Occurrence of Nitrosamines in Industrial Atmospheres

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Until as recently as 1975, the primary interest in the environmental occurrence of the carcinogenic N-nitroso compounds (nitrosamines) centered around nitrite preserved meats, foodstuffs, cheese products, fish, fish meal and biological samples. This emphasis began to change when N-nitrosodimethylamine (NDMA), one of the more potent of these carcinogens (1), was found in the atmosphere near a Baltimore, Maryland facility producing 1,1-dimethylhydrazine (a rocket fuel) (2,3) and in the atmospheres near West Virginia (4) and West Germany (5) facilities producing dimethylamine.

It has been demonstrated that NDMA is produced from the mixing of gas phase dimethylamine (DMA) and oxides of nitrogen, even when the concentration of the initial substances are at the ppm level (6,7,8). These reactions have also been shown to occur in either organic solvents or basic aqueous solutions when gas containing oxides of nitrogen are passed through the solvent containing secondary amines (9). In a test of air sampling sorbents, it was shown that surface bound secondary amines form nitrosamines when gas containing mixtures of NO and NO_2 are passed over them (10). It is apparent from these studies that nitrosamines can be formed in environments that have the needed precursors either in the air, in solution, or bound on surfaces.

The reactions for the formation of nitrosamines from secondary amines is as follows:

$$R_2\ N\text{-}H + NOX \rightarrow R_2\ N\text{-}NO + HX\ (X = Cl,\ I,\ NO_3,\ NO_2,\ etc.)$$

Further discoveries of consumer and industrial products contaminated with N-nitroso compounds (11) led to the speculation that industrial workers that either use or manufacture these products may be exposed to significant amounts of these carcinogenic agents. These discoveries of environmentally occurring N-nitroso compounds plus increased understanding of the mechanism by which they can be formed from their widely available precursor amines (12) and oxides of nitrogen (13), has resulted in this study of worker

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exposure to N-nitroso compounds sponsored by the National Institute for Occupational Safety and Health (NIOSH).

During Part I of this study a total of 40 site visits were made to 28 separate manufacturing facilities representing five categories of industrial activity. The industries included in this study were:

- Leather manufacturing
- Rubber manufacturing
- Use and manufacture of synthetic metal working fluids
- Azo dye manufacture
- Fish processing plant

The basis for selecting the industries included in this study were: the known or suspected use of N-nitroso compounds, the use of products or manufacture of products shown to be contaminated with N-nitroso compounds, the use of chemical or manufacturing processes which could give rise to these compounds, the consideration of epidemiological data which suggested worker exposure to a chemical carcinogen and the results of this study as it proceeded. For example, the leather tanning industry, was included in this study because dimethylamine sulfate (a precursor to NDMA) is used in some leather tanneries as a depilatory agent in the unhairing process (12) and some leather workers have been reported to have an increased risk of cancer (14).

N-nitroso compounds were found in 21 of 28 plants surveyed. The highest levels of airborne nitrosamine was the finding of 47 $\mu g/m^3$ of NDMA in a leather tannery (15) and 27 $\mu g/m^3$ of N-nitrosomorpholine (NMOR) in a rubber tire plant (16). The results of the overall study have also been presented (17). In this report we discuss our findings of N-nitroso compounds in five leather manufacturing facilities (Table I). While the findings of the first tannery have been reported, the results from the other four tanneries surveyed in this study have not been previously discussed. In order to present a more complete report of our survey for N-nitroso compounds in the leather industry and to examine why these compounds are present as contaminants, we include the findings from all five tanneries in this paper. Because NDMA had been previously found in more than one tannery we selected tanneries with limited or specific operations (Fig. 1) in an effort to determine the source of this discovered NDMA or to determine the mechanism by which it was produced. If the mechanisms which produced NDMA in the atmosphere of leather tanneries are found not to be unique to this industry, then other plants and industries which use nitrosatable amines may also be contaminated with N-nitroso compounds. With the exception of the use of the artifact-free ThermoSorb /N air cartridges (10), the experimental method and apparatus used to conduct these surveys and to analyze the samples are essentially the same as previously reported (15).

