Vortex Engine Like New Technology of Flue Gas Discharging with Wet Desulfurization

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Resumen: *Estudios recientes sobre tecnologías de descarga de gases de escape residuales posterior a la desulfurización a través de torres de enfriamiento se focalizan en dos sistemas chimeneas y torres de enfriamiento, por lo tanto combinar estos sistemas con un motor de vórtice genera un nuevo concepto de desarrollo y mejora de este tipo de tecnologías. El análisis de exergía realizado fue desarrollado para determinar las principales características que debe tener un motor de vórtice para torres de enfriamiento como un uso eficiente de energía y desarrollo de estructuras, por esto se introduce las tecnología de descarga de gases posterior a la desulfurización por humedad a través de una torre de enfriamiento adhiriendo un motor de vórtice para el proceso.*

Palabras clave: *Motor de vórtice, desulfurización, torre de enfriamiento, energía, exergía.*

Abstract: *Recently studies about the technology of discharging flue gas after wet flue gas desulfurization through natural draft cooling tower focused in two system smoke chimney and natural draft cooling tower, despite of the fact that combine these systems with a vortex engine generate a new concept to develop and improve this technology. The exergy analysis inside this paper was developed to determine main features of vortex engine for cooling tower chimney such efficient used of energy and structural's height, so that this project introduce the technology of discharging flue gas after wet gas flue desulfurization through natural draft cooling tower adhering a vortex engine.*

Keywords: *Vortex engine, desulfurization, cooling tower, energy, exergy.*

1. INTRODUCTION

1.1 Economic Benefits

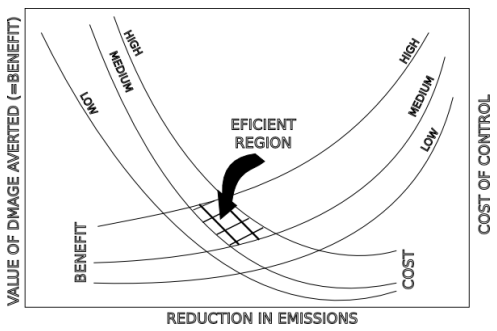

Fig. 1: Curves for the relationship between cost of control and degree of reduction of emissions, based on probability data.

Economic efficiency requires that investment for improving the quality of the air in a region should be made as long as the value of the net increment of environment improvement is greater than, or equal to, the cost of that increment.

As long as the improvement, i.e., reduction in damage is quantifiable in monetary terms shown in figure 1, the matching of benefits and costs is straightforward and can be carry out objectively [2]. So the Vortex engine look like an attractive research because of investment and benefits.

1.2 The Vortex Engine

The investigation about Application Vortex Process to Cleaner Energy Generation allowed us understanding a tornado as energy camp which will be using not only in energy fields, but also like a natural pump to impulse gas fuel for reducing the height of a cooling tower with gas discharge, figure 2 showing the shape of tornado.

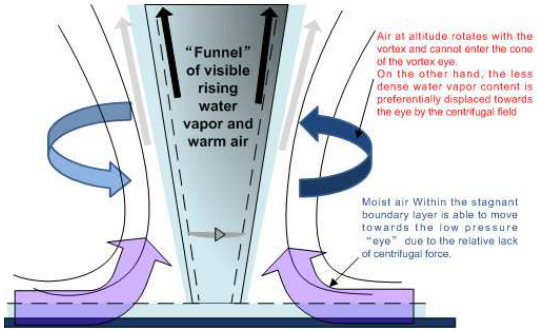

Fig. 2: Diagrammatic representation of the dynamic vortex chimney in a tornado (the vortex naturally concentrates a highly buoyant and high âĂŞ enthalpy air and water vapour mixture at its centre. It is thus extremely non - linear system [1].

