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# Managing Occupational Safety and Health in Aluminum Production: Case Study of Aluminum Production Factory, Mostar, Bosnia and Herzegovina

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**Aim** To assess the effect of modernization of the aluminium production on physical and chemical health hazards at work environment in the *Aluminium Mostar* factory. The modernization included introduction of automatic equipment, computerized management, and rationalized coke manipulation in Anoda, Electrolysis, and Cast House plants.

**Method** Periodical measurements of chemical (gas concentrations and aerosols) and physical (microclimatic factors, noise, and illumination) factors were performed at the same workplaces by the same methods of measurements before (1982-1988) and after the modernization (2004). The measured values were compared with the recommended Occupational Safety and Health Standards of Bosnia and Herzegovina.

**Results** The number of workplaces with a high noise level was reduced from 65.0% (89/137) in 1982-1988 to 28.7% (51/178) in 2004. The best results were achieved in Cast House plant. The illumination of the workplace was partly improved. Values of microclimatic factors did not considerably change; they deviated from the recommended values at nearly all the workplaces in the factory. The concentrations of chemical agents were above the recommended standards in 56.3% (196/348) of the samples in 1982-1988, and in only 15.4% (99/645) of the samples tested in 2004. High concentrations of hydrogen fluoride have remained the primary pollutant in Electrolysis plant.

**Conclusion** The modernization of the factory has considerably reduced the amount of harmful substances at work environment in the *Aluminum Mostar*. However, the exposure to unfavorable physical factors has been only partly reduced.

The process of reducing alumina to aluminum and the transformation of aluminum ingots into the end products have not changed significantly over the past 100 years. What has changed, though, are the working conditions. Due to technical improvements, the job of aluminum workers has become physically less demanding (1). However, the exposure to hazardous chemical and physical agents at the workplace due to the aluminum production process cannot be completely avoided (2-4).

Heat (5) and noise (6) are the most important physical hazards. In all the phases of aluminum production, different chemical agents are also released into the work environment from the raw materials used for aluminum production and its technological processing. The most important air contaminants are gasses (hydrogen fluoride

[HF], sulphur dioxide [$SO_2$], carbon monoxide [CO], carbon dioxide [$CO_2$], nitrogen dioxide [$NO_2$], chlorine [Cl], and polycyclic aromatic hydrocarbons [PAH]), aerosols (aluminum oxide dust [$Al_2O_3$], cryolite [$Na_2AlF_6$], silicone dioxide [$SiO_2$]), and fluorides and fumes from evaporation and condensation of aluminum and its oxides (6).

These pollutants have harmful effects on the lungs, skin, and central nervous system. Inhalation and accumulation of aluminum dust and aluminum oxide fumes can cause pneumoconiosis and aluminosis (7,8). The exposure to fluorides along with exposure to aluminum dust can cause "potroom asthma" (9,10). Of the skin diseases, workers often develop dermatitis, characterized by edema, erythema, and sometimes skin erosion (11). Harmful effects on the central nervous system manifest as behavior disorders, tremors, movement difficulties, and memory and concentration disorders (12,13).

The *Aluminum Mostar* was founded in 1977 and destroyed in 1991/1992 during the war (14,15). In 1997, after the war, the steps to rebuild all the plants of the factory started. The reconstruction of the *Aluminum Mostar* was completed by the end of 1999, including the renewal of all 256 pots that worked before the war. However, that 30-years old technology could not compete with other aluminum manufactures, so the *Aluminum Mostar* management decided in 2000 to start with the modernization.

The process of production of aluminum and aluminum alloys in the *Aluminum Mostar* factory takes place in several different plants, Anode, Electrolysis, Casting, and Gas Processing plants (Fig. 1), and begins with the production of liquid aluminum through the electrolysis of alumina (15). The main technological changes were made in the Anode plant (Table 1). The Electrolysis plant, with the introduction of the so-called technique of dotted piercing, alumina and aluminum fluorine dosage into the pots, and computerized control, has now technologically the most advanced production of liquid aluminum (Table 1). With the use of modern devices for removing gas pollutants, their emissions have been reduced significantly, as in other similar plants in the world (16). The modernization of technological process in the Cast House enabled the production of more tons of billets per year. Computerized systems were introduced in offices, laboratories, and the production areas as well. Due to these changes, the *Aluminum Mostar* has become the largest and technologically most advanced aluminum manufacturer in the Southeastern Europe, with the yearly production of 114,000 tons of high quality

