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REVIEW

Effect of Aluminium Smelters on Health and Vegetation

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INTRODUCTION

Pollution may be defined as the alternation of physical and chemical properties of parameter or a combination of parameters in the environment consisting of air, water or soil which is harmful to the ultimate beneficiaries of the media. Though industrialisation is the prime necessity for proper utilisation of natural resources and to sustain the exploding population, a huge quantity of waste materials/pollutant are generated in the process which need treatment before disposal. If these are discharged untreated environmental degradation and ecological imbalance are inevitable.

Aluminium industry is considered to be a major industry, next to iron as far as the raw material consumption, capital investment, per-capita production and high employment potential are concerned. Because of its versatile electrical, metallurgical and physical properties, aluminium has become an indispensable commodity for developed and developing societies. Nearly half of the raw materials used in aluminium industry ultimately become waste products. Disposal and dumping of these wastes not only create aesthetic but also public health problems. As waste treatment and disposal costs increase and public concern over waste handling practices rises pollution prevention becomes an essential element of the nation's immediate and long term strategy concerning management of wastes and pollutants.

Starting from bauxite to aluminium production, it is basically a combination of Bayer's process and Hall-Heroult process which can be divided into four segments: mining of bauxite, production of alumina, power plant and pot house. Each segment is associated with its own ecological problems and, as a whole, responsible for air, water, land and noise pollution. Though numerous attempts have been made worldwide for the effective control/prevention of pollution either in the form of modernisation or renovation with updated technologies and enactment of stricter pollution prevention laws, the globe is not yet free from its harmful effects.

Alumina Plant

The major pollutant in alumina production facilities is red mud, an alkaline waste produced in Bayer's process. Recovery of a tonne of alumina generates an almost equivalent quantity of red mud. About 1.4 million tonnes of red mud are produced per year in India alone. On one hand there is no economically viable process for the utilisation of this huge waste, while, on the other, it is to be stored carefully over a long period to avoid contamination of the environment. Details of work done worldwide and the problems associated with the analysis and utilisation of red mud have been critically dealt with in a recent book of Thakur and Das.[1] Alumina is further processed by Hall-Heroult process in electrolytic cells to produce aluminium metal. The pots are high energy consuming units operating at high temperatures and generating a number of hazardous pollutants causing serious health problems especially for persons working there. In this review the authors have made an attempt to discuss the effects of aluminium smelters on health and vegetation.

Pot House

A number of exhaustive reviews were published on harmful aspects of pollutants associated with primary aluminium plants. A review with 59 references was published by Massot *et al.*[2] dealing with Al in the environment, chemistry of aluminium including the aluminium cycle, its behaviour in aqueous solution, acidification of neutral aquatic systems, reactions and speciation in soil. Reviews were also published by Crawn[3] and Oostdam *et. al.*[4] covering the assignment of Alzheimer's disease, epidemiological disorders due to aluminium uptake, relation between exposure and retention of the metal in human brain etc. It also covers the assessment of exposure of the Canadian population to aluminium in water, food, consumer products, air, pharmaceuticals and soil. A review with a number of references on environmental protection measures taken in aluminium plants was written by Akselrod *et al.*[5] at Alumar, Brazil to prevent environmental pollution due to atmospheric emissions, waste discharges and disposal of solid wastes. Another review on human exposure to aluminium was published by Epstein[6] without recording any definite conclusion. His study did raise genuine doubts as to the causes of Alzheimer's disease, biological significance of aluminium in the brain though it is poorly absorbed by the human body. The author, however, concluded that the normal ingestion of aluminium from food and water should have no adverse effect on human health.

Serum and urine levels of the metal in workers of aluminium industries were studied by Rockette *et al.*[7] and it was inferred that urinary aluminium levels are a better sensitive index of exposure than blood serum. Again, it was also observed that the average preshift differences in serum aluminium levels for the exposed group versus controls was 1.32 μg/L whereas for postshift it was 0.96 μg/L. Average preshift and postshift differences betwen exposed and control workers for aluminium/creatinine ratio were 5.67 and 8.01 μg/g respectively. Fernandez *et al.*[8] have made similar types of investigation in order to find out the effect of age and environmental exposure on serum aluminium levels and normal renal function. The serum aluminium levels in volunteers with normal renal function having different jobs, including people working in the main unit, were studied. However, there was no significant difference in serum aluminium levels irrespective of sex, alcohol consumption, smoking habits and working conditions. On the contrary, the urinary aluminium excretion was higher in workers. However, a significant increase in the serum aluminium value was found to be proportional to the increase in age. It was concluded that the known dedline in renal function observed with the increasing age and the likely decrease in aluminium clearance could be responsible for the increase in serum aluminium values.

