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FINE-IMPURITY REMOVAL FROM SEED COTTON: COMPARATIVE ASSESSMENT AND A FRAMEWORK FOR CLEANER IMPROVEMENT

Ergashev Muminjon Yoqubjon o‘g‘li
Namangan State Technical University, an independent researcher.,
Analytical review and engineering framework
mominjonergashev59@20gmail.com

Abstract. Improving seed-cotton cleaning requires balancing impurity removal against useful-material loss, fiber quality, energy demand, and operational stability. This study develops a comparative framework for evaluating spiked-cylinder cleaners, cleaning surfaces, and flexi-ble working strips. A purposive synthesis of selected publications and a technical manuscript was combined with material-balance analysis and simplified mechanical relationships. The literature-based comparison identified configuration-dependent effects of cylinder speed, grid geometry, paddles, and contaminant type, rather than a universally preferable operating con-dition. The analytical assessment distinguishes impurity-mass removal from reductions in impurity concentration. In an explicitly hypothetical example, these measures were 60.00% and 58.33%, respectively, despite describing the same material streams. A cantilever approximation also shows why free strip length must be assessed together with stiffness and working clear-ance. The resulting framework prioritizes stable feeding, interchangeable strip configurations, clearance monitoring, and stage-resolved measurements. Candidate designs are first screened against geometric and quality constraints and then compared using measured cleaning, loss, and energy indicators. These findings provide a basis for comparative testing, not evidence of an experimentally validated cleaner or an optimum operating speed. Their application requires matched machine trials and characterization of the processed material.

Keywords: cylinder cleaner; fiber loss; flexible strip; impurity removal; material balance; seed cotton.

Introduction

Seed-cotton cleaning is not adequately described by the mass of material discharged as waste. A waste stream can contain both foreign matter and useful fibrous material. Tests of cylinder cleaners have demonstrated that changing grid geometry or cylinder speed can alter cleaning and fiber loss together [1, 2]. A cleaner should therefore be evaluated as an interacting mechanical and material-handling system rather than by a single removal percentage.

A practical comparison must distinguish seed-cotton cleaning before ginning from lint clean-ing after fiber–seed separation. It must also account for differences in the material being removed. Results obtained for plant debris, sheet plastic, lint, and lint-cleaner waste cannot be treated as interchangeable evidence for the same operating condition [1, 3].

The objective of this study is to organize selected evidence into a consistent framework for comparing working elements and prioritizing improvements to spiked-cylinder cleaners. Its contribution is the combined use of functional comparison,

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explicit performance definitions, and testable design constraints. The study addresses how cleaning intensity can be increased without overlooking useful-material loss, energy consumption, and stability. It does not report a new machine experiment or claim a universally optimal configuration.

Materials and methods

Study design and evidence base

The study was conducted as a purposive analytical review, not a systematic review or meta-analysis. The research evidence comprises three journal articles addressing cleaner configu-ration or contaminant removal [1, 4, 3] and one conference paper on cleaner speed [2]. A handbook review provides background on fiber-quality considerations [5]. An unpublished technical manuscript supplies the spiked-cylinder and flexible-strip design context [6]. A stan-dard cantilever model is used only as a mechanical idealization [7].

The publications were selected for direct relevance to cylinder speed, cleaning-surface geom-etry, propulsion paddles, contaminant transport, or quality preservation. This was a bounded source set derived from the initial manuscript, not an exhaustive database search. Bibliographic details and reported findings were checked against publisher pages and USDA Agricultural Research Service records. Ray's journal article was used in preference to the earlier confer-ence version of the same configuration study to avoid treating the two reports as independent experiments.

The unpublished manuscript was used to define the engineering problem, not to establish a numerical performance advantage. No unreported measurements, replicate counts, significance tests, or production outcomes were inferred from it. Findings available only as summaries were restricted to the information explicitly reported; missing trial details were not reconstructed.

Comparison and synthesis procedure

For each research source, the comparison considered the processed material, working configura-tion, varied parameters, removal outcome, and useful-material loss where reported. Claims were separated into three categories: published observations, analytical deductions, and proposals requiring experimental verification. Differences among cultivars, moisture conditions, machine sequences, and response definitions precluded pooling the reported cleaning percentages.