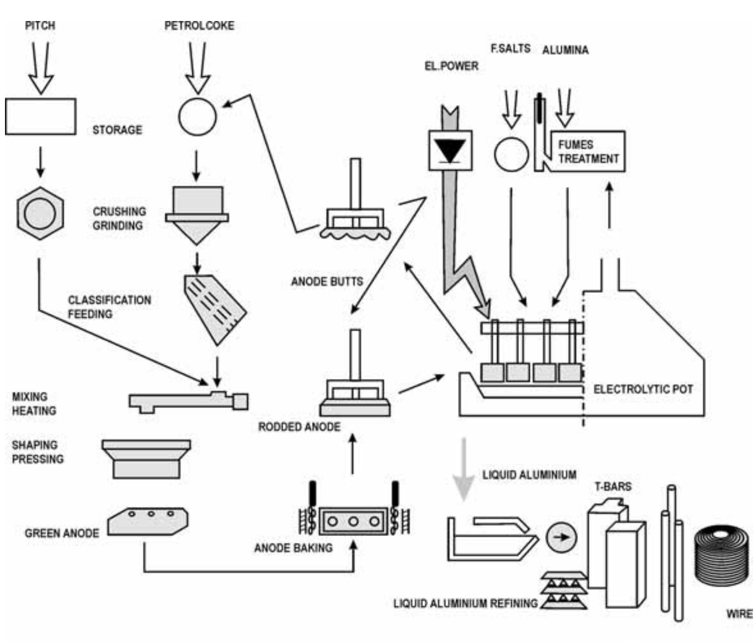


**Figure 1.** Aluminium production flow diagram in the *Aluminum Mostar*.

**Table 1.** The basic characteristics of the *Aluminum Mostar* factory after the reconstruction and the modernization

| Plant | No. of employees (n=531) | Technological processes | Materials | Modernization of process | Harmful agents | |
|---|---|---|---|---|---|---|
| | | | | | chemical | physical |
| Anode | 121 | manufacturing green and baked anodes | petrolcoke, pitch, anode bits | semi-automatic equipment for anode butts cleaning, system of resin manipulation, computerized dosing process, new process of alumina mixing | dust: petrol coke and pitch; gasses: carbon dioxide, carbon monoxide, sulphur dioxide, hydrogen fluoride, nitrogen oxide, polycyclic aromatic hydrocarbons (PAHs) | noise, microclimatic factors (temperature, humidity, air flow), illumination |
| Electrolysis | 208 | reducing alumina to aluminium | alumina, cryolite, Al-, Na- Ca-fluoride, pitch, anodes, cathodes | technology of dotted piercing, alumina and alumina fluoride dosage, computerized management, control and supervision of all parameters, filters, new coverlids on pots, the pmeumatic transportation alumina | dust (alumina, fluorides), gases: hydrogen fluoride, carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxide, PAHs | noise, microclimatic factors, illumination, electric magnetic fields |
| Cast House | 133 | transformation of aluminium ingots by rolling, casting and extrusion | liquid aluminum Si, Mg, pre-alloys Al-Mn, Al-Fe | modernization of existing furnaces, appliances for degazation and filtering, furnaces for continuous homogenisation | fume, dust, gasses: carbon dioxide and monoxide, sulphur dioxide, hydrogen fluoride, nitrogen oxide, chlorine, PAHs, metal fluids, ozone | noise, microclimatic factors, illumination |
| Gas Processing | 65 | dry cleaning (gas and fume treatment) | | | fume, hydrogen fluoride, carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxide, PAH-s | noise, microclimatic factors, illumination |
| Raw Materials receiving and warehousing | 4 | receiving and warehousing materials | petrolcoke, pitch | rationalisation of coke manipulation | fume, dust | noise, microclimatic factors, illumination |

aluminum, and its purity up to 99.9% (15). In 1999, *Aluminum Mostar* received the ISO 9001 certificate for quality control systems.

Along with the care about the quality of products and profit, the management invests a great effort in protection of health of their employees and the environment, as confirmed by the ISO 14.001 certificate. Measurements of hazardous chemical and physical agents in the work environment are performed regularly in accordance with the Occupational Safety and Health laws and regulations of Bosnia and Herzegovina (17,18). On the basis of the results of these measurements, health risks are assessed according to the official recommendations at the time (19,20).

Our aim was to establish if the introduction of new technologies and modernization in the existing plants reduced the number of occupational hazardous factors and the concentration of pollutants at the *Aluminum Mostar*.

## Materials and Methods

The *Aluminum Mostar* consists of several plants that make independent technological entities – Anode, Electrolysis, Cast House, Gas treatment, and Raw Material receiving and warehousing (Fig. 1).

Mandatory periodical measurements of chemical and physical agents in the work environment in these plants were performed in the period 1982-1988 and April 2004 after the reconstruction and modernization of the factory. The mean values of three individual measurements of the chemical and physical hazards at workplaces in the plants were taken as the probable value of the true measurement. In both study periods, measurements were done at the same workplaces by using the same methods. The measurement results were compared to the recommended standards (19,20).

### *Chemical Factors*

*Dust*. Dust in the work environment was collected by an aerosol monitor device (Model 8520, Dust Trak, TSI Incorporated, Shoreview, MN, USA) and measured as the concentration of total and respirable dust particles. Dust samples were collected during work shifts in the presence of workers. At least two measurements were made at different locations in the plant. The mean value of measured concentrations (mg/m$^3$) was compared with the maximum concentrations recommended by the standards (21).