Pettersen *et al.*[9] investigated on neuropsychological effects from long occupational exposure in an aluminium plant in Norway and found that impairment of the nervous system was caused by occupational exposure in the pot room. A comparison was made between the workers with ten years of occupational exposure in the smelter or foundry and those who had never worked in these areas. The workers were put to medical examinations, mental function tests, blood and urine analysis and were interviewed about life style, smoking habits, alcohol consumption and health complaints. Pot room workers had subclinical tremor and a slightly impaired visual intellectual ability. However, there was no sign of cognitive impairment in the foundry workers. Alessandri *et al.*[10] studied chronic bronchitis and respiratory function of workers in a primary aluminium plant. Authors selected a group of 323 workers of a primary aluminium production plant and compared them with the general working population of the same industrial area. Results showed a higher prevalence of chronic bronchitis (5.6% *vs.* 2.6%) and a greater reduction in vital capacity amongst nonsmokers (5.4% *vs.* 1.7%). The highest prevalence of chronic bronchitis (20%) and reduced vital capacity (27%) was observed in the rodding section. The frequency of bronchial obstruction was similar to that observed in pot room and casting workers.

A comprehensive study on eosinophil-related respiratory disease in aluminium workers was carried out by Sorgdrager *et al.*[11] and it was found that pre-employment eosinophil counts were strongly related to the occurrence of work-related obstructive respiratory disease. Results of laryngoscopic investigation performed in the two year period (1988–89) on 347 workers of the two different primary aluminium production plants were presented by D'Ambrosio *et al.*[12] and a model was proposed for classification of the laryngeal state into four classes of increasing severity of clinical findings. Analysis was made on the statistical relationship between laryngeal class, occupational exposure, cigarette smoking, alcohol consumption and age. It was reported that smoking and age have a statistically significant influence ($p < 0.0001$ and $p < 0.005$ respectively) on the development of chronic laryngitis, whereas no significant statistical difference was observed for alcohol consumption as well as in the comparison between workers and controls.

Mortality among primary aluminium foundry workers was investigated by Carta *et al.*[13] The standard mortality rates (SMR) were calculated selecting 1148 workers of a primary aluminium plant at Portovesme in Sardinia, employed between 1971 and 1980. Observations were completed by 31st December 1990 and a comparison was drawn between the observed and expected figures of death based on age-specific regional rates for each calendar year with 95% confidence limits. The standard mortality rate for all causes due to 48 deaths was calculated and found to be 81 with confidence limits of 61–108. There was no difference in the mortality due to malignant neoplasms in the observed and expected rates. The observed death rates due to lung cancer and cancer of the pancreas showed substantial deviation from what was expected, *i.e.*, 3 observed versus 4.7 *expected* and 3 observed versus 0.8 expected respectively. Lack of knowledge about the causes of death due to environmental exposure and multitude of nonoccupational factors in addition to the young age of workers under study made it difficult to relate occurrence of pancreatic cancer to workers in a primary aluminium industry. However, it was emphasised that all the results should be considered as preliminary.

Dermal exposure to polycyclic aromatic hydrocarbons (PAHs) among primary aluminium workers was studied by Vanrooij *et al.*[14] Large amounts of PAHs were released in the electrode production departments of prebake cell. Investigations were carried out to quantify the importance of dermal uptake of PAHs among exposed workers. Monitoring was performed for five consecutive days selecting 20 workers in the anode production plant. Parameters used were personal air sampling, dermal contamination sampling, biological monitoring and the concentration of pyrene in the respirable air which was found to be < 320 $\mu g/m^3$. Dermal contamination of pyrene was monitored at three skin sites such as wrist, jaw/neck and groin using exposure pads as pseudo-skin and the pyrene concentration was found to be < 375 ng/cm^2 in skin whereas in the groin skin site covered by work clothes was < 106 ng/cm^2. The concentration of 1-hydroxy pyrene in pre- and post-shift urine was found to be < 27 μmol/mol creatinine which showed an increase during the day and a decrease during the night. In order to find out a correlation, pyrene in air and on skin was tested and it was found that the correlation coefficients between pyrene air concentration and urinary 1-hydroxy pyrene were either equal or lower than that between dermal contamination and urinary 1-hydroxy pyrene. The total skin contamination in exposed workers was found to be more than three times higher than the intake via the respiratory tract. Therefore, the concentration of dermal exposure to the total PAH of exposed workers in primary aluminium plant appeared to be significant.

