PNCDI II – Program 4 Proiect 31-045/2007

INSTALLATIONS FOR THE CONCENTRATION, SEPARATION AND ENTRAPPMENT OF SOLID AND GASEOUS POLLUTANTS INCLUDING GREEN HOUSE EFFECT INDUCING EMISSIONS

Competition: **National R&D and Innovation Plan II - PNCDI II 2007 - 2013**

Program: **Program 4 "PARTNERSHIP IN PRIORITY FIELDS"**

Project duration:

2007 ÷ 2010

The partnership for running the project is composed of:

PROJECT MANAGER SITON **- the Project Coordinator** - is a company with rich experience in design and research including the management of new industrial product assimilation. SITON has participated in R&D Projects in the water and air depollution and results were good.
The Project Coordinator has managed national projects upon several programs: RELANSIN, CERES and MENER, CEEX and international projects such as "Dedusting Installation with Cyclone and Electrostatic Bag", Contract 121/16.10.2001, "Impact of Partitioning, Transmutation and Waste Reduction Technologies on Nuclear Waste Disposal", RED-IMPACT, 2004 – 2007, Contract FI6W-CT-2004-002408.

PARTENER 1: *UPB CCEPM*

UPB CCEPM – is an academic educational unit with large experience in participating and managing international and national research programs (RELANSAN,CERES,CEEX); UPB – Faculty of Energy – has managed the national program called MENER. The experience of the researches within Partner 1 team is fully illustrated by the attached CVs.
Partner 1 Responsible – Prof. Dr. Eng Ilie Prisecaru – is a researcher with large experience in the research and management domain: as responsible/manager he coordinated 68 research works (contracts) among which: (PC5-ENEN (contract no. FI6O-2001- 80127), PC6-NEPTUNO (contract no. FI6O-2003-508849), ENEN-II (contract no. 036414/2006).
In the line of scientific research activity, Prof. I. Prisecaru has fulfillled some tasks and held positions such as Nuclear Energy Sub-program Director upon MENER national program (Environment, Energy, Resourses), 2002n-2006; member of the national committee assigned by the Ministry of Research for the approval and monitoring RAAN- Research Plan. The results of the researches developed by Prof Prisecaru have been published in more than 140 papers published in various national and international magazines out of which 21 were included in the data bases of ISI – Thomson , INSPEC and COMPEDEX (*http://www.engineeringvillage.com/*) and 48 in INIS data base *(http://inisdb.iaea.org/inis/php/)*.

PARTENER 2: *SC SIGMA STAR SERVICE SRL*

SC SIGMA STAR SERVICE SRL – is a commercial society with the main activity domain the applicative research. SIGMA SRL has participated in national programs such as RELANSAN,CERES, MENER and CEEX (Dedusting cyclon & electrostatic bag installation, contract 121/16.10.2001, Dedusting installation with mobile colection surface, contract 1422 din 30.07.2001, Technology & technical equipment for soil agriculture works as per EU concept – SUSTAINABLE AGRICULTURE, contract 142/18.10.2001).

The Project Manager for the project titled: "Installation of Concentrating, Separating and Entrapping Solid and Gaseous Pollutants" – Ph.D, Eng Viorel Serban, is the author of many invention patents which are the basis of many research works upon some national programs (ORIZONT 2000, RELANSAN,CERES, MENER) and his experience of more than 35 years in the field of design, research and "turn-key" projects developed on basis of his own invention patents, some of them already applied in industry (e.g. reduction of shocks and vibrations generated by the forging hammer operation in IUS Brasov), the protection against shocks, vibrations and seismic movements of the electric cabinets in ROMAG PROD, etc.

SHORT PRESENTATION OF THE PROJECT:

The research work is aimed to conceive, accomplish and experiment a compact installation for the concentration, entrapping and retaining the solid and gaseous pollutants including the green house effect inducing emissions from fuel burning, on basis of some Romanian inventions protected by OSIM.
At present, the entire world is dependant on the fossil fuels and the modification of the energy system cannot be made over one night but in the long run. Entrapping, retaining and storing the pollutants, specially the carbon dioxide (known in the literature as CCS) will sustain the gradual transition from the fossil-based generation of energy to a diversified system capable to minimize the effect on the global climate.
About 60% of the CO_2 emissions worldwide are generated by large stationary sources such as electrical power plants, oil refineries, gas processing plants and industrial units. With most of these processes the gaseous effluents in the stacks contain diluted CO_2 (between 5% and 15%).
The concentration of CO_2 and other pollutants in a residual flow, D_r encompassed between 1/100 – 1/1000 from the initial flow Do and their entrapping, is a gaseous effluent depollution solution, technically and economically efficient which is to be developed upon the Project.
The depollution installation shall have a compact structure and it will carry out the separation, concentration and entrapping of the solid and gaseous pollutants in a sequential manner, in steps. The pollutants such as CO_2, SO_2, NO_2, dust particles, resulted from classic fuel burning, are concentrated and retained in the first step representing a residual flow of 1/10 of the initial flow. The balance of the gas flow is released to the atmosphere directly because it contains no pollutants exceeding the allowable limits.
Next, the dust particles are separated from the rest of the gaseous pollutants in the same manner, by an expanding procedure in a specialized separation device.
A depollution installation will consist of 2 or 3 steps for concentration, separation and entrapping through which the gaseous pollutants are concentrated in a gas flow of 100 – 1000 times smaller than the initial flow. In the next step, the gaseous pollutants are retained in the residual flow by

