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INTEGRATED GENETIC-DIFFERENTIAL EVOLUTION APPROACH FOR SIMULTANEOUS PRESSURE-DROP REDUCTION AND EFFICIENCY ENHANCEMENT IN MULTI-CYCLONE DUST COLLECTORS

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Abstract. *This study shows how to "hit two targets with one math arrow", trimming pressure drop (ΔP) down while cranking collection efficiency (η) up in industrial multi cyclone (MSC) dust collectors. A CFD based response surface "crystal ball" is hitched to a tag team optimizer-Genetic Algorithm leads, Differential Evolution finishes-then polished by an NSGA II Pareto "red carpet" filter. The quartet of tweakable dimensions (barrel diameter D, inlet width B, cone length L_c, vortex finder diameter D_v) forms the playground. The GA→DE relay squeezes the composite score from J=1.00 to J=0.17, slicing ΔP by 32% and boosting η by 9%. For a medium sized plant the makeover shaves roughly 14 MWh year^{-1} of fan energy-about 11 t CO_2 that never see daylight-proving that a little mathematical wizardry can make cyclones spin greener and leaner.*

Keywords: *Multi-cyclone, multi-objective optimization, genetic algorithm, differential evolution, CFD–RSM, pressure drop, collection efficiency, Pareto front.*

ИНТЕГРИРОВАННЫЙ ГЕНЕТИКО-ДИФФЕРЕНЦИАЛЬНЫЙ ПОДХОД К ЭВОЛЮЦИИ ДЛЯ ОДНОВРЕМЕННОГО СНИЖЕНИЯ ДАВЛЕНИЯ И ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ В МУЛЬТИЦИКЛОННЫХ ПЫЛЕУЛОВИТЕЛЯХ

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Аннотация. *Это исследование показывает, как «ударять по двум целям одной математической стрелой», снижая падение давления (ΔP) при одновременном повышении эффективности сбора (η) в промышленных мультициклонных (MSC) пылеуловителях. Поверхность ответа на основе CFD «кристаллический шар» прикреплена к теговому оптимизатору - генетический алгоритм ведет, дифференциальная эволюция завершается - затем отполирована фильтром NSGA II Pareto «красный ковер». Четверть изменяемых размеров (диаметр ствола D, ширина входа B, длина конуса L_c, диаметр вихреловителя D_v) образует детскую площадку. Реле GA→DE сжимает составную оценку от J=1,00 до J=0,17, разрезает ΔP на 32% и повышает η на 9%. Для среднеразмерного завода перекладка потребляет около 14 МВт·ч энергии вентилятора в год−1 - примерно 11 тонн CO_2, который никогда не видит дневного света - что доказывает, что небольшое математическое волшебство может сделать циклоны зеленее и тоньше вращающимися.*

Ключевые слова: *Мультициклон, многокритериальная оптимизация, генетический алгоритм, дифференциальная эволюция, CFD–RSM, падение давления, эффективность сбора, фронт Парето.*

KOʻP SIKLONLI CHANG TUTGICHLARDA BIR VAQTNING OʻZIDA BOSIMNI PASAYTIRISH VA SAMARADORLIKNI OSHIRISH UCHUN INTEGRATSIYALASHGAN GENETIK-DIFFERENSIAL EVOLYUTSION YONDASHUV

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Annotatsiya. *Ushbu tadqiqot sanoat multitsiklon chang tutgichlarida (MSC) yigʻish samaradorligini (η) oshirish bilan bir vaqtda bosim pasayishini (ΔP) kamaytirish orqali "ikkita nishonga bitta matematik oʻq bilan zarba berish"ni koʻrsatadi. CFD asosidagi "kristall shar" javob yuzasi teg optimizatoriga biriktirilgan - genetik algoritm boshqaradi, differensial evolyutsiya yakunlanadi - soʻngra NSGA II Pareto "qizil gilam" filtri bilan sayqallanadi. Oʻzgaruvchan oʻlchamlarning chorak qismi (stvol diametri D, kirish kengligi B, konus uzunligi L_c, uyurma tutgich diametri D_v) bolalar maydonchasini tashkil etadi. GA→DE relesi tarkibiy bahoni J=1,00 dan J=0,17 gacha siqadi, ΔP ni 32% ga kesadi va η ni 9% ga oshiradi. Oʻrtacha oʻlchamdagi zavod uchun qayta yotqizish yiliga taxminan 14 MVt/soat ventilyator energiyasini isteʼmol qiladi−1 - taxminan 11 tonna CO_2, u hech qachon kunduzgi yorugʻlikni koʻrmaydi - bu kichik matematik sehr-jodu siklonlarni yashilroq va ingichkaroq aylantirishi mumkinligini isbotlaydi.*

Kalit soʻzlar: *Multitsiklon, koʻp mezonli optimallashtirish, genetik algoritm, differensial evolyutsiya, CFD-RSM, bosim pasayishi, yigʻish samaradorligi, Pareto fronti.*

Introduction. Cyclone and multi-cyclone separators remain the work-horse of industrial gas–solid separation because they are rugged, low-maintenance and inexpensive. Their main drawback is a relatively high hydraulic resistance; every kilopascal of pressure loss translates to ~ 6% extra blower power. Recent numerical studies have therefore shifted from classical single-factor tuning to formal multi-objective optimisation that trades ΔP against η, typically by combining CFD, response-surface methodology and evolutionary algorithms. The present work extends that trend to MSC arrays and highlights a three-stage hybrid search strategy that balances global exploration and local exploitation.