Schlatter *et al.*[15] measured the concentrations of aluminium in the blood and urine of persons working in the primary aluminium industries and it was found that the concentrations were 2–3 times in foundry and 5–10 times in electrolysis plant compared to that of the controls but 10–30 times below the critical value for kidney patients to develop brain damage. Even after interrupting the exposure, the concentration of aluminium remains high due to the fact that the kidney or any other tissue serves as a temporary storage. Mussi *et al.*[16] studied the behaviour of plasma and urinary aluminium levels in occupationally exposed workers. Al(III) in urine (AlU) and Al(III) in plasma (AlP) were determined in occupationally exposed subjects and it was found that concentrations of aluminium were below or equal to TWA (time weighed average; 5 mg/m^3). The AlU levels in the exposed workers were significantly higher than those found in the control group. The AlU levels were higher on Friday morning than on Monday morning. After 2 weeks, the values of the indicator underwent a marked reduction and were only slightly higher than those of the control group. Higher AlU levels in persons having occupational exposure to fumes as compared to those having exposure to dusts, indicated that the AlU levels were clearly influenced by the degree of exposure. On the other hand, the levels of aluminium in plasma in the exposed workers hardly differed from levels found in the control group. From all these data it was concluded that AlP could not be used as an indicator of occupational exposure whereas AlU allowed evaluation of daily and weekly exposures.

Miller *et al.*[17] carried out investigation on relationship between pulmonary alvelor proteinosis and aluminium dust exposure taking a 44 year old male patient with shortness of breath and working as an aluminium rail grinder in a very dusty environment for the last 6 years. Analysis of his lung tissue showed 300×10^6 particles of Al/g dry lung tissue and all of the particles appeared as spheres of 1 μ diameter representing an example of pulmonary alveolar proteinosis induced by inhalation of aluminium particles. This finding suggested that proteinosis could be produced by large doses of many types of finely divided mineral dusts. Some limitations of biological monitoring of aluminium exposure were established by Schlatter *et al.*[18] with reference to sampling contamination (especially urine samples), analytical techniques, and physiological factors. Investigations were carried out on the kinetic parameters of aluminium for the development of criteria for biological monitoring. For the above said purpose aluminium was determined in urine and blood plasma by flameless atomic absorption spectroscopy. It was observed that the aluminium levels in blood plasma reflect aluminium exposure adequately.

Physiological investigations on blood were carried out by Ijomah *et al.*[19] There was no evidence of an increased prevalence of dementia in elderly people near an aluminium smelter when compared with population in a relatively pollution free control area. Blood samples collected from 20 healthy people in the smelter area and 30 in the control area exhibited significant differences in the phospholipid fatty acid levels and it was proposed that the above difference could be due to the atmospheric aluminium and cadmium levels in the study area. Street[20] conducted a study on toxicity of waste water from aluminium anodising plants on *Pimephales promelas* and observed that well treated effluents from a specific aluminium plant operation were not toxic to the fish.

Carta[21] and colleagues studied the respiratory symptoms and lung functions of the workers in a primary aluminium industry in Italy. A number of variables taken into consideration for the above study were the prevalence and incidence of chronic obstructive lung disease, chronic bronchitis, bronchial asthma and analysis of lung function deterioration over time in relation to occupational exposure and individual non-occupational features. It was reported that the incidence of respiratory symptoms of chronic cough and expectoration was significantly higher among electrolytic shop workers. It was further observed that the incidence and prevalence of asthma manifestations were higher compared to casting and office workers. Though asthmatic symptoms showed a short latency period in relation to exposure in pot rooms, it seemed to be characterized by a marked deterioration in lung function even after withdrawal from exposure. All these established health hazards for pot room workers.