Table I. Summary of *N*-Nitrosodimethylamine in Each Tannery

	Airborne ($\mu g/m^3$)		Bulk Samples (ppb)			
Tannery	Maximum	Average	Waste Water	Process Water	Chemicals	Other[1]
A[2]	33	13	6	-	-	-
A[3]	47	18	-	1.5	500[4]	N.D.[6]
A[5]	3.4	2.4	-	N.D.	-	-
B	8	1.5	N.D.	-	-	N.D.
C	2.0	1.6	N.D.	N.D.		N.D.
D	trace	-	-	-		-
E	N.D.	-	-	-		-

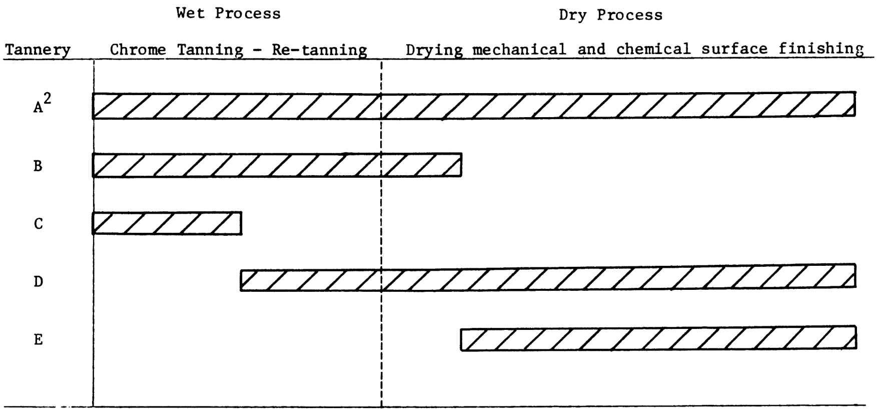
1. Other samples include raw hide, tanned leather, condensed steam, etc.
2. Tannery A was the only tannery visited that was using Dimethylamine sulfate in the hide dehairing process.
3. Re-visit to Tannery A two days after the first
4. 500 ng/ml of NDMA was found in a 36% solution of Dimethylamine sulfate
5. Third visit to Tannery A 50 days after the first site visit. At this time they had ceased using Dimethylamine sulfate.
6. N.D. - None detected, detection limit of 0.05 $\mu g/m^3$ for NDMA in air and 0.5 ng/g for NDMA in bulk samples.

Tannery Description and Results

Tannery A. The first tannery surveyed was located in New England. Approximately 300 workers were processing about 2000 hides per day into finished leather. This tannery used methods of tanning that are characteristic of the industry (New England Tanners Club, 1977). In addition, they used dimethylamine sulfate in the unhairing process. All of the 300 or so tanning operations were performed in a one-story building divided into wet and dry operations areas (Figure 2). Three visits were made to the factory and the entire leather tanning and finishing processes were examined for the presence of N-nitroso compounds. During the first visit (April 11, 1978) six area air samples representing a cross section of the air in the tannery were collected and during the following visit (April 13, 1978) 20 air samples were taken along with several bulk samples. The third visit was made on June 1, 1978 when 10 air samples and numerous bulk samples of process water were collected. A total of 27 bulk samples were examined for N-nitroso compounds. These samples consisted of 11 chemicals or chemical mixes, two from the hide and leather, two of the waste water, and 12 of the process water from the wet operation of the tannery.

