Advanced
Cyclone
Systems

Particulate Matter
Emission Control
& Air Dedusting

Hurricane & ReCyclone® Systems

Advanced Cyclone Systems (ACS)

Towards total particle capture with optimized cyclone systems

ACS is a company exclusively dedicated to the development and supply of the most efficient cyclone systems worldwide.

ACS Focus

We focus on **particulate matter (PM) emission control (EC)** in boilers, furnaces and dryers.
We also work on enhancing **powder recovery (PR)** in pharmaceutical, food and chemical processes.

ACS Mission

Achieving particle capture **exclusively with cyclones** by continuously researching and innovating, freeing the client from the costs and problems of **Electrostatic Precipitators (ESPs) and Bag filters (BF)**.

ACS Approach

We work in close cooperation with our clients, designing customized cyclones that solve their filtration problems. Unlike most cyclone providers, we give **strict guarantees of emissions and efficiency**.

ACS has been the chosen company for over 350 projects in 37 countries all over the world.

About ACS Cyclones

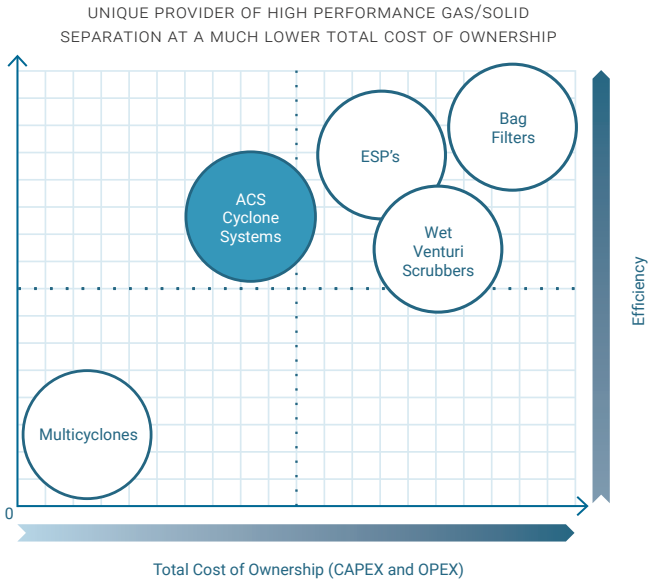
ACS cyclone systems contradict the general thinking that cyclones are inefficient powder collectors.

Hurricane cyclone geometries, with the possibility of recirculation (**ReCyclone Systems**) have proven to be an alternative to ESPs and BFs in numerous plants all over the world to comply with strict limits, reaching emissions as low as 30mg/Nm^3.

Why are our cyclones better?

We have a **specialized scientific knowledge** in particle agglomeration modeling (PACyc) and numerical optimization in partnership with the Engineering Faculty of Porto (FEUP) where we run a pilot system for R&D.

The revolutionary concept of **particle agglomeration** is essential to explain how cyclones really work and, consequently, to optimise them. The outcome of our research is not an universal solution, but a set of very different cyclone families and systems serving particular client needs and customizable for each given application.



Particulate Matter Emission Control & Air Dedusting

A problem common to many industries

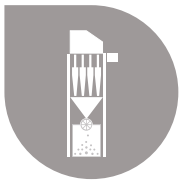
Application Fields

- Biomass and Coal Combustion
- Biomass Dryers
- Pyrolisis, Incineration and Gasification
- High Temperature Separation Processes for Energy Recovery
- Clinker Cooler and Pre Heater Dedusting
- Calcination Processes
- Steel and Ferroalloys
- Fuel Oil Combustion
- Glass & Ceramic Furnaces
- Air Caption & Dedusting

Particulate matter (PM) emission control is a common problem in industries that operate **boilers** or **incinerators** for **energy production**, or **furnaces**, **kilns** and **dryers** for the manufacturing of products, such as **ceramics**, **cement** or **pellets**.

Complying with stack emission limits, **avoiding the carry-over of particles** to downstream processes or **purifying ambient air**, are the main motivations for clients to **reduce PM emissions**.

Main dedusters and drawbacks



Regular Cyclones and Multicyclones | Problem: **Low Efficiency**

Preferred technology for particle collection in industrial boilers and furnaces due to its robust construction, absence of moving parts and general application (low CAPEX).
Main drawback: low efficiency for small particles (<10µm) leading to non-compliance with new emission limits.

Bag & Ceramic Filters | Problem: **O&M costs**

Bag filters are very efficient (> 99.9 %) but can be very maintenance demanding in the presence of high temperatures due to frequent cleaning and changing of filter elements, which are frequently attacked by glowing particles. The ceramic filter solution is more expensive and costly to operate. In drying applications, filter clogging is a frequent problem due to high moisture.

ESPs | Problem: **High Investment**

Robust equipment with low pressure drop and very effective for a given range of dust required. However, efficiency may drop outside that range as a consequence of temperature changes. Require to be operated by trained and specialized personnel. Ultimately, ESPs high investment costs are out of reach of many companies.