*Gasses*. The presence and concentration of gasses were measured with a universal device for detecting and measuring the emission and diffusion of gasses in the atmosphere of the work environment MIRAN SapphIRE-100/100c (Foxboro Co., Foxboro, MA, USA). The gasses measured were carbon monoxide (CO), carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), hydrogen fluoride (HF), nitrogen dioxide ($N_2O$), difluoro sulphide ($F_2S$), benzene ($C_6H_{12}$), phenol ($C_6H_5OH$), chlorine ($Cl_2$), butane ($C_4H_{10}$), propane ($C_3H_8$). At least three measurements were made at different locations in the plants. The mean concentrations were compared with the maximum concentrations recommended by the standards (21).

### Physical Factors

*Microclimatic factors*. Temperature, humidity, and air flow were measured with the TESTO 350M/XL, TESTO 454, (Test GmbH, Lenzkirch, Germany) during normal working conditions at a height of 1.5 m above the floor. During measurements, the external air temperature was 12°C and relative humidity was 52.0%. The results of the microclimatic measurements were compared with the values recommended by the standards (22).

*Illumination*. The amount of illumination from electrical lighting sources at the workplace was measured by a Luxmetar direct readout device (Iskra, type MI 7065, Velenje, Slovenia). Measurements were taken at a height of 0.85 m above the floor. Values of illumination (lx) at the workplace were compared with the values recommended by the standards (23).

*Noise*. The noise levels at the workplace were measured by a noise measurement device DELTA OHM, type HD 9020 (Delta Ohm, Padova, Italy) at the ear level of the employees. The measured values (dBA), were compared with those recommended by the standards (24).

### Statistical Analysis

Chi-square test or Fisher's exact test were used for testing the differences in the measured values of chemical and physical agents at the workplace before and after the reconstruction and modernization of the plants. The level of $P<0.05$ was considered statistically significant. All statistical analyses were performed with SAS

**Table 2.** Results of the measurement of physical factors before (1982-88) and after reconstruction and modernization (2004) of all plants at *Aluminum Mostar*, Mostar, Bosnia and Herzegovina

| | Concentration of harmful substances in year | | | | |
|---|---|---|---|---|---|
| | 1982-1988 | | 2004 | | |
| Physical factors in a plant (units) | median (range) | No. of samples (>MAC*/total) | median (range) | No. of samples (>MAC/total) | MAC* |
| Anode: | | | | | |
| temperature (°C) | 12.7 (7.6-34.7) | 34/41 | 11.7 (4.8-42.0) | 72/83 | 14-22 |
| humidity (%) | 26.9 (19.4-50.9) | 40/41 | 27.0 (9.4-45.0) | 83/83 | 50-60 |
| air flow (m/s) | 0.3 (0.12-1.5) | 8/41 | 0.3 (0.0-2.0) | 8/83 | ≤0.5 |
| illumination (lx) | 69.0 (30.0-200.0) | 19/32 | 89.0 (20.0-600.0) | 43/83 | 80/150 |
| noise (dB(A)) | 94.0 (6.1-106.) | 29/41 | 85.8 (67.0-112.0) | 17/83* | 90 |
| Electrolysis: | | | | | |
| temperature (°C) | 24.9 (13.2-45.7) | 18/25 | 24.4 (14.4-42.7) | 18/28 | 14-22 |
| humidity (%) | 34.2 (10.3-53.1) | 23/25 | 13.1 (9.1-37.0) | 28/28* | 50-60 |
| air flow (m/s) | 0.9 (0.2-2.9) | 18/25 | 0.9 (0.0-1.9) | 15/28 | ≤0.5 |
| illumination (lx) | 70.0 (4.0-170.0) | 12/25 | 120.0 (80.0-300.0) | 3/28 | 80/150 |
| noise (dB(A)) | 91.5 (65.0-102.0) | 14/25 | 84.6 (62.0-101.9) | 11/28 | 90 |
| Cast House: | | | | | |
| temperature (°C) | 12.6 (8.2-29.6) | 28/37 | 15.0 (8.9-30.4) | 8/23* | 14-22 |
| humidity (%) | 48.2 (29.6-6) | 23/37 | 48.2 (31.4-74.9) | 7/23* | 50-60 |
| air flow (m/s) | 0.6 (0.1-5.4) | 18/28 | 0.5 (0.1-6.0) | 12/23 | ≤0.5 |
| illumination (lx) | 70.0 (40.0-200.0) | 18/31 | 80.0 (40.0-750.0) | 9/23 | 80/150 |
| noise (dB(A)) | 91.5 (83.5-102.0) | 29/37 | 83.0 (63.9-94.2) | 3/23* | 90 |
| Gas Processing: | | | | | |
| temperature (°C) | 20.9 (7.8-38.6) | 27/36 | 14.8 (8.0-24.8) | 19/37* | 14-22 |
| humidity (%) | 29.0 (14.0-58.5) | 5/36 | 27.4 (1.1-41.2) | 37/37* | 50-60 |
| air flow (m/s) | 0.6 (0.0-7.6) | 13/25 | 0.5 (0.0-7.6) | 20/37 | ≤0.5 |
| illumination (lx) | 77.5 (20.0-200.0) | 14/24 | 150.0 (20.0-460.0) | 4/37* | 80/150 |
| noise (dB(A)) | 90.1 (64.0-106.0) | 17/31 | 90.1 (61.0-98.5) | 19/37 | 90 |
| Raw Material receiving and warehousing: | | | | | |
| temperature (°C) | ND† | ND | 8.0 (7.6-11.4) | 7/7 | 14-22 |
| humidity (%) | ND | ND | 25.7 (24.6-48.1) | 6/7 | 50-60 |
| air flow (m/s) | ND | ND | 0.3 (0.1-1.1) | 3/7 | do 0.5 |
| illumination (lx) | ND | ND | 100.0 (15.0-200.0) | 3/7 | 80/150 |
| noise (dB(A)) | ND | ND | 82.6 (77.0-91.3) | 1/7 | 90 |

