 80	Ability to cool and clean high – temperatures. Corrosive gases and mists can be recovered and neutralized. Reduced dust expansion risk. Efficiency can be varied.	Added cost of wastewater treatment and reclamation. Low efficiency on submicron particles. Contamination of effluent steam by liquid entrainment. Freezing problems in cold weather. Reduction in buoyancy and plume rise.
Electrostatic Precipitator	>1	95.99	An efficiency of 99% can be obtainable. Very small particle can be collected. Pressure drops and power requirements are small.	Relatively high initial cost. Precipitators are sensitive to variable dust loading or flow rates.
Fabric filtration	<1	>99	Dry collection is possible. Decrease of performance is noticeable, collection of small particles and high efficiencies possible.	Sensitivity to filtering velocity. High – temperature gases must be cooled to 100 to 450 ⁰ C. Affected by relative humidity. Susceptibility of fabric to chemical attack.

(Source: Coulson and Richardson, 1975, 1979)

Therefore, in order to protect millers, workers, as well as the environment, a low cost, simple air purification system has a paramount importance than high cost advanced technologies for the small-scale operations. Details of various commercially available dust filtration systems are summarized in the above table (Table 01) to understand the effectiveness and limitations of different commercial systems.

OBJECTIVES

The major objective of this research was to develop an appropriate a low-cost air purification system suitable for the dust and odor filtration in spice grinding mills. The specific objective was the construction and testing and, evaluation of the unit under field conditions.

MATERIALS AND METHODS

Design and fabrication of the dust filtration system

The dust filtration system was designed based on a similar principle as in the existing spray columns. However, it was designed to operate at a relatively low pumping pressure. The unit consists of six major components: plastic barrel, centrifugal type blower, nylon and PVC fiber filter, axial flow pump, steel frame work and a detergent reservoir (Figure 01). A locally available used plastic barrel was used as the housing of the unit. The plastic barrel in which the filter was fixed was 40cm in diameter with a height of 80cm. Dust contaminated air is sucked by the blower fan passes through the special filter bed

made of nylon lathe shavings. Those fine shavings were coated with charcoal powder using a paint to increase the contact surface area and to use the chemical adsorptive properties of charcoal. The filter bed was 40 cm in diameter and 20 cm in height. A 0.373 kW (0.5hp) motor operated the centrifugal blower used to pass air through the filter bed. The blower sucked the dust and aroma contaminated air through the inlet and through the wet filter filled with detergent foam. The filter bed was continuously sprinkled with a liquid detergent by the axial flow pump installed inside the barrel. The pump was operated by a 100W motor to minimize the energy cost while maintaining the required layer of foams in the bed. Dust and the irritating odor were retained in the foam and soap solution and washed off through the drain outlet to the water-collecting bucket kept underneath the barrel. Filtered clean air discharged through the air outlet while the dust suspended in the detergent solution. The axial pump had a 1m long, 5mm diameter stainless steel rod as the axis. A spiral was made using a plastic rod and fixed at the far end of the rod and it was placed in an aluminum tube to suck the detergent solution and pump out continuously. The motor had an rpm of 9000 and therefore the required amount of liquid could be pumped easily on to the bed. A disk with veins was fixed at the upper end of the rod and above the filter bed to sprinkle water-detergent mixture over the bed. The complete filter unit was mounted on a stable mild steel frame for easy handling. The unit is light in weight and portable as shown in the Figure 02.

