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METHOD FOR EVALUATION OF PERFORMANCE OF WET FLUE GAS DESULPHURIZATION INSTALLED IN "ROVINARI" POWER PLANT

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The SOx emissions represent one of the most pressing issue for the coal powered power plants. As a result of the enviromental protection regulations of the past years, the desulphurization of the burnt gases from such power plants is required. This solution represents the classical approach to desulphurization of coal burning power plants which has been improved in the last 30 years. Article presents the measured performance of the desulphurization solution that was implemented at the Rovinari power plant and also the visual representation of the results, most being recalculated accordingly to the actual conditions

Keywords: desulphurization, SO_2, limestone, performance, measurements

1. Introduction

The biggest source of SO_2 emissions is represented by the high power coal burning power plants. The Rovinari power plant is one of these polluters located in S-W Romania. It has an installed power of 1320 MWel (4x330), this is provided by 4 units number: 3, 4, 5 and 6, which were built and put in operation from 1976 to 1979. Each group is built in the so-called block scheme, where the boiler, the steam turbine, the generator as well as all the other auxiliary systems form a single unit. One of the most important factor is the SO_2 emission concentration in the inlet and outlet of the desulphurization plant installed for unit 4 Rovinari [1], [6], [3]. The SOx (mostly SO_2) and NOx emission represents the major source of acid rain. These gasses turn to acid when in contact with water in the atmosphere, thus resulting acid rain, which is a major factor of pollution affecting the environment.

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In order to reduce the air pollution (SO_2 primarily), the proposed solution consists in implementing of a wet flue gas desulphurization unit with limestone on a 1035 tons of steam per hour boiler with a nominal power of 330MW, block no.4 of Rovinari power plant (fig.1) [8], [9]. The solution pursues drop of the SOx emissions, SO_2 particularly from an average quantity of 4700-5000 mg/ Nm^3 to under 400 mg/Nm^3 in the exhaust gases. In conformity with the technical proposal for the Wet Flue Gas Desulfurization (WFGD) at Rovinari Power Plant Unit 4, the SOx concentration at the outlet of the installation the SOx concentration should not exceed 400 mg/m^3 at the standard conditions (standard temperature-pressure STP: 273.15K/ 1,013.25hPa) dry at 6%O_2 [8]. The measurements of performance and comparison to the guarantee conditions of the implemented solution will be discussed further. Before the actual performance tests were conducted, grid-measurements were made at the inlet and outlet of the wet flue gas desulphurization (WFGD) to evaluate the uniformity of the concentrations in order to establish the optimal position for the measuring probes.[5]

The simplified process scheme (fig.1) presents the WFGD plant with the following main systems: gas ducting, absorber, limestone supply and processing, limestone solution (about 30% $CaCO_3$ solution) distribution, gypsum slurry dehydration, gypsum slurry transfer and other auxiliary systems like oxidation and limestone unloading from trucks[5],[7]:

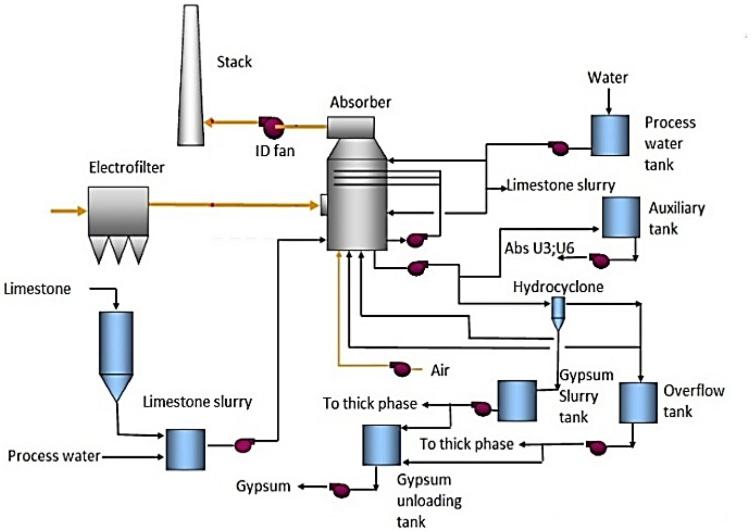


Fig. 1. The flow diagram of the wet flue gas desulphurization (WFGD) applied in the case of Rovinari Power plant