Investigations were carried out by Theriauit *et al.*[22] to have a better understanding of the morbidity accompanying the development of skin telangiectasia on aluminium workers. Fifty workers affected with multiple telangiectasia when matched with normal controls, the same percentage of illness was found in both the cases. However, incidence of ischemia on the ECG was found in 9 cases and 1 control. The cases did not show an excess of abnormal biochemical tests. It was also observed that the basic histopathological lesion affected the surrounding tissue rather than the vessels themselves. Wearing of masks was recommended to young workers in the current environment in order to protect them from developing lesions. Among the available processes the Soderberg process was associated with the lesions which was, probably, due to a gas containing both hydrocarbons and fluoride compounds emitted from electrolytic reactors.

Industrial hygiene problems in alumina and aluminium production plants were monitored by Casula *et al.*[23] Authors found that the particulates and respirable particulates in the air of a bauxite processing plant and of an aluminium smelter were in the range of 0.04–14.7 and 0.04–2.10 mg/m^3, and 0.22–6.95 and 0.20–1.76 mg/m^3 respectively. Furthermore, it was observed that Al and F^- concentrations in aluminium smelter air were 0.03–2.85 and 0.34–3.00 mg/m^3 respectively. In order to find out the effect of waste gas emission on the elemental composition of human biosubstrates, a detailed study was carried out by Zhuk *et al.*[24] As per their evaluation the composition of reproductive organs, hair, amniotic fluid, placenta, blood and milk of mothers living in areas affected by emissions from an aluminium-manufacturing plant showed high concentrations of fluoride and significant changes in elemental composition.

Mutagenicity of emission and immission samples around an aluminium plant were studied in detail by Pinter and colleagues.[25] For the above study the authors selected two towns: Ajka and Papa. Both the towns were of same size but Papa did not have many heavy industries. Analysis of parameters like air particulates including both suspended and settling dust emitted by a Soderberg aluminium production plant and a coal burning power plant, polycyclic aromatic hydrocarbons (PAH) content, mutagenic activity (Salmonella microsome test) were carried out and the data obtained were compared. It was found that the values were higher in case of the former than the latter. Further, it was observed that the mutagenicity of airborne particulates showed a clear seasonality being maximum in winter and minimum in summer. However, the amount of extractable organic material and mutagenic potency per unit quantity of airborne particulate matter were higher in Papa samples. In case of deposited dust similar differences were observed. As to the emitted dusts, the aluminium plant emissions were responsible for much more mutagenicity of the urban air than the power plant emission which was the chief component of air dust pollution in Ajka.

Alfheim *et al.*[26] made similar studies and the data obtained from the analysis of PAHs and testing of mutagenic activity were discussed with reference to the meteorological conditions prevailing during sampling. It was observed that the ambient air concentrations were significantly influenced by the emissions from the smelting plant in summer than in winter. The mutagenic activity of the particles from this area was either equal to or lower than that reported from other urban areas in Scandinavia. The contribution of PAH and mutagens to the concentrations of these compounds in ambient air was established based on parallel measurements of fluoride and emission values of F^-, PAHs and mutagens. Further, though the contribution of mutagens from smelter emissions were significantly less, the PAHs could account for 50% of the annual average of ambient air. The aluminium levels in the blood plasma of pot room and cast house workers were determined by Schlatter[27] *et al.* and were found to be 5–15 and *ca.* 5 μg/L respectively as compared to 1–3 μg/L in case of a healthy non-occupationally exposed control group.

Uptake and excretion of aluminium in workers exposed to fluoride and aluminum oxide were investigated by Drabloes *et al.*[28] The observations were recorded over a 5 day work week and aluminium was determined in blood serum and urine. Al was observed in the lungs of workers occupationally exposed and was shown by enhanced excretion. The concentrations of aluminium in air at both the work places, *i.e.* AlF_3 manufacturing plant and smelter, were well below the Norwegian current respiratory exposure limits (Al_2O_3 10, soluble Al compounds 2 mg/m^3). A significant correlation was also found between the weekly mean aluminium concentration in air and aluminium excretion in urine for each worker in the pot room and foundry. The group mean for urinary excretion of aluminium was much lower for workers exposed to AlF_3, even with greater aluminium air pollution, as compared to the foundry workers and this could be due to lower solubility of AlF_3 containing particles in the lungs.

A comparative study of the fluorine content in biological substrates among plant workers was done by Medvedeva *et al.*[29] For the above study urine samples of persons working in electrolysis department, crane operators and machine operators of the dust collection department etc. of various age groups and exposure records were collected. It was found that fluoride content in the urine of the aforementioned workers was comparatively higher than that of the control group. The concentration of fluoride in bile and gastric juice was higher in workers with and without fluorosis than in the control group. It was found that liver is important in fluoride excretion and there was 38 times as much fluorine in bladder bile than that in liver bile.