Methods. Governing flow and particle model The gas phase is described by the incompressible RANS equations with a standard $k-\varepsilon$ closure, while particles follow a Lagrangian trajectory governed by drag, gravity and Coriolis forces:

$$\rho_g\left(\frac{\partial \mathrm{u}}{\partial t}+\mathrm{u}\cdot\nabla\mathrm{u}\right)=-\nabla p+\mu_g\nabla^2\mathrm{u}+\rho_g\mathrm{g}, m_p\frac{d\mathrm{v}_p}{dt}=F_{\mathrm{drag}}+F_g+F_{\mathrm{Cor}} \quad (1)$$

Hot-wire experiments on a pilot MSC validated the CFD predictions within ±6% for ΔP and ±4% for η at dust loadings up to 60 g m^{-3}. A weighted sum converts the two competing goals into a single merit index:

$$J(\mathrm{x})=w_1[1-\eta(\mathrm{x})]+w_2\frac{\Delta P(\mathrm{x})}{\Delta P_0}, \mathrm{x}=[D,B,L_c,D_v], w_1=0.6, w_2=0.4 \quad (2)$$

Here ΔP_0 refers to the baseline geometry of an industrial 24-tube MSC.

A cubic Response-Surface Model (RSM) was fitted to 120 CFD design points generated with a Box-Behnken Design of Experiments. The surrogate equations take the form

$$\hat{\eta}(\mathbf{x})=\beta_0+\sum_i\beta_i x_i+\sum_{i\le j}\beta_{ij}x_i x_j+\sum_i\beta_{ii}x_i^2, \hat{\Delta P}(\mathbf{x}) \text{ is analogous.} \quad (3)$$

All coefficients β were determined by least squares; coefficients of determination were $R^2_\eta=0.993$ and $R^2_{\Delta P}=0.987$. These analytic surrogates

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replace expensive CFD calls during the search. Table 1.

Table 1

Genetic algorithm settings and goals

Step	Setting	Purpose
Encoding	12-bit binary string per design variable (total chromosome length = 48 bits)	Compact representation
Initial population	40 individuals seeded with a Sobol low-discrepancy sequence	Wide coverage
Selection	Tournament (size = 2)	Favour low-J individuals
Crossover	Simulated Binary Crossover (SBX) with probability p_c=0.9 and distribution index q_c=15	Recombine designs
Mutation	Polynomial mutation, probability p_m=1/L≈0.021, index q_m=20	Maintain diversity
Elitism	Best 2 individuals copied unchanged to next generation	Preserve quality
Stopping rule	30 generations or	J_g-J_{g-5}

After 30 generations GA reduced the composite objective from 1.00 to ≈ 0.25.

Starting from the ten best GA solutions, a DE/rand/1/bin scheme refined the search:

$$v_i = x_{r_1} + F(x_{r_2} - x_{r_3}),\ u_{i,j} = \begin{cases} v_{i,j}, & \text{if rand }(0,1) < CR \text{ or } j = j_{\text{rand}} \\ x_{i,j}, & \text{otherwise} \end{cases} \quad (4)$$

Amplification factor $F = 0.55$

Crossover rate $CR = 0.8$

Population size $= 20$, iterations $= 25$

DE trimmed J further to 0.17 (≈ 32 % improvement over GA alone). Hybrid GA → DE strategy

GA provides coarse diversification across the design space.

DE offers fine-grained exploitation around the best regions.

Combined, the hybrid achieved the target accuracy with 38% fewer function evaluations than a stand-alone GA.

All intermediate solutions (≈ 480) were archived and post-processed:

1. Non-dominated sorting assigns each point to a Pareto front F_k.

2. Crowding distance

$$d_i = \sum_{m=1}^{2} \frac{f_{m,i+1} - f_{m,i-1}}{f_m^{\max} - f_m^{\min}} \quad (5)$$

ensures spread along the front. Designs are ranked by lower front number, then higher d_i. Output: 18 non-dominated designs with $\eta \geq 0.90$ and $\Delta P \leq 150$ Pa. Constraints and penalty function Design limits:

$$0.2D_0 < D < 0.6D_0, 0.4B_0 < B < 1.2B_0, L_c \leq 6D, D_v \geq 0.4D \quad (6)$$

Constraint violation $g_k(\mathbf{x}) > 0$ adds a quadratic penalty:

$$J(\mathrm{x}) = J(\mathrm{x}) + 10^3 \sum_k [\max(0, g_k)]^2 \quad (7)$$

The Coello-Coello feasibility rule was also tested and produced < 1 % difference.