Results. During the first visit to this facility, NDMA was found in all six air samples at levels ranging from 6 $\mu g/m^3$ in the spray finishing area to 33 $\mu g/m^3$ near the chrome tanning operation. All of the inside air samples taken on the second visit, two days following the first, contained NDMA with levels ranging from 0.1 $\mu g/m^3$ in the lunch room, 1.4 $\mu g/m^3$ in the shipping room to 47 $\mu g/m^3$ in the re-tanning area. The average amount of airborne NDMA found on these two visits was 19 $\mu g/m^3$. This figure is based on the area air volumes. On the second visit, in addition to NDMA, N-nitrosomorpholine was found at a level of 2.0 $\mu g/m^3$ in three air samples taken in the leather finishing area. During the third visit, 50 days after the first, NDMA was again found in the atmosphere at all the sampled sites. However, these levels were considerably reduced, ranging from 1.1 to 3.4 $\mu g/m^3$ in the re-tanning area. The highest levels of airborne NDMA and their locations with respect to the tanning process are shown in Figure 3.

Only four of the 27 bulk samples contained NDMA (Table 2). The highest level of NDMA (0.5 $\mu g/ml$) was found in a sample from a 36.5% aqueous solution of dimethylamine sulfate (DMAS). According to plant personnel, 117 liters of DMAS are used each day in the hide unhairing process. This would amount to less than 60 mg NDMA/day potential exposure from the contaminated DMAS. NDMA (0.0015 $\mu g/ml$) was also found in the re-lime pit (unhairing vat) process water. This process water contained 5.7 liters of DMAS in 8000 L of lime-saturated water. The other samples which contained NDMA (0.004 $\mu g/ml$ and 0.006 $\mu g/ml$) were waste-water from the tannery outlet pipe collected at the local municipal waste-



▨ Extent of the tanning process performed at each facility

1. New England Tanners Club

2. Tannery A is a fully tannery which produces finished leather from raw hides

Figure 1. Leather tanning operations[1] of the five tanneries surveyed for N-*nitroso compounds*

