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## Main Aspects of Improvements for Centrifugal Soot Removal from Exhaust Gas

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# Main Aspects of Improvements for Centrifugal Soot Removal from Exhaust Gas

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**Abstract.** In order to study the horizontal particle separator, equipped in the External-Fired Gas Turbine system (EFGT), the model experimental investigation and numerical simulation have been set up. The particle separator is used for separate small particles from gas by passing the flow through a spiral, which creates a centrifugal force. The particles will be trapped to a collector before reaching the gas exist. This study aims to analyze the efficiency of separation based on various designs of screw and cone. The experimental results show that decreasing of the cone length, the system pressure loss could be significantly reduced and the capacity of particles capture could be increased. However, the deepest cone position provides the higher loss comparing to the others. Moreover, it is evidently that the reducing number of screw's turn and it's pitch, the better capture capacity of the separator could be obtained. In parallel, the numerical simulation has been setup to support the experimental studies. The conditional parameters, including number of mesh, air mass flow rate and outlet condition, have been varied. In addition, the validation of flow simulation has been accomplished. The results show that there is the compatibility between the numerical simulation and experimental investigation as well.

## 1. Introduction

Large amount of particle-laden flow appears in many conventional engineering processes. Gas cyclones have been widely used as gas-solids separators for more than a century because of their simple construction and high reliability, which results from the lack of moving parts and the ability to withstand harsh operating conditions, such as high pressure and temperature applications [1]. Many researches have been done in the past to study various aspects of cyclone, for example, geometrical design [2, 3], its efficiency and performance [4, 5], optimization [6, 7] and flow characteristics [8]. Both on experimental investigation and also numerical simulation [9, 10]. However, comparing with the cyclone separator, the horizontal particle separator could provide less pressure drop and it is more suitable for a design of the EFGT system. The general flow pattern on a spiral can be deduced from basic considerations of fluid dynamics. It consists of a primary (down trough) flow component with a secondary (transverse) circulation superimposed [11].

The separator is equipped between the burner and recuperator in the External-Fired Gas Turbine system (EFGT) to split the burned ash out from the hot air. In principle, it uses the centrifugal force to



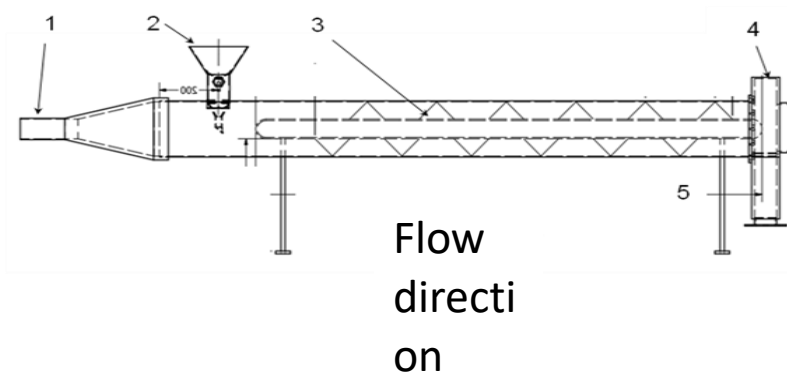
separate the particles, produced by combustion of alternative fuel. The flue gas, produced from the burners, flows along the exhaust pipe. Before it reaches the heat exchanger, the exhaust gas has to be washed out. Inside the separator, the screw profile is constructed to govern the flow direction. The centrifugal force is applied to the flow. The particles, mixed in flow, will be filtered out and conveyed to the collector, whereas the cleaned air flows out on another outlet into the heat exchanger.

It is evident that the performance of a spiral would depend strongly on its design parameters, including diameter, height, number of turns, pitch and slope [12]. In order to study the effects from spiral and cone geometries, the experimental model has been built up from transparent acrylic. The test on variation of spiral's span, cone length and position has been achieved. Moreover, the different air mass flow rates from 0.025 kg/s to 0.150 kg/s have been also altered. In addition, the numerical simulation has been also setup. Their results are compared together to validate the simulation results.