*MAC –maximum allowed concentrations; asterisk indicates significant differences in number of samples (chi-square test, $P<0.05$).
†ND – not done.

statistical package (SAS Institute Inc., rel. 6.03, Cary, NC, USA, 1988).

## Results

In 1982-1988, 643 measurements of temperature, humidity, air flow, illumination, and noise were done at 139 workplaces (Table 2). The presence and concentration of harmful substances were determined in 348 samples. In 2004, 890 measurements of physical agents and 645 measurements of the presence and concentration of harmful substances were done at 178 workplaces. Concentrations of fume, respirable dust, nitrogen

**Table 3.** Results of the measurement of concentrations of the harmful substances before (1982-88) and after reconstruction and modernization (2004) of all plants at *Aluminum Mostar*, Mostar, Bosnia and Herzegovina

| Plant and harmful substance (units) | Concentration of harmful substances in year | | | | |
|---|---|---|---|---|---|
| | 1982-1988 | | 2004 | | |
| | median (range) | No. of samples (>MAC/total) | median (range) | No. of samples (>MAC*/total) | MAC* |
| Anode: | | | | | |
| fume (mg/m³) | ND† | ND | 1.6 (1.4-6.0) | 1/15 | 5 |
| total dust (mg/m³) | 18.2 (3.2-126.7) | 17/27 | 8.7 (2.7-50.2) | 5/14 | 15 |
| respirable dust (mg/m³) | ND | ND | 1.4 (0.02-25.9) | 5/72 | 5 |
| carbon dioxide (ppm) | 1665.0 (0.0-10,970) | 7/23 | 190.0 (109-2,160) | 0/19‡ | 5,000 |
| carbon monoxide (ppm) | 32.0 (0-65.0) | 9/23 | 0.0 (0-10.6) | 0/17‡ | 50 |
| sulphur dioxide (ppm) | 3.3 (0-20.0) | 7/20 | 2.9 (0.02-14.3) | 3/10 | 4 |
| hidrogen fluoride (ppm) | 3.0 (0.8-12.0) | 6/15 | 2.1 (0-6.4) | 2/15 | 2.5 |
| nitrogen oxide (ppm) | ND | ND | 3.2 (1.1-14.9) | 1/12 | 5 |
| benzene (ppm) | ND | ND | 0.0 (0-12.7) | 0/11 | 15 |
| phenol (ppm) | 1.0 (0-6.3) | 5/11 | 0.0 (0-4.4) | 1/11 | 1.2 |
| fluoride (mg/m³) | 3.1 (0.66-11. 1) | 5/8 | ND | ND | 1 |
| Electrolysis: | | | | | |
| fume (mg/m³) | ND | ND | 4.2 (2.2-11.2) | 7/23 | 5 |
| total dust (mg/m³) | 21.2 (14.1-158.6) | 21/24 | 9.1 (3.1-140.0) | 6/27‡ | 1.2 |
| respirable dust (mg/m³) | ND | ND | 5.2 (1.2-37.0) | 14/30 | 5 |
| carbon dioxide (ppm) | 5240.0 (109-14,200) | 15/21 | 680.0 (0-2,700) | 0/25‡ | 5,000 |
| carbon monoxide (ppm) | 60.0 (10.0-258.0) | 16/20 | 3.2 (0-29.8) | 0/25 | 50 |
| sulphur dioxide (ppm) | 12.5 (1.7-28.2) | 15/21 | 2.0 (0-9.3) | 5/25 | 4 |
| hidrogen fluoride (ppm) | 9.7 (1.9-19.1) | 22/24 | 5.3 (0.12-16.9) | 24/28 | 2.5 |
| nitrogen oxide (ppm) | ND | ND | 1.4 (0-4.3) | 0/26 | 5 |
| phenol (ppm) | 3.9 (0.75-4.1) | 6/11 | ND | ND | 15 |
| fluor sulphide (ppm) | ND | ND | 409.5 (11.5-931) | 0/28 | 1,000 |
| Cast House: | | | | | |
| fume (mg/m³) | ND | ND | 2.7 (0.03-5.3) | 2/12 | 5 |
| total dust (mg/m³) | 20.6 (3.9-46.8) | 7/14 | 12.3-39.0§ | 1/2 | 15 |
| respirable dust (mg/m³) | ND | ND | 0.5 (0.1-11.0) | 1/22 | 5 |
| carbon dioxide (ppm) | 2770.0 (980-11,900) | 4/12 | 1,145 (360-11,370) | 1/14 | 5,000 |
| carbon monoxide (ppm) | 50.0 (0.9-68.0) | 10/21 | 8.1 (0-15.0) | 0/13‡ | 50 |
| sulphur dioxide (ppm) | 4.1 (2.2-5.9) | 2/3 | 1.2 (0.6-2.16) | 0/12‡ | 4 |
| hidrogen fluoride (ppm) | 0.0 (0-3. 9) | 1/3 | 1.2 (0.3-1.9) | 0/12 | 2.5 |
| nitrogen oxide (ppm) | ND | ND | 3.9 (0.7-4.4) | 0/13 | 5 |
| fluor sulphide (ppm) | ND | ND | 112.3¶ | 0/1 | 1,000 |
| chlorine (ppm) | ND | ND | 1.2 (0-3.6) | 5/7 | 0.5 |
| butane (ppm) | ND | ND | 360.3¶ | 0/1 | 800 |
| propane (ppm) | ND | ND | 75.0¶ | 0/1 | 1,000 |
| Gas Processing: | | | | | |
| fume (mg/m³) | ND | ND | 2.2 (0.8-3.4) | 0/4 | 5 |
| total dust with fluor (mg/m³) | ND | ND | 1.2 (0.07-23.6) | 9/13 | 1 |
| respirable dust (mg/m³) | ND | ND | 0.8 (0.06-2.84) | 0/17 | 5 |
| carbon dioxide (ppm) | 5440.0 (450-11,320) | 6/12 | 430.0 (200-1,200) | 0/8‡ | 5,000 |
| carbon monoxide (ppm) | 36.9 (0-68.0) | 8/19 | 13.2 (12.2-14.1) | 0/5 | 50 |
| sulphur dioxide (ppm) | 5.1 (1.7-6.0) | 4/8 | 1.1 (0-2.7) | 0/11‡ | 4 |
| hidrogen fluoride (ppm) | 2.5 (1.2-3.96) | 3/8 | 1.6 (0.4-6.8) | 3/19 | 2.5 |
| nitrogen oxide (ppm) | ND | ND | 1.9 (1.0-4.7) | 0/11 | 5 |
| fluor sulphide (ppm) | ND | ND | 375-399§ | 0/2 | 1,000 |
| Raw material receiving and warehousing: | | | | | |
| total dust (mg/m³) | ND | ND | 15.4-16.4§ | 1/2 | 15 |
| respirable dust (mg/m³) | ND | ND | 2.9 (1.87-8.3) | 1/8 | 5 |
| carbon dioxide (ppm) | ND | ND | 2,160¶ | 0/1 | 5,000 |
| sulphur dioxide (ppm) | ND | ND | 4.7¶ | 1/1 | 4 |
| nitrogen oxide (ppm) | ND | ND | 1.4¶ | 0/1 | 5 |