1.3 Nomenclature

AVE	Atmospheric Vortex Engine	
FV	Finite Volume	
CFD	Computational Fluid	
CFX	CFD software package from ANSYS	
N	Extensive property	
η	Intensive property	
$d\boldsymbol{A}$	Differential vector of area	m^2
$\boldsymbol{v}$	velocity vector	m/s
∇	Nabla operator	
ρ	Density	kg/m^3
Γ	Circulation	m^2/s
dV	Differential of Volume	m^3
ϕ	Generic variables u, v, w	
u	Velocity component in x direction	m/s
v	Velocity component in y direction	m/s
w	Velocity component in z direction	m/s
S	ϕ generalised source term	m^2
e	Exergy	kJ/kg

1.4 About Authors

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2. DESCRIPTION OF THE PROTOTYPE

A solar chimney with built in LHS (= Latent Heat Storage) module was fabricated. [3]. It is possible to compare with a heat pipe to make ideas about working functionality and the main goal was combining the cooling tower like figure 3 with vortex engine figure 2.

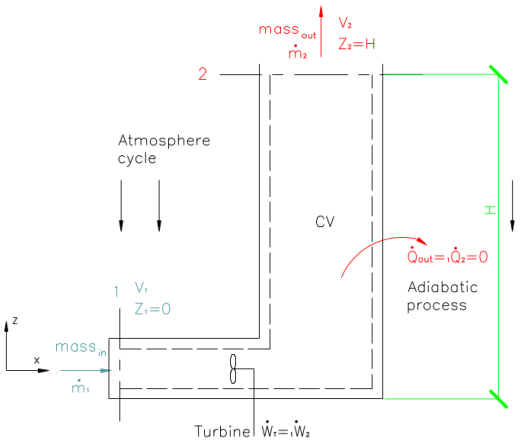

Fig. 3: Basic Thermodynamics model for Chimney Tower [1].

2.1 Main Characteristics of Physical Model

Figure 4 indicate the principal parts of Vortex Engine for Chimney Cooling Tower with flue gas discharge and wet desulfurization. The model is based on ideas about working with several flows in a process of multi-flow, two gases and wet go into the model and mix all of them, flue gas inlet is the part black down of the machinery, heat water drop simulate the cooling tower phenomenon and air go into the machine foe the middle. The vortex generation is producing by blades for flue gas and air chamber inside of machine figure 4 which change stream lines direction an induce a vortex, but it is a irrotational flow.

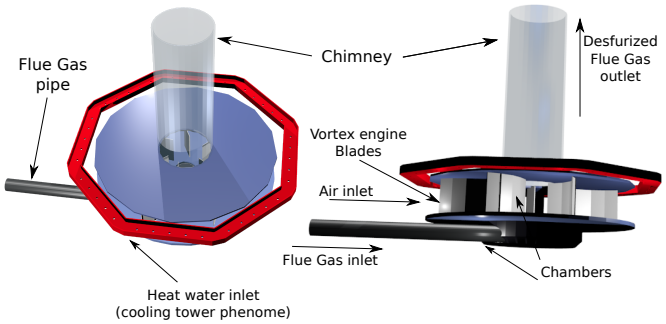

Fig. 4: Vortex Engine for Chimney Cooling Tower with flue gas discharge.

2.2 CFD Simulation Model

Computational Fluid Dynamics was used to simulate and develop the phenomenon of Atmospheric Vortex Engine (AVE) according figure 5 for flue gas discharge. The milestones were: working in the shape using a CAD software

which was SolidWORK , choosing a CFD software was CFX of ANSYS company and prove those results from simulation were correct and they will be to employ and experimental model.

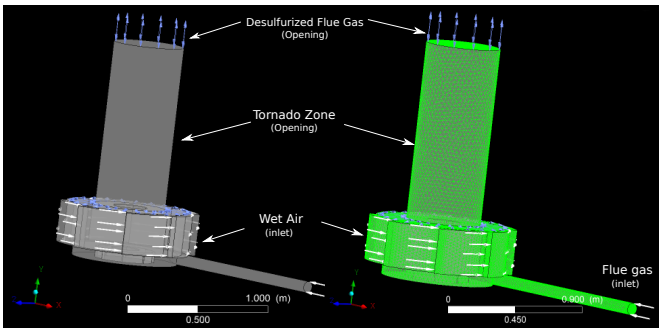

Fig. 5: CFD and Numerical Simulation for AVE.