Fluoride emission from aluminium smelters covered by New Source Performance Standards (NSPS) was studied by Clark *et al.*[30] It was mentioned that even though the control technologies were similar for different aluminium plants, the rates of fluoride emissions varied from plant to plant as well as within a single plant. The data confirmed judicious decision of the EPA to allow an excursion for Al plant workers to account for the change in the fluoride uptake. EPA regulations were found to be satisfactory in this regard.

Fluoride in bones of small rodents near an aluminium reduction plant was estimated by Walton.[31] Field voles (*Micro us agrestis*) and wood mice (*Apodemus sylvaticus*) were trapped in 5 km intervals in specified areas on two transects radiating north-eastern and south-eastern from around aluminium reduction plant on the Island of Anglesey. Bone F^- concentration in these animals showed a downward trend along each of the transects. Further the F^- concentration in animals living close to the aluminium reduction plant showed wide variation which is indicative of uneven pollution from the pot rooms. For field voles F^- concentration was 60–3700 μg/g and that for wood mice it was 13–8500 μg/g. Long term retention of fluoride in the bones of former aluminium industry workers was studied by Baud[32] and colleagues. It was reported that the fluoride deposits were removed progressively by osteoclastic resorption but a small part of the released fluoride was further recycled in newly formed bone. The crystallographic properties of the bone mineral were closely monitored and correlated to the local F^- concentration. The findings obtained from the studies on biochemical parameters of aluminium industry workers were reported by Vido[33] and coworkers. For the above study a selected group of 52 exposed workers along with a control group of same number of persons was chosen. The results showed that low or moderate exposure to F^- did not have a detrimental effect on workers.

The corrosion aspect of fluoride compounds emitted from aluminium manufacturing plants on metals was studied by Goroshko and Tsarev.[34] For these experiments the area under study was divided into two zones: (a) moderate summer temperature and high humidity, (b) high temperature and low humidity. The observance of high corrosion rate in some regions was due to the atmospheric release of F^- containing compounds like HF. Further, it was also recorded that with the F^- containing compounds in the atmosphere, the corrosion rate was directly proportional to the humidity in air. Hence corrosion rate was found to be two-fold in zone A as compared to zone B. Structure and function of the gastric and small intestine mucosa in aluminium production workers were examined by Medvedeva.[35] The study was conducted taking 157 workers occupationally exposed to HF, NaF, Na_3AlF_6 well above the permissible limits. It was observed that the exposed workers affected with various stages of fluorosis or having no signs of fluorosis showed ulcer-like course of development of chronic gastritis. Further, it was observed that the increase of fluoride concentration in the gastrointestinal system caused cytotoxic and cytolytic effects on the surface epithelial cells resulting in the erosion of the mucous membranes and formation of ulcers.

Soil pollution by fluorine from industrial waste gases was investigated by Rauta[36] and others in the vicinity of an aluminium plant at different distances in order to correlate the concentration of fluoride in soil with distance from the pollution source. Decrease of fluoride in soil was registered as the distance from the plant site increased and the distribution was as follows: 200–650 ppm for < 50 m, 29–66 ppm up to 1000 m, 5 ppm at 1600 m, and 1 ppm beyond 1600 m. Kuz'minykh *et al.*[37] discussed the probabilities of carcinogenic effect of hydrocarbons like phenol and N-base emitted during aluminium manufacture where coal tar pitch was used. The phenol and N-base contents of the aerosol were higher than those of the pitch which is assessed for the risk of cancer in aluminium production facilities.

Collection of air samples and their analysis for the presence of gaseous fluoride compounds were carried out by Buck *et al.*[38] According to them most of the fluoride pollutants came from the plant only. Studies on the effect of wind direction on the distribution of HF and particulate fluoride emissions from an aluminium plant were made by Tsarev.[39] He found that wind direction as well as its velocity play crucial roles on the spreading out of fluorides. Pearson *et al.*[40] reviewed the morality of workers in the aluminium industry from diseases like cancer, cardio-vascular disease, respiratory cancer and non-malignant respiratory diseases etc. Studies on potential carcinogens in aluminium industries workers have been reported and they are said to have serious repercussions. Smoking histories of the workers were, however, not taken into account.