## 2. Experimental Research

### 2.1. Experimental setup

The investigations of the developing particle separator have been carried out on a test bench at the chair's laboratory. The doser is used for supplying metal powders by rotating its feeder arm. The amount of particles is weighed before and feeding time is also counted during the test. The particle mass flow rate is achieved at the end. The structure of the test bench could be shown in figure 1.



**Figure 1.** Principle structure of the test bench, including air inlet diffuser (1), doser (2), screw (3), collector (4) and drainage (5).

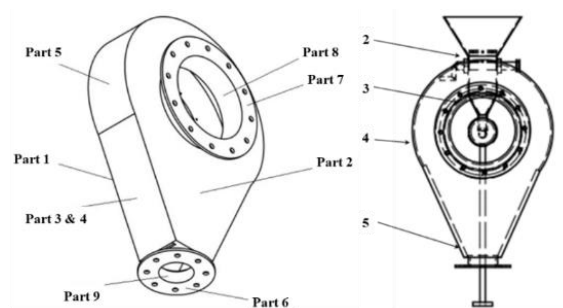
The air is supplied via the air inlet diffuser to the particle doser. There, the metal particles are added to the air flow. The rotation of the doser axis was synchronized with a pendulum, in order to have a constant mass flow during the test. The mixture of the air and particles is circulated along the screw and finally a majority of particles are collected by the collector. The low particulate air is then directed into the environment through the exit port. Figure 2 illustrates the test stand from inlet side.



**Figure 2.** Test bench (view from the inlet side).

The effect of the centrifugal forces causes the separation of solid particles before the flow reaches the collector, which is shown in figure 3. The particles are collected in the lower part of the container and at the end of the experiment they are fed via flange 6 (figure 3) into the measuring vessel. Purified air is discharged via the flange 7 into the environment through the flexible tubes.

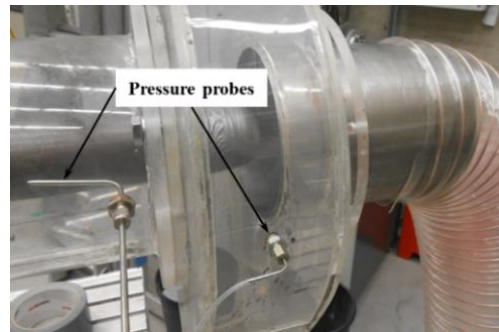
The mass flow measurement is carried out with a standardized measuring orifice according to DIN EN ISO 5167-1. The control of the air mass flow via the bypass and the separators were organized by two pneumatically controllable valves. These valves have a regulator that places the air valve piston and throttle in the appropriate position. The air is led into a separator. Here again the observation of pressure and temperature takes place. At the front of the separator is the mounting plate to which temperature probes, pressure measurement and the tested modules can be attached.



**Figure 3.** Basic structure of the collector, including doser (2), screw (3), collector (4) and drainage (5).

## 2.2. Measurement technique

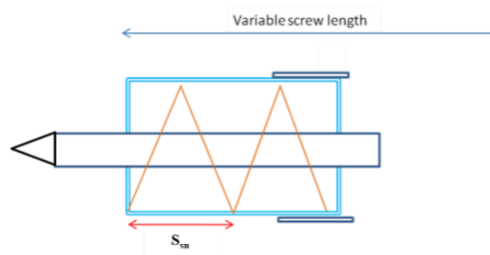
The data acquisition on the test bench was carried out for pressure and mass flow measurements. The air mass flow was measured by means of a metering orifice. The DSA 3018 from Scanivalve Inc. with 16 parallel channels has been used for pressure measurement. The temperature measurements were carried out by means of temperature sensors at the exist of the compressor. The evaluation of the measurement signals took place in LabView. Application of the pressure sensors at the test bench is shown in figure 4.



**Figure 4.** Application of the measuring on the test bench.

### 2.3. Design principal of the test bench geometry variation

In order to determine optimal configuration of the separator, various geometric parameters of the particle separator have been investigated during testing. First of all, the length and span ( $S_{sn}$ ) of the spiral have been considered to be varied (figure 5). The geometry variation of the screw could be concluded as in the table 1.