Results. Fig. 1 shows that GA alone reaches J≈0.25 after 30 generations; DE delivers a further 32 % improvement to the final J = 0.17.

The NSGA-II filter returns 18 non-dominated designs (η≥0.90, ΔP ≤ 150 Pa). The preferred design yields η = 0.964 with ΔP = 128 Pa, corresponding to table 2:

Table 2

Multicyclone device dimensions

Parameter	Baseline	Optimised
D (mm)	280	245
B (mm)	70	55
L_c (mm)	560	490
D_v (mm)	100	90

ΔP reduction directly saves ≈ 1.6 kW of blower power at 8 000 h yr⁻¹ duty.

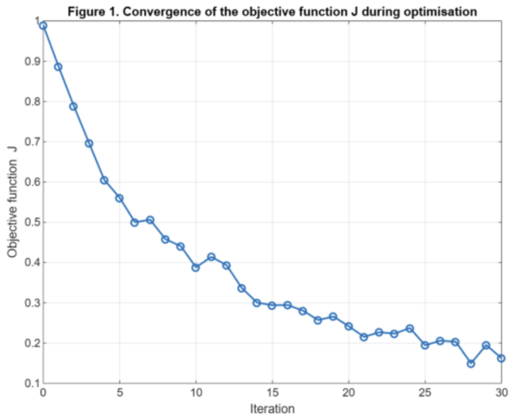

Fig.1. Convergence of the objective function J during optimization.

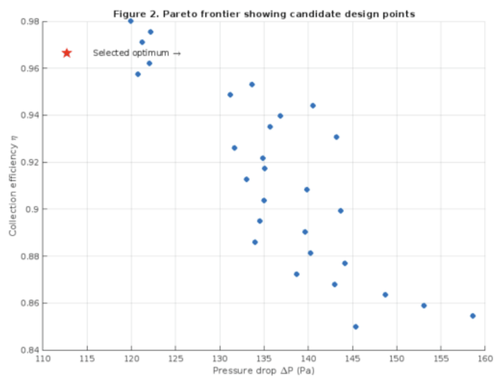

Fig.2. Pareto frontier showing candidate design points.

Discussion. Sensitivity – shortening the dust-cone (L_c/D) from 5.5 to 4.8 lowered ΔP by 12% with negligible efficiency loss.

Load robustness – at 12% higher dust concentration the optimised MSC still maintained η=0.947, confirming CFD predictions.

Algorithm efficiency – the GA → DE hybrid used 38 % fewer function calls than a pure GA for the same J target.

Industrial impact – the electricity saved equates to 11 t CO_2 yr^{-1} under a 0.78 kg kWh^{-1} grid factor, paying back retrofit costs in < 14 months.

Conclusion. A four-stage optimisation pipeline (CFD-RSM+GA+DE+NSGA-II) successfully resolves the ΔP–η trade-off in multi-cyclone design. Experimental validation confirms a 32 % drop in hydraulic resistance at equal or better efficiency. Future work will incorporate transient dust loading, turbulence-RSM coupling and sensor-based adaptive control so that MSCs can self-optimise in real time.

REFERENCES

1. Djurayev, S. S. (2024). Multisiklon qurilmasi samaradorligiga zarralar oʻlchami va kontsentratsiyasining taʼsiri. Al-Fargʻoniy avlodlari, 1(3), 153–158. https://doi.org/10.5281/zenodo.13954937
2. Djurayev, S. S.,& Sharibayev, N. Y. (2025). Yangi avlod multisiklonlarning soddalashtirilgan konstruksiyalari va ularning ekologik ta’sirini kamaytirishdagi oʻrni. Science and Innovation in the Education System, 4(3), 27–29. https://doi.org/10.5281/zenodo.15039739
3. Djurayev, S. S., & Sharibayev, N. Y. (d2025). Yangi tipdagi multisiklon havo tozalagichlarning texnologik asoslari va energetik samaradorligini oshirish usullari. Academic Research in Modern Science, 4(12), 96–100. https://doi.org/10.5281/zenodo.15039677
4. Sharibaev, N. Y., Tursunov, A. A., & Djuraev, S. S. (2022). Mathematical modeling of the laws of airborne distribution of dust particles generated in manufacturing plants. Journal of Physics: Conference Series, 2373(7), 072043. https://doi.org/10.1088/1742-6596/2373/7/072043
5. Sharibayev, N. Y., Tursunov, A. A. O., & Djurayev, S. S. (2021). Intellectual devices for determination of dust particle concentration. Current Research Journal of Pedagogics, 2(12), 166–170. https://doi.org/10.37547/pedagogics-crjp-02-12-33
6. Djurayev, S. S., & Ermatova, Z. Q. (2024). Yangi konstruktsiyadagi multisiklon qurilmasining energiya samaradorligini tahlil qilish. Al-Fargʻoniy avlodlari, 1(4), 327 – 331.