# DESIGN & CONSTRUCTIONS OF A PROTOTYPE MODULAR SYSTEM FOR INDUSTRIAL GASES DEPOLLUTION

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*Many of the technological processes are generating gases which contain a high quantity of solid and gaseous pollutants. The current procedures are quite well solving the problem of entrapping the solid particle type pollutants, with high costs and investments.*

*Entrapping and storage of CO2 and SO2 type gaseous pollutants has not been solved yet, technically and economically. The today solutions are requiring very high costs and investments and yet, they cannot be implemented.*

*This document presents the researches which have been developed until today in finding a new procedure to simultaneously retain both the solid and gaseous pollutants. The new solution is definitely superior in point of lower costs and investments, following that after experimental testing, the degree of retaining the pollutants, be determined.*

**Keywords:** solid and gaseous pollutants, exhausters, centrifugal device.

## 1. Introduction

The industrial gases contain pollutants in the form of particles of various sizes, electrostatic and adherence characteristics that many times make the depollution process difficult. The gaseous pollutants in the form of SO2, CO2, NOx, etc, are new very much exceeding the allowable concentrations in the atmosphere, are difficult to retain because of their chemical and physical characteristics and due to their dispersion into a very large volume of gases that need to be treated.

The new modular depolluting system is so designed that the concentration and entrapping of the pollutants is performed in sequencial stages that result in a reduction of the energy consumption and an efficient entrapping of the pollutants.

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In the First Stage there is a process of concentrating the solid and gaseous pollutants in a residual flow , Dr, ranging between 1/5 and 1/10 of the initial flow, (Do), the rest of the gases of (Dc) flow, are released to the atmosphere because the contents of pollutants is below the allowable limits imposed by law for the atmosphere protection.
The residual gas flow, Dr, concentrated in the gaseous pollutants and dust particles is expanded in a special cyclone where a dust particle separation is taking place. The gaseous pollutants CO2, SO2, NOx in the residual flow, Dr, are collected together with the flow from other installations installed in parallel, than delivered to the Second Stage of depollution for to entrap them. Function of the residual flow resulted from the depollution Stage 2 and the noxes concentrations, it may be passed or not to Stage 3 which functionally is similar to Stage 1 & Stage 2. After the gases have passed through 2 or 3 depollution stages connected in series and each of them made-up of several modules connected in parallel, the resulted residual flow has a high concentration of gaseous pollutants (CO2, SO2, Nox) in a flow which is 25 – 100 times smaller than the initial flow, after two depollution stages and 125 –1000 times smaller after three depollution stages.
The residual flow from Stage 1 is taken over by a compressor for to increase the pressure and next it is passed through the cooling and fractionate condensation installation typical to each gaseous pollutant. In the first cooling and fractionate condensation stage, $SO_2$ is condensed and collected as fluid and in the second stage CO2 is condensed and collected as fluid. Function of the pollutant contents in the residual gas flow, other stages of the pollutant fractionate condensation may be carried-out. The Stage 2 of depollution will be the scope of a future research phase.

## 2. Presentation of the new depollution system

With the new solution for the industrial gases depollution , the entrapping of the pollutants is carried –out in stages:
Stage 1 of the new depollution system containing gaseous and solid pollutants may be made in 1,2 or 3 steps, function of the gas flow and their pollutant concentration. Fig. 2.1 shows the scheme of the modular industrial gases depollution system for Step 1 that consists in the entrapping of dust particles and the concentration of the gaseous pollutants in a very small residual flow.
Fig. 2.2 shows the diagram of the gas flows, polluted and depolluted in Stage 1 - Step 1 and Step 2. Step 2 of depollution that is to be the scope of a future work, consists in the entrapping of the gaseous pollutants in a step of cooling and fractionate condensation of the residual flow.
According to Fig. 2.1, Step 1 of Stage 1, the depollution consists in 4 modules (A) for depollution, concentration and entrapping , installed in parallel into a polluting