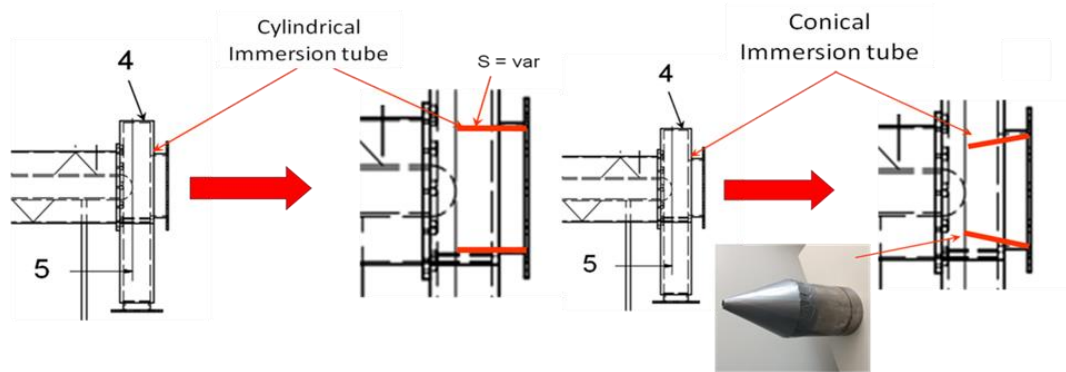


**Figure 5.** Variation of the screw parameters.

**Table 1.** Geometry parameters of screw.

Screw number	$S_{sn}$ [mm]	Number of strand
Scw11	235	6
Scw12	235	5
Scw13	235	4
Scw21	165	10
Scw22	165	9
Scw23	165	8

In addition, the shape of dip tube, i.e. cylindrical and conical shown in figure 6, have been investigated. In both cases, the installation distance ( $s$ ) was varied in 3 steps and the position of cone was also changed in 5 different steps.



**Figure 6.** Positioning of the cylindrical (left) and conical (right) immersion tube.

The test bench is designed based on the similarity law [13]. The equations of fluid mechanics describing a class of flows, i.e. equations for frictional incompressible flows are necessary to know.

If the variables of these equations could be made dimensionless with constant values of velocity, length, time, etc. that are characteristic of the flow problem, then dimensionless measures like  $Re$  as factors to the terms of the equations automatically result. Problems with the same  $Re$  are described with identical equations and therefore lead to identical solutions in the dimensionless variables.

Based on existing standard part sizes of Plexiglas tubes in the market, the 200 mm diameter is selected for the housing pipe. For the model (mo) and original (or) their relationship could be written down as following:

$$\left(\frac{w \cdot l \cdot \rho}{\mu}\right)_{mo} = \left(\frac{w \cdot l \cdot \rho}{\mu}\right)_{or} \rightarrow Re_{mo} = Re_{or} \quad (1)$$

Where  $w$  is speed of flow,  $l$  is the characteristic length,  $\rho$  is the air density and  $\mu$  is the air viscosity.

### 3. Simulation Setup

#### 3.1. Geometry model

In parallel, the numerical simulation to study the fluid flow inside the separator has been also prepared. The calculation volume and meshes have been created. Two different quantities of mesh, i.e. 1.3 million and 2.6 million elements, on Scw22 have been varied in this study. Basically, the grid consists of air inlet, particle inlet, spiral, air outlet and outlet portion for particles as same as the model on the test rig.

#### 3.2. Boundary conditions and numerical setup

In order to perform the simulation, the commercial program, ANSYS Fluent, has been used. The air inlet condition has been set as mass flow inlet, which its value is taken from the experimental data. The pressure at air outlet has been also specified. At the beginning, the particles have not been loaded into the calculation. Their particle in-/outlet have been set as no-slip wall. The realizable  $k-\epsilon$  turbulence model has been implemented in this case. The model value could be shown in the table 1. The pressure at air outlet has been evaluated to calculate the pressure drop and compare with the experimental results achieving the validation of the simulation.