All the chemical reactions take place in the absorber, generally in the reaction tank (fig. 2). These reactions are as follows:

a) Absorbtion is the first step in the filtration process. It refers to the reaction between SO_2 and the spraying solution, it involves the mass transfer from a soluble gas component into a liquid.

b) Neutralizing represents the actual chemical reaction between SO_2 and the limestone solution. In this phase CO_2 is released as a gas, as shown in the involved reaction: $SO_2(g) + CaCO_3(s) \rightarrow CaSO_3(s) + CO_2(g)$.[2][3]

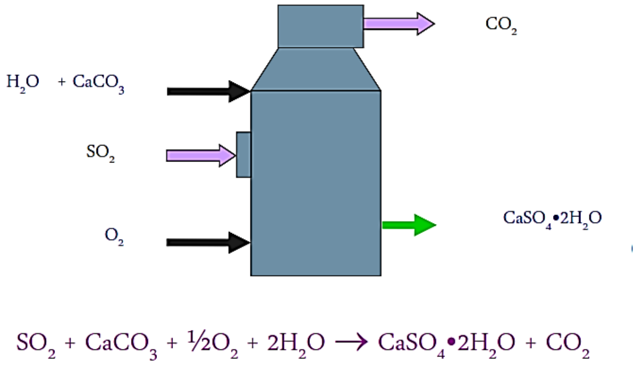
c) Regeneration means the adding of limestone solution in order to form the Calcium sulphite ($CaSO_3$), and also to help balance the PH of the resulting slurry which is acid by nature.

d) Oxidation, is the process which turns the calcium sulphite in calcium sulphate (CaSO4) , also known as gypsum by means of adding oxygen trough a series of oxy blowers.[1]

e) Precipitation is the process through a substance is separated from a solution by a chemical reaction. In the reaction zone of the absorber, when the solution becomes saturated, the calcium sulphate precipitates forming crystals.

The reactions that take place in the process can be organized in three groups: gas-liquid reactions, liquid-liquid reactions, liquid- solid reactions. The desulfurization process is composed of three main activities:

- the SO_2 absorbtion;
- the limestone solution preparing
- the gypsum preparing- drying activity.



$$SO_2 + CaCO_3 + \frac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$$

Fig. 2. The chemical process that takes place in the absorber of the WFGD installation studied, the reaction between calcium carbonate (limestone), water and Sulphur dioxide

For the measurements, different sampling sections were studied. In advance of the performance test core period, a number of measurements were carried out to determine flow and concentration profiles at the FGD inlet and outlet. Within the test period, which was evaluated with respect to the guarantee assessments, the boiler was operated closest possible to “design conditions” (88% of nominal boiler load, approx. 290 MWel) with lignite from a local mine.

The electrostatic precipitator (ESP) was in regular operation, the WFGD scrubber was operated with three out of five recirculation pumps and with one out of two oxidation air blowers. Boiler soot blowing was activated manually at fix times in the night to avoid an impact on measurements. In the following, a detailed presentation of the zone where gas measuring was done, is described [5].