*MAC – maximum allowed concentrations.
†ND – not done.
‡Significant differences in the number of samples ($\chi^2$-test, P<0.05).
§Only two measurements were available so that median could not be calculated.
¶Only one measurement was available.

oxide, fluoride, and sulphur dioxide were measured at all workplaces; concentration of benzene was determined in the Anode plant, whereas concentrations of chlorine, butane, and propane were measured in the Cast House (Table 3).

#### *Chemical Factors*

Total dust and carbon monoxide, carbon dioxide, sulphur dioxide, hydrogen fluoride, and phenol at all plants during the period from 1982-1988 showed considerably higher values than the maximum allowed concentrations recommended by the occupational safety and health standards of Bosnia and Herzegovina (21) in 56.3% (196/348) of the samples, even up to 10 times (Table 3). The measurements of the same harmful substances in 2004 showed considerably lower concentration of those hazards in 15.4% (99/645) of the samples.

In the Anode plant, the concentrations of harmful substances before the reconstruction of the factory were above the allowed maximum values in 44.1% (56/127) of the samples. The recent measurements have shown that the concentration was above the recommended value in only 9.2% (18/196) of the samples (Table 3).

In the Electrolysis, the concentration of gasses and aerosols in the period 1982-1988 exceeded the recommended maximum values in 78.5% (95/121) of the samples. Concentrations of carbon monoxide, carbon dioxide, sulphur dioxide, and phenol were above the allowed values in more than half of all the samples, whereas the concentrations of total dust and hydrogen fluoride exceeded the recommended values in 21 and 22 out of 24 samples, respectively. With the modernization, the number of hazardous chemical agents was reduced and the number of samples with concentrations higher than the recommended decreased three-fold (Table 3). There is still a problem of high concentrations of hydrogen fluoride, which were measured in 24 out of 28 samples. The highest concentration of these gasses was measured while the pots were open.

The presence of carbon dioxide, carbon monoxide, sulphur dioxide, and hydrogen fluoride in concentrations above the maximum allowed values were significantly reduced in the Cast House after the reconstruction. Chlorine, which was not measured in the period 1982-88, was found in high concentrations in 2004 and thus became the primary pollutant in the plant (Table 3).

In the Gas Processing plant, the presence of all gasses has been reduced, although the dust containing fluoride still poses a hazard for the exposed workers (Table 3).

