

IV. ENVIRONMENTAL DATA AND ENGINEERING CONTROLS

Measurements of atmospheric concentrations of chromic acid around industrial operations before and after controls were instituted attest to the marked effect of controls in lowering the airborne levels of this contaminant. In 1928, Bloomfield and Blum [9] studied six plating plants with varying degrees of ventilation control and changing operating conditions. In one plant, concentrations were as high as 6.9 mg of chromic acid per cubic meter of air with no ventilation in use while plating with a current density of 300 amperes per square foot. However, at the same current density but with ventilation operating at an air velocity of 1700 feet per minute at the face of the slot, there was no detectable chromic acid in the workers' breathing zone. In order to insure a reasonable safety factor, they recommended a lateral slot-type exhaust system operating at an air velocity of 2,000 fpm at the face of the slot, drawing air no more than 18 inches laterally. They also recommended that the exhaust slots be flush with the top of the tank and that the plating solution be at least 8 inches below the top of the tanks to allow ample time for the mist to be directed to the exhaust slot.

Sampling in the approximate breathing zone of workers plating at a tank measuring 20 x 4 feet with a current density of 150-200 amperes/square foot of surface, Riley and Goldman [42] reported an atmospheric concentration of 3.68 mg chromic acid/cu m with good general ventilation but no local exhaust ventilation. With the local exhaust (two slots, one on each of the long sides of the tank)

operating at a face velocity of 600 feet per minute (approximately 37.5 cubic feet/minute/square foot of tank surface), the atmospheric concentration was reduced to 1.12 mg/cu m. When the face velocity was 1800 fpm (approximately 112.5 cfm/sq ft), the atmospheric level was further reduced to 0.034 mg/cu m. Reiterating and confirming the earlier recommendations of Bloomfield and Blum, [9] the authors considered the capacity of the system a better criterion than face velocity, and recommended a cross-draft exhaust system operating with a control velocity of 100 fpm.

In 1944, Gresh [41] measured the effectiveness of ventilation in controlling chromic acid mist at an anodizing tank in which the solution was constantly agitated by an air line through the solution. Although equipped with an enclosed hood, ventilation at a rate of 148 cfm/sq ft of tank area reduced the atmospheric concentrations of chromic acid only to 0.09 mg/cu m. When a lateral exhaust system was installed, ventilation at 134 cfm/sq ft produced negligible atmospheric concentrations of chromic acid. The exhaust stacks on the roof of the plant were intended to be sufficiently high to permit dissipation of the mist, but nasal irritation of workers in other areas persisted. After moisture collectors were added to the ventilation system, tests indicated no emissions of chromic acid to the atmosphere from the exhaust stacks. After four weeks, the nasal irritation of the workers subsided. On this basis, the author recommended the inclusion of moisture collectors in ventilation systems to completely prevent escape of the chromic acid mist.

Kleinfeld and Rosso [25] in measuring atmospheric chromic acid concentrations at a chromium plating operation found levels ranging from 0.18 to 1.40 mg/cu m. The tanks had no exhaust ventilation. General room ventilation was provided by fans and opened windows. The ventilation rate was not reported, but installation of a local exhaust system reduced atmospheric concentrations of chromic acid to levels ranging from 0.003 to 0.009 mg/cu m.

Minimum design specifications for local exhaust ventilation of open surface tanks have been promulgated under the Occupational Safety and Health Act of 1970. Both the latest recommendations from the American National Standards Institute Z9.1-1971 [43] and the current OSHA regulations (29 CFR 1910.94, published in the Federal Register, vol 37, dated October 18, 1972, which were based on ANSI Z9.2-1960) call for ventilation at a control velocity of 150 fpm, with ventilation rates up to 375 cfm/sq ft, depending on tank size and hood type.