3. COMPUTATIONAL FLUID DYNAMICS ANALYSIS "CFD"

3.1 Math Models

Finite Volumes (FV) theorem was occupied in the fact that CFX is based on FV, therefore the transport equation refer to (1) is the most important to understand CFD.

$$\frac{DN}{Dt} = \frac{\partial N}{\partial t} + \oint_A \eta\rho\boldsymbol{v} \bullet d\boldsymbol{A} \qquad (1)$$

if $\eta = \varnothing$ and equilibration with rotation analysis, hence:

$$\frac{\partial}{\partial t}\int_V \rho\varnothing dV + \oint_A \varnothing\rho\boldsymbol{v}\bullet d\boldsymbol{A} = \oint_A \Gamma\nabla\varnothing\bullet d\boldsymbol{A} + \int_V SdV \quad (2)$$

$$\underbrace{\frac{\partial}{\partial t}\int_V \rho\varnothing dV}_{\text{Unsteady}} + \underbrace{\oint_A \varnothing\rho\boldsymbol{v}\bullet d\boldsymbol{A}}_{\text{Advection}} = \underbrace{\oint_A \Gamma\nabla\varnothing\bullet d\boldsymbol{A}}_{\text{Diffusion}} + \underbrace{\int_V SdV}_{\text{Generation}}$$

Equation (2) give important information to know FV and the discretization method which is used inside of CFD program.

CFX is friendly program for discretization is not only refer to (2), but also different equations like energy and continuum, but all of them from (1).

If it's necessary considerate Gauss law of camp change from Volume to Area, thus:

$$\frac{\nabla(\rho\varnothing)}{\nabla t} + \nabla\bullet(\boldsymbol{v}\rho\varnothing) = \nabla\bullet(\Gamma\nabla\varnothing) + S \qquad (3)$$

Equation (3) is part of the math model used for CFX to analyze this system of AVE like new technology of flue gas discharging with wet desulfurization.

3.2 Shape and Mesh Model

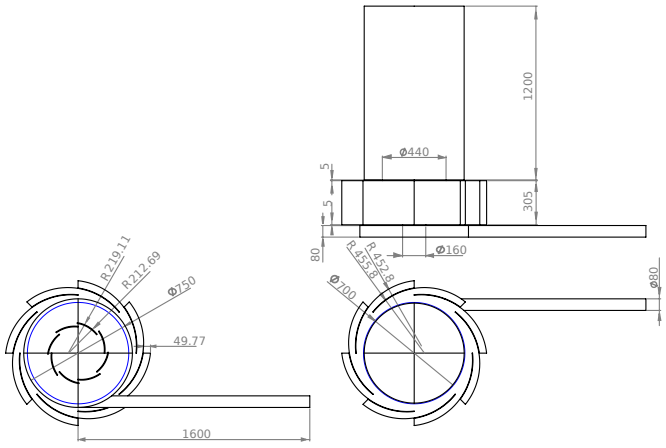

Fig. 6: Cooling Tower with AVE.

According to figure 4 the shape of AVE to simulate look like figure 6. This shape allowed a good precision onto math analysis and meshing.

Working with CFD the mesh should be unstructured because of geometry and facilities that model of discretization give see figure 7. On the other hand structured mesh is limited by small configuration and ordering system which increase the difficult of research and both of them probe to be so similar resolution. Therefore unstructured mesh was selected.

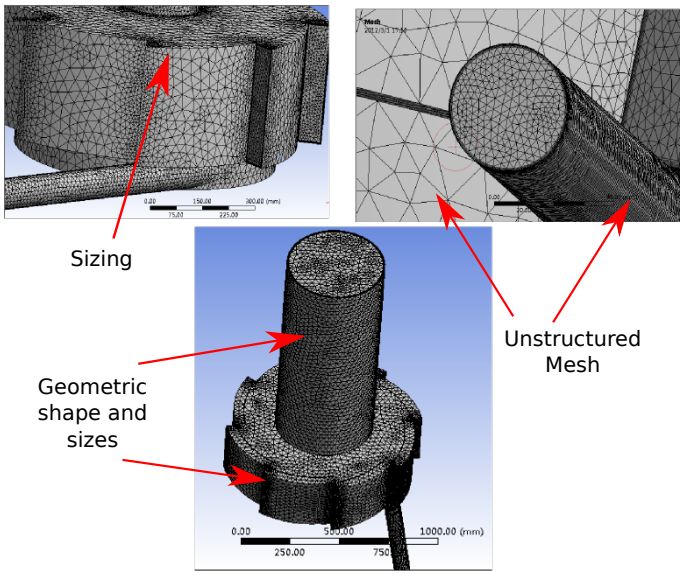

Fig. 7: Modeling Mesh.