Wet Venturi Scubbers and WESPs | Problem: **Secondary Pollution**

Scrubbers can be very efficient by increasing pressure drop and energy costs. WESPs work with low pressure drops but have high OPEX and CAPEX. Both require the use of water, originating secondary pollution.

ACS Solution: Very high efficiency cyclones complying with strict emission guarantees

About Hurricane Cyclones

ACS numerically optimized cyclones

hurricane

How can cyclones be improved?

Since the early 1900's, cyclones have been mostly designed and improved by empirical means, due to the difficulty of building a good prediction method that handles with the modeling complexity related with multiphase and highly turbulent flows. Computerized Flow Dynamics (CFD) can be used for partial cyclone optimization but it is still incomplete for full cyclone optimization, due to the very large computational burden associated with highly vorticial, assimetrical and multiphase flows with polidispersity. Sub-optimization of cyclones, and notably low collection efficiency result from the fact that **particle agglomeration in cyclones** has been disregarded until present days.

How can cyclones be improved?

Near 350 projects implemented in the past 12 years, helped ACS develop a complete line of very different **Hurricane cyclone** families, with each family responding to a particular need from the client and considering how inter-particle agglomeration / clustering affects collection efficiency. From coarse particle pre-separation proportioned by compact and low pressure drop cyclones, such as the **SD and DX**, to fine particulate capture with high-end geometries such as the **EX and MK**, ACS provides solutions for a wide range of industrial cases, being able to reach emissions comparable to ESPs (down to less than 30mg/Nm^3).

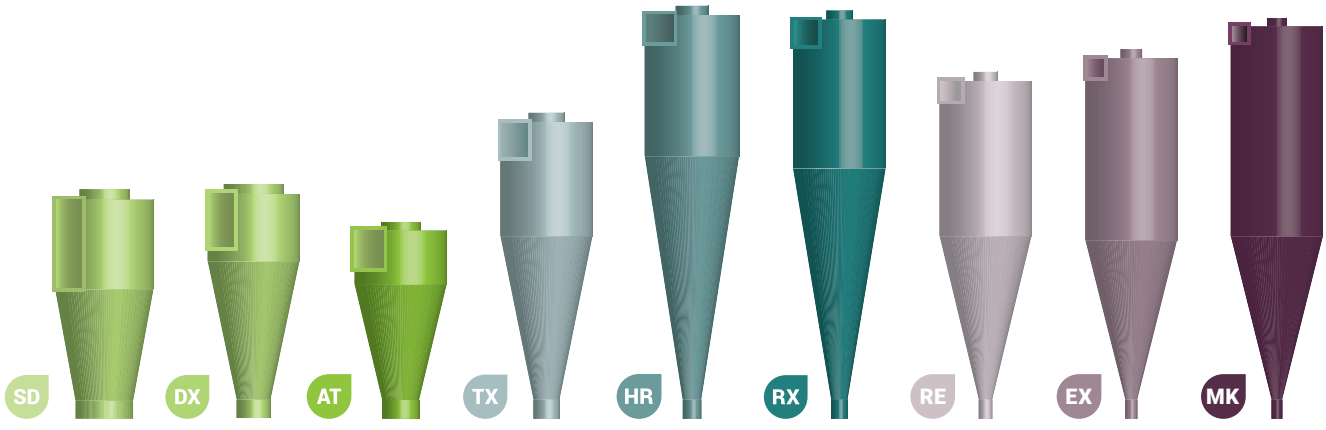
Particle Agglomeration and Numerical Optimization

ACS research team has been investigating this phenomenon since its foundation. Several related technical and scientific articles were published, among which the **"Impact of particle agglomeration in cyclones" (Chemical Engineering Journal 162 (2010) 861–876)".** This knowledge has helped ACS build very accurate models of efficiency prediction, capable of explaining why sub-micrometer particles are often captured with much higher efficiency than expected. Indeed, particles tend to form bigger agglomerates (clusters) much easier to collect than the original particles. Agglomeration increases in the **presence of wide particle size distributions, long residence times in the cyclone and high inlet particle concentrations.** This knowledge has been incorporated in ACS numerical simulation tool, combining a sophisticated stochastic algorithm with a classical numerical model to predict cyclone performance: **the PACyc (Particle Agglomeration in Cyclones) model.**

Creating multiple cyclones for multiple needs

Thanks to the PACyc Model, and considering several economic and operation constraints (such as size and pressure loss), it is possible to **simulate millions of virtual prototypes** with numerical optimization within an affordable period. Considering this approach as the best path to obtain truly optimized cyclones, sound theories of cyclone collection and pressure loss were chosen for each process application. These numerical optimization problems have resulted in several families of cyclones, some of those patented. Indeed, different industrial cases have **different needs** for which the optimization functions to incorporate in the PACyc model may be as complex as **minimizing cost or space, subject to a minimum efficiency result**.

The following cyclone families, always subject to further customization, are the result of very different client demands ACS has come across until now.



