NOVEL HYBRID CYCLONE GEOMETRIES IN CFB SYSTEMS AS A TOOL FOR REDUCING PRESSURE LOSSES AND IMPROVING ENERGY EFFICIENCY

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Introduction

Circulating Fluidized Bed (CFB) boilers are recognized as one of the most advanced technologies for energy generation from solid fuels, providing stable combustion, flexible load regulation, and in-situ removal of gaseous pollutants. Cyclone separators, a key component of these systems, recover solid particles from the flue gas and return them to the bed, ensuring a stable thermal balance and reducing particulate emissions.

Conventional cylindrical cyclones offer high collection efficiency but suffer from major drawbacks: significant pressure losses increasing fan power demand and difficulties in applying multi-layer refractory linings required at high CFB operating temperatures. Square cyclones, by contrast, allow easier lining installation on flat surfaces and better integration with the boiler, thus reducing system complexity and energy losses.

Recent advances in Computational Fluid Dynamics (CFD) and flow diagnostics enable the investigation of novel cyclone geometries designed to combine high separation efficiency with reduced pressure losses, without costly system modifications. This poster presents recent research on innovative cyclone designs for CFB applications.

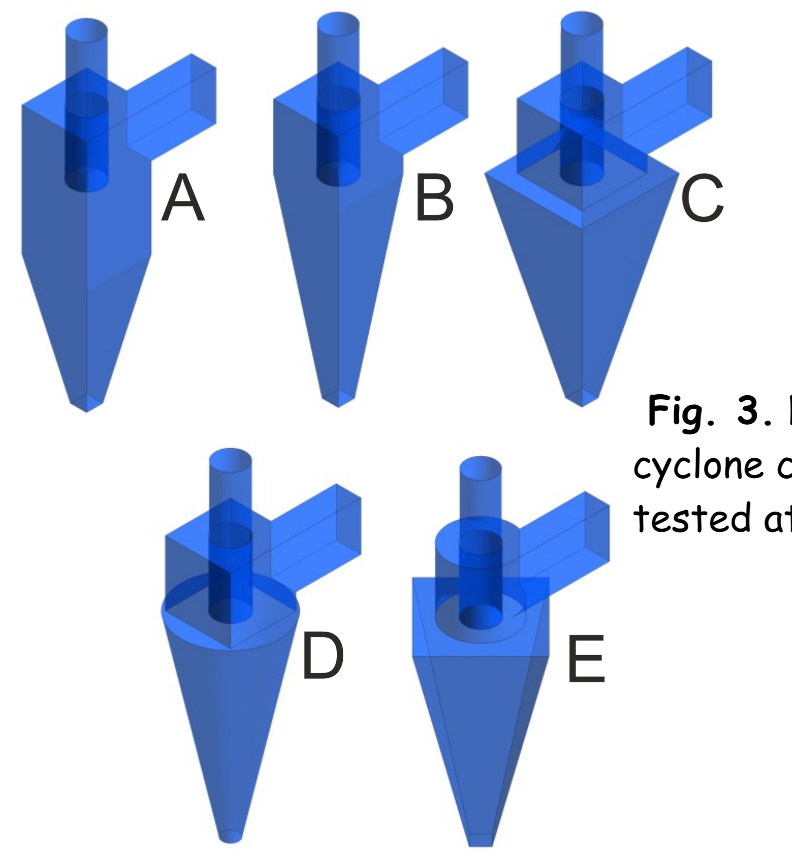

Fig. 3. Novel hybrid cyclone configurations tested at 300–1000 K.

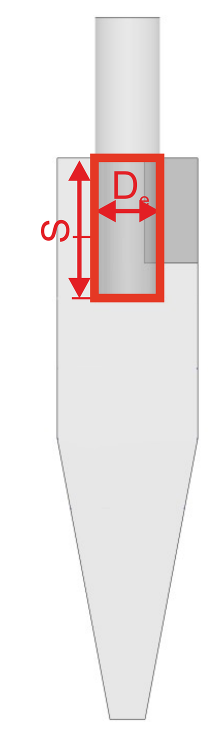

Fig. 4. Vortex finder geometry

Objective

The aim of this study was to analyze selected non-standard design solutions of cyclone separators used in CFB systems in the context of improving energy efficiency and enhancing their performance as air pollution control devices. Particular attention was given to assessing the influence of geometric modifications on the efficiency of fine particle separation, the reduction of pressure losses, and the stability of the internal flow field. The objective was to identify configurations that would simultaneously increase dust collection efficiency and improve the overall energy balance of the installation, thereby supporting compliance with increasingly stringent environmental regulations.

