Remote SO_2 Monitoring with UV Cameras for Stack Emissions

GHEORGHE CATALIN NISULESCU[1]*, IOANA IONEL[1], BASSIM MALAN[1], MARIAN DOBRIN[2]

[1] Politehnica University of Timisoara, Faculty of Mechanical Engineering, 1 Mihai Viteazu Blv., 300222, Timisoara, Romania

[2] Institute for Studies and Power Engineering – ISPE, 1-3 Lacul Tei Blvd, Bucharest, Romania

Sulfur dioxide SO_2 is one of the most aggressive pollutant and plays an important role between the gases for air pollution monitoring. Sulphur oxides have a significant impact on human health and are responsible for fauna and flora modifications, as well are considered to be precursor for the acid rain and other atmospheric effects toxic effects on ecosystems. Anthropogenic SO_2 is almost exclusively formed during combustion of fossil fuels with sulfur content, relevant and most commonly used is the S containing coal. The paper presents results of experiments performed with standard methods and, in comparison, applying last generation methods such as the UV cameras. Scope of this paper is comparing these results with each other and to demonstrate their effectiveness. Based on the Camera UV original program developed on the measured values, the conclusion driven from the study is that the SO_2 concentration data delivered by remote sensing using UV cameras are appropriate to be used for stack emission evaluations. The developed calculation algorithm is based on the phenomenon of absorption.

Keywords: Camera in UV – ultraviolet, remote sensing, sulfur dioxide, pollution, SO_2 monitoring

Air pollution issues are important and huge issues nowadays [1, 2, 4]. World population has evolved over time, in terms of population and have diversified industrial and residential activities based on intensive energy consumption based on fossil fuel that have led to the pollution, a phenomenon that has increased over time. In the past, indifference to the environment was generally caused by lack of scientific knowledge and technology.

Presently, industrialized or developed countries, major economic and political, do not always give priority to the protecting of the environment [9].

Measurements of main air pollutants must be carried out both at the location of their formation, thus determining the emissions level and also at other different location, where the effect of the pollutant must be known, thus speaking about air quality, in respect to the particular pollutant' concentration in air. Sulfur oxides represent a major air pollutant and have significant impacts upon human health. SO_2 is considered also as a prominent greenhouse gas that contributes to global warming. The sulfur based oxides are responsible for a lot of respiratory and cardiovascular problems. Also sulfur oxides are known as precursor to acid rain and other atmospheric effects, with major toxicity and effects towards soil and vegetation [7]. The concentration of sulfur dioxide in the atmosphere influences the habitat suitability for plant communities as well as animal life, not at last upon human health. Anthropogenic SO_2 is almost exclusively formed during the combustion of fossil fuels with sulfur content and the most important is for this reason sulfur dioxide can burn the respiratory tract upon inhalation. High doses of sulfur dioxide can cause death quite rapidly.

Sulphur dioxide is an important gas for geologists and environmentalists, as it is known as having natural sources, as well, such as natural phenomena, of non-atrophic origin. Human locations such as metropolitan areas and even smaller towns or villages, when situated nearby power plants, are affected directly by pollution with SO_2 [12], as it is known that the pollution is acting for several species also in the vicinity but also far away from the source location, as result of dispersion.

Sulphur dioxide is a highly toxic gas which poisons its victims via inhalation through the lungs. SO_2 combines with water to form sulphuric acid (H_2SO_4).

Post-combustion CO_2 capture or special flue gas treatments technologies applied in industrial power plants running on fossil fuels is one solution for reducing the content of CO_2 or heavy metals in the free atmosphere and contribute to reducing global effects such as warming and ozone depletion, climate change and restructure of land and water communities [9, 13].

Remote sensing measurement for SO_2 was used successfully in the recent past for volcanoes activities and monitoring the exhaust emissions [1, 4]. Presently, this novel technique is proposed for power plants too. The technology is based on charge-coupled device (CCD), that is based on sensors capable to get information versus the UV portion of the spectrum [1] under the condition that the camera is directed into the main central core of the stack flue gas plume, where the concentration of SO_2 is expected to be major.