Alternative Cyclone Solutions

A Real Case Analysis: **Biomass Industrial Boiler Dedusting**

Designing a cyclone solution for PM reduction:

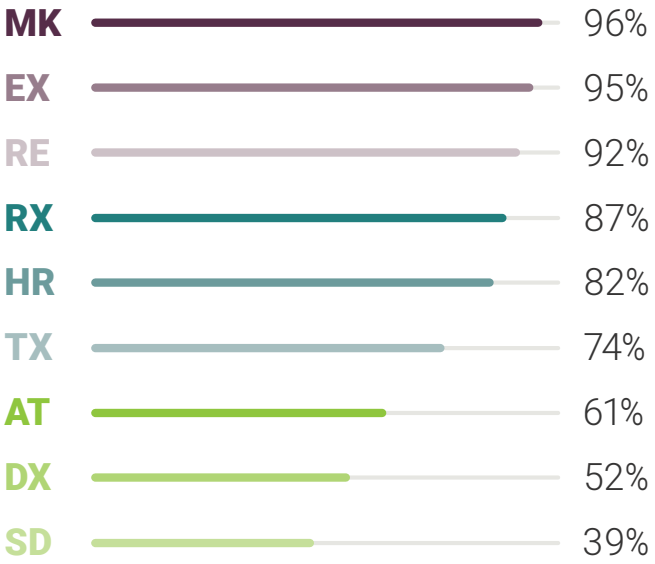
Depending on the requirements of the client ACS may design solutions that go from a **compact pre-separator** for sparks and silica reduction (protection of downstream equipment) to a **final stage dust collector.** The more efficient the solution is, the larger the number of cyclones needed to increase residence time and promote particle agglomeration with impact of space and cost. ACS will always search for the most cost efficient solution. Please compare the performance of several products below for the given industrial example.

Industrial example operating conditions:

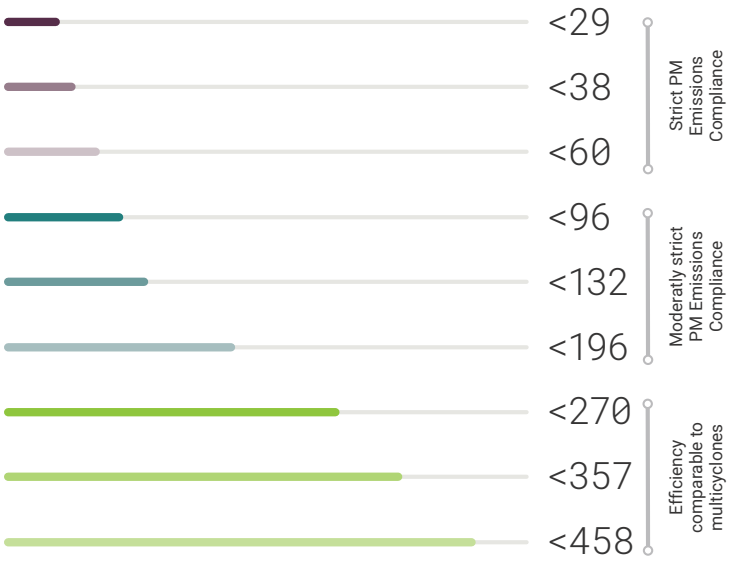
4MW$_{th}$ wood chips moving grate boiler

FUEL	Wood Chips
MEDIAN VOLUME BASED PARTICLE SIZE	11µm
INLET CONCENTRATION	750mg/Nm^3
GAS TEMPERATURE	180°C
FLOW RATE	18 000m^3/h
MOISTURE CONTENT IN FLUE GASES	8%(v/v)

Global Efficiency (%):



Emissions (mg/Nm^3):



Cyclones needed (ø1000mm):

System size:

100%
65%
53%
33%
23%
15%
10%
7%
6%

Objectives / Applications:

- The agglomerator cyclone – Maximum agglomeration
  Most efficient cyclones available on the market
- Ultra high effciency with agglomeration to compete with ESPs
- Very high efficiency cyclone with agglomeration for strict emissions
- Final stage dedusting for stricter emission limits
- Compact high efficiency cyclones for multiple applications
  Half the emissions of Multicyclones
- Final stage dedusting for moderate emission limits
  Better performance than multicyclones
- Enhanced Pre-Separation
  Sparks & silica reduction upstream of dryers
- Improved pre-Separation for coarse and medium particle size
  Alternative to axial multicyclones
- Coarse particle separation
  Abrasion reduction before other cyclones and fans

ReCyclone Systems®

Mechanical and Electrostatic Recirculation

ReCyclone® System

ReCyclone® (MH and EH)

A ReCyclone is made up of a high efficiency **Hurricane** and a **particle separator**, placed downstream, called the **"recirculator"** (please see figure) and which can be purely mechanical or electrostatic.

The main purpose of the recirculators is to reintroduce the uncaptured particles into the cyclones after they have been driven to the outer walls of the recirculators by centrifugal and/or electrostatic forces. While this gas is enriched in particles, the axial gas stream exhaust to the stack is clean of particles. Recirculation is achieved by an additional fan.