gas intake tubes(item 1), the clean gas outlet tubes (item 2), the tubes of exhaust residual gases (item 3) concentrated in the gaseous pollutants and the very fine particles and the dust collector ( item 4).
The residual flow in collector 3 resulted from the first step, is usually introduced in Step 2 of Stage 1 that consists in a separation, concentration and entrapping module that may be identical with module A or smaller, function of the residual gas flow resulted from the first step.
The clean gas flow in pipe 2, ranging between 4/5 and 9/10 of the initial gas flow, is usually released to the atmosphere because its solid and gaseous pollutant concentration is below the allowable limits specified in the atmosphere protection laws. The collected dust is usually discharged continuously by means of a helical conveyer and stored or introduced in the economic circuit.
With the new modular depollution system, gases are usually circulated by means of two exhausters installed on the clean gas exhaustion tubes (item2) and on the tubes of residual gases concentrated in the gaseous pollutants (item 3).
Under certain circumstances it is possible to install two low air flow fans on each module, on the clean gas exhaustion outlet and the residual gas outlet, as the prototype of depollution module is made.
The evaluation of the possibilities to separate the gaseous and solid pollutants from the clean gases was conducted on several alternatives. The application of the classical mechanics formulae was made considering only the centrifugal force that is acting on the particles and/or on the pollutant molecules ( that have a mass several times bigger than the non-polluting molecules in the burn-up gases) focusing it in the pheripherical area of the coiled channel.
The analysis made possible the determination of the number of circular movements one polluting particle must make in order to reach the channel boundary contour. The analyses were developed for the case in which the gas pressure is constant throughout the channel radius.

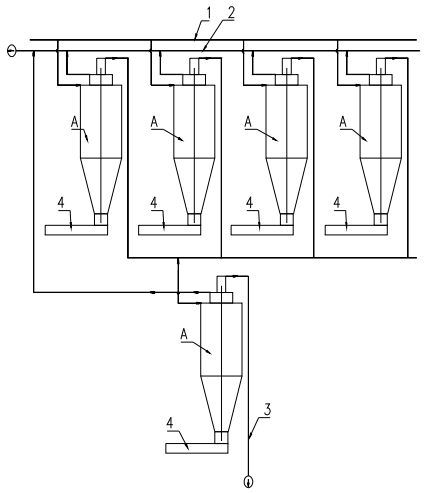


Fig. 2.1 - Model of a modular depollution system for industrial gaseous pollutants - functional scheme – Stage 1-Step 1 & 2

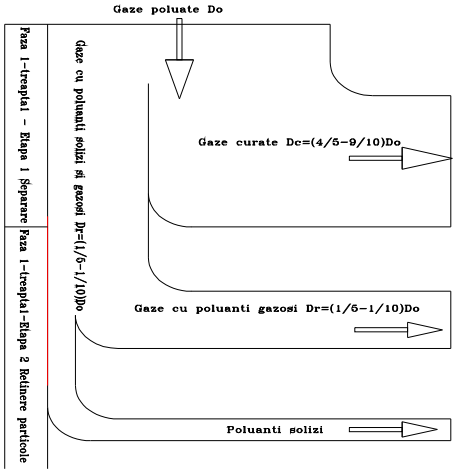


Fig. 2.2 - Diagram of gases polluted and de-polluted in Stage 1 –Step 1 & 2

The evaluation of the separation between the gaseous and solid pollutants in a residual flow was made starting from the laws of mechanics and the theory of perfect gases. Both evaluations are for information only, for the following reasons:

- in the application of the classical mechanics laws, the polluting particle ( dust or molecule) is considered a material point that is not interacting with the other particles ( the effect of increasing the pressure with the increase of the radius during the process of separation is not considered);
- in the application of the ideal gas theory, all the particles are considered to have the same size ( mass) and they do not interact among themselves while in practice, the particles that make-up a gas, are different in point of mass and size and they interact among themselves.

In the application of the classical mechanics theory, the polluting particle in a gas is considered a material point engaged in a rotation movement with an angular speed, w. The centrifugal acceleration that is radially acting on the particle, is given by the relation:

$$a_r = \omega^2 r$$

The law of movement becomes: $\ddot{r} = \omega^2 r$

That is: $\ddot{r} - \omega^2 r = 0$

The solutions have an exponential form : $r = C \cdot e^{\lambda t}$

The solutions are inserted in the equation of movement and the constants $\lambda, C_1$ and $C_2$ are obtained: $\lambda^2 - \omega^2 = 0$; $\lambda = \pm\omega$

The equation of movement becomes: $r(t) = C_1 \cdot e^{\omega t} + C_2 \cdot e^{-\omega t}$

The radial speed is: $\dot{r}(t) = \omega \cdot (C_1 \cdot e^{\omega t} - C_2 \cdot e^{-\omega t})$ $t = 0$

$\dot{r}_0 = C_1 - C_2 = 0$

Where: $r_o$= inner radius $\dot{r}_0$ = initial radial speed;

The following constants are obtained: $C_1 = C_2 = \frac{r_0}{2}$

The solution becomes; $r(t) = \frac{r_0}{2} \cdot (e^{\omega t} + e^{-\omega t}) = r_0 \cdot \cosh(\omega t)$

The gas particle reaches the outer edge of the cylinder when the radius becomes equal to the outer radius ( as a mean):

$r(t) = R_0 = r_0 \cdot \cosh(\omega t)$; I.e. $\cosh(\omega\tau) = \frac{R_0}{r_0}$

In this case, we have the ratio: $\frac{R_0}{r_0} = 3$

It results: $\omega\tau = 1.76 rad = 101^0$ .i.e. 28% winding.