**Table 2.** Turbulence model values.

Parameters	Value
C <sub>2</sub> -Epsilon	1.9
TKE Prandtl number	1.0
TDR Prandtl number	1.2

#### 4. Experimental Results

The test results on different configurations of cones, i.e. lengths and immersed position, could be shown significant variation on the percentage of pressure loss over the particle separator with screw 11 in figure 8. In the picture the letter “C” refers to the cone configuration, which C1 is the longest one, C2 and C3 is 20 mm shorter respectively. The letter “Pos” refers to the position of each cone, where “Pos 5” is the deepest position immersed into the separator. In addition, the percent pressure loss could be defined as the equation 2.

$$\% \text{ pressure loss} = \left( \frac{P_{t,in} - P_{t,out}}{P_{atm}} \right) \times 100\% \quad (2)$$

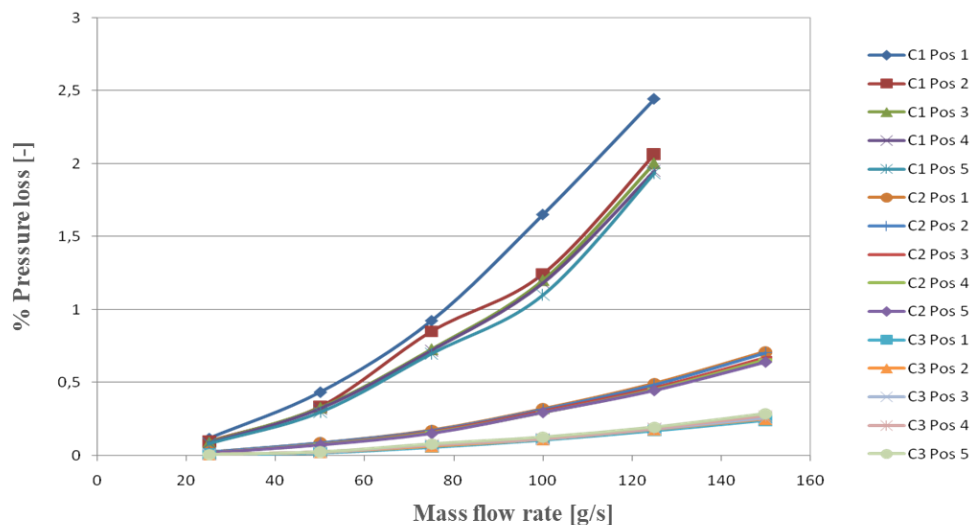
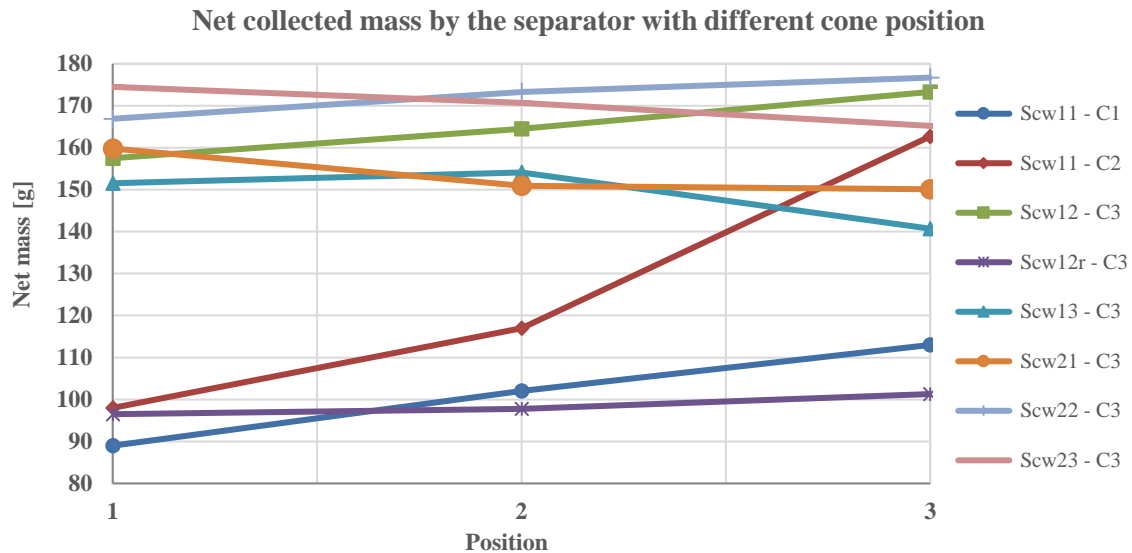
**Pressure loss on separator with different cone configuration****Figure 7.** Comparison of pressure losses on different cone configurations.