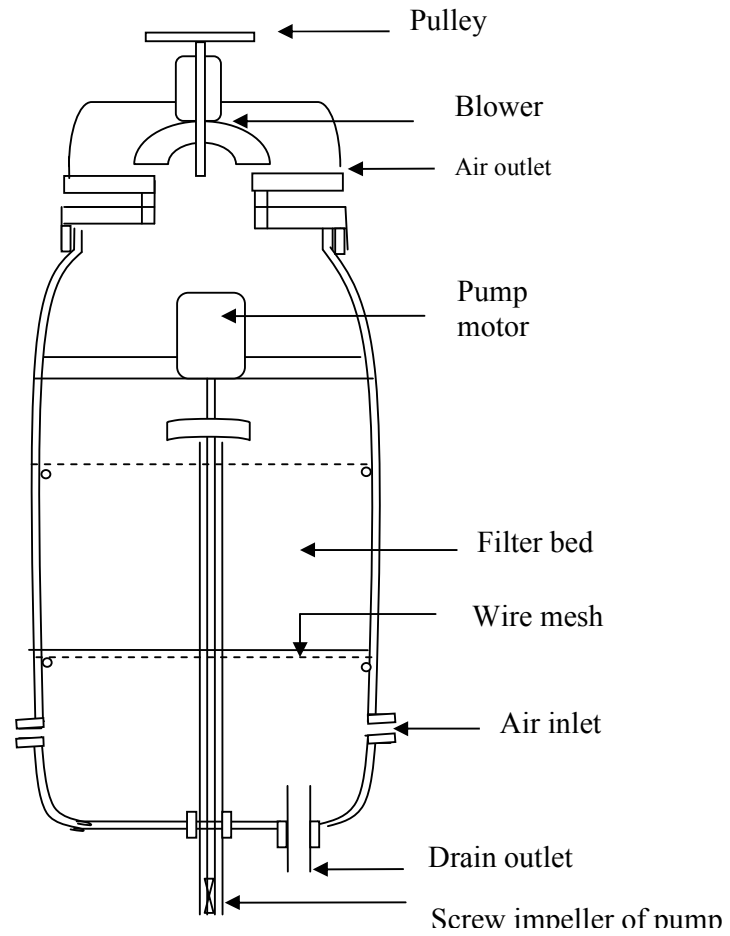


Figure 01: Components of the dust filtration system



Figure 02: The dust filtration system fitted on the stand

Testing and evaluation of the dust filtration system

Determination of the dust removal rate of the unit

To quantify the dust removal rate of the system, a filter bag method was used. Dust contaminated air was blown into a special cotton filter bag using an electric blower. The efficiency of filtration was calculated by measuring the difference of dust load between the inlet air and the outlet air of the filtration unit at a given time period. Air was blown at a constant flow rate through a special cloth filtering bag and the mass of dust was quantified using the mass balance. To avoid the errors from moisture absorption, all the mass values were recorded after removing moisture at 105 °C. Six measurements were made for each detergent concentration. Dust load at the inlet and the outlet were determined at the same time using two dust collectors.

Determination of the pressure drop along the filtering unit and the fan efficiency

Two manometers were connected to the inlet and the outlet of the unit. While the unit is working, the change of the pressure of each manometer was noted down. Pressure drop between the outlet and inlet was calculated using those values.

Determination of the pumping rate of the detergent

The volume of detergent liquid pumped by the pump at a given time was measured. This was replicated three times and the average value was calculated (Chattopadhyay,1993) .

Determination of the power consumption of the unit

Power requirements for the fan and the pump were measured separately using a voltmeter and an ampere meter. Then the power consumption was calculated based on the average power intake. Power requirement to the fan and the fan efficiency were calculated using following equations (Cory, 1991).

$$\begin{aligned} \text{Power required for blowing air sectional} &= \text{Pressure drop} \times \text{Air Velocity} \times \text{Cross area of duct} && - (1) \\ \text{Pressure drop} &= \text{dwgh} && - (2) \\ \text{Where,} & && \\ \text{h} &= \text{Height of the water column in meters} && \\ \text{dw} &= \text{Density of the water kg/m}^3 && \\ \text{g} &= \text{Gravitational acceleration m/s}^2 && \\ \text{Fan efficiency} &= \frac{\text{Power required for blowing air}}{\text{Power used to drive the fan}} \times 100 && - (3) \end{aligned}$$

Power used to drive the fan

Table 02: Results with the foaming shampoo ('Lifebuoy' shampoo) solution

Concentration of soap	Avg. dust collected at inlet (g/min)	Avg. dust weight at outlet (g/min)	Amount of dust filtered per 20 min (g/min)	Dust filtering efficiency (%)
C ₁	1.70	0.25	1.45	85.29
C ₂	1.70	0.20	1.50	88.23
C ₃	2.30	0.25	2.05	89.13
C ₄	2.20	0.20	2.00	90.90
C ₅	1.70	0.15	1.55	91.17
C ₆	2.35	0.20	2.15	91.48

Testing of odor

This was done by using a sensory panel of 12 people. The data obtained was used for testing the removal of odor by the filtration system.

Analysis of the cost of the system and estimation of the running cost

Total cost for the system was calculated by the method given by Perry (1979) based on the materials and the running costs. The variable cost was estimated based on power consumption for the blower, pump and the cost of detergent.

RESULTS AND DISCUSSION

Testing of the dust filtration system

The test was conducted to evaluate the filtration efficiency of dust under different concentrations of foaming shampoo (Lifebuoy shampoo) and non-foaming detergent (Rinso automatic

washing machine powder). After fixing and running the unit in a spice-grinding center, following results were obtained (Table 02 and 03).