Representative energy source is fossil coal, because the sulphur content of other fuels, such as liquid and gaseous fossil fuels, can be easily removed before combustion [3] or is missing.

Experimental part

This paper exposes the experimental results obtained from monitoring of the SO_2 concentrations, in comparison, exhausted by a large power plant located in Halânga, using simultaneous stack point measurement and remote sensing. Halânga power plant use low rank Romanian lignite as main fuel [5]. The comparative measurements are necessary as one of the main purposes of the research is to develop a method of a correct evaluating method. The method is also necessary for an overview or generating a prevention system of accidents or in case of exhausting of higher level of pollutants, which might be signalized and detected from distance, thus by remote control, by independent monitoring [8].

An UV camera was used with the following characteristics: Apogee e2V model CCD47-10 backlit

* email: cnisulescu@mec.upt.ro

1024x1024 pixels, inlet filter wheel for 9 filters. The room is fitted with 4 filters wavelengths 310, 315 325 and 330 nm. The filters have a width of bandwidth of 10 nm at half maximum response (FWHM). The 3 UV lens size cover the range of 50, 78, 105 mm f/3.5, F/3.8, f/4.0. The camera has a 16-bit digitization. Camera field of view (FOV) is (15.2 - 23.7) °. Detection distance is up to about 10 km. The accuracy for SO_2 is 0.1 gm-1 [2, 7, 22].

Different fuels are characterized by a wide range of sulfur content, most of which is released as sulfur dioxides, developed through combustion [6].

Oil and its by-products contain between 0.1 % by mass sulfur (paraffin) and 3-4 % by mass (heavy fuel oil) in the form of sulfides and thiols. Presently there are special commercial techniques to extract the sulfur and reduce its amount, thus the chance to generate SO_2 (ex. diesel) as well.

Coal contains 0.1–4 % sulfur by mass, mainly as flakes of iron pyrites (FeS_2). The average sulfur content of European coal reservoirs is 1.7 % by mass, in Romania even more.

Natural gas (known as being mainly methane CH_4) is normally sulfur free, but some gaseous fuels, according to their special origin or as byproducts of industrial processes, may contain also, up to 40 % by volume, hydrogen sulfide H_2S, that is generating SO_2 through combustion.

If the sulfur content (S) of the fuel is totally combusted, independent of its origin and bounds, SO_2 is formed through the general reaction [4, 6]:

$$CH_3 - SH + 3O_2 \rightarrow SO_2 + CO_2 + 2H_2O \quad (1)$$

During the incomplete combustion, with lack of oxygen, elementary sulfur and hydrogen sulfide (H_2S) can be formed, at high temperatures, as well [6]:

$$CH_3 - SH + 0.5O_2 \rightarrow H_2S + HCHO \quad (2)$$

$$2H_2S + O_2 \rightarrow 2H_2O + 2S \quad (3)$$

Hydrogen sulfide (H_2S) occurs during the combustion process of low quality coals like lignite or in the exhaust pipes of the piston engines exhaust gases, after their catalytic reduction, if the engine works at high load and low air-fuel ratio. During the combustion and in the exhaust channels, the SO_2 can be oxidized to SO_3 which will form, with the water from the flue gases sulfuric, the acid H_2SO_4. The SO_2 conversion to SO_3 is increased in the presence of vanadium of iron oxides at temperatures over 800°C, phenomena that is known as high temperature corrosion, specific to main combustion facilities (internal and external). Evacuated into the atmosphere, SO_2 reacts in proportion of (1 – 2) ‰/ h with oxygen, under the presence of ultraviolet radiation (*uvr*) and forms SO_3 [6]:

$$2SO_2 + O_2 + uvr \rightarrow 2SO_3 \quad (4)$$

Afterwards, the SO_3 reacts with water vapors from the atmosphere to form sulfuric acid H_2SO_4. In periods of fog or days with high humidity the transformation rate of SO_3 to H_2SO_4 can be up to 15 % [7].