A. FGD Inlet

Location: Vertical down coming duct from ESP, platform at level H = +34 m
Shape: Circular, Di = 7.98 m
Suitability: Sufficiently long straight, undisturbed inlet (≥5 x Di) and outlet (≥2 x Di) sections, requirements of EN 15259 fulfilled. Test ports:4 test ports (DN 150) at circumference (every 90°).
Measuring/Sampling positions:

- 4 x 6 sampling positions for grid measurements;
- 1 reference sampling position for monitoring of SO_2 / O_2/CO_2 concentration;
- 1 reference measurement position for monitoring of temperature, pressure, flow;
- 1 random sampling position for wet chemical measurements (HCl, HF, SO_3)

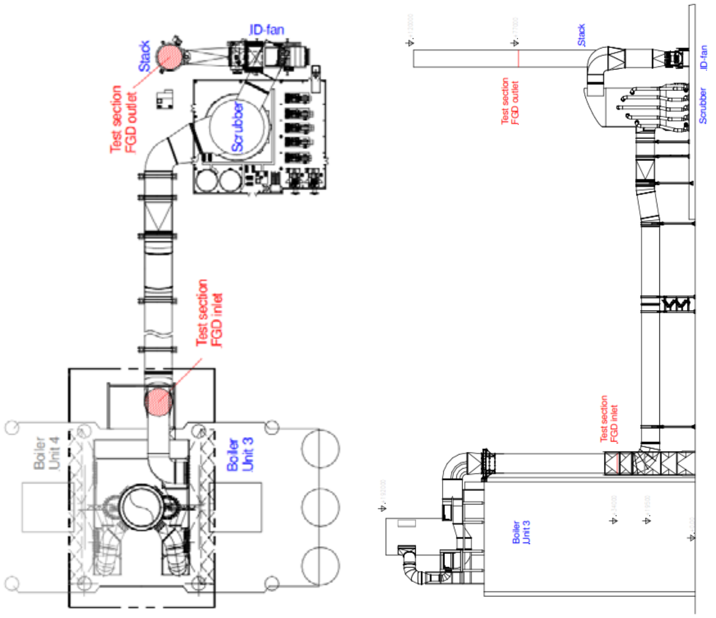
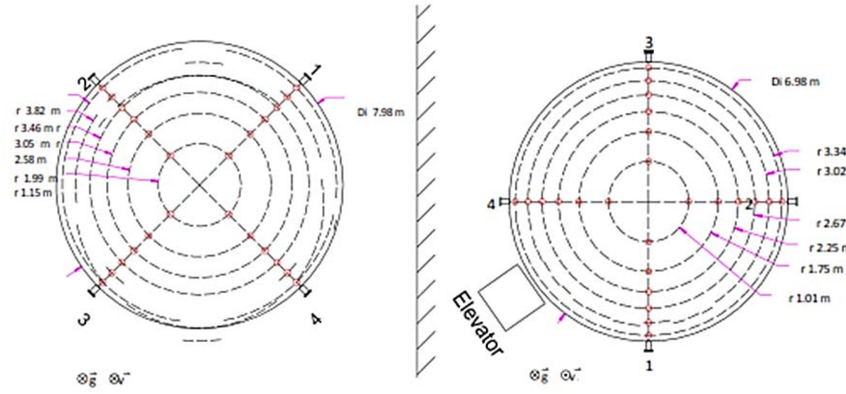


Fig. 3. Top view and side view of the the FGD Plant. Flue gas path and location of the Test Sections for flue gas measurements.

B. FGD Outlet (Stack, Emission Control Section)
Location - Stack at elevation H = +77m
Shape - circular, Di = 6.98 m
Suitability - Sufficiently long straight, undisturbed inlet (≥5xDi) andoutlet (≥2 x Di) sections, requirements of EN 15259 fulfilled [10]
Test ports - 4 test ports (DN 150) at circumference (every 90°) according to fig.4
Measuring /sampling positions:
- 4 x 6 sampling positions for grid measurements;
- 1 reference sampling position for monitoring of SO_2 /O_2 /CO_2 concentration;
- 1 random sampling position for wet chemical measurements (HCl, HF, SO_3).



a. b.