Fluoride uptake of mixed eucalyptus open forest of an area polluted by the aluminium smelter at Kurri Kurri, New South Wales, Australia was studied by Murray[41] who compared the data with an unpolluted area at Tomago. The inputs were found to be 17.8 and 0.75 kg/ha yr respectively and the data was used to establish the fluoride uptake rates. Further the author discussed the inputs in relation to transfer processes, with special reference to wild fires which release fluoride from vegetation and also emphasised the role of ecosystem particularly soil as a sink for atmospheric fluoride. Soil contamination by atmospheric F^- was investigated by Haidouti[42] in the vicinity of an aluminium production plant. Samples for the above purpose were collected at depths of 0–5, 5–15, 15–30 cm. F^- levels in natural vegetation were used to determine areas of relatively high and low airborne fluoride impact, and soil sampling locations within these respective areas. Soil samples were analysed for both total and water extractable fluoride. The fluoride concentration in the soil exhibited a reasonable dependence upon distance from the emission source. A correlation between total soil and depth of soil, distance from emission source, water soluble fluoride, low and high impact site etc. were established by the author to a distance of 20 km. The water extractable fluoride concentration significantly increased with depth at high impact areas. Total soil fluoride for all depths decreased with distance from the source and approximated to background levels at about 20 km. The fluoride levels in forest trees such as pine and spruce needles in the vicinity of Al smelters were reported by Horntvedt[43] and it was found to be a function of distance from the smelter. Near a smelter, he observed, the birch leaves had accumulated more fluoride than conifer needles while the conifer needles were more susceptible to fluoride injury as compared to birch leaves. Further, the fluoride levels of 10–20 mg/kg/needle caused needle injury and a level of 100 mg/kg/needle was quite detrimental.

Observation and analysis of vegetation was taken as a primary factor to evaluate and detect atmospheric pollution by Impens and Paul.[44] The polluted areas were restricted for growing essentially pastures, some vegetable gardens and orchards. Considering the emission circumstances it was reported that though the damage was restricted, the most important risk was the contamination of cattle forages. Damages caused by three aluminium factories (1400 ton F^- emission in 1970) created an alarming and irreversible situation. Fluoride is toxic when it accumulates and gets fixed by not being metabolised in the limb and as soon as it reaches the threshold, the tissue necroses. Fluoride exposure in an aluminium production plant was evaluated by Caroldi[45] and Clonfero. Data from fixed samples furnished reliable information on environmental pollution in the plants. However, sampling difficulties and reproducible results were problematic under the prevailing conditions of different variable parameters.

The effect of tar bearing particulates emitted from aluminium manufacturing units on plants was reported by Bonte[46] and colleagues. They observed swellings on *Pelargonium X. hortorum* and characterised the leaves, petioles and flower stems by subepidermal cell hyperplasy and hypertrophy. However, woody species near the factories showed similar symptoms whereas corn and adventitious grass were unaffacted. Solvent extraction of the particulates and their analysis indicated that the active product was contained in the lipid solution phase. A detailed investigation on the fluoride concentrations in dust, agricultural products, human finger nail and hair near an aluminium factory were carried out by Muramoto *et al.*[47] It was observed that the fluoride content of the dust was 1400 to 42500 μg/g dry weight, 190,000 to 380, 000 μg/g aluminium. It was also recorded that rice grains contained fluoride 3–4 times more than those in control areas. It was noteworthy that agricultural products such as egg plants, mulberry plants and soybeans were not affected significantly. Further, high fluoride concentration in the hair and nails of some workers was due to F^- emission from the factory as well as in food and water available in the surroundings compared to the control area.

Nishonhodjaeva *et al.*[48] reported the contamination of mulberry and grape leaves by fluoride emitted from the Tadzhik aluminium plant which consisted of HF, H_2S, CO, NO_2 and hydrocarbon dusts. It was established that HF was the most toxic pollutant among all those described causing mass mortality of silkworms, specific cattle diseases and wilting of grape and stone-fruit tree leaves. At a distance of 10 km from the smelter the mulberry leaves contained 280 Mg F/kg in June and 650 Mg F/kg in August and in summer there was fluoride build-up in grape and mulberry leaves. Further, it was stressed that within the polluted area, the silkworm and dairy cattle breeding were adversely affected due to fluoride fall-out.