Since the recirculation system only serves the purpose of dust separation (and not collection), the particles are exclusively collected in the cyclones and the need of rapping mechanisms is avoided. ReCyclone systems are arranged in groups of cyclones and recirculators.

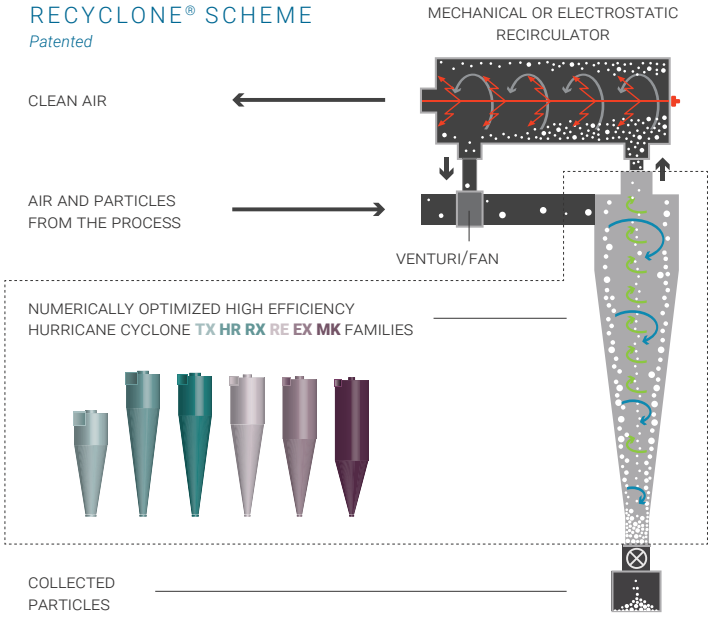
Efficiency increase

Efficiency increases due to recirculation and agglomeration of very small particles with larger ones coming directly from the process. A **ReCyclone** decreases emissions of Hurricane cyclones alone by 30 to 80%. Controlling recirculation has the benefit of handling **variable flowrates** better than with cyclones alone.

A ReCyclone® enhances the efficiency of any given cyclone family, decreasing its emissions by 30 to 80%

RECYCLONE® SCHEME

Patented



RECYCLONE® FEATURES

- Very high efficiencies: decreases emissions of any ACS Cyclones by [30-80]%
- Very low emissions: [10-45]mg/Nm³ is achievable for many combustion sources
- Pressure drop: [150-220] mm w. g.
- No temperature restrictions with an appropriate alloy steel or refractory selection
- Recirculation assures a reasonable velocity in the cyclones
- Robust construction with no moving parts (no rapping mechanisms)
- Low maintenance and downtime costs
- Low investment costs

Examples of finished and ongoing projects

APPLICATION	EFFECTIVE FLOW RATE (m³/h)	TEMP. (°C)	MEDIAN PARTICLE SIZE (µm)	CYCLONES DIAMETER (mm)	PRESSURE DROP (mm w. g.)	INLET CONCENT. (g/Nm³)	EFFICIENCY (%)	EMISSIONS (mg/Nm³)
MH | Wood chips grate boiler | France	5 460	180	8	600	200	0.25	> 86	< 50
MH | Drying of organic fertilizer | Spain	50 400	40	35	1050	200	1.58	> 97	< 50
EH | Wood pellet grate boiler | D.Republic	25.306	250	8	800	150	0.30	> 95	< 15
EH | Pine residues grate boiler | France	3.900	180	11	600	160	0.2	> 90	< 20