Fig. 4. Projection of the test section: a. - “FGD inlet” in the vertical down coming raw gas duct (+34 m) from ESP fo WFGD scrubber, measurement and sampling positions and designation of the measurement ports resp. axes. View in flow direction. b. - "FGD outlet“ (Stack +77 m), measurement and sampling positions and designation of the measurement ports resp. axes. View against flow direction

2. Practical gas measurements in the Unit 4 Rovinari Power Plant

For the SO_2 concentration measuring we used a continuous gas analyzer (ISO7935,EPA Method 6c). All the manual measurements are presented along side the DCS (Distributed Control System) readings for comparison purposes. Instruments used: Non-dispersive infrared/ultraviolet photometric analyzers. Manufacturer - type: ABB Advance Optima, URAS 14, NDIR (inlet), Emerson NGA 2000 MLT, NDUV (outlet). The article presents two principal measurement sets, one at the inlet and one at the outlet of the desulphurization plant. [4],[11] In order to obtain traceable results, in conformity with the parameters that should be evaluated (dry; hum; 6%O_2), the measured gas quantities were adjusted to the standard conditions (STP : T_S = 273,15 K; P_S = 1013.25 hPa **)** with the following equations:

- for pressure $$\frac{p_{gm}}{p_s} = \frac{p_{gm}}{1013.25} \tag{1}$$

(Pgm [hPa] = actual measured gas pressure)

- for temperature $$\frac{T_S}{(T_S+t_{gm})} = \frac{237.15}{273.15+t_{gm}} \tag{2}$$

(tgm [°C] = actual measured gas temperature)

So the volume at standard conditions STP (273.15K □i 1013,25 hPA) was calculated as follows:

$$V_{STP} = V_{gm} \cdot \frac{273.15}{273.15+t_{gm}} \cdot \frac{p_{gm}}{1013.25} \tag{3}$$

For recalculation of water vapor content in the measured volume, the following equation was used:

$$V_{hum} = V_{dry} \cdot \left(\frac{100}{100-h_{abs}}\right) = V_{dry\cdot} \cdot \left(1 + \frac{c_{H2O}}{\rho_{H2O}}\right) = V_{dry} \cdot \frac{p}{p-p_{H2O}} \tag{4}$$

Where:: h_{abs} [Vol%] = absolute humidity of gas (hum);c_{H2O} [g/m3] = water vapor concentration in the gas referring to a dry volume at STP; ρ_{H2O}[g/m3] = density of water vapors at STP = 804 g/m^3; P [hPa] = absolute pressure; P_{H2O}[hPa] = partial water vapor pressure;[11], [10]

In order to recalculate the flue gas flow volume for a 6% volume concentration of O_2, equation 5 was used:

$$V_{6\,Vol\%\,O_2} = V_{O_2} \cdot \frac{20.95-O_{2,act}}{20.95-6.0} \tag{5}$$

Where: O_2, act [Vol%] = the actual measured O_2 concentration in the flue gas;
20,95 [Vol%] = standard concentration of O_2 in the atmospheric air.

2.1. Measurement of the SO_2 and O_2 concentration profiles at the FGD inlet

This subchapter presents the trend curves from mobile (grid) analyzer in accordance to data provided by the DCS of the plant the measurements have the following coordinates: Test section location: vertical down coming FGD inlet duct, H = +34m, Duct diameter: D = 7.98 m, Equipment: Heated probe, gas cooler: ABB Advance Optima(SO_2-NDIR, O_2-Paramagn.).

DCS data (averages for measured time interval) FGD inlet

Boiler load = 87.9 %

Volume of flue gas = 1 940 000 m³/h STP hum

O_2 = 9.5 Vol% dry, SO_2 =4685 mg/m³ STPdry, SO_2 = 6 127 mg/m³ STPdry 6%O_2

Experimental measurements at FGD inlet - Grid averages

O_2 = 8.5 Vol% dry, SO_2 = 4446 mg/m³ STP dry, SO_2 =5338 mg/m³ STP dry 6%,

$SO_{2,DCS}$ / $SO_{2,grid}$ = 1.05 (STP dry) ,1.15 (STP dry 6% O_2)

According to measurements, figure 5 presents SO2 concentration profiles at FGD inlet. The discontinuity of the profile is caused by the stoppage of the measuring equipment within the testing intervals.