Before the reconstruction and modernization of the factory the employees were exposed to numerous harmful agents at the same time at 51% (71/139) of the workplaces. After the modernization, the number of such workplaces decreased to 15.2% (27/178). Most of these workplaces were in the Electrolysis plant, especially where anode covering and changing takes place.

#### *Physical Factors*

The number of workplaces with high noise levels was reduced from 66.4% (89/134) in 1982-1988 period to 28.7% (51/178) in 2004. The biggest reduction was achieved in the Cast House, from 78.4% (29/37) to 13% (3/23) (Table 2). Noise level remained high at 19 out of 37 workplaces in the Gas processing plant.

Illumination was partially improved. Levels of illumination that were below the recommended values were found at workplaces where lighting fixtures were not maintained (Table 2).

The values of temperature, air flow, and relative humidity before and after the reconstruction did not considerably change. They deviated from the recommended values at nearly all the workplaces in the factory (Table 2).

### Discussion

After the modernization, the level of workers' exposure to harmful substances in the plants in *Aluminum Mostar* has decreased significantly. The concentrations of harmful agents that considerably exceeded the maximum recommended levels have been reduced from 56.6% to 15.3%, and the concentrations of particular harmful substances have been reduced up to ten times.

Due to the nature of the aluminum production process, it is impossible to eliminate all the harmful substances by the current safety technology (4). However, according to our results, the working conditions in *Aluminum Mostar* today can be compared with the working conditions in the majority of the modern aluminum factories in the world (4,25).

Unfavorable physical conditions are much more common than the presence of chemical agents (26). Our measurements from 2004 showed considerably lower noise levels in the Cast House, probably due to the modernization of the existing furnaces that receive and prepare liquid metal, devices for filtering liquid metal, and the new equipment for casting rods. In the Electrolysis, the modernization of the pot electrolysis and pneumatic transport of alumina decreased the noise levels at 17% of workplaces. Noise remains a problem, especially in the Gas Processing plant where recent measurements have shown that the noise level was too high at more than half of the workplaces. Generally, in aluminum industry, it is difficult to completely eliminate the noise, which has been confirmed by research in seven most technically advanced aluminum factories in Canada (26,27).

Depending on the demands of the job, unfavorable microclimatic conditions, such as temperature, air flow, and relative humidity, can put the health of exposed employees at risk. The most common problem is high temperature. High temperature levels have been measured in about 20% of the workplaces. The measurements were made in spring and fall when the outside air temperature was up to 12°C and relative humidity 54%. The results of the measurements of microclimatic conditions in the aluminum industry are greatly influenced by the season when the measuring is performed and the climate in which the factory is located. The air temperature during summer months in Herzegovina, where the factory is located, reaches over 40°C, making the microclimatic conditions in that period of the year even less favorable.

Our measurements from 2004 showed that health hazard was the greatest for the employees in the Electrolysis, because most of them were exposed to numerous physical and chemical hazards at the same time. A research in Swedish aluminum industry showed that the electrolytic processing of alumina produces large amounts of air pollutants, which are hard to eliminate (16,28). Among the pollutants, there are compounds of fluorine, which pose the greatest threat in the profession. Hydrogen fluoride is definitely the most significant of the compounds. High concentrations of hydrogen fluoride were present in all the plants. Measurements done in the period 1982-1988 showed the presence of hydrogen fluoride at all workplaces in the Electrolysis at a concentration up to 10 times higher than the maximum allowed value. After the modernization of the technological process, the concentration of hydrogen fluoride decreased to or below the recommended values in all the plants except the Electrolysis.

Considerable concentrations of hydrogen fluoride in the Electrolysis plant can hardly be achieved with the standard safety measurement technology. This is confirmed by a study from Norway (6), where the concentrations of hydrogen fluoride in their plants reached between 0.2 and 5.7 ppm. Norway, which is one of the largest manufacturers of aluminum, has set the maximum allowed concentration (MAC) values for fluoride in the Electrolysis plant at 0.6 mg/m$^3$. The reason why MAC for fluoride is so low is to prevent chronic and acute respiratory diseases in the exposed employees. In Europe today, professional fluorosis is considered to be a disease of the past. In South America, the MAC for fluoride is set at 25 mg/m$^3$, which is significantly higher than in Europe. However, this value is set to prevent fluorosis, not respiratory diseases (29-32).

In addition to hydrogen fluoride, dust with fluoride compounds, carbon and alumina is present in the Electrolysis area. Before the modernization, high levels of these pollutants were measured at almost every workplace. However, the concentrations after the modernization did not exceed the recommended maximum values, except at a few workplaces, such as those at open pots where corrections are made, the pour bath, and the crust removal station. Semi-automatic equipment for cleaning anode bits decreased the dust concentrations and physical activity of the employee, who is situated in an air-conditioned cabin. The *Aluminum Mostar* uses the most advanced technology for the production of baked anodes, which reduces the concentration of polycyclic aromatic hydrocarbons that is emitted into the workplace. This is not the case with these compounds in other factories where the Soderbeng anode type is used.