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (5)$$

For all mentioned reasons it is very important to monitor the concentration of SO_2 in the atmosphere, and especially control the sources (the larger ones), according to maximum admitted values in exhaust and further, generating through dispersion, and the air quality [7].

Coal consists of three components: organic mass (substances with a complex structure consisting of carbon, oxygen, sulfur and nitrogen) mass inorganic (mineral substances ignition turn into ash) and water.

All three components are related physico-chemical [11].

Desulphurization of flue gases from power plants is one of the best ways to reduce SO_2 pollution by reducing the amount of the source emissions according to hi-tech technologies, that are really needed in Romania and represent state of art for European energy systems [20, 21].

A solution proposed for cooling and removal of carbon dioxide and sulfur dioxide from burning gases is that wherein a direct contact occurs between burning gases and calcium carbonate suspension and between purified gases and potassium carbonate solution [10].

A solution for reducing pollution is using renewable energy sources to replace the fossil fuel energy demand, in accordance to the extreme need of energy consumption for development and covering the development of population, in number and expectations for the life and work standards [17].

The cameras have been successful used for determining SO_2 concentrations during volcanoes hazards [1, 3, 8]. The high temporal resolution of the UV cameras (assuring an order of 1 Hz) has been used to study the dynamics of strombolian volcanism, by characterizing the amount of gas released in active (explosions and puffing) vs. passive ways and through detailed comparison of the gas fluxes with contemporaneously acquired geophysical information [8].

The present method is developed in order to complement these investigation methods by remote and use them versus power plant using S containing fuel and controlling the exhaust plumb from distance.

Another solution for determining pollution is using sunphotometer which determine aerosol properties and not only. General physics laws and phenomena are applied and finally complementary information, in the vicinity of earth soil or in the free atmosphere, even up to aerosol characteristics show the degree of pollution in a certain area [14, 15, 18].

For aerosol and cloud study is used LIDAR system due its relative low cost, high reliability and easy operation [22].

The *Camera UV* program was developed to enable users to see the concentration of SO_2 and SO_2 flow. The method is based on measuring the UV absorption of SO_2 by UV in narrow wavelength to 320 nm. UV cameras have image sensors that detect light in the ultraviolet range [16]. UV light is electromagnetic radiation with wavelength shorter than visible light but longer than X-ray. UV solar irradiance is an important indicator for measuring with UV camera [19]. It measures the concentration of SO_2 in natural and artificial sources. UV chamber proved to be practical and effective for use on land. Installation time is less than ten minutes and in less than half an hour it can capture dozens of images.

Figure 1 presents the interface of the developed program. The camera UV program has a friendly interface and a lot of functionalities. Camera UV is achieved in Java language and uses thus latest technologies. The user is able to choose the point of intersection of the axes of measurement and thus the left panel and bottom are shown with gray values of variation of SO_2 concentration.

According to the developed program of processing the data measured with the UV camera during a representative