Control strategies beyond ventilation include the use of surface-active agents [44] and plastic chips. [44,45] By reducing the surface tension of the plating solution, the surface-active substances help to retard mist formation and carryover by the hydrogen bubbles generated during plating. Hama et al [44] reported values for chromic acid mist in the workers' breathing zone ranging from 0.002 to 0.06 mg/cu m in three plants in which only a fluorocarbon surface-active agent was in use. In a fourth plant in which ventilation was in use at a rate of 90 cfm/sq ft (the ventilation rate recommended at the

time for the tank was 175 cfm/sq ft), chromic acid was not detected in one sample and was 0.002 mg/cu m in a second sample. In the discharge stacks of three plants using both local exhaust ventilation and the fluorocarbon surface-active agent, chromic acid concentrations ranged from not detected to 0.02 mg/cu m.

Molos [45] sampled for chromic acid in a plant using floating plastic chips as a control measure. Samples were collected 8 inches above the level of the plating solution, the same level as the lateral exhaust slots. Chromic acid concentrations were 4.5-5.0 mg/cu m with ventilation off, and 0.02-0.05 mg/cu m with the ventilation system operating at 170 cfm/sq ft. In the workers' breathing zone, the concentration was 16.0-17.0 mg/cu m with only plastic chips in use. No breathing zone samples were reported for this plant with both plastic chips and local exhaust ventilation in use, but it was stated that "All tests, which were made under conditions where plastic chips were used as well as exhaust ventilation, showed no chromic acid concentration whatever in the workers' breathing zone." Molos concluded that a floating baffle of plastic chips is effective in reducing chromic acid mist and that they result in substantial conservation of chromic acid. Nevertheless, he considered local exhaust ventilation as necessary to ensure healthful working conditions, even when plastic chips are used.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

The first standard for chromic acid (chromium trioxide) was published by the United States of America Standards Institute (now the American National Standards Institute) in 1943. [46] That standard specified a maximum allowable concentration of 1.0 milligram as chromic acid anhydride in 10 cubic meters of air for exposures not exceeding a total of 8 hours daily. This standard apparently was based on the 1928 report by Bloomfield and Blum. [9] Although there has been confusion about the meaning of some maximum allowable concentrations, whether a time-weighted average or ceiling was intended, the intent in this case apparently was for a ceiling of 1.0 mg/10 cubic meters.

In Manual of Industrial Hygiene and Medical Service in War Industries, published in 1943, [47] the USPHS listed the ANSI MAC of 0.1 mg/cu m for chromic acid.

In 1947 the American Conference of Governmental Industrial Hygienists adopted a Threshold Limit Value for chromic acid and chromates of 0.1 mg/cu m, which has remained unchanged since. The reports by the U.S. Public Health Service, [3] Bloomfield and Blum, [9] Machle and Gregorius, [11] Mancuso and Hueper, [12] Bidstrup, [14] Mancuso, [21] Kleinfeld and Rosso, [25] Vigliani and Zurlo, [29] and Baetjer [32] were considered when documentation for the TLVs was published in 1971. [48] The documentation states "A review of the present status of the suitability of the TLV between TLV subcommittee

members and industrial hygiene representatives of the chromate industry 10 years after improved controls had been in operation revealed that (1) the TLV for chromic acid mist was satisfactory in preventing nasal perforation; (2) contained a safety factor of three or four; and (3) that the limit was probably satisfactory for the prevention of lung cancer, as no new cases had appeared during the ten-year period; but (4) that the ten-year period was probably too short to be certain of its validity in this respect." [48] Data, however, were not presented to support points 1, 2, and 3.

The American Industrial Hygiene Association's Hygienic Guide on Chromic Acid, published in 1956, recommends a Maximum Acceptable Concentration (8 hours) of 0.1 mg/cu m for chromic acid. [49] Data from the same reports considered by the American Conference of Governmental Industrial Hygienists were used as the basis for the value.

The present Federal standard for chromic acid is a ceiling concentration not to be exceeded during any 8-hour period of 1.0 mg/10 cu m, (29 CFR 1910.93, published in the Federal Register, vol 37, dated October 18, 1972) based on the American National Standard Z37.7-1971 (year 1971 is in error, it should be 1943).