Figure 7 illustrates evidently that the cone 1 creates highest drop on the system. Based on this cone configuration, the shallower position, i.e. position 1, provides also the higher loss comparing to other positions. However, the cone's position does not provide much effect on the cone 2 and 3, which create lower pressure loss on the system.

The deposit mass after separation as a function of cone position could be illustrated in figure 8. Considering between the different cone's length cases, i.e. “Scw11 - C1” and “Scw11 - C2”, it is obviously that the shorter cone configuration can capture more particles in the system. In addition, on the most cases it seems that the position of cone has no effect on the capture capability of the separator. Moreover, this diagram shows that maximal deposit of particles in separator can be achieved by the case of screw

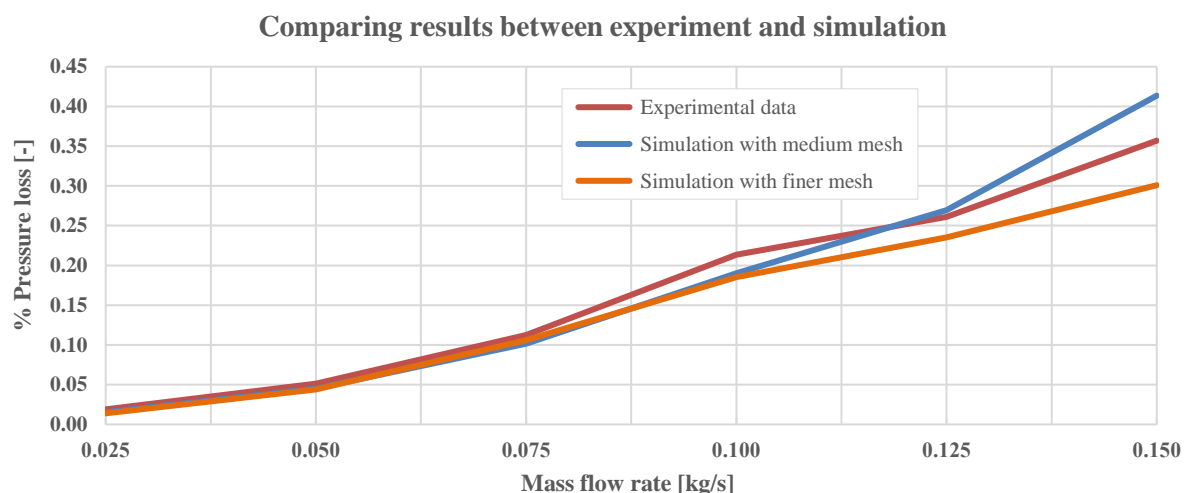
with higher step, i.e. screw 22 or screw 23. However, this screw design causes also higher pressure loss over the separator as well.



**Figure 8.** Comparison deposit mass function of cone type and cone position.

## 5. Simulation Results

For validation of simulation, the experimental result on screw 22 with cone 3 at position 3 has been selected. The results on mesh variation between medium (1.3 million elements) and finer (2.6 million elements) meshes comparing with the experimental data could be illustrated in figure 9. In these cases the simulation is finished at 2000 iterations. It is evidently that the medium mesh can provide more corresponding results with the test. This mesh has been performed further study on variation of air mass flow rate.