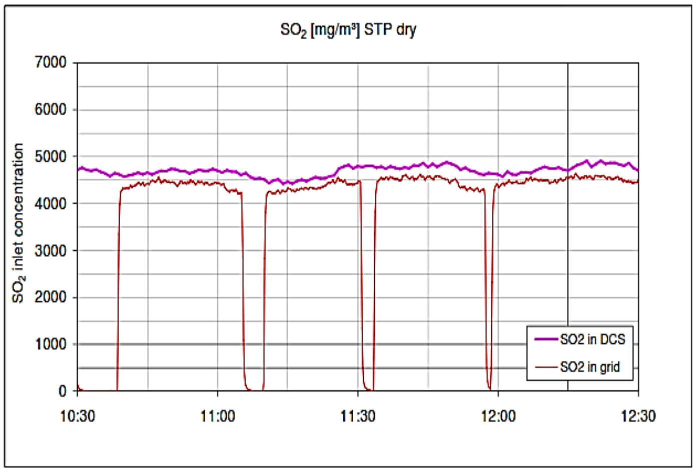


Fig. 5. SO_2 STP dry at FGD inlet

According to measurements, table 1 presents the O_2 concentration

Table 1

O_2 dry concentration[%]

r[m]	axis1	axis2	axis3	axis4	average
1.15	8.6	9.1	8.4	8.3	8.6
2.00	8.5	8.9	8.4	8.2	8.5
2.58	8.4	8.8	8.4	8.2	8.5
3.05	8.5	8.7	8.4	8.2	8.4
3.46	8.2	8.4	8.4	8.4	8.4
3.82	8.2	8.6	8.9	8.9	8.7
average	8.4	8.7	8.5	8.4	**8.5**

In table 2 the SO_2 measured concentration is presented corrected to STP conditions.

Table 2

SO_2 [mg/m³] dry STP

r [m]	axis 1	axis 2	axis 3	axis 4	average
1.15	4447	4258	4474	4539	4429
2	4488	4290	4449	4555	4445
2.58	4497	4322	4453	4562	4459
3.05	4462	4390	4438	4560	4463
3.46	4544	4484	4426	4486	4485
3.82	4561	4416	4273	4329	4395
average	4500	4360	4419	4505	4446

In table 3 the SO_2 corrected at 6% O_2 concentration is presented

Table 3

SO_2 [mg/m³] STP dry at 6% volume O_2

r [m]	axis 1	axis 2	axis 3	axis 4	average
1.15	5366	5350	5311	5358	5346
2	5369	5337	5307	5352	5341
2.58	5347	5338	5294	5362	5335
3.05	5346	5344	5285	5355	5332
3.46	5348	5335	5282	5358	5331
3.82	5361	5336	5290	5383	5343
average	5356	5340	5295	5362	5338

Min: 5282 mg/m³, Max: 5383 mg/m³

2.2. Measurement of the SO_2 and O_2 concentration profiles at the FGD outlet (stack)

In the same way as the inlet measurements, the readings from the installation integrated DCS are presented in comparison with the experimental data. Test section: Emission control section, stack at H = +77 m; Duct diameter: D = 6.98 m; Equipment: Heated probe, gas cooler, Emerson MLT4 (SO_2-NDUV, O_2 - Paramagn.)

DCS data (averages for measured time interval) at FGD outlet

Boiler load P = 87.9 %

Volume of flue gas V = 1940 000 m³/h STP hum

O_2 = 9.0 Vol% dry, SO_2 = 262 mg/m³ STPdry, SO_2 = 328 mg/m³ STPdry 6%O_2

FGD outlet experimental averages (mobile analyzer)

O_2grid = 8.7 Vol% dry, SO_2grid = 265 mg/m³ STP dry, SO_2 = 323 mg/m³ STP dry 6%O_2, SO_{2DCS} /SO_{2grid} = 0.97 (STP dry)

In this situation, according to fig. 4 the SO_2 concentrations at FGD outlet is presented. The discontinuities are caused by pauses marking the testing intervals.