The dust filtering efficiency and dust filtering rate were calculated under foaming detergent, non-foaming detergent and without any detergent (pure water) separately. The Figure 02 illustrates the relationship between the concentration of soap and filtering efficiency. According to the graph, filtration efficiency of foaming soap was greater than the non-foaming soaps. There is an increase of efficiency of filtration with the increasing concentration of detergent and then reach a maximum. The maximum efficiency achieved is 91%. Using the constant airflow rate data to the dust collection bag, the mass of dust per unit volume of air was calculated. The initial dust load of 108-150mg/m³ was reduced to 9.6mg/m³ with the foaming

Table 03: Results of the non-foaming detergent ('Rinso' washing machine powder) solution.

Concentration of soap	Ave. dust weight at inlet (g/min)	Ave. dust weight at outlet (g/min)	Amount of dust filtered per 20 min	Filtering efficiency (%)
C ₁	2.10	0.5	1.60	76.19
C ₂	1.70	0.4	1.30	76.47
C ₃	1.95	0.5	1.45	74.30
C ₄	2.25	0.5	1.75	77.78
C ₅	2.35	0.5	1.85	78.72
C ₆	2.15	0.5	1.50	76.74

C₁ = 1g/L , C₂ = 2g/L, C₃ =3g/L, C₄ =4g/L, C₅ = 5g/L, C₆ =6g/L

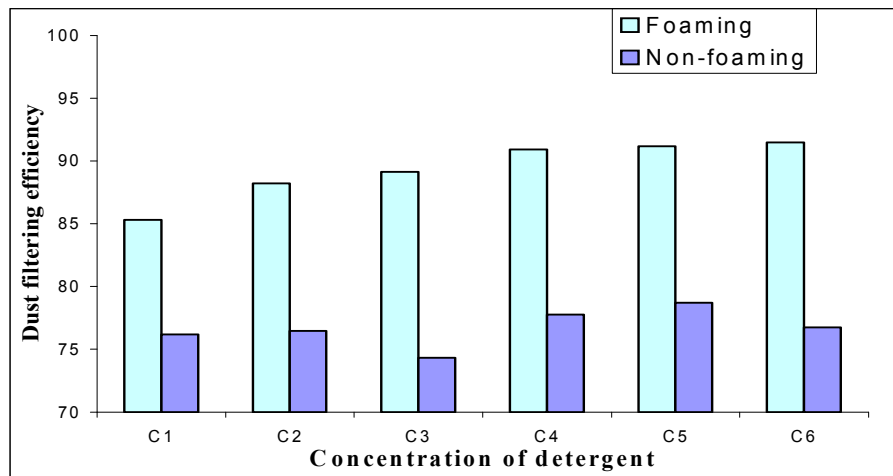


Figure 03: Variation of dust filtration efficiency with detergent concentration

detergent and to 31.8mg/m³ with the non-foaming detergent. When the unit was tested using tap water without any detergent, an initial dust load of 121mg/m³ was reduced to 32 mg/m³ with an efficiency of 74%.

Therefore the degree of filtration is acceptable only with the foaming detergent as the dust load of the filtered air follows the British regulation standards of 10mg/m³ for grain (Health and safety executive, 1997). The allowable lint-free respirable cotton dust in the textile processes; slashing and weaving is 750

µg/m³ averaged over an eight hour period (Anon_a, 2005). Dust standards given by different agencies are based on the industry and for coal it is 2mg (Watzman, 2003) and for office equipment 0.15 mg/m³ (Anon_b, 2005).

To find the economically sound concentration of soap for the system, Duncan's multiple range test (DNMRT) was carried out for the calculated readings. It was found that the optimum detergent concentrations were 3g/L for the foaming type and 4g/L for the non-foaming type.

Determination of the pressure drop along the filtration system and calculation of the fan efficiency

Following results were obtained in evaluating the efficiency of the fan used in the filtration system

Average water manometer reading at inlet flow	=	4.36 cm
Average water manometer reading at outlet flow	=	1.53 cm
Therefore, pressure drop at the unit	=	2.85 cm
Velocity of air	=	25.52 m/s
Diameters of two circular inlets	=	10 cm and 10 cm
The power consumption to drive the fan	=	278.4 (0. 373 hp)

Therefore, the actual power requirement to blow air through the system was calculated as 116.3 W (0.1558 hp) using the equations 1 and

2. Fan efficiency was calculated using equation 3. There was relatively low fan efficiency value of 42%.

Determination of the pumping rate of the pump

The following results were obtained in the pump test.

Average time taken to pump one litre of water	=	17.23 s
Therefore pumping rate	=	1000mL/17.23
	=	58.038 mL/s

Although the pumping rate of the pump was low, it was sufficient to maintain a sufficient foam layer and filter the incoming dust load.

Costing of dust filtration system

The total cost of fabricating this unit was Rs. 9100.00 and the selling price was estimated as Rs. 10920.00. The unit is maintenance free and will have a lifetime of minimum 10 years.