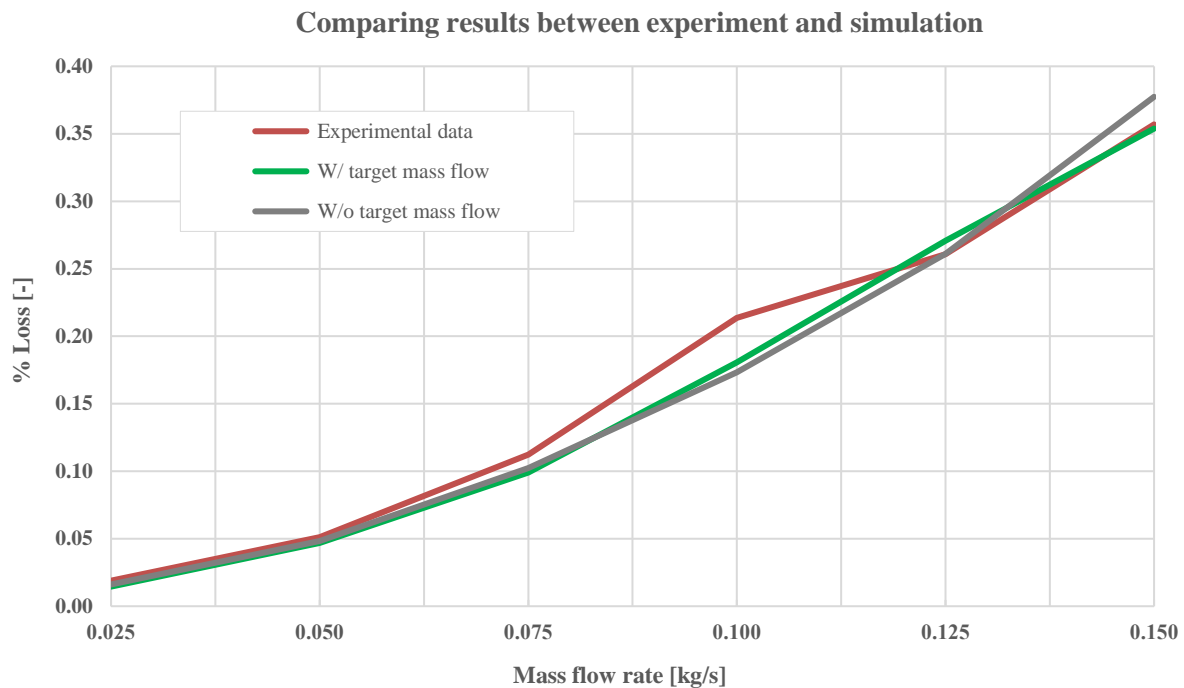


**Figure 9.** Comparing results on different number of meshes.

The outlet condition, i.e. target mass flow, has been further tested to achieve the better conformity with the experimental data. The results until 5000 iteration comparing on this parameter could be



presented in figure 10. It is clearly that with this option the correspondent comparison with the experiment is obtained.



**Figure 10.** Comparing various mass flow rates on pressure drop.

## 6. Conclusion

It has to be mentioned, that any changes of screw geometry or immersion tube arrangement may increase the pressure losses over the separator. Therefore, the optimal solution for particle separator is based on estimation of both parameters - particle deposit and pressure losses as function of geometric characteristics of the separator screw and immersion tube.

The experiments show that the number of steps of a screw has a direct effect on the deposit mass trapped in the collector. The maximal deposit of particles in separator can be achieved by the case of screw with higher step, however, this screw design causes also higher pressure loss over the separator.

It was also shown, that the configuration of the immersion tube at the bunker inlet is the main tool improving the rate of deposit. The shorter cone configuration can capture more particles from the system. Moreover, it creates also lower pressure drop over the system. Based on the same cone configuration, the shallower position of the cone at the inlet collector provides higher loss comparing to the others, however, its position has not so much effect on the capture capability of the separator.

The simulation results show that the medium mesh quantity is good enough to predict the flow phenomena of the separator. The results show well correspondence comparing with the experimental data. For further investigation, the simulation could be benefited to capture more details of separation mechanism of the device. To achieve the optimal solution for particle separator, a large optimization work using modern simulation tools and sophisticated experimental set-up are required.

## Acknowledgments

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