classic methods including the fractionate cooling of the residual flow so to be collected in a liquid or solid condition as per each type of pollutant.
Upon the Project the research work developed shall consist in the conception, design, accomplishment and experiment of an experimental model of installation for the concentration, separation and entrapping the solid and gaseous pollutants from the burn-up gases.

THE PURPOSE OF THE PROJECT:

The purpose of the Project is to concieve, accomplish and experiment an installation for the depollution of gases by the concentration of the pollutants in a very small residual flow. The solid pollutants are entrapped and the gaseous pollutants are taken over for to be stored or fractionally separated, function of the local interest.

THE OBJECTIVES OF THE PROJECT:

1. ***A general analysis of the atmosphere pollution as a result of the fossil fuel burning processes for to obtain thermal energy and the analysis of the pollution consequences;***
2. ***An analysys of fuels, their burning and the resulted burn-up polluting products correlated with aspects related to the pollution generated by thermal plants, also mentioning some aspects related to the pollution and regulations in Romania;***
3. ***An analysis on the classic procedures for the depollution of burn-up gases from thermal plants, the main air pollutants, procedures related specially to gas dedusting that was the first technically and economically satisfactoryly solved problem at industrial level;***
4. ***The analysis opf the today yechnical and economic issues related to the entrapping, retaining and storage of main solid and gaseous pollutants in the atmosphere. Special problem is represented by the entrapping and storage of C)2 whose presence in the atmosphere is negatively affecting the global climate;***
5. ***The analysis of modern solutions to reduice the environment pollution by a brief presentation of the best current technological solutions known as BATs;***
6. ***The elaboration of a new system to concentrate, separate , entrap and store, simultaneously, all the solid and gaseous pollutants; the general, functional and constructive presentation of the new modular depolluting system with small surfaces and sizes, low investments and operation costs, that can be applied to any low, large and average flow rate;***
7. ***The assessment of the separation capacity of the solid and gaseous pollutants by simple mathematical models, for the new depollution system;***
8. ***The construction of a phisical model of depolluting installation;***
9. ***The running of experiments on the phisical model;***
10. ***The analysis of the experimental results and the improvement of the phisical model;***
11. ***The dissemination of the results.***

MAIN RESPONSIBILITIES OF THE PROJECT MANAGER:

General Presentation:

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 SO_2, CO_2, NO_x, 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.
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 CO_2, SO_2, NO_x 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 (CO_2, SO_2, NO_x) 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 CO_2 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.

1. 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. 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 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. 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.

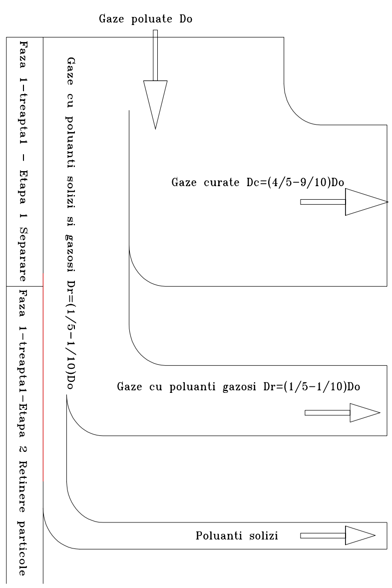

Fig. 1. Model of a modular depollution system for industrial gaseous pollutants - functional scheme – Stage 1-Step 1 & 2