Air pollution and consequent injury to vegetation around an aluminium smelting plant using Soderberg electrodes was studied by Moriyama and colleagues.[49] Leaf scorch of gladiolus and leaf bending and glazing of spinach, Chinese cabbage, radish and eggplant in the vicinity was observed and the reason ascribed thereto could be pollution due to fluoride. A correlation was established between the leaf damage and atmospheric fluoride emitted from a Soderberg electrode. But no such phenomenaon was observed in the vicinity of a phosphate fertilizer factory. For fluoride damage the atmospheric soluble fluoride levels should also be correlated with the atmospheric aromatic hydrocarbon levels.

A number of trees and shrubs useful for planting in protection zone around the Konin aluminium smelter and other polluted regions were screened for their tolerance to high concentrations of fluoride compounds by Kluczynski.[50] In 1970–78 he selected six experimental areas planted with 86 species, varieties of clones of trees and shrubs. It was observed that plants were largely influenced by various air pollutants including fluoride compounds. During a 20 min. period the F^- concentration was found to have reached 0.47 and even 1.7 mg/m^3 air.

Kozlovskii[51] reported the physiological evaluation of the pothouse workers while following the policy of work and rest during working hours. This significantly increased the cost effectiveness of the labour by decreasing the rate of physiological disorders caused by fatigue. Resting in rest rooms also decreased the occupational exposures to harmful levels and toxic substances helping overall health standards. Physiological and hygienic evaluation of working conditions in an aluminium plant were investigated by Babaev and Sergeev.[52] Workers such as repairmen, electrowelders during repairing of gas cleaners were exposed to uncomfortably high concentrations of carbon monoxide, Me_2CO, EtOAc, BuOAc, xylene, PhMe, pigment Khv-1100 dust containing 67–81% crystalline SiO_2. Besides dehydration, the temperature of body and skin changed considerably. Nervous and emotional responses to work in closed and high places were recorded. Necessary safety measures were discussed to alleviate thermal stress and exposure to harmful pollutants.

Biomonitoring of genotoxic exposure of aluminium plant workers was investigated in detail by Haugen *et al.*[53] The genotoxic effects of PAHs were evaluated by analysing air and urine samples. Blood samples were analysed for benzo(a)-pyrene-diol-epoxide-DNA (BPDE-DNA) adducts. Data obtained from the analysis of DNA adducts in lymphocytes were used for the study of genotoxic effects of human exposure to carcinogens. BPDE-DNA adducts in lymphocytes were used as internal dosimeters of exposure to PAHs for several studies. These adducts were measured with immune assay and physico-chemical methods in the workers of an aluminium plant. The polyaromatic hydrocarbon-DNA adducts detected in persons working in aluminium plants were found to be less compared to those working in a coke oven plant.

Alessio[54] and colleagues have studied the behaviour of biological indicators of internal dose and some neuro-endocrine tests in aluminium workers. At the start of the exposure to aluminium concentrations, there was an effect on the hypothalamus-pitutary axis. Studies were made on 227 workers, exposed to aluminium dust and welding fumes in the concentration range of 0.1–1.0 mg/m^3. Further, the aluminium levels in serum and urine seem to indicate that aluminium in urine could be an indicator of current exposure and that in blood serum as an indicator of cumulative exposure. The results of the determination of hormone levels showed that prolactin and thyroid stimulated hormone (TSH) values decreased after 1 year of work and the trend continued for the next 6 months. But the subsequent increase in the levels could be ascribed to an adaptation mechanism of the body.

Conclusion

Numerous R & D activities were undertaken to study the extent of pollution due to aluminium industries on workers occupationally exposed and vegetative plants sorrounding the industrial area. These studies revealed that the industries, as claimed, are not totally free from pollution due to either aluminium exposure or fluoride emission from pot houses. This fact is very well corroborated by data obtained/collected in this regard. Of course the level of pollution has been brought down comparatively by employing some pollution alleviating measures such as the modernisation, renovation and updating some facilities *e.g.* replacement of Soderberg smelters by prebake smelters; however these measures were found to be rather unfavourable so far as the investment costs are concerned. The application of mechanization to prebake operations promotes the hooding efficiency and reduces emission to safe levels, *i.e.* below 1 kg F^-/ton aluminium and this eliminates the use of working masks during pot room work. Sometimes it was observed that though the control technologies used were similar for different aluminium plants the rates of fluoride emission varied from plant to plant as well as within a single plant. Besides, as a part of the ecosystem, soil served as a sink for atmospheric fluoride emission. However, the extent of damage done by fluoride or aluminium exposure could not be quantified.

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