After the modernization, high concentration of chlorine has remained the biggest problem in the Cast House. Chlorine not only irritates the respiratory system and eyes, but is also described as a factor that increases the risk of lung cancer (16).

Due to the use of tar with low percentages of sulphur, the presence of sulphur dioxide

($SO_2$), carbon monoxide (CO), and carbon dioxide ($CO_2$) has been lowered to a minimum in all the plants, and work conditions that meet the most recent standards of aluminum production have been achieved (33).

Decreased emission of harmful gasses, primarily hydrogen fluoride, in work environment is the result of introducing dotted piercing and the computerized feeding of raw materials into the pots, of new filters and changed coverlids to the pots (Fig. 2). The results of the pot modernization and the introduction of modern devices for processing anode gases eliminated 96-99% of all pot emissions (16).

**Figure 2.** Modernized electrolytic cells and new way of alumina dosage.

After the modernization, the number of workplaces where the employees are exposed to chemical and physical hazards has been drastically decreased in all plants, especially in the Electrolysis plant.

The problem of working in overheated or cold areas has been solved according to ISO standards by taking an estimate of heat burden and calculating the duration of exposure and the duration of an adequate rest (34). Thus, periods of work in hot or cold environments are alternated with periods of easier work in less hot or cold environments, which reduces the level of physical stress. Automated processes, air-conditioned or isolated cabins, and the use of heat-protective gear also safeguard the employee against heat radiation.

The work in the *Aluminum Mostar* factory is organized in four 6-hour shifts, which is also a way of reducing the exposure to unfavorable factors in the work environment. According to the work safety guidelines, employees have to wear protective gear, headphones or ear plugs if they are exposed to high levels of noise, protective suits for unfavorable temperature conditions, protective goggles and helmets, as well as respiratory protection for harmful gases and aerosols (17).

Health hazards are estimated for each workplace and each individual employee. Due to health monitoring as another step in protecting the employees' health and safety (17,18), all 531 employees undergo a specialist medical examination once a year, with an emphasis on possible effects of individual hazards.

Monitoring the employees' exposure to harmful factors at the workplace also shows if the enforcement of protective health measures was successful. In the *Aluminum Mostar*, urinalysis is performed before and after the shift to estimate the exposure of hydrogen fluoride. Systematical monitoring of safety and health reduces the number of job-related injuries and sick leaves. The yearly report for the first 6 months of 2003 showed that the number of job-related injuries had decreased from 60 to 29, compared with the same period the previous year (35).

Besides improving the air quality inside the factory the *Aluminum Mostar* also protects the environment outside the factory. The vegetation outside the aluminum industries is quickly renewed if fluoride emissions are reduced to 1kg/t of aluminum produced (35). Whereas fluoride emissions in the work environment from 1940 to 1955 reached 12-15 kg/t of produced aluminum, in 1974 they reached 3.9 kg/t (34), and today for each ton of aluminum produced 0.3 to 1 kg of fluoride is emitted. Soil, air, and water quality is periodically monitored at over 400,000 $m^2$ of green landscape, fruit orchards, vineyards, and mini-farms that surround the factory. Employees with impaired working capabilities maintain the area in order to sustain their remaining capabilities and to prevent further deterioration.

The modernization of the factory has considerably reduced the amount of harmful chemical agents in the working environment of the *Aluminum Mostar* plants. However, the exposure to unfavorable physical factors has been only partially reduced.

#### References

1 Kelly JW. Overview of health issues for the past twenty-five years in the aluminium industry. In: Priest

ND, O'Donnell TV, editors. Health in the aluminium industry. London: Middlesex University Press; 1998. p. 1-7.

2 Stewart PA, Lees PS, Francis M. Quantification of historical exposures in occupational cohort studies. Scand J Work Environ Health. 1996;22:405-14.

3 Wald P, Stave G. Physical and biological hazards in the workplace. 2nd ed. New York: John Wiley and Sons; 2001.

4 Westberg HB, Selden AI, Bellander T. Exposure to chemical agents in Swedish aluminum foundries and aluminum remelting plants—a comprehensive survey. Appl Occup Environ Hyg. 2001;16:66-77.

5 Lariviere C. Hot environments, control of exposure. In: Priest ND, O'Donnell TV. Managing health in the aluminium industry. London: Middlesex University Press; 1999. p. 37-43.

6 Damiano J. What do we need to monitor in the workplace. In: Priest ND, O'Donnell TV. Managing health in the aluminium industry. London: Middlesex University Press; 1999. p. 8-20.

7 Voisin C, Fisekci F, Buclez B, Didier A, Couste B, Bastien F, et al. Mineralogical analysis of the respiratory tract in aluminium oxide-exposed workers. Eur Respir J. 1996;9:1874-9.

8 Gibbs GW. Mortality of aluminum reduction plant workers, 1950 through 1977. J Occup Med. 1985;27: 761-70.

9 Hjortsberg U, Nise G, Orbaek P, Soes-Petersen U, Arborelius M Jr. Bronchial asthma due to exposure to potassium aluminumtetrafluoride. Scand J Work Environ Health. 1986;12:223.