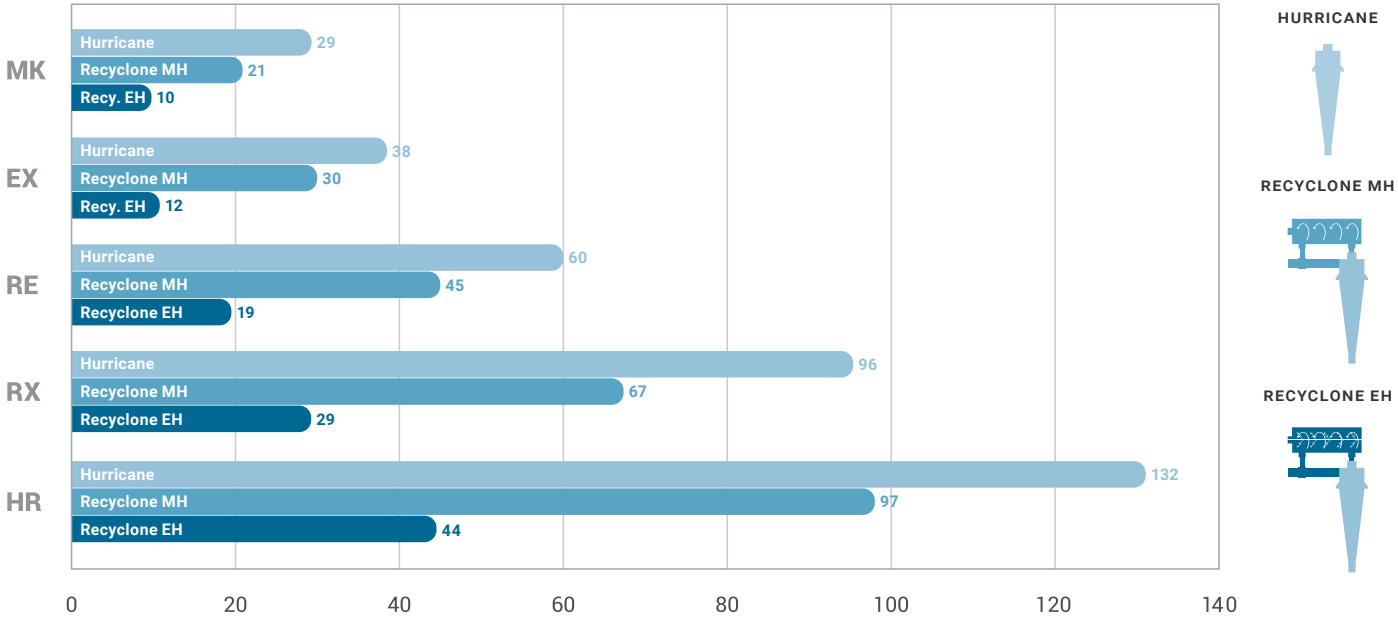
Technology Comparison

Hurricane® Cyclones | ReCyclone® MH | ReCyclone® EH | Other Technologies

Approach to any new project

Whenever it is possible to achieve a requested emission limit or efficiency with a given optimized cyclone geometry, ACS will avoid recirculation, in order to reduce investment and operating costs (mainly power consumption of fans). In case emission limits become stricter, in the future, any hurricane family can be coupled with mechanical or electrostatic recirculation to increase efficiency. This staged investment is much easier to support than a one shot expenditure in a Bag Filter or ESP.

Residual emissions comparison between ACS produtcs



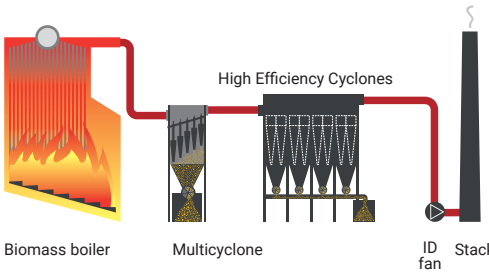
Residual emissions (mg/Nm³) at the stack from page 5. Example: 4MW$_{th}$ biomass boiler

Technology comparison between ACS and other products

Technology comparison for wood chip combustion	Multicyclones	Wet Venturi Scrubbers	Bag filters	ESP´s	Hurricane systems	ReCyclone® MH systems	ReCyclone® EH systems	
Efficiency (%)	50 to 80	89 to 93	98-99 +	95 to 99	82 to 96	87 to 97	94 to 99	Maximize Efficiency
Emissions: (depending on Hurricane collector)	> 150	49 to 70	< 20	5 to 35	29 to 132	21 to 97	10 to 44	
Temperature limitations (°C)	No	No	< 250	Yes	No	No	<400	
Fire risk	No	No	Yes	No	No	No	No	Universal Application
Resistivity sensitivity?	No	No	No	High	No	No	Low	
Pre-separation needed?	No	No	Always	Frequently	Unfrequent	Unfrequent	Unfrequent	
Consequences of electrical field failure	None	None	None	Plant shut down	None	None	Works mechanically	
Moving/replacement parts	No	No	Yes	Yes	No	No	No	
Relative investment costs	20/100	(45 to 55)/100	60/100	100/100	(35 to 55)/100	(45 to 65)/100	(60 to 70)/100	Minimize Total Cost of Ownership
Relative operating costs (Energy and Maint.)	4/100	20/100	20/100	10/100	4/100	6/100	10/100	
Future retrofitting costs	Very low	Low	Low	Very high	Very low	Very low	Very low	
Downtime costs	Very low	Low	High	Low	Very low	Very low	Low	
Comments	Dry-System	Sec. Pollution Needs Treatment	Dry-System	Dry-System	Dry-System	Dry-System	Dry-System	

Indicated values are from page 5. Example: 4MW$_{th}$ biomass boiler. Range of emissions figures depend on the type of cyclone family used

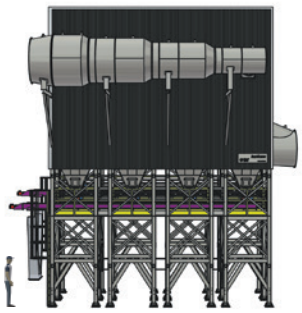
Case Studies for Biomass Industrial Boilers



ACS has supplied hundreds of high efficiency cyclone systems worldwide to comply with strict particulate matter (PM) emission limits in industrial biomass boilers. Typically, the cyclones are placed after the boiler's pre-separator (Multicyclone) instead of a Bag Filter or an ESP. Depending on the case, they can also operate without any pre-separator upstream.
The system is supplied in pre-assembled modules of cyclones to be very easily transported and installed.