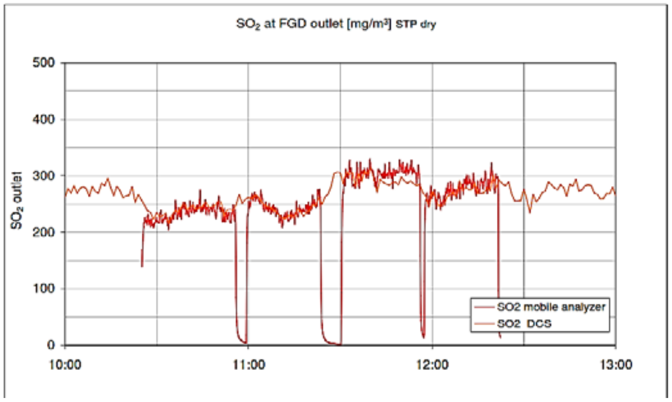


Fig. 6. SO_2 STP dry concentrations at FGD outlet

For the FGD outlet stack, in the following the measurement are presented according to the tables. Table 4 presents the O_2 measurement.

Table 4

O_2 dry [Vol%]

r [m]	**axis 1**	**axis 2**	**axis 3**	**axis 4**	**average**
1.01	8.6	8.5	8.5	9	8.6
1.75	8.7	8.7	8.5	8.8	8.7
2.25	8.8	9	8.5	8.7	8.8
2.67	8.7	9.2	8.4	8.5	8.7
3.02	8.7	9.2	8.4	8.6	8.7
3.34	8.9	9.1	8.7	8.4	8.8
average	8.7	8.9	8.5	8.7	**8.7**

Table 5 presents the SO_2 STP dry measurements.

Table 5

SO_2 [mg/m³] dry STP

r [m]	**axis 1**	**axis 2**	**axis 3**	**axis 4**	**average**
1.01	224	259	298	264	261
1.75	231	248	303	260	261
2.25	243	233	299	272	262
2.67	245	229	305	287	266
3.02	241	238	311	280	268
3.34	237	253	309	290	272
average	237	243	304	275	**265**

For the correction of the profile for transient concentration level variation the assumption is: proportional variation coefficient is constant in the grid.

Correction factor for each local measurement calculation taken from DCS, SO_2 concentration profile, corrected for transients. Table 6 presents the SO_2 STP dry concentrations corrected in accordance to transients.[11]

Table 6

SO_2 [mg/m³] dry STP corrected

r [m]	axis 1	axis 2	axis 3	axis 4	average
1.01	253	258	261	269	260
1.75	263	261	263	264	263
2.25	258	261	267	260	262
2.67	262	264	279	269	269
3.02	255	264	281	270	267
3.34	254	266	283	265	267
average	258	262	272	266	**265**

Table 7 presents the SO_2 STP dry at 6% O_2 concentrations after correction.

Table 7

SO_2 [mg/m³] dry STP at 6% O_2

r [m]	axis 1	axis 2	axis 3	axis 4	average
1.01	305	311	312	335	316
1.75	322	318	316	326	321
2.25	319	327	320	318	321
2.67	320	335	333	324	328
3.02	311	336	334	325	326
3.34	314	335	344	315	327
average	315	327	327	324	**323**