Basis for Recommended Environmental Standard

Industrial exposure to mixed chromite and chromate compounds has been shown to cause ulceration of the skin, [3,7,21] dermatitis, [3,22,24] ulceration and perforation of the nasal septum, [3,7,21,29] inflamed mucosa, [3,29] irritation of the conjunctiva, [3,7,29] and

cancer of the lung. [3,11-16,32] Other effects [21] reported as a result of mixed exposures include nasal mucosal polyps, chromitotic pneumoconiosis, chronic rhinitis, sinusitis, mucosal polyps and hydrops of nasal sinuses, inflammatory and ulcerative conditions of the gastrointestinal tract, and, often, an imbalanced ratio of the formed elements of the blood as well as lengthened bleeding time.

Occupational exposure to chromic acid has been shown to cause ulceration of the skin, [8,9,27,30] ulceration and perforation of the nasal septum, [8,9,25-27,30,31] inflamed or bleeding nasal mucosa, [8,9,25,26,28,31] and ulceration or congestion of the turbinates. [25,26] Erosion and discoloration of the teeth has been attributed to chromic acid exposure [27] as has discoloration of the skin. [8] Apparent liver damage has been reported, [31] but other reports have indicated there was no evidence either of hepatic or of renal damage after acute [28] and chronic [25] exposure. An increased incidence of lung cancer has not been found reported from exposure to chromic acid alone.

In one epidemiologic study [11] of seven chromate plants, it is suggested that the carcinogen is a monochromate found in the processing of the chromite ore. In that study, the crude death rate (ie, the death rate not corrected for age) from cancer of the lung was 25 times higher than normal, but all observed lung cancer deaths were confined to five of the seven plants. One plant was quite small and there were no deaths among its employees during the nine years surveyed. There were no lung cancer deaths in another plant which was one of two

plants in the study owned by a single company. The worker populations of the two plants were "similar with respect to age distribution, exposure history, color, geographic location, and were not greatly different in size." There was, however, an obvious difference in exposure, since one plant produced sodium bichromate from chromite ore, while the second plant produced chromic acid and basic chromic sulfate from the sodium bichromate. The incidence of death by lung cancer was 18 times normal in the plant producing sodium bichromate, while there were no lung cancer deaths in the plant processing the bichromate. Monochromates were suggested as the etiologic agent on the basis that the lung cancer was widely distributed in the first plant among all occupations entailing exposure to monochromates.

Thus, there is ample evidence that workers with mixed exposure in the chromate-producing industry have been at increased risk of lung cancer. [3,11-16,32] Unfortunately, no epidemiological study of workers exposed only to chromic acid has been undertaken. There is reason to suspect other chromium compounds as the carcinogens responsible for the increased lung cancer observed in chromate plants. The chromite ore itself has been suggested as the etiologic agent, [12] as have the monochromates, [11] and intermediate water insoluble-acid soluble compounds. [3] The animal studies by Hueper, [34,35] Payne, [37] Hueper and Payne, [36] and Roe and Carter [38] suggest that the etiologic agent is a moderately soluble chromate which can be slowly released from a tissue "reservoir" in amounts which are not sufficiently toxic to cause necrosis. Calcium chromate has been

implicated as a lung carcinogen by Laskin et al [39] and by Kuschner. [40] Hueper [50] has indicated the risk of cancer is negligible when chromic acid is used medicinally. This judgment was based in part on the "extreme rarity of such sequelae" to chronic ulcerative defects of the skin and nasal mucous membranes in workers having occupational contact with chromic acid mist and chromates. [50] Therefore, while there is no positive evidence that chromic acid in the workplace has contributed to an increase in cancer, neither is there definitive evidence that absolves chromic acid.

At least one report [31] has suggested that liver damage is a possible consequence of exposure to chromic acid. Other reports have indicated that neither hepatic nor renal involvement was observed after acute [28] and chronic [25] exposure. In the one report of liver damage, urinary excretion of chromium and the clinical findings of nasal ulceration or mucosal injection and hyperemia suggest significant exposures to chromic acid.