3.3 Boundary Conditions and Pre-set

Figure 5 give information about the main boundary conditions and a brief resume is in table 1. In this investigation the steady state was studied and $K-\varepsilon$ model was necessary to solve (3).

Table 1: Simulation Parameters.

PARAMETER	
State	Steady – state
Fluid Type	ideal air, Gravity -9.81 m/s2 onto vertical axes
Simulation Type	K – epsilon standard, blend factor = 075
Inlet setting	Inlet, partial pressure 0 Pa. 313 K for Air entrance and 400 K for flue gas entrance
Outlet setting	Partial Pressure 0 Pa. 288 K outlet Temperature
Tornado zone	Opening option, 278K

4. RESULTS

4.1 Velocity Field

Streamlines are considerate in this research due to the fact that they describe possible motion of different particles inside cooling tower with AVE. Figure 8 allowed to know that vortex was generated in to parts, Part (a) the phenomenon was inside of flue gas discharge chamber according figure 4 and part (b) was inside the air chamber.

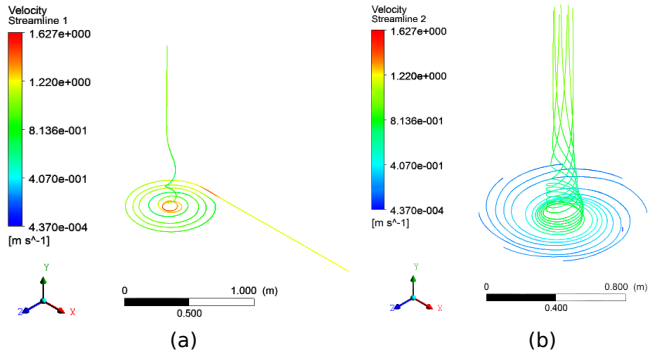

Fig. 8: Streamlines inside of atmospheric vortex engine (a) Flue Gas discharge (b)Air.

Figure 8 is possible because guide vanes or blades which change the direction of streamlines and the results is a vortex and a tornado.

After flue gas got a shape of tornado over this first AVE there is a second AVE phenomenon, but in this case is air with wet that shows in figure 8 part (b). This two gases mix and producing a desulfurization process and a tornado and this tornado brings up these gases to atmosphere.

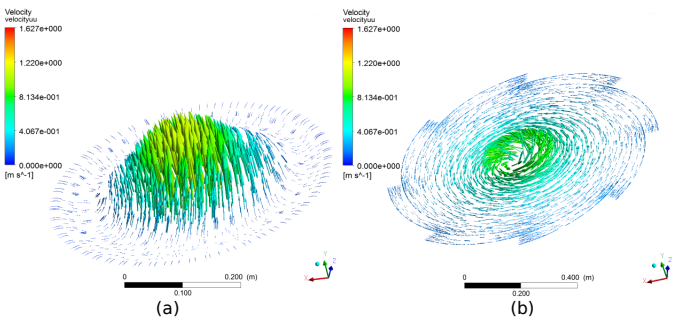

Fig. 9: Vector velocity plane ZX, (a) Y = 308 mm (b)Y = 115 mm.

Results of velocity vectors is possible to see at figure 9 they are in the air chamber on XZ plane with Y = 303 mm for (a) and Y = 115 mm for (b). This graph confirm tornado formation and motion, one of main characteristics is high velocity close to center of vortex with average velocity of 0.81 m/s or 2.91 km/h.

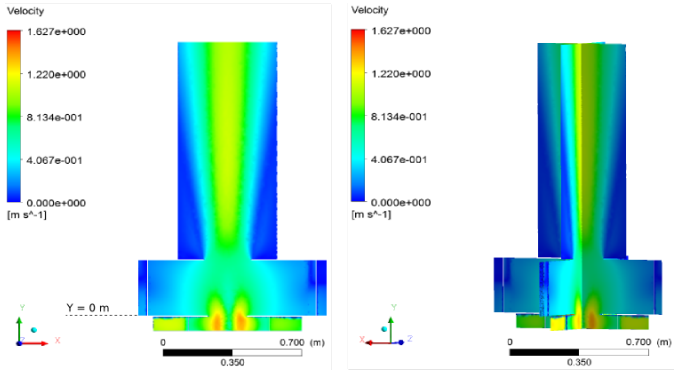

Fig. 10: Veocity Field on vertical plane XY.