The result is overestimated because the force due to the pressure gradient occurring in time because of the gas particle clogging, was not considered. This pressure gradient is opposing the gas particle movement, slowing-down the movement and consequently, leading to an increase of time and next the particle reaches the outer edge , which is equivalent to the travel of a bigger distance.
The occurrence of the pressure gradient is based on the clogging of particles towards the outer part of the cylinder.

$dF = \rho S dr \omega^2 r = S dp$; namely: $\omega^2 r = \frac{1}{\rho} \cdot \frac{dp}{dr}$

So, the contribution of pressure to the movement of the gas particle is given by: $\frac{1}{\rho} \cdot \frac{dp}{dr}$

In this case, the complete law of gas particle movement becomes: $\ddot{r} = \omega^2 r - \frac{1}{\rho} \cdot \frac{dp}{dr}$

Knowing the momentum and radial variation of pressure, one may calculate the variation of the gas particle radial distance in time, realistically estimating the duration after which the gas particle reaches the outer part of the cylinder.

In the moment the pressure gradient reaches a sufficient value, it is balancing the centrifugal force and determining the stop of the gas particle (the average value of the distance being statistically constant).

$\omega^2 r = \frac{1}{\rho} \cdot \frac{dp}{dr}$,.for any time moment.

To determine the variation of pressure, one may consider the theory of ideal gas and it is determined as follows:

Gas density, ρ, may be substituted with its expression in the ideal gas law: $\rho = \frac{pM}{RT}$

So, like a pseudo-stationary condition, we have: $\omega^2 r = \frac{RT}{M} \cdot \frac{1}{p} \frac{dp}{dr}$

After the integration, it results: $p(r) = p_0 e^{\frac{M\omega^2 r^2}{2RT}}$,

Where $p_o$ is the pressure on the gas at the distance r=0

Considering that the pressure is proportional to the number of molecules in the volume unit ( $p = \frac{RT}{N_A} \cdot n$, n- volumetric concentration), the relation may also be written:

$n(r) = n_0 e^{\frac{M\omega^2 r^2}{2RT}}$ .where $n_0$ is the concentration on the gas at the distance r=0.

The concentration $n_0$ is varying with the angular speed, ω.

Applying the normalization condition (irrespective of the rotation speed, the total number of particles remains constant) the concentration $n_0$. corresponding to the initial idle condition (the condition before applying the centrifugal force) is determined.

$$N = \int_0^{R_0} n(r)dV = 2\pi h \int_0^{R_0} n(r) r dr = 2\pi h \int_0^{R_0} n_{00} r dr$$

The concentration at the distance $r$=0 becomes:

$$n(0,\omega) = n_{00} \cdot \frac{M\omega^2 R_0^2}{2RT} \cdot \frac{1}{e^{\frac{M\omega^2 R_0^2}{2RT}} - 1}$$

As extremes, there are the following cases:

$\omega \to \infty \quad \Rightarrow \quad n(0,\omega) \to 0$ (vacuum phenomenon)

$\omega \to 0 \quad \Rightarrow \quad n(0,\omega) \to n_{00}$ (initial concentration).

So, it is evidenced that during the centrifugal movement, the concentration around the rotation axis is decreasing and thus, the pressure is decreasing with the increase of the angular speed ,$\omega$ Also, the concentration also depends on the type of gas described by the molecular mass, M.

The resulted concentration of particles at distance "r" for the angular speed, ω is :

$$n(r,\omega) = n_{00} \cdot \frac{M\omega^2 R_0^2}{2RT} \cdot \frac{e^{\frac{M\omega^2 r^2}{2RT}}}{e^{\frac{M\omega^2 R_0^2}{2RT}} - 1}$$

Where: $n_{00}$.is the initial particle concentration, without centrifugal force, the samee at any distance"r".

As extremes, there are the following cases:

$\omega \to \infty \quad \Rightarrow \quad n(R_0,\omega) \to \infty$ .( total clogging on the cylinder outer face)

$\omega \to 0 \quad \Rightarrow \quad n(0,\omega) \to n_{00}$ .( initial concentration, constant throughout the volume)

$\omega \to \infty \quad \Rightarrow \quad n(r < R_0,\omega) \to 0$ (vacuum in all the cylinder volume, except the outer face)

That is: $\omega \to \infty \quad \Rightarrow \quad n(r,\omega) \to \delta_{(r-R_0)}$ - Dirac function.