10 Abramson MJ, Wlodarczyk JH, Saunders NA, Hensley MJ. Does aluminum smelting cause lung disease? Am Rev Respir Dis. 1989;139:1042-57.

11 Chandrasekaran NK. Welding and heath–a practical perspective. Indian Journal of Occupational and Environmental Medicine. 2001;5:166-8.

12 Sjogren B, Iregren A, Frech W, Hagman M, Johansson L, Tesarz M, et al. Effects on the nervous system among welders exposed to aluminium and manganese. Occup Environ Med. 1996;53:32-40.

13 Racette BA, McGee-Minnich L, Moerlein SM, Mink JW, Videen TO, Perlmutter JS. Welding-related parkinsonism: clinical features, treatment, and pathophysiology. Neurology. 2001;56:8-13.

14 Bagarić I. Medical services of Croat people in Bosnia and Herzegovina during 1992-1995 war: losses, adaptation, organization, and transformation. Croat Med J. 2000;41:124-40.

15 Aluminij d.d. Mostar. Available at: *www.aluminij.ba*. Accessed: February 21, 2005.

16 Westberg HB, Selden AI, Bellander T. Emissions of some organochlorine compounds in experimental aluminium degassing with hexachloroethane. Appl Occup Environ Hyg. 1997;12:178-83.

17 Occupational safety law [in Croatian]. Službeni list Socijalističke Republike Bosne i Herzegovine; 1990. Vol. 22.

18 Regulations on the periodical medical checkup procedures and testing in occupational safety areas [in Croatian]. Službeni list Socijalističke Republike Bosne i Herzegovine; 1991. Vol. 2.

19 Bogadi-Šare A. Health protection in working environment. In: Šarić M, Žuškin E, editors. Occupational medicine and environment [in Croatian]. Zagreb: Medicinska naklada; 2002. p. 706-17.

20 Regulations on general safety measures in work buildings and secondary areas and work spaces [in Croatian]. Službeni list Socijalističke Republike Bosne i Hercegovine; 1988; Vol. 5.

21 Maximum allowed concentrations of harmful gasses, fumes and aerosoles in the workplace atmosphere. Yugoslavian standards. JUS.Z.BO.001 [in Croatian]. Službeni list Socijalističke Federativne Republike Jugoslavije; 1971. Vol. 35.

22 Temperature norms, relative humidity, and air flow at a workplace. Yugoslavian standards U.JP.600/80 [in Croatian]. Službeni list Socijalističke Federativne Republike Jugoslavije; 1967. Vol. 27.

23 Daylight and electric illumination at workplaces in buildings. Yugoslavian standards, JUS U.C9.100/62 [in Croatian]. Službeni list Federativne Narodne Republike Jugoslavije; 1962. Vol. 48.

24 Regulations for maximum allowed noise levels in working and living environment [in Croatian]. Narodne novine; 1990. Vol. 37.

25 Romundstad P, Haldorsen T, Ronneberg A. Exposure to PAH and fluoride in aluminum reduction plants in Norway: historical estimation of exposure using process parameters and industrial hygiene measurements. Am J Ind Med. 1999;35:164-74.

26 Priante E, Marcuzzo G, Gori G, Saia B, Bartolucci GB. The occupational risks in a company producing aluminum alloy wheels [in Italian]. Med Lav. 1992;83:461-5.

27 Korczynski RE. Occupational health concerns in the welding industry. Appl Occup Environ Hyg. 2000;15: 936-45.

28 Dinman BD. The respiratory condition of potroom workers: survey of IPAI member companies – preliminary report. In: Hughes JP, editor. Health protection in primary aluminium production. London: International Primary Aluminium Institute; 1977. p. 95-105.

29 Lund K, Ekstrand J, Boe J, Sostrand P, Kongerud J. Exposure to hydrogen fluoride: an experimental study in humans of concentrations of fluoride in plasma, symptoms, and lung function. Occup Environ Med. 1997;54: 32-7.

30 Pierre F, Diebold F, Baruthio F. Biomonitoring of aluminium in production workers In: Priest ND, O'Donnell TV, editors. Managing health in the aluminium industry. London: Middlesex University Press; 1999. p. 68-87.

31 Schlatter C, Steinegger A. Significance of fluoride monitoring in the aluminum industry [in German]. Soz Praventivmed. 1988;33:122-4.

32 Sanderson EG, Farant JP. Use of benzo[a]pyrene relative abundance ratios to assess exposure to polycyclic aromatic hydrocarbons in the ambient atmosphere in the vicinity of a Soderberg aluminum smelter. J Air Waste Manag Assoc. 2000;50:2085-92.

33 Farant JP, Gariepy M. Relationship between benzo[a]pyrene and individual polycyclic aromatic hydrocarbons in a Soderberg primary aluminium smelter. Am Ind Hyg Assoc J. 1998;59:758-65.

34 International Organization for Standardization (ISO). ISO 7243: Hot environments – estimation of the heat stress on working man, based on the WBGT-index (wet

bulb globe temperature). Geneva (Switzerland): ISO; 1989.

35 Ćavar V. Realized productions above the planned [in Croatian]. Aluminij. 2003;3:12-3.

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