The functional synthesis used five criteria: separation mechanism, contact with the cotton, adjustable parameters, material-retention constraints, and operational sensitivity. Table 1 reports this synthesis rather than a measured ranking. The validation requirements in Table 2 were then formulated as engineering proposals, not as results of completed trials.

Analytical procedure and scope

Material-balance relationships were evaluated for a common measurement interval and moisture basis. An illustrative calculation used 100 kg of incoming material containing 6% impurities and 96 kg of outgoing material containing 2.5% impurities. These inputs were selected solely to expose differences between response definitions. No empirical uncertainty distribution or statistical inference was assigned to them.

Mechanical relationships describe a rotating working point, a small-deflection cantilever, and a sequence of stages acting on remaining impurity mass. Their assumptions and symbols are specified with the equations in the Results section. Here, free strip length means the deformable length beyond the clamp; it is distinct from axial

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width and radial projection. A flexible strip is not necessarily made of rubber, and a perforated screen is distinguished from a grid assembled from separate bars.

Results

Functional comparison and configuration dependence

The source synthesis identified five functional arrangements relevant to the design problem (Table 1). They are not mutually exclusive: a cleaner can combine repeated cylinder stages, flexible elements, and airflow. The constraints listed are questions to be checked, not faults demonstrated in every machine. The flexible-strip row represents a design option requiring validation rather than an established performance improvement.

Table 1: Functional synthesis of cleaner arrangements and parameters requiring joint assessment.

Arrangement	Main action	Adjustable factors	Constraint to assess
Spiked cylinder, strips, and screen	Opening, conveying, and screening	Speed, clearance, and feed rate	Blockage, impact, and useful-material loss
Cylinder and grid bars	Contact at bar edges and separation through gaps	Bar shape and spacing	Cleaning–fiber-loss trade-off
Flexible working strip	Deformable contact	Free length, thickness, and material	Dynamic clearance, fatigue, and wear
Successive modules	Repeated separation stages	Stage count and stage-specific settings	Additional benefit of each stage
Mechanical action with airflow	Transport of detached material	Airflow rate and flow path	Entrainment of useful fibrous material

Whitelock and Anthony reported that more aggressive square grid bars improved removal but also increased fiber escape during seed-cotton cleaning [1]. This observation supports assessing the output and waste streams together; a favorable result for lint-cleaner waste does not establish the preferred configuration for seed cotton.

Ray reported 28% cleaning efficiency for a paddled configuration using 9.5-mm flat-square grid bars at 980 rpm, compared with 24% for the conventional configuration. Without paddles, the two configurations each achieved approximately 26% in that study [4]. These are published, configuration-specific observations, not results of the present work or operating recommenda-tions for a 1XK cleaner. They demonstrate why a change in speed cannot be separated from the configuration in which it was tested.

Hardin's speed study likewise reported increased material removal together with greater cylinder-cleaner fiber loss at higher speeds [2]. Conversely, Hardin and Byler found greater sheet-plastic removal at lower cylinder speeds within their tested conditions, while increased airflow involved a trade-off with fiber loss [3]. Thus, contaminant type and operating configuration alter the interpretation of a nominal increase in cleaning intensity.

Material-balance indicators and illustrative calculation

Let M_{in} ,M_{out} , and M_w denote incoming seed cotton, outgoing product, and total waste masses measured over the same interval. For steady operation, a common moisture basis, and no unmeasured stream or net accumulation:

$$M_{in}=M_{out}+M_w.(1)$$

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With incoming and outgoing impurity mass fractions z_{in} and z_{out}, impurity-mass removal is

$$\eta_m = \frac{M_{in}\, z_{in} - M_{out}\, z_{out}}{M_{in}\, z_{in}} 100\%,\ z_{in} > 0. \quad (2)$$

Reduction in impurity concentration is a different response. Under Eq. (1), its relationship to mass-based removal is

$$\eta_z = \frac{z_{in} - z_{out}}{z_{in}} 100\%,$$

$$\eta_m - \eta_z = \frac{M_w}{M_{in}} \frac{z_{out}}{z_{in}} 100\%. \quad (3)$$

The second line follows by direct subtraction; its value is a difference in percentage points. The indicators can differ because the output mass changes, not because two different cleaning events occurred.