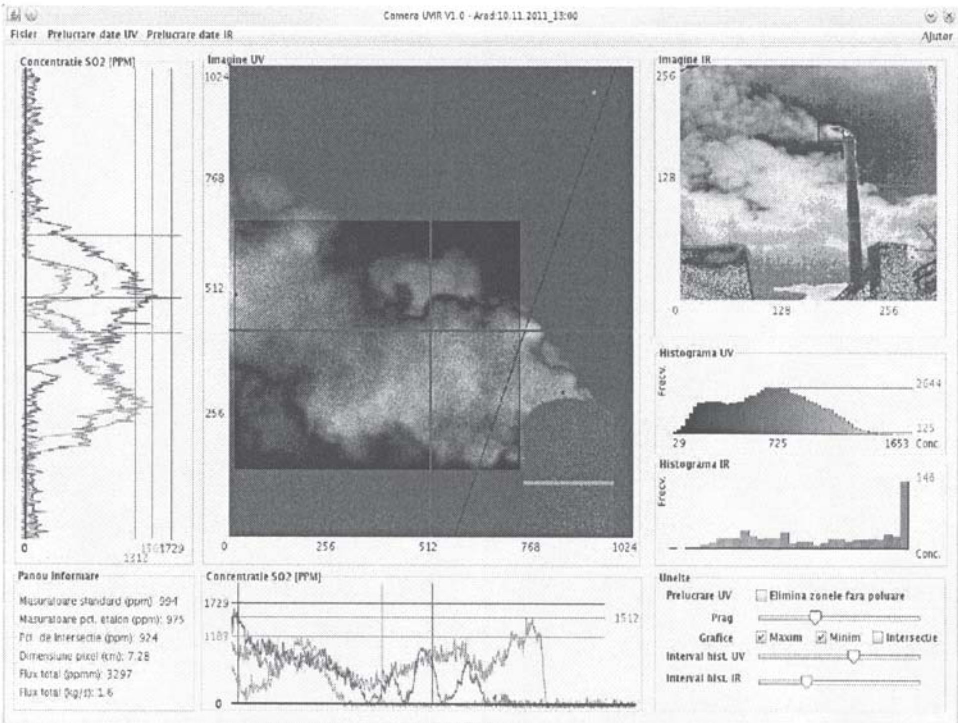

Fig. 1. Developed Interface for the UV Camera data interpretation

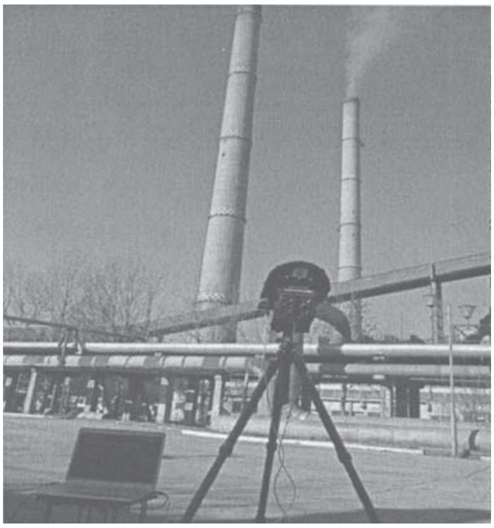

Fig.2. UV camera [5, 7]

episode concerning the SO_2 emission from the stack of the power plant, important results were obtained.

To choose the point of zero concentration for the pollutant SO_2, the user must access the main menu data UV processing, choose the location “zero”, and using the cursor an item from a clear sky, where the concentration of SO_2 is assumed to be zero, is selected. The SO_2 concentration is calculated in this point and represents the last step of the algorithm used to calculate the flow & concentration of SO_2.

To choose the standard SO_2 measurement point, the user must access the main menu of the UV data processing and select the standard measuring point, and then using the cursor, a point from the outlet of the chimney must be selected. This option allows comparison of the calculated concentration value UV images of direct measurements.

The direct standard measurement (in stack) as well as the calculated are presented for comparison in panel information.

The application allows the user to define a rectangular area of the exhaust polluted plum.

In order to start the SO_2 measurement, the user must select from the UV data processing menu the item “choose the measurement”, and use the cursor to define the area.

For the SO_2 measurement in the left panels and the bottom red line picture is displayed; the SO_2 concentration variations for horizontal and vertical axes of the panel maximum concentration are calculated from the measurement.

Also, the green line shows the variation of SO_2 concentration for vertical and horizontal axes in terms of minimum concentration, calculated in the measurement.

Graphics display can be disabled using the appropriate checkboxes tools panel. Selected area displays thus in accordance a histogram on the right side of the mean values calculated.

Results and discussions

According to the developed Camera UVIR program of processing the data measured with the UV camera during a representative episode concerning the SO_2 emission from the stack of the power plant, specific and representative results were obtained. The values shown in table 1 are indicating a range of data, supporting an overview of the technique.