Hurricane RX system for a moving grate 60t 67bar ICAVI boiler burning wood chips.

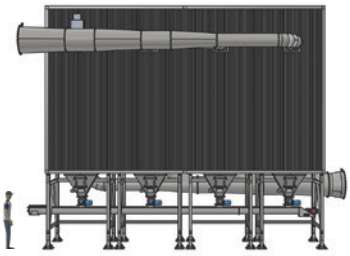
Flowrate: 188 861m³/h at 153°C
Emissions: <100mg/Nm³ at 8%O_2
Country: Brazil | 2017
Client: **SSB Energia**



H 11m **L** 10m **W** 5m

Hurricane RE system for a moving grate 15t/h wood chip Bremer boiler to reduce PM from 400mg/Nm³, after MC, to less than 65mg/Nm³ at 8% O_2.

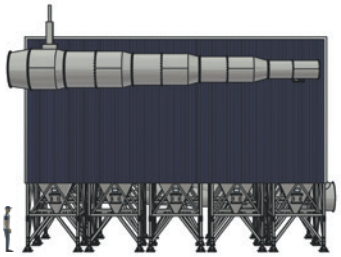
Flowrate: 35 000m³/h at 170°C
Emissions: <65mg/Nm³ at 8%O_2
Country: Brazil | 2016
Client: **Bremer** / User: Santa Clara



H 7,5m **L** 9m **W** 2m

Hurricane EX System to reduce particulate matter from sawdust & wood shavings from a 20MWth biomass boiler.

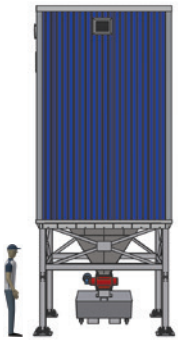
Flowrate: 99 000m³/h at 200°C
Emissions: <100mg/Nm³ at 12%CO_2
Country: Australia | 2018
Client: **OneFortyOne**



H 9m **L** 13m **W** 5m

Hurricane MK system to reduce particulate matter from an Agrofrost moving grate wood chip boiler.

Flowrate: 3 200m³/h at 180°C
Emissions: <50mg/Nm³ at 6%O_2
Country: France | 2014
Client: **Sciérie de Miremont**



H 6m **L** 1,7m **W** 2,5m

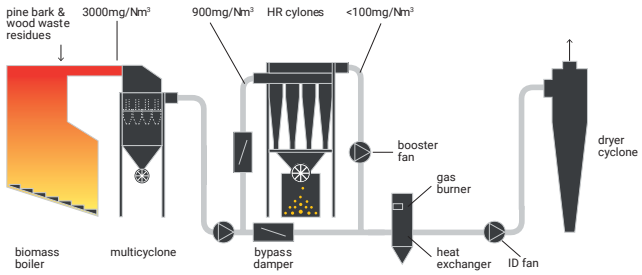
Case Studies in the Wood Panel Board & Pellet making industries

ACS technology has multiple benefits whenever there are biomass furnaces and dryers. That is especially the case in the wood panel and pellet making industries. ACS cyclones can be optimized to serve as compact **1st stage separators** before ESPs or Bag Filers in **large combustion plants** or before **dryers** in order to reduce silica and sparks content or unburnt content in the dried wood chips or shavings, thereby improving product quality. Additionally, numerically optimized cyclones can serve as **end stage dedusters** both after **biomass furnaces (boilers / thermo-oil heaters)** and after **rotary dryers** in particle board and pellet plants. There are multiple other separation challenges for which cyclones are useful such as the **hammer mills** and the **flakers**.

Hurricane HR cyclones to reduce fly-ash and unburnt particulate before the dryer

Sonae Indústria is one of the largest wood-based panel producers in the world.

Problem and solution Sonae was forced to use a natural gas hot gas generator for drying fiber, despite having the necessary amount of thermal energy available in the exhaust stream of a wood waste thermal oil heater (TOH). The problem of using the TOH laid on the emissions of ash and unburnt particulate which were carried over with the dried fiber and deposited on the final product – the wood panel boards. These were systematically rejected by quality inspections. ACS enabled using the TOH with a system comprising 60 Hurricane HR numerically optimized cyclones with ø800mm designed to reduce particulate under 100mg/Nm³ and unburnt particulate to a level which could fully eliminate quality control rejections.