Materials and Methods

Four analyses were carried out addressing design modifications of cyclone separators applied in CFB installations. The study was based on Computational Fluid Dynamics (CFD) and, in selected cases, supported by experimental investigations and Particle Image Velocimetry (PIV) measurements. Simulations were performed in ANSYS Fluent using the finite volume method and Large-Eddy Simulation (LES) turbulence models, considered most suitable for capturing anisotropic flow structures. A single-phase description of the gas medium with a dispersed solid phase was adopted in the Euler–Lagrange framework. The efficiency of separation was evaluated using grade efficiency curves (GEC), overall collection efficiencies, and the critical cut-off diameter Stk_{50}.

- **Prismatic section height of the square cyclone** (Fig. 1) – Seven variants with different prismatic section heights were investigated.
- **Hybrid square–cylindrical geometries** (Fig. 2) – Five variants were analyzed: a baseline square model and four hybrid configurations combining square and cylindrical segments in different arrangements.
- **Effect of gas temperature on cyclone performance** (Fig. 3) – Five novel hybrid variants were examined over a temperature range of 300–1000 K.
- **Vortex finder geometry in square cyclones** (Fig. 4) – Fifteen configurations were studied, differing in diameter and insertion length of the clean gas outlet channel.

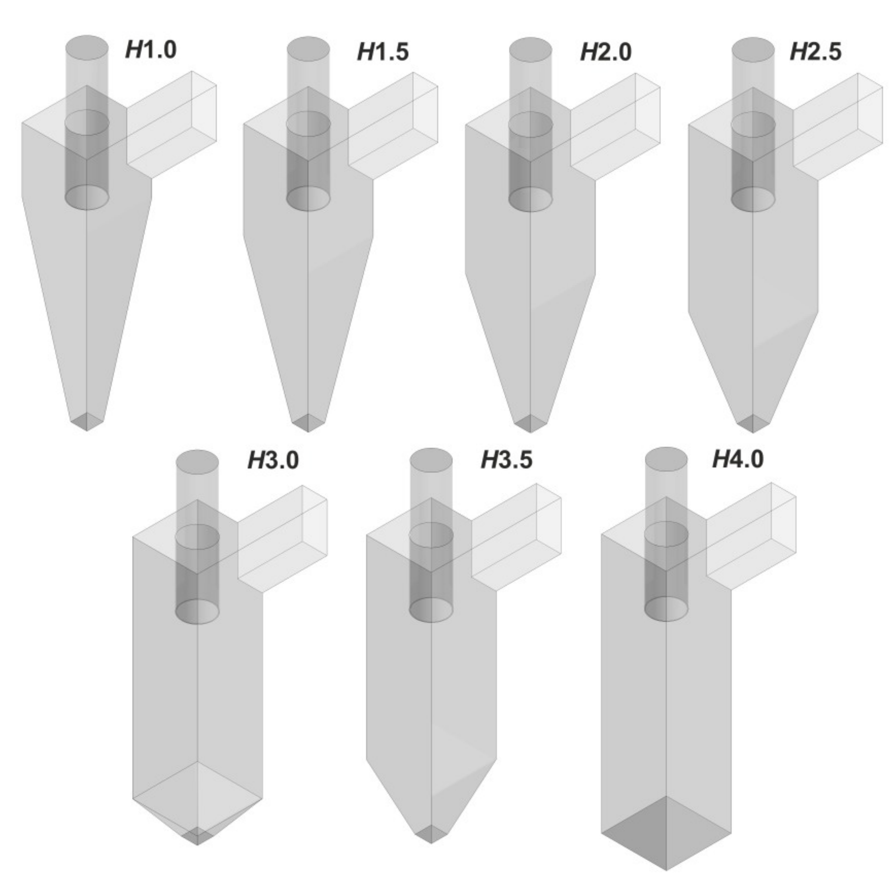

Fig. 1. Prismatic section height of the square cyclone

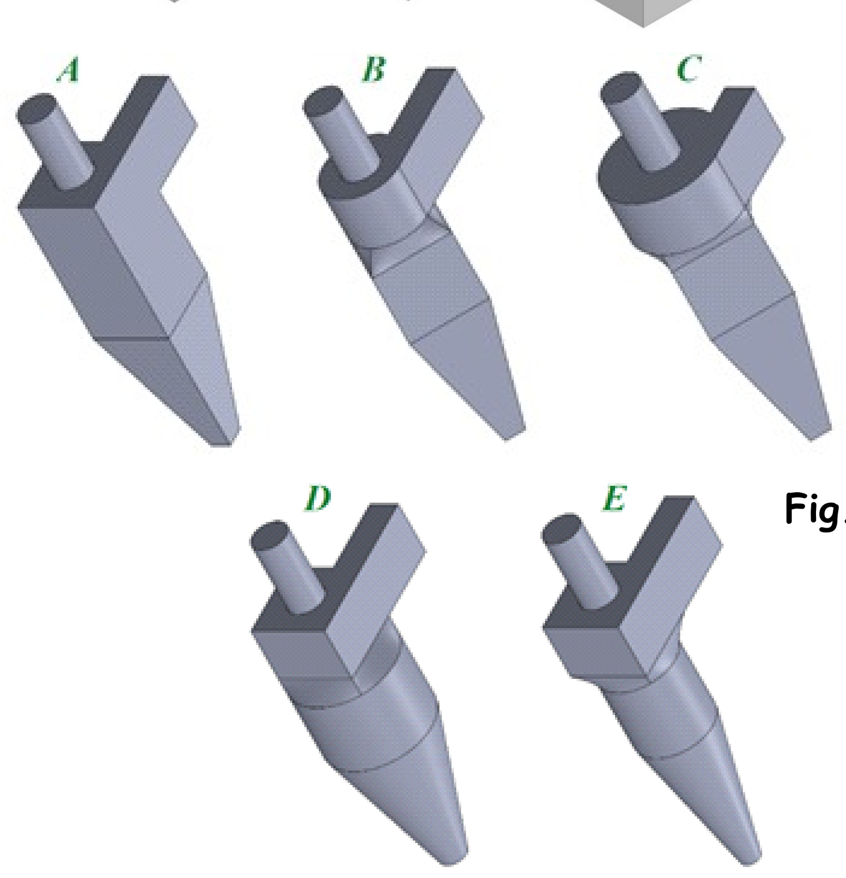

Fig. 2. Hybrid square–cylindrical geometries

Results

1. Prismatic section height (PH) of the square cyclone

- Increasing the prismatic section height (PH) improved the collection efficiency for fine particles <20 μm.
- The Stk_{50} decreased, enhancing the separation of smaller fractions.
- Pressure losses increased moderately (Eu + 8–12%).
- Higher PH values resulted in more uniform axial and tangential velocity profiles.
- Intermediate PH variants (e.g., H2.0 and H3.0) provided the best compromise: η increased by approximately 10% with Δp rising by less than 12%.
- Excessively large PH (H4.0) led to higher Δp without proportional improvement in η.

2. Hybrid square–cylindrical configurations

- Hybrid constructions improved collection efficiency by 6–8% compared to the baseline square variant A.
- Variants with a cylindrical lower section (D and E) enhanced particle transport toward the solids discharge.
