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A Survey of Solar-Powered Cyclone and Filtration Systems for Localized Dust Collection: Design Considerations for a Traffic-Signal-Pole Prototype

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ABSTRACT

Road dust and resuspended particulate matter are persistent concerns at busy traffic junctions. This paper surveys the mechanical and energy-system knowledge needed to design a small, solar-powered dust collection and air filtration unit for a traffic-signal-pole demonstration model. The survey covers four areas: (i) the nature of roadside particulate matter, (ii) cyclone separators as inertial pre-cleaners, (iii) fibrous filtration as a fine-cleaning stage, and (iv) photovoltaic (PV) power supply and battery sizing for a DC blower. Design relationships such as cyclone cut diameter, pressure drop, blower power and battery capacity are summarized, and the trade-off between collection efficiency and airflow resistance is highlighted. The survey shows that the individual subsystems are well documented, while integrated, pole-mounted, solar-driven units at small scale lack published performance data. This gap motivates an experimental prototype, whose removal efficiency, airflow and battery endurance must be measured rather than assumed.

Keywords: solar photovoltaic, cyclone separator, dust collection, air filtration, DC blower, traffic signal pole, particulate matter.

1. INTRODUCTION

Vehicle movement, tyre and brake wear, construction activity and dry road surfaces all contribute to airborne dust at urban intersections. Particles smaller than 10 µm (PM10) and 2.5 µm (PM2.5) remain suspended for long periods and are the fractions of main health concern [5]. Removing particles from a moving air stream needs three mechanical ingredients: a blower to create flow, a separator that removes coarse particles, and a filter that captures fine particles.

A solar-powered unit is attractive because traffic poles already stand in open, sunlit locations and a self-contained PV supply avoids new electrical connections. For a diploma-level mechanical project, such a unit also brings together fluid mechanics, fabrication, CAD and basic electrical sizing.

The aim of this paper is to review what is known about each subsystem and to derive design guidance for a compact prototype consisting of a PV panel, charge controller, battery, DC blower, cyclone, dust bin, pre-filter and fine filter. The paper is a literature-based survey. It does not report experimental results and makes no claim of ambient-air improvement.

2. Roadside Particulate Matter

Roadside dust is a mixture of coarse mineral particles raised from the road surface and finer combustion and wear particles. Aerosol science describes particle behaviour by size, density and shape, and the dominant removal mechanisms change with size [3]. Coarse particles (tens of micrometres) settle and impact easily, so inertial devices such as cyclones capture them well. Particles around 0.1–1 µm are the hardest to collect by any mechanism and are where fine filters are most needed. Health guidance for PM2.5 and PM10 is set out in the WHO global air quality guidelines [5].

Two consequences follow for design. First, a single device is unlikely to be efficient across the full size range, so a staged arrangement (separator, then filter) is logical. Second, the size distribution of the test dust strongly affects measured efficiency, so tests must state what dust was used.

3. Cyclone Separators

3.1 Principle

In a cyclone, dust-laden air enters tangentially and spins in a downward spiral. Centrifugal force pushes particles toward the wall, where they slide into a hopper or bin, while cleaned air reverses and leaves through a central outlet tube (vortex finder). The standard reference on their principles and design is Hoffmann and Stein [2].

3.2 Geometry families

Early experimental work on flow patterns and pressure drop was reported by Shepherd and Lapple [6]. Stairmand [7] proposed widely used high-efficiency and high-throughput geometries in which all dimensions are fixed as ratios of the cyclone body diameter. Such standard ratios let a designer scale a cyclone to a required flow rate without a full analysis, which is useful for a student prototype.

3.3 Cut diameter and efficiency

A classical estimate of the particle size collected with 50% efficiency (the cut diameter, d50) was given by Lapple, and models by Barth [8] relate it to the balance between centrifugal and drag forces on a particle. Qualitatively, the cut diameter decreases (better collection of fine particles) when the inlet velocity increases, the body diameter decreases, the particle density increases, or the gas viscosity decreases. Efficiency is therefore improved by smaller, faster cyclones, but at a price.

3.4 Pressure drop

Pressure drop across a cyclone is commonly expressed as a number of inlet velocity heads, so that it rises with the square of inlet velocity [2], [6]. A higher inlet velocity improves collection but demands more blower pressure and power. This is the central design trade-off for a battery-powered unit: the cyclone should be sized for adequate collection at an inlet velocity that the available blower can sustain.

3.5 Practical notes

Survey sources agree on several practical points: air-tight sealing of the dust outlet is essential because leakage re-entrains collected dust; small cyclones perform poorly on very fine dust; and sticky or wet dust can build up on walls. For a prototype, a removable, sealed dust bin and smooth internal walls are recommended.

4. Filtration Stages

4.1 Capture mechanisms

Fibrous filters capture particles by interception, inertial impaction, diffusion and, with some media, electrostatic attraction [3], [9]. Diffusion dominates for the smallest particles and impaction and interception for larger ones, which produces a characteristic minimum in collection efficiency at an intermediate size, often called the most penetrating particle size. This explains why filter performance is usually quoted by size range rather than as one number.

4.2 Pressure drop and loading

A clean filter has a low, nearly linear pressure drop at a given face velocity. As dust loads the medium, resistance rises and airflow falls unless the blower can compensate [9]. For a fixed small DC blower, loading directly reduces flow, so a pre-filter or cyclone upstream of the fine filter extends the life of the fine stage.