In case of small angular speeds, the particle concentration is actually equal to the initial concentration ( without centrifugal movement) : $n(0,\omega) \to n_{00}$ ,.so that it no longer depends on the molecular mass, M.

The concentration of particles at distance "r" for the angular speed, ω, becomes:

$$n(r,\omega) = n_0 \cdot e^{\frac{M\omega^2 r^2}{2RT}}$$

.

Where: $n_0$ is the concentration of particles around the rotation axis.

If the gas is made-up of a mixture if two gases, n1 being the light concentration of M1 mass and n2 being the heavy concentration of M2 mass, on balance condition, the relation is valid for both concentrations and their ratio at distance "r" versus the axis, is given by the relation:

$$\frac{n_2}{n_1} = (\frac{n_2}{n_1})_0 \cdot e^{\frac{(M_2 - M_1)\omega^2 r^2}{2RT}}$$

Where: $n_{10}$ and $n_{20}$.represent the concentrations of the two fractions at distance r=0. Considering that the ratio of the concentrations at the limit distance r=r0 (on axis) represents exactly the separation coefficient, the relation may have the form:

$$\alpha = (\frac{n_2}{n_1})_{r=R_0} / (\frac{n_2}{n_1})_0 = e^{\frac{(M_2 - M_1)\omega^2 r^2}{2RT}}$$

For small rotation frequencies ( 2-10 rot/sec) and small molecular masses, the calculated separation coefficient $\alpha$ is not realistic because on air flow regime, the air charged with particles of different masses, no longer behaves as a perfect gas.
The gas flow speed is ranging between 10-20 m/sec and it is obtained due to the pressure difference of about 120 mm H2O between the in-coming gas and out-going gas .
The concentration of the pollutants, both of the dust particles ( including the very fine ones, below 10 μm) and the gaseous pollutants ( SO2,CO2,Nox) is due to the centrifugal force $F = \frac{mv^2}{R}$ where:
- $v$ is the peripheral speed ( average speed in gases) in "m/sec";
- $m$ is the molecular mass of gaseous pollutants or of the dust particle , in "kg";
-R is the mean radius of the coiled tube, in "m".
After travelling a distance equivalent to a length encompassed between 1 to 6 windings, both the solid and the gaseous pollutants get concentrated at the coiled tube boundary limit, function of the size of the centrifugal force that is acting on them, i.e. their mass.
The gas flow containing the pollutants is about 1/5 of the total circulated gas flow and it is separated from the balance of clean gases.
The clean gases ( about 4/5 of the initial gas flow) are passed to the exhaustion stack by means of the main exhaustor.

The residual gases containing solid and gaseous pollutants, get expanded into the collector- separator cyclone where, due to the mass difference between the solid (dust particle) and gaseous ($SO_2$,$CO_2$,Nox) pollutants, a separation process is developing, i.e. the dust particles continue their descending winding travel to the housing boundary limit because of the centrifugal and gravity force while the gas molecules are collected in the middle area and absorbed through the central exhausting tube towards the secondary exhaustor.
The residual gases get into a second gas depollution module where a new concentration of the gaseous and solid pollutants is developed, resulting in a second-order residual flow, ranging between 1/5 and 1/10 of the initial residual gas flow.
The clean gases are directed to the stack and the gases concentrated into the gaseous pollutants are passing to the fractionate condensation module for their entrapping by condensation (that will be the scope of a future research work).

Fig. 2.1 Prototype of a modular system for industrial gas depolluation – General View

Fig. 2.2 Prototype of a modular system for industrial gas depollution – Measurement Connectores

## 3. Conclusions

The conducted thoretical evaluations and preliminary tests are pointing-out the fact that the new solution for the total depollution of industrial gases by physical methods may lead to very efficient practical solutions, technically and economically.

The concentration of pollutants in a residual flow and their selective entrapping is efficient both in point of energy consumption and of the installation performances.

The straight exhaustion to the atmosphere, of a flow ranging between 90-95% of the initial flow and the concentration of the pollutants into a residual flow of 5-10% of the initial flow, represent a very good solution.

The subsequent researches will point-out the efficiency of the new depollution solution , both quantitatively and qualitatively.

The new depollution system with a simple structure and high reliability, is a small -sized and low investment and maintenance costs system.

The new system for the depollution of industrial gases is contributing to the reduction of pollution, including the case of low and average flow sources for which the current depollution systems are not efficient.

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