Resumed Design Conditions:

Fuel	Pine bark and wood waste residues
Inlet dust concentration (after multicyclone)	900mg/Nm³
Gas flow temperature	303°C
Actual flow rate	247 000m³/h

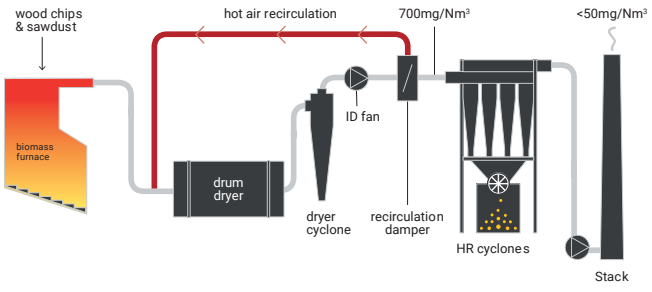
Output/Performance:

Residual emissions	<100mg/Nm³
Pressure drop	1.0kPa

Hurricane HR cyclones to control fly ash & sawdust fines emissions before the stack

Glowood produces 100,000 tons of **pellets** per year in Cercal, Alentejo, Portugal, mainly for export.

Problem and solution Glowood runs a biomass furnace with the exhaust stream drying the feedstock in a drum dryer. Due to furnace and cyclone inefficiency, PM emissions at the stack were as high as 700mg/Nm³, representing losses of material and essentially an environmental problem. ACS designed a system comprising 6 Hurricane HR numerically optimized cyclones with ø1550mm, disposed in line, to reduce emissions under 50mg/Nm³.



Resumed Design Conditions:

Fuel	Fines of mill sawdust escaping dryer cyclones
Inlet dust concentration	700mg/Nm³
Gas flow temperature	87°C
Actual flow rate	71 839m³/h

Output/Performance:

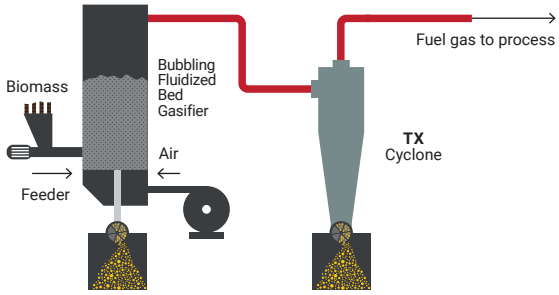
Residual emissions	<50mg/Nm³
Pressure drop	1.2kPa

Case Studies High Temperature Processes (Combustion, Incineration, Gasification, Pyrolysis)

ACS has been involved in multiple **waste-to-energy** projects where cyclones can separate particles at very high temperatures (up to 1000°C). Fuel can include various types of biomass, from forestry biomass to animal waste and from Municipal Solid Waste (MSW) to Refuse Derived Fuel (RDF). The use of customized cyclones unfolds in several advantages which includes **protecting downstream equipment, reducing operating costs** and **enabling energy recovery** and **carbon capture** in the form of biochar after fast pyrolysis or via solid sorbents.

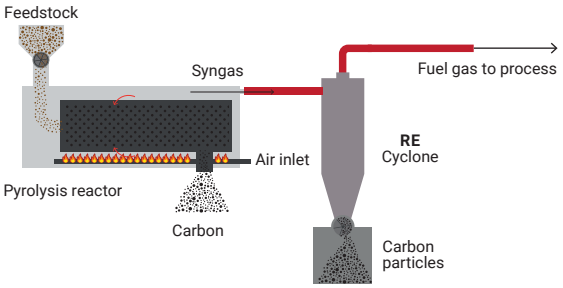
Hurricane TX type to separate particulate matter from syngas, coming from the gasification of meat and bone meal (MBM) on a Bubbling Fluidized Bed gasifier.

System: 1 TX ø1750
Actual flow rate: 30 000 m³/h
Temperature: 750°C
Expected efficiency: 91.1 - 96.3%
Country: Spain
Client: **WTEnergy**



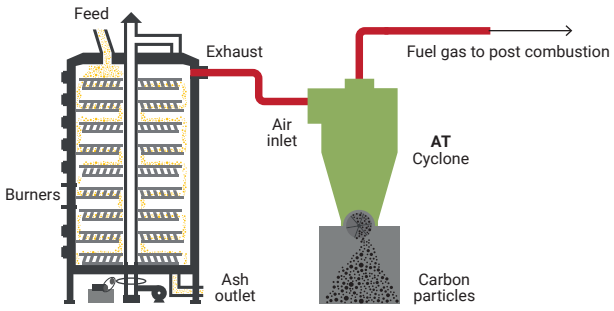
Hurricane RE type cyclone to capture particulates of carbon originated in a pyrolysis process of urban residues thereby cleaning the gas for combustion with minimal CO_2 emissions.

System: 1 RE ø 1100
Actual flow rate: 4 000m³/h
Temperature: 600°C
Expected efficiency: 77 - 89%
Country: Brazil
Client: **ZEG**



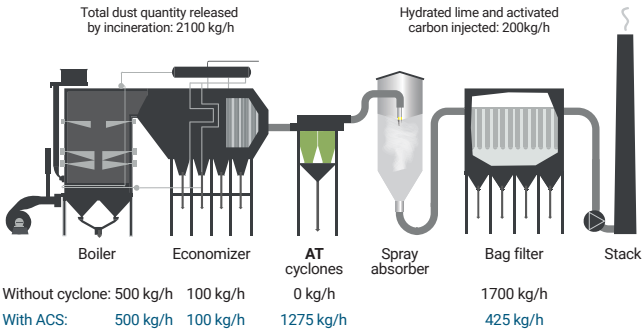
Hurricane AT type cyclone to separate particulate matter from the flue gas coming from a regenerator of activated carbon (Multiple Hearth Furnace technology), before post combustion.