- Models D and E exhibited more symmetrical flow fields and reduced local recirculation in the corner regions.
- Pressure losses in these variants remained comparable to the baseline cyclone.
- Variant D (square upper section, cylindrical lower section) achieved the highest η, increased by 7–8% with Eu close to the baseline.
- Variant E (cylindrical upper section, square lower section) also improved η, though slightly less than D.

3. Effect of temperature on the performance of hybrid constructions

- In the baseline square cyclone A, η decreased by as much as 6–7% at T=1000 K.
- Hybrid constructions maintained η >85% across the entire temperature range studied.
- Increasing temperature resulted in only a moderate rise in Δp (+ 5–8%).
- The growth of Stk_{50} was significantly slower in hybrid variants than in the baseline.
- Flow fields in variants D and E were more stable compared to A.
- Variant D delivered the best results: η above 87% at T=1000 K with Δp increased by only ~6% compared to T=300 K.

4. Vortex finder geometry in square cyclones

- The smallest diameters increased η by 10–16% but caused a substantial rise in Δp (Eu increased by 660% vs baseline).
- Intermediate diameters (e.g., variants C2 and C3) improved η by about 8–10% with a moderate increase in Δp.
- Extending the vortex finder insertion length reduced Stk_{50}, favoring the separation of finer particles.
- Changes in insertion length affected the distribution of recirculation zones and the balance of axial and tangential flows.
- The most stable flow fields were obtained with intermediate diameters and moderate insertion lengths.
- Extreme configurations (smallest diameters with large insertion lengths) achieved the highest η but at the cost of very high Δp.

Conclusion

The conducted analyses demonstrated that design modifications of cyclone separators in CFB systems can significantly enhance particle separation efficiency while maintaining pressure losses at an acceptable level. The most favorable results were obtained for hybrid configurations combining square and cylindrical segments and for vortex finder variants with intermediate diameters, which provided a beneficial compromise between collection efficiency and energy performance. The studies further revealed that properly selected prismatic section heights and temperature-resistant configurations maintained high separation efficiency even under the demanding operating conditions of CFB boilers. These findings highlight the practical potential of implementing novel cyclone designs to improve energy efficiency and reduce particulate emissions.