NB	Locality	Date	Hour	Direct measurement (ppm)	UV measurement (ppm)	Flow (g/s)	Speed wind (m/s)
1	Halânga	29.03.2012	09:46	717	822	1,500	1.08
2	Halânga	29.03.2012	09:47	720	747	1,170	0.91
3	Halânga	29.03.2012	09:49	716	735	1,220	0.87
4	Halânga	29.03.2012	09:50	715	713	1,320	0.95
5	Halânga	29.03.2012	09:51	713	755	1,020	0.8
6	Halânga	29.03.2012	09:52	719	730	1,120	0.76
7	Halânga	29.03.2012	10:04	710	742	1,480	0.86
8	Halânga	29.03.2012	10:05	718	759	830	0.87
9	Halânga	29.03.2012	10:06	715	719	1,570	1.16
10	Halânga	29.03.2012	10:07	715	767	1,490	0.84

Table 1
HALANGA MEASUREMENTS

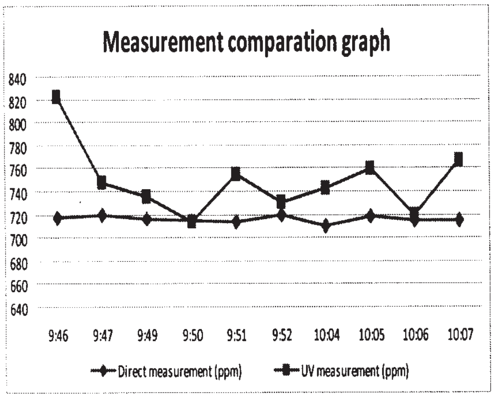

Fig.3 Measurement comparison graph between direct classic measurements and UV camera detection

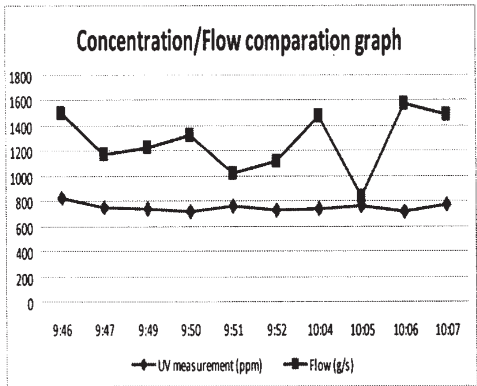

Fig.4. Concentration and flow comparison graph in the case of UV measurements

All passive remote sensing methods and most of the assets do not measure the concentration of a substance, but rather inclined column density S. S inclined column density absorber represents the full concentration on the path that follows radiation on its way from the light source to the instrument. Active instruments have the advantage of their light path is well defined.

In figure 2 is represented a picture taken during a Halânga measurement campaign. The location was selected because one is running in the stack of the plant regular (monthly) representative classic point emission measurements, and thus one has data for comparison and interpretation.

The resulted comparative measurement values are represented by figure 3. It is observed that standard measurement values do not differ much from those measured with UV camera.

In figure 4 is represented a graph with a comparison between SO_2 concentration and SO_2 flow. The flow varies less, and from the figure it is seen that the maximum values occur at 10:06.

Conclusions

Camera UVIR allows users to see the SO_2 concentration obtained from camera UV measurements.

Values measured with camera UV do not differ much than stack emission measuremeents.

Remote sensing is an option that is much more simple to be used, not being connected to the stack and offering thus a mobility and much more accessibility for external monitoring.

Remote sensing technique is becoming a future option for remote pollution measurement.

Furthermore, the camera images can be used to directly measure the plume transport velocity, potentially a major source of uncertainty in these measurements.

The proposed methods, even at beginning, must be further developed, but it is for sure that it might be used as alarming from distance method and a possibility to investigate from remote the sources of pollution.

In conclusion, in this studied case the SO_2 flue gases emitted by antropic power plants, running on sulfur containing fuels, with no other filtering systems for the SO_2, the remote control using UV cameras is helpful and recommended for a control from distance (remote measurement).

Present research concerning the UV camera utilization is a novel technology that will gain new insights into air quality in the vicinity of power plants, thus being a complementary option to depict and analyze air quality.

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