System: 1 AT 1600
Actual flow rate: 17 391 m³/h
Temperature: 450°C
Expected efficiency: 89 - 89.5%
Country: Belgium
Client: **JOHN COCKERILL**



Hurricane AT cyclones to reduce the amount of hazardous fly ash before spray absorber in an incineration plant.

System: 8 AT 2000
Actual flow rate: 280 000m³/h
Temperature: 360°C
Expected efficiency: 85%
Country: United Kingdom
Client: Confidencial

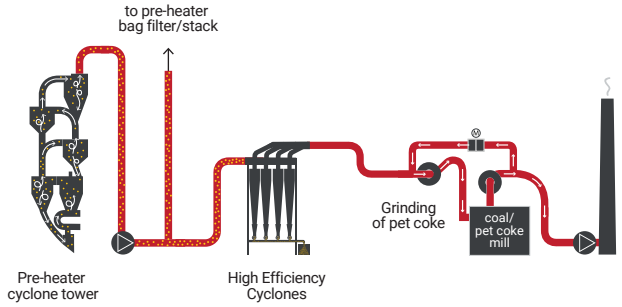


Case Studies in the Steel, Cement and Oil & Gas Industries

Thermal energy can also be recovered in large gas streams in the Steel & Cement industries after properly cleaned from dust originated in the cement preheater, in the clinker cooler or in sintering processes. ACS can offer large **heavy-duty cyclones** with an internal ceramic-based lining to resist abrasive dusts.
Cyclones can also be built to handle **high pressures** very effectively. In the Oil & Gas Industry, that includes the **separation** of iron oxide powders before **critical components** such as compressors.

Hurricane HR cyclones to pre-separate dust from hot gas after the pre-heater tower

Duna Drava is a member of the Heidelberg Cement Group.
Problem and solution In order to ensure that the ground Pet Coke is within the ash content specifications, the dust inert particles needed to be removed from the gas stream. The goal was to minimize the dust concentration in about 10% of the total hot air (37,513m³/h @ 327°C) with the lowest impact to the gas temperature. To design the most efficient cyclone system, ACS used the specific operating conditions of the plant, such as the particle size distribution, density, inlet concentration, temperature and gas flow rate.
Emissions were reduced by 87.15–92.92%.



Resumed Design Conditions:

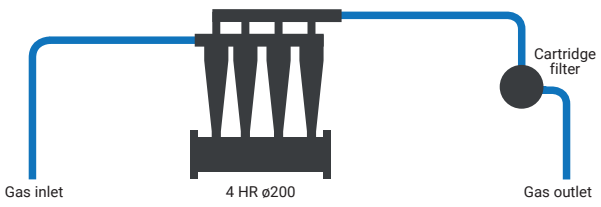
Particles	Ash
Product load into cyclone system	42 100mg/Nm³
Gas flow temperature	327°C
Actual flow rate	37 513m³/h

Output/Performance:

Guaranteed efficiency	<87%
Pressure drop	1.3kPa

Hurricane HR cyclones to remove black powder in natural gas lines

EDP is a public service company for natural gas distribution.
Problem and solution EDP was experiencing problems deriving from the presence of black powder resulting in the contamination of the natural gas, wear of the compressors, instrumentation clogging and sealing problems in valves.
ACS designed a system for efficient dust removal that can ensure the capture of particles in the entire size spectrum at very high pressure (16 Bar), while drastically reducing operating and maintenance costs. This system comprises a set of 4 HR cyclones that are designed to work at maximum flow associated with winter conditions. Each cyclone can independently be turned off to better optimize performance according to very low flow conditions, for example in the summer time.



Resumed Design Conditions:

Particles	Iron dust/black powder
Inlet dust concentration	100mg/Nm³
Gas flow temperature	11°C
Actual flow rate	842m³/h

Output/Performance:

Residual emissions	<10mg/Nm³
Pressure drop	19kPa

Official Sales Agent in Thailand

TSK

T.S.K. ENGINEERING CO., LTD.
6 Moo 5, Nongree, Muang,
Chonburi 20000 Thailand
Tel: +66 81 9788389
Email: contact@tskengineering.co.th
Website: www.tsengineering.co.th
Facebook: TSK Engineering
Line: @tskengineering

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ACS Development, Commercialization and Installation of Industrial Filtering Systems | Tel: +351 226 003 268
Rua de Vilar, 235 3 Esq. | Edifício Scala | 4050-626 Porto | Portugal | www.advancedcyclonesystems.com | info@acsystems.pt

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