3. Discussions

The O_2 and SO_2 concentrations at the FGD inlet and outlet were monitored with the mobile gas analyzers and the stationary installed probes in the time period from 10AM to 7PM 21st July. This period of 9h was divided into 3 test runs of 3h duration each. 3 average SO_2 (= SOx) emission concentrations (each comprising 3h) of 378, 417 and 383 mg/m³ were determined, thus exceeding the maximum guaranteed level of 400 mg/m³ by 4% in one test run. The evaluation of the DCS-records of the in-plant SO_2 emission analyzer, applying the SRM (Standard Reference Method) calibration function, results in respective test averages of 375, 403 and 367 mg/m³. The applied measurement procedure is afflicted with an intrinsic measurement uncertainty “F” in the range of 5 - 6%, or 20-25 mg/m³ for the guaranteed maximum emission concentration. For the assessment of compliance of the recorded emissions with the legal emission limits this uncertainty is taken into account by subtracting it from the measured concentrations according to VDI guideline 2048 (Uncertainties of measurement during acceptance tests on energy-conversion and power plants) which states, that this 95% confidence interval shall be implied when assessing the fulfilment of a performance guarantee. The application of aforesaid to the measurements in question will appraise the SOx emission guarantee as fulfilled in all three test runs.[3] The corresponding inlet conditions with average SO_2 concentrations of 5680, 6290 and 6290 mg/Nm^3 and flue gas flow rates of 2050-2080 $10^3 m^3$/h STP ranged well beyond the design conditions for the performance tests (4400 mg/m^3 SO_2; 1850 $10^3 m^3$/h) and required an operation of the absorber with 3 slurry recycling pumps and with an increased oxidation air flow rate. In follow up of the actual performance test program an additional test with respect to the SO_2 removal capacity of the FGD plant was launched with 4 out of 5 slurry recirculation pumps in operation. Within a period of 10h (2 PM - 12 PM) thus the SO_2 emission concentration was reduced to a level of 76 - 136 mg/m^3 (hourly averages) at an inlet flow rate of 2010- 2100 10^3 $m^{3/}$h and a raw gas SO_2 concentration level of 6500 -5600 mg/m^3. A summary of the measurements in this article and the assessment of the related guarantees is presented in Tab. 8.

Table 8

Item	**Design Guarantee**	**Results**
Flue gas flow rate at FGD inlet	1850000m^3/h STP hum	***2000- 2100 $10^3 m^3$/h STP hum***
SOx concentration at FGD inlet	4400 mg/m^3	***5400- 6400 mg/m^3***
SO_3concentration at FGD inlet	30 mg/m^3	***2 mg/m^3***
Solid particle conc. at FGD inlet	100 mg/m^3	***760- 960 mg/m^3***
SO_xemission	≤400 mg/m^3	378- 417 mg/m^3
Solid particle(dust/ash)	≤50 mg/m^3	5- 13 mg/m^3

4. Conclusions

The results of the grid measurement in the inlet showed a very uniform O_2 and SO_2 distributions, the SO_2 profile features a flow coefficient (C_V) of 0.5% at a cross sectional average of 5340 mg/m^3. Also at the outlet a rather homogeneous concentration profile was determined, the C_V accounted for 3% at an average SO_2 concentration of 330 mg/m^3.

Taking into account the superposed fluctuations in the process (boiler, scrubber,etc.), the results of the grid measurements proofed the expected uniformities of the concentration profiles at the inlet as well as in the emission measurement section at the stack and approve the monitoring of the inlet and outlet concentrations by sampling with fix probes in reference positions for the following test period. For further monitoring of the O_2 and SO_2 concentrations a fix sampling probe was installed in the reference position „axis 1, r = 2.6 m” for the inlet test section and " axis 1, r = 1.75m" for the outlet concentration where the deviations from average were minimal.

Even though the measurement results are exceeding the design parameters (gas flow, SO2 and O2 concentrations as shown in Table 8) it is well proven that the desulphurization plant has a rather high efficiency in the SO_2 removal, ranging from 92% to 94% with only 3 recirculation pumps (normal operation). Anyhow, this can be increased to over 98% if the plant operates with 4 or 5 recirculation pumps. Also, very important to point out is the excessive concentration of solid particles at the FGD inlet, ranging between 760- 960 mg/m³. At the outlet section the concentration of solid particles ranged between 5- 13 mg/m³, which shows a great efficiency in dust removal of the desulphurization plant (over 99%), it is known however that wet desulphurization techniques provide good results in this field.

Acknowledgment:

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