Calculation of the additional cost for dust filtration per one kg of chilli powder

The total cost for fabricating the dust filtration system was Rs 9100.00. When considering the prices of other available air cleaning equipment in industrial level, this system is very cheap and appropriate to the small industries.

Fixed costs

Depreciation (straight line method)	=	Cost new/Probable life
Cost new	=	Rs. 9100.00 * 120%
Probable life	=	10 yrs.
Depreciation value for one year	=	1092.00 Rs./yr
If the number of hours working per day is 6 and 200 working days per year		
Depreciation cost per hour	=	Rs 0.91
Average number of kg ground per hour	=	12.0 kg
Depreciation cost per kg	=	0.08 Rs./kg
Annual interest charge	=	0.5*costnew*Interest rate
Interest rate at 10%	=	546 Rs./yr
	=	0.04 Rs./kg

Operating cost

Power consumption per one hour	=	(373+100)W
	=	0.473 kWh
If 1kWh is Rs. 6.50, then cost for power	=	Rs 0.26/kg
Maintenance cost	=	Cost new *5%Rs./yr
Maintenance cost per 1 kg chilli	=	0.04 Rs./kg
Cost of detergent per 1 kg of chilli	=	0.10/kg
Therefore, total additional cost for one kg	=	0.52 Rs./kg (\$ 0.005/kg)

However, the additional cost for milling 1kg of chilli is about 52 cents. However, considering the benefits to the environment, environmental regulations and health and safety of workers and neighbors, this additional cost per 1kg of processed spice will provide more returns in the long run. Further, this machine does not need any additional labor or skill for operation. Therefore, it is an advantage to minimize the additional labor cost for small-scale industries. Since this machine is small in comparison to the other available air pollution control equipments, the space requirement for this unit is extremely low. The unit needs less capital investment and low maintenance cost. Therefore, this is an ideal solution to the needs of small-scale industries. Since this machine operates on a wet filtration technique, the size of dust particles removed is greater than 10 μ m and it is much better than gravity filtration equipment. Attention was paid on the safety of the machine operator in the design and it was found that the safety is at a satisfactory level. The data collected from the sensory evaluation panel revealed that the system is efficient in removing the irritating aromatic smell.

CONCLUSIONS

According to the results, the unit is capable of filtering airborne dust with an efficiency of 91% with a foaming detergent reducing the dust level to about 10 mg/m³. The non-foaming detergent or water are not satisfactory in removing dust to the required level and efficiency of 78% and 74% were recorded with non-foaming detergent and tap water respectively. The selling price of the system is about Rs.11000.00 and the additional cost for dust filtration per one kg processed chilli powder is about 52 cents. Therefore, the machine is a low-cost and an appropriate unit for small and medium-scale grinders. However, the capacity of the unit should be matched with the dust load generated by the mill. The actual power requirement for the operation of this experimental unit was 0.473kW. Therefore, the operating cost of the machine is relatively low. The rate of pumping the detergent by the specially designed spiral spray pump was 58mL/s. In addition to removal of dust, the unit is capable of removing irritating odors from air. However, the detergent solution has to be replaced periodically to maintain the maximum efficiency of the unit.

REFERENCES

- Anon_a, (2005). The prevention of occupational diseases as a result of excessive exposure to Dust in the coal industry.
http://www.minesafe.org/health_safety/dust.html (Sited on 15.08.2005).
- Anon_b, (2005). <http://www.complianceregs.com/29cfr/1910/subZ/1910-1043.html>. sited on 15.08.2005).
- Chattopadhyay, P. (1993). Unit operations of chemical engineering, Vol. 1, Khanna publishers, Delhi, India.
- Cory, W. I. W. (1991). Theory of centrifugal fans, soil and water engineering, Vol.46. No. 2, 34 – 38pp.
- Coulson, J..M. and Richardson, J. F., 1975. Chemical Engineering, Vol. 1, Pergmon press Oxford.
- Coulson, J..M. and J. F Richardson, (1977). Chemical Engineering, Vol. 3, Pergmon press Oxford.
- Health and safety executive, (1997). Grain dust – maximum exposure limit, Agricultural sheet No.3,NIS/09/03 C150 5/92. Printed in the UK HSE.
- Perry, H. (1979). Agricultural Process Engineering, Third Edition, The AVI PublishingCompany, Inc. Westport, Connecticut.
- Shen, T. T. (1995). Industrial pollution prevention, Spring, Verlag, Germany.
- Watzman B. (2003). MSHA Coal Dust Standard 5-22-03.
http://www.nma.org/pdf/other_test/dust_testimony_052203.pdf.