Velocity field figure 10 shows that the vortex produced is a Rankine Vortex and this kind of tornado is a real phenomenon. The Rankine vortex model is an attempt to describe the velocity profile through vortices in real, viscous, fluids.

4.2 Temperature Profile

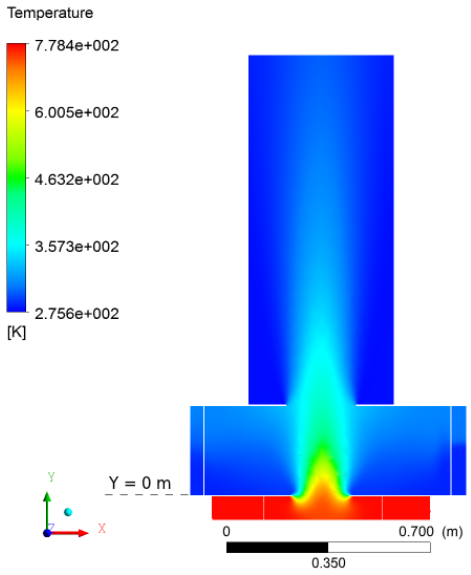

Fig. 11: Temperature Contour on vertical Plane XY.

Figure 11 gives information about temperature profile. Red zone corresponding a flue gas discharge and up this is wet air, desulfurization zone starting close to center, so that there is a change on temperature because of gas mix.

4.3 Exergy Analysis

The exergy analysis is based on data from simulation results, Python an R language were used to do math and statistic part, therefore figure 12 was obtained.

Exergy is very important to analyze in fact that this is an indicator of stability and height of tower which permit to generate a tornado.

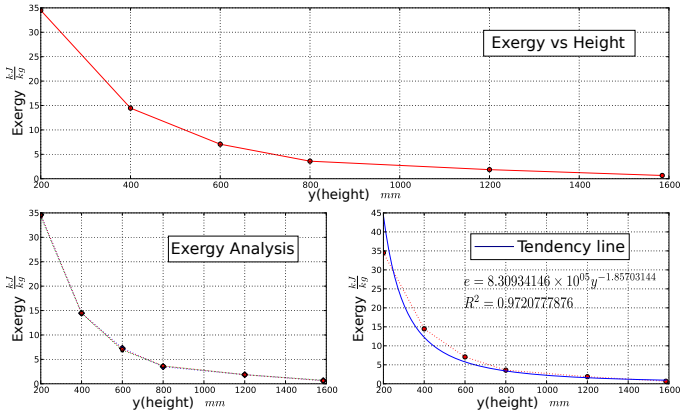

Fig. 12: Charts of Exergy Analysis.

According figure 12 tornado is starting establish after 1000 mm of height. Not only the height is interesting, but also desulfurization process is guaranteed when there is a exergy in steady state.

$$e = 8.304 \times 10^5 y^{-1.857} \tag{4}$$

Equation (4) refers about a tendency line, exergy (e) in function of tower height (y).

5. CONCLUSIONS

In this research was made several simulation as a introduction to Vortex Engine for new technology of flue gas desulfurization and discharge, next step will be prove this one in a experimental research.

Velocity field gave us not only information about that it is possible to simulate a real vortex phenomenon like Rankine votex, but also desulfurization process is able to be real because of gas mix and equal velocity of particles close to center of vortex.

Temperature profile is very clear example that after gas mix it will be able to homogeneous process and it is a guaranteed of wet flue gas desulfurization.

Height of tower is necessary to form a steady tornado that is going to bring gas mix to atmosphere, so that exergy analysis demonstrated that AVE require a base which measure is 75 $\sim$ 80 % of height of tower, due to the fact that steady exergy is in case of height is 1000 $\sim$ 1200 mm and AVE base is 750 mm according figure 6. Therefore economic benefits inside of cooling tower structure is warranted in fact that exergy analysis permits to reduce structural height and design and compacted cooling tower.

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