For the hypothetical inputs defined in the Methods, $M_{in} = 100$ kg, $z_{in} = 0.06$, $M_{out} = 96$ kg, and $z_{out} = 0.025$. The incoming and outgoing impurity masses are 6.0 and 2.4 kg. Accordingly, $\eta_m = 60.00\%$ and $\eta_z = 58.33\%$, a difference of approximately 1.67 percentage points. Total waste is 4.0 kg, comprising 3.6 kg of removed impurities and 0.4 kg of other material under the stated balance. The latter cannot be identified as pure fiber without composition measurements.

If waste analysis determines useful fibrous material M_{fw}, its loss relative to incoming seed cotton is

$$L_f = \frac{M_{fw}}{M_{in}} 100\%. \quad (4)$$

Specific electrical energy consumption is

$$e = \frac{E_{el}}{M_p}\ [\mathrm{kWh\,t^{-1}}], \quad (5)$$

where E_{el} is measured electrical energy in kWh and M_p is seed-cotton throughput over the same interval in tonnes. The measurement boundary must state whether auxiliary fans are included. Rated motor power is not a substitute for integrated electrical energy. Together, η_m, L_f, e, throughput, and separately measured quality attributes define a comparison that cannot be reduced to total waste output alone.

Mechanical coupling and stage-wise constraints

For a working point at radius R rotating at n revolutions per minute, circumferential speed is

$$v = \frac{2\pi R n}{60}, \quad (6)$$

and its normal acceleration is

$$a_n = \frac{v^2}{R}. \quad (7)$$

Here R is in metres, v in $\mathrm{m\,s^{-1}}$, and a_n in $\mathrm{m\,s^{-2}}$. These expressions describe the rotating working point, not necessarily the cotton tuft. Slip, deformation, and intermittent contact prevent direct conversion of a_n into a cleaning percentage.

For a uniform cantilever with a transverse tip load and small deflection, the equivalent bending stiffness is [7]

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$$k_{eq}=\frac{3E_sI}{l^3},\ I=\frac{bh^3}{12}.(8)$$

E_s is the effective elastic modulus in Pa; I is the cross-sectional second moment in m^4;b,h, and l are width, bending-direction thickness, and free length in metres. Stiffness is in Nm^{-1}. For fixed E_s and section geometry, increasing l by 20% gives $k_{eq}/k_{eq,0}=1/1.2^3\approx0.579$. This is a theoretical sensitivity result, not a measured improvement in contact or cleaning.

The approximation neglects large deformation, support compliance, shear deformation, and frequency-dependent material behavior. It should not be applied to a rubber strip without checking the force-displacement response over the relevant loading range. Static flexibility does not establish a safe dynamic amplitude.

Let δ_0 be a reference strip-to-screen clearance and $u_r(t)$ the displacement component toward the screen. An idealized geometric relation is

$$\delta(t)=\delta_0-u_r(t).(9)$$

Changing free length and radial projection together changes both compliance and reference clearance. Measurements must therefore distinguish these parameters. Runout, assembly tolerances, transient impacts, and other deformations require additional allowance before a permissible minimum clearance can be assessed.

For N stages, let ε_j be the fraction of the impurity mass entering stage j that is removed there. With no new contamination or re-entry, the total removed fraction is

$$\eta_N=1-\prod_{j=1}^{N}(1-\varepsilon_j).(10)$$

Both ε_j and η_N are fractions, not percentages. If every stage is assigned $\varepsilon_j=0.20$ in a hypothetical three-stage example, $\eta_3=0.488$, or 48.8%. The model describes sequential impurity accounting; it does not predict stage efficiencies, fiber loss, or energy demand. Equal stage efficiencies are an illustrative assumption and cannot justify identical settings throughout an actual cleaning line.

Discussion

Implications for cleaner improvement

The analytical results indicate that increasing removal intensity is a constrained design prob-lem. The useful comparison is between configurations operated on comparable material, with simultaneous measurement of product, impurities, and useful-material loss. A component that improves one response may remain unsuitable if it violates a clearance, quality, or reliability requirement.

Four development priorities follow from this framework. First, stable feeding is proposed as a way to reduce uncontrolled variation in loading. Second, interchangeable strips can permit controlled comparisons without changing several geometric factors at once. Third, flexible-element development requires measurements of deformation and working clearance rather than selection by nominal material alone. Fourth, stage-specific settings should be assessed using the material entering each stage, not only the final outlet condition. These are testable proposals, not demonstrated benefits of a new cleaner.