4.3 Staged design

Common practice is a coarse pre-filter, then a finer medium. Manufacturer data for airflow and pressure drop should be used to select media. Filters must be mounted in removable holders with gaskets so air cannot bypass the medium, since leakage can reduce effective efficiency more than the choice of medium itself.

5. Blower and Air-Path Design

The blower must deliver the required flow against the total system resistance, which is the sum of losses in ducts, cyclone, pre-filter, fine filter and bends. Matching is done by plotting the blower's pressure–flow curve against the system curve and checking that the operating point lies in the blower's efficient range. Hydraulic power is the product of flow rate and pressure rise, and electrical input power is this value divided by overall blower efficiency. Small DC blowers deliver limited pressure, so the design must keep losses low by using short ducts, gentle bends and a modest filter face velocity.

A suggested air path for the prototype is: dusty air, cyclone, pre-filter, fine filter, blower, outlet. Placing the blower after the filters means the fan handles cleaned air, which reduces wear, although the casing then operates under negative pressure and must be well sealed.

6. Solar PV Power Supply

PV system references describe how to size a stand-alone system from the load [4]. The usual steps are:

1. Daily load energy equals load power multiplied by operating hours.
2. Battery capacity is the load energy divided by the battery voltage, allowed depth of discharge and system efficiency, with extra allowance for days of autonomy.
3. Panel rating is set by the daily energy requirement divided by the equivalent peak-sun-hours at the site, with a derating allowance for losses.
4. A charge controller protects the battery from overcharge and deep discharge, and a fuse and correctly sized wiring protect the circuit.

Because the blower is a continuous DC load, the system is more sensitive to battery capacity than to short-term sunlight variation. Intermittent operation, such as running only during selected hours, is one way to reduce battery size. Local peak-sun-hour data for Maharashtra should be obtained from measured or published solar-resource data when final ratings are chosen.

7. Mechanical Structure and Mounting

A pole-mounted unit adds loads that bench equipment does not have: self-weight of the panel, filter housing and battery; wind loading on the panel and enclosure; vibration from the blower; and the need for weather protection and safe maintenance access. For a classroom demonstration model, these can be handled by a stable frame, low-mass housings and accessible service doors. For a real traffic pole, structural analysis, electrical safety review and permission from the responsible authority would be mandatory; these are outside the scope of a diploma prototype.

8. Summary of Survey Findings

Subsystem	Main finding from literature	Design implication
Cyclone	Collects coarse particles well; efficiency rises with inlet velocity and so does pressure drop [2], [6], [7]	Use a standard proportioned cyclone; choose an inlet velocity the blower can supply
Filter	Efficiency varies with particle size; resistance rises as dust loads [3], [9]	Use coarse pre-filter plus fine filter in sealed, removable holders
Blower	Operating point is set by the system curve [2]	Select from pressure–flow data after estimating total losses
Solar supply	Sized from load energy, sun hours and battery autonomy [4]	Estimate energy first, then choose panel, battery and controller
Structure	Pole mounting adds wind, weight and safety issues	Keep the prototype a controlled demonstration model

9. Research Gap

The subsystems above are well covered in textbooks and journal literature, but the survey found little published, quantified performance for small integrated units that combine a cyclone, staged filters and a solar-battery supply on a pole-type support. Specifically, data on removal efficiency by particle size, airflow against pressure, filter-loading effects and battery endurance for such a unit are not available from the sources consulted. Textbook sources [2]–[4] provide design methods, not validation of any specific prototype, and the project synopsis [1] is a planning document rather than a research paper. The prototype therefore needs its own tests.

10. Proposed Evaluation Plan

To fill this gap, the project will record the following where instruments are available: airflow rate, pressure drop across the filters, mass of dust collected in the bin, blower voltage, current and power, battery operating time, filter condition after testing, and upstream and downstream particle concentration if a particle counter can be arranged. Any measurement that cannot be completed will be reported as such, and no efficiency figure will be quoted in advance.

11. Conclusion

The literature supports a staged design in which a cyclone removes coarse dust, filters capture fine particles and a DC blower driven from a PV-battery supply provides flow. The key engineering trade-off is between collection efficiency and pressure drop, which must be balanced against the limited power of a solar-battery system. Using standard cyclone proportions, manufacturer-rated filter media and a load-based PV sizing procedure gives a sound basis for a prototype. Its real-world value for roadside air quality can only be established by measured testing, safety validation and proper authorization, not by this survey.

References

[1] Solar-Powered Air Filter & Dust Collection System for Installation on a Traffic Signal Pole. Project synopsis, Department of Mechanical Engineering, SBGI Miraj, 2026. (Project document, not peer-reviewed.)

[2] A. C. Hoffmann and L. E. Stein, Gas Cyclones and Swirl Tubes: Principles, Design and Operation. Springer, 2002.

[3] W. C. Hinds, Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, 2nd ed. Wiley, 1999.

[4] R. A. Messenger and J. Ventre, Photovoltaic Systems Engineering, 3rd ed. CRC Press, 2010.

[5] World Health Organization, WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva, 2021.

[6] C. B. Shepherd and C. E. Lapple, "Flow pattern and pressure drop in cyclone dust collectors," Industrial & Engineering Chemistry, vol. 31, no. 8, pp. 972–984, 1939.

[7] C. J. Stairmand, "The design and performance of cyclone separators," Transactions of the Institution of Chemical Engineers, vol. 29, pp. 356–383, 1951.

[8] W. Barth, "Design and layout of the cyclone separator on the basis of new investigations," Brennstoff-Wärme-Kraft, vol. 8, pp. 1–9, 1956.

[9] C. N. Davies, Air Filtration. Academic Press, 1973.