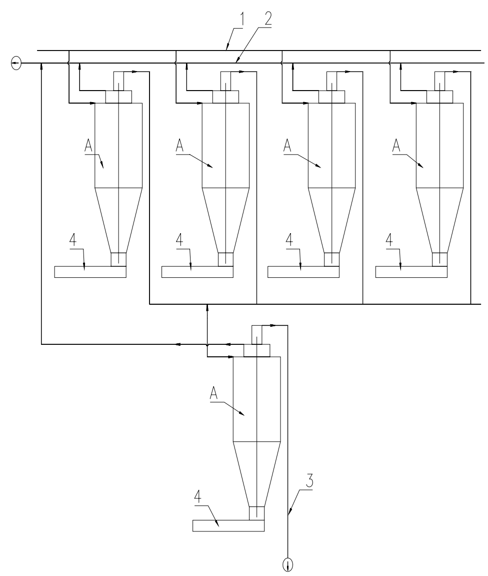

Fig. 2. Diagram of gases polluted and de-polluted in Stage 1 –Step 1 & 2

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 that come into cylinder along a straight-line and reaches the outer edge of the cylinder after some distance. After that, the particle is trained along the outer edge of the cylinder by the depression done by exhaustors.

The angle made by particle with the entrance of cylinder, is: $\cos\theta = \frac{r}{R_0}$,

where: r - radius and R_0 – outer radius.

The maximum value of angle becomes for $r = r_0$ (inner radius).

In case of: $\frac{R_0}{r_0} = 3$ it results: $\theta = 71^0$ .i.e. 20% 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.

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

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

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).

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

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

Gas density 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: $p(r) = p_0 \cdot e^{\frac{M\omega^2 (r^2 - r_0^2)}{2RT}}$, where p_o is the pressure on the gas at the distance $r = r_0$

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 as:

$n(r) = n_0 \cdot e^{\frac{M\omega^2(r^2-r_0^2)}{2RT}}$, where n_0 is the concentration on the gas at the distance $r = r_0$. 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_{00}, corresponding to the initial idle condition (the condition before applying the centrifugal force) is considered.

$$N = \int_{r_0}^{R_0} n(r)dV = 2\pi h \int_{r_0}^{R_0} n(r) r dr = 2\pi h \int_{r_0}^{R_0} n_{00} r dr$$

The concentration at the distance $r = r_0$ becomes:

$$n(r_0,\omega) = n_{00} \cdot \frac{M\omega^2(R_0^2 - r_0^2)}{2RT} \cdot \frac{1}{e^{\frac{M\omega^2(R_0^2-r_0^2)}{2RT}} - 1}$$

As extremes, there are the following cases:

$\omega \to \infty \quad \Rightarrow \quad n(r_0,\omega) \to 0$ (vacuum phenomenon)

$\omega \to 0 \quad \Rightarrow \quad n(r_0,\omega) \to n_{00}$ (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, *ω*.
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 :

$$n(r,\omega) = n_{00} \cdot \frac{M\omega^2(R_0^2 - r_0^2)}{2RT} \cdot \frac{e^{\frac{M\omega^2(r^2-r_0^2)}{2RT}}}{e^{\frac{M\omega^2(R_0^2-r_0^2)}{2RT}} - 1}$$

where, n_{00}.is the initial particle concentration, without centrifugal force, the same 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)

$\omega \to 0 \quad \Rightarrow \quad n(R_0,0) \to n_{00}$, (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): $n(r_0,\omega) \to n_{00}$, so that it no longer depends on the molecular mass, M.
The concentration of particles at distance "r" for the angular speed, ω, becomes:

$$n(r,\omega) = n_0 e^{\frac{M\omega^2(r^2-r_0^2)}{2RT}}$$

where n_0 is the concentration of particles around the rotation axis.

If the gas is made-up of a mixture if two gases, n_1 being the light concentration of M_1 mass and n_2 being the heavy concentration of M_2 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:

$$(\frac{n_2}{n_1})_r = (\frac{n_2}{n_1})_{r_0} \cdot e^{\frac{(M_2 - M_1)\omega^2 (r^2 - r_0^2)}{2RT}}$$

where, n_{10} and n_{20} represent the concentrations of the two fractions at distance $r = r_0$. Considering that the ratio of the concentrations at the limit distance $r = r_0$ (on axis) represents exactly the separation coefficient, the relation may have the form:

$$\alpha = (\frac{n_2}{n_1})_{R_0} / (\frac{n_2}{n_1})_{r_0} = e^{\frac{(M_2 - M_1)\omega^2 (R_0^2 - r_0^2)}{2RT}}$$

For small rotation frequencies (2-10 rot/sec) and small molecular masses, the calculated separation coefficient α 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).

CONTACT:

Coordonator>
web site: http://www.citon.ro
email: serbanv@router.citon.ro
andronem@router.citon.ro

Partener 1>
web site: http://www.cne.pub.ro
email: prisec@cne.pub.ro

Partener 2>
web site: http://www.serb.ro
email: serbv@rdslink.ro