Table 2: Proposed improvements and evidence required before accepting a performance claim.

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Proposal	Intended function	Required evidence
Interchangeable strips	Adapt contact geometry	Repeated comparison under matched conditions
Adjusted flexibility	Control deformable contact	Force–displacement, clearance, quality, and wear measurements
Stage-specific settings	Limit unnecessary repeated action	Separate material balances and energy records by stage
Stabilized feeding	Reduce loading variability	Time-resolved feed-rate and power measurements

The criteria in Table 2 support a two-step decision process. Configurations that fail predefined geometric or quality constraints are excluded first. Remaining variants are compared for cleaning, useful-material retention, energy demand, and maintenance. The framework does not assign arbitrary weights to these objectives or hide an unfavorable response inside an unsupported overall score.

Interpretation limits

The reported literature results concern different machines, contaminants, and operating condi-tions. They support configuration dependence, but not transfer of a particular cylinder speed or cleaning percentage to every spiked-cylinder cleaner. The importance of measuring fiber properties separately from waste composition is also consistent with the quality considerations discussed in the ginning handbook [5].

The present synthesis is limited by its purposive source selection and the absence of a harmonized dataset. It cannot establish current best-in-class performance, a pooled effect size, or a statistically validated optimum. The simplified models omit detailed tuft dynamics, impurity attachment, screen-passage probability, and contaminant re-entry. They define accounting relationships and preliminary constraints rather than a complete separation model.

Proposed validation and reporting

A subsequent experiment should compare the baseline and candidate designs under matched operating conditions. This validation program is a recommendation for future work, not a description of tests performed in this study. The baseline machine should be inspected before testing; comparing a worn baseline component with a new candidate would confound design and wear effects.

Free strip length, reference clearance, and cylinder speed may serve as initial factors. Other geometric and material properties should be held constant where possible. Where a change in length also changes radial projection, the coupled modification should be declared explicitly. Factor ranges must follow geometric compatibility and the permitted operating envelope rather than assumptions about the desired result.

Cultivar, incoming impurity content, moisture content, and feed rate should be recorded for every run. Moisture measurements must identify whether they describe fiber or seed cotton and specify the reporting basis. Runs should be blocked by comparable material lots, with baseline and candidate order randomized within each block. Independent machine runs should be distinguished from multiple laboratory subsamples collected from a single run.

The number of independent replicates should be justified from pilot variability and the smallest practically relevant difference. Reporting should include replicate counts, measures of dispersion, measurement uncertainty, and the assumptions of any

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statistical analysis. The present analytical examples provide no basis for assigning a replicate count, confidence interval, or significance level to a future machine trial.

All stream measurements should use the same time interval. Differences in material retained within the machine at the beginning and end of a run, unmeasured dust flows, or changing moisture can invalidate a simple balance. Such discrepancies must be resolved or explicitly included before calculating removal indicators. Waste composition and fiber quality should be assessed separately, since low fiber loss does not by itself establish preservation of product quality.

An economic assessment should follow physical validation. Changes in saleable output must be considered together with additional electricity, replacement components, downtime, and maintenance. No annual savings or production-scale advantage can be derived from the hypothetical example alone.

Conclusions

1. Selected evidence supports joint assessment of cylinders, working strips, cleaning surfaces, and material flow. The effect of a parameter change depends on the surrounding configuration and contaminant type.

2. Impurity-mass removal, concentration reduction, and total waste discharge are distinct re-sponses. In the hypothetical balance, mass-based removal was 60.00% while concentration reduction was 58.33%; neither number represents a machine trial.

3. Free strip length, stiffness, radial projection, and dynamic clearance must be distinguished. Simplified mechanical and stage-wise relationships provide screening tools, not validated cleaning predictions.

4. A constraint-first comparison is proposed, followed by matched trials measuring cleaning, useful-material loss, quality, energy consumption, and operational stability. Experimental validation is required before recommending a production configuration.

5. Declarations

Data availability. No new experimental dataset was generated. All inputs for the illustrative calculations are specified in the article. Access to the unpublished technical source requires confirmation by its author.

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