The 1928 report by Bloomfield and Blum [9] has served to a great extent as the basis for the previously recommended chromic acid standards of 0.1 mg/cu m. In that paper, the authors concluded that "Continuous daily exposure to concentrations of chromic acid greater than 1 milligram in 10 cubic meters of air is likely to cause definite injury to the nasal tissues of the operators." The lowest concentration to which chromium platers were estimated to have been exposed was 0.12 mg/cu m. Six platers were estimated to have been exposed to that level. One of these had been employed in the plating

room approximately one week and two approximately three weeks, yet all six platers suffered slightly (2 of 6) to markedly (4 of 6) inflamed mucosa. Three of these six, including the individual employed only one week, suffered nosebleeds. One plater who had been employed one year was estimated to be exposed to 2.8 mg/cu m at the time of the survey, but suffered no ill effects, apparently due to personal prophylactic measures. The mucous membranes can be protected, therefore, even against high concentrations of the mist. If the estimates were accurate, the experience of the six platers exposed to 0.12 mg/cu m demonstrates that adverse effects result fairly rapidly from exposures only slightly higher than 0.1 mg/cu m. Thus, the conclusion of the authors that damage is likely at concentrations above 0.1 mg/cu m seems less an endorsement of that as a safe exposure level, but rather an indication of the level at which adverse effects can be expected.

Zvaifler [26] and Gresh [41] in 1944 reported on over 100 cases observed in an anodizing plant. The majority of these involved superficial greyish ulceration of the nasal mucosa with engorgement of the vessels and small areas of bleeding in workers not directly associated with the anodizing tanks. Among those working directly at the tanks, the ulceration involved more of the septum, was deeper, and involved the turbinates and nasal septum as well as the mucosa. Atmospheric levels of chromic acid at the anodizing tank ranged from 0.42-1.2 mg/cu m. With increased ventilation, the atmospheric concentration at the tanks was reduced to 0.09-0.10 mg/cu m, but after

four weeks the worker's physical condition had not improved, although no worker's condition worsened. After a new ventilation system reduced atmospheric concentrations to negligible levels, the nasal irritation subsided.

After a three-year observation period in areas involving the preparation of chromic acid anhydride and alkali chromates, and use of electrolysis baths, Vigliani and Zurlo [29] reported inflammation and ulceration of the nasal mucosa, chronic asthmatic bronchitis, and inflammation of the conjunctiva in areas where air concentrations averaged 0.11-0.15 mg/cu m. These investigators concluded that the time-weighted average level of 0.1 mg/cu m should be lowered to 0.05 mg/cu m.

Kleinfeld and Rosso in 1965 [25] reported nine cases of nasal damage, ranging from moderate injection of the nasal septum and turbinates to septal perforation. Atmospheric levels at the time the workers were examined ranged from 0.18-1.4 mg/cu m. Atmospheric levels were determined during the summer and, according to the authors, levels probably would be higher in the winter. Nevertheless, these levels are indicative of the exposure of those employed only a short time. One person employed approximately two weeks had moderate injection of the septum and turbinates. Another employed one month had an ulcerated septum, while a perforated septum was observed in an individual employed only two months.

The most recent data available are those reported by Gomes. [27] For this survey of the electroplating industries, atmospheric levels

were determined for 81 workers to characterize the work environment. Of these 43.2% were exposed to atmospheric levels of 0.1 mg/cu m or less, but of the 303 workers who were examined clinically, only 37.6% were free of nasal ulceration and perforation, and only 13.3% were free of cutaneous lesions. The high incidence of cutaneous lesions reflects poor work practices and the low level of sanitary education pointed out by Gomes, since skin lesions apparently occur only on direct contact with the plating solution. [9,25,30] The percentage of workers with nasal ulceration or perforation is only slightly greater than the percentage of workers exposed to levels greater than 0.1 mg/cu m. The difference is not great enough to conclude that 0.1 mg/cu m definitely will result in damage to the nasal mucosa. It does demonstrate that 0.1 mg/cu m offers no margin of safety, since nasal ulceration and perforation apparently occur at this level.

Thus, there are reports [9,25,26,27,29,41] of nasal ulceration occurring at atmospheric concentrations only slightly above 0.1 mg/cu m. As a strong oxidizing agent, chromic acid can act in a short time, as evidenced by the short exposures necessary to cause ulceration or inflammation of the nasal mucosa. [9,25] Even very short exposures above 0.1 mg/cu m are likely to cause definite injury to the nasal tissues, so it is recommended that the current Federal standard of 0.1 mg/cu m as a ceiling concentration be retained.

The chronic effects reported, lung cancer [3,11-16,32] and liver damage, [31] have not been proved to be a result of exposure to chromic acid, but the possibility of a correlation cannot be rejected.

Without better data, it is not possible to establish with confidence what atmospheric concentration will protect against chronic effects if a correlation does exist. Nevertheless, because chronic effects are a possibility, it is recommended that the worker be afforded an additional factor of protection by supplementing the allowable ceiling of 0.1 mg/cu m with a time weighted average of 0.05 mg/cu m for an eight hour work day.

Special procedures are recommended any time the anhydride is being used, handled, or processed in other than fully enclosed operations. These recommendations include full protective clothing, respiratory protection, and eye protection. When handling the anhydride, contact with discrete particles is a distinct possibility, even if air sampling indicates an undetectably low atmospheric concentration. Because of its powerful oxidizing action, a single particle of chromic acid anhydride can cause ulceration of the skin or nasal mucosa, and severe damage to the eyes, so that these special precautions are necessary to adequately protect the worker.

Basis for Air Sampling and Analytical Methods

Two principal methods have been used to determine the concentration of chromic acid (Chromium VI) mist in air. Methods of collection have included absorption in distilled water and alkaline solutions, using impingers or sintered-glass bubblers, and filtration with absorbent paper. [3,48,51-53] Analytical methods have included titration of liberated iodine with standardized sodium thiosulfate solution, [51] colorimetry with hematoxylin [51] or s-diphenylcarba-

zide, [3,48,51,52,54] and field analysis by means of an impregnated filter paper, based on the colorimetric reaction between chromium and s-diphenylcarbazine and comparison with permanent standards.

Of the methods of collection, filtration offers the greatest collection efficiency and ease of collection of breathing zone samples. The AA type of membrane filter has a 0.8 micron pore size and provides a highly retentive matrix for particulates. The use of scrubbing liquids is inconvenient for personal breathing-zone sampling and is thus not recommended.

The iodide-thiosulfate method is subject to interferences from a wide variety of compounds with its nonspecific iodide reaction and the color definition is subject to a slight error. The hematoxylin method is suggested only as a check for very small amounts of chromium and is a visual colorimetric method. The use of the colorimetric field analysis technique involving a grab sample and visual analysis must be considered to be only semiquantitative, and useful only for that purpose.

The colorimetric diphenylcarbazine method does not react with trivalent chromium but produces a color with only the hexavalent form (present in chromic acid). However, cyanides, organic matter and other reducing agents, iron, copper, and molybdenum at concentrations above 200 ppm and vanadium above 4 ppm, interfere and must be separated or complexed before this method may be expected to provide chromic acid analytical data of an acceptable degree of accuracy and precision. [54]

The atomic absorption spectrophotometric method, applied directly, determines the total chromium and cannot make the desired distinction between the hexavalent chromium in chromic acid and the trivalent forms of chromium which may be present in the collected sample. Hence, it is necessary to separate the hexavalent from the trivalent chromium compounds by extracting the chelated complex of hexavalent chromium with ammonium pyrrolidine dithiocarbamate into methyl isobutyl ketone and then applying the atomic absorption spectrophotometric method to the extract for a specific determination of hexavalent chromium. [55] It is not subject to the interferences which affect the diphenylcarbazide method. The atomic absorption method is therefore recommended.

VI. REFERENCES

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