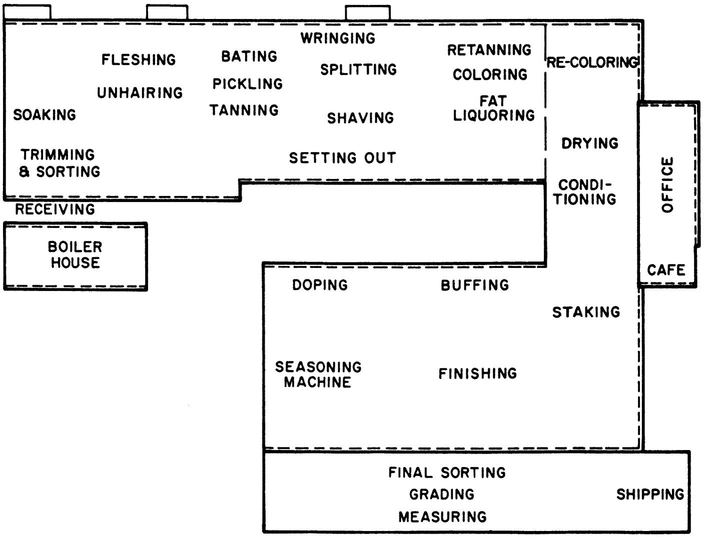


Figure 2. Process flow diagram for Plant A

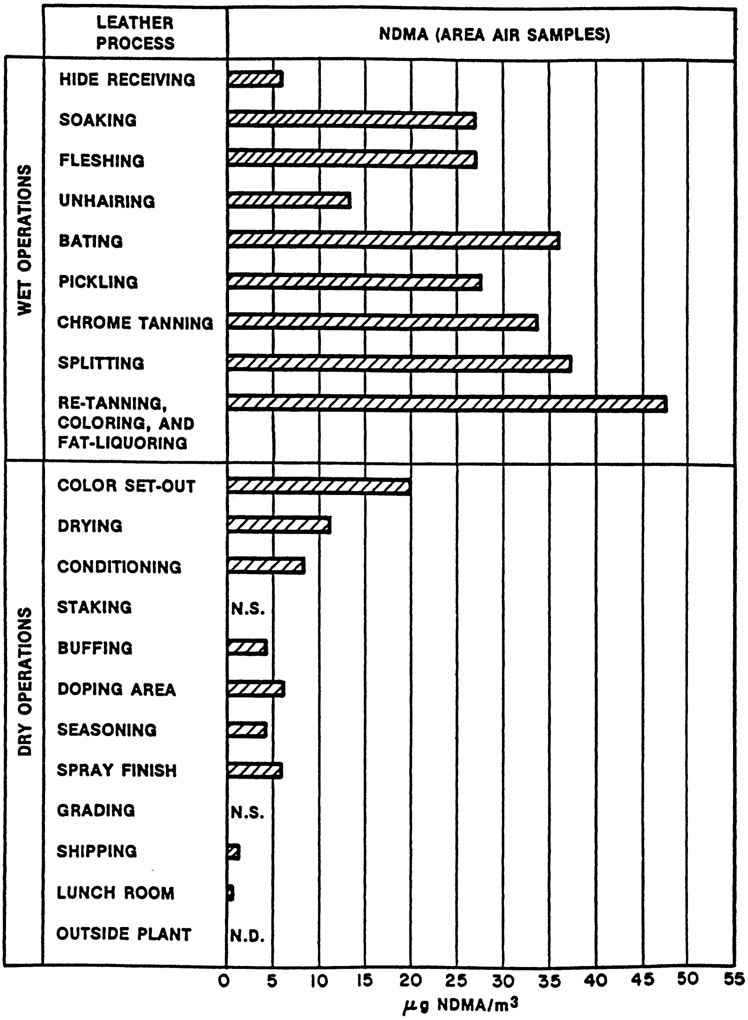


Figure 3. The highest levels of NDMA in the atmosphere at various stages of the tanning process (combined data from the first two visits to Tannery A): ND = not detected; NS = not sampled

Table II. NDMA Levels in Liquid and Solid Bulk Samples

Sample Description	NDMA (μg/g)
Chemicals	
Azo Rubine Dye	ND
Penetrator L-219	ND
Nigrosine Blue L	ND
Polar Sol 5	ND
Betz Formula NA-6	ND
Boiler rush inhibitor mix	ND
Ammonia paste wash	ND
ρ-Nitrophenol	ND
KITO-40 (fungicide)	ND
Fresh brine	ND
Aqueous dimethylamine sulphate (36.5%)	0-5
Leather Samples	
Chrome-tanned leather	
Raw-salted cowhide	ND
Waste Water	
Beam-house waste water	0-004
Tanning-house waste water	0-006
Process Water	
Re-lime pit	0-0014
Bating solution (two samples)	ND
Pickling solution (two samples)	ND
Chrome-tanning solution (two samples)	ND
Final rinse from chrome tanning (two samples)	ND
Wash out of colouring	ND
First rinse from fat-liquoring	ND
Final rinse from fat-liquoring	ND

ND = Not detected

water treatment plant. It waw reported that the waste-water from the tannery amounted to about 4 x 10^6 liters/day. Approximately 20 g of NDMA would be required to produce 0.006 μg/ml NDMA in this volume of water. A sample of the salted cowhide was also examined for NDMA, but none was detected (detection limit 0.05 μg/g). In order to test the salted cowhide for any material which could possibly nitrosate dimethylamine, a 1 g piece of cowhide was placed in 5 ml sulfuric acid pH (3) containing 50 mg of dimethylamine hydrochloride for 4 hrs at 25°C. At a detection limit of 0.05 μg/g neither NDMA, nor any other TEA-responsive compounds were found. Finally, process water was sampled from all phases of the wet tanning operations and, except for the re-lime pit, none of these contained NDMA at a detection limit of 0.005 μg/ml.

During the first and second visit to the tannery, a strong odor (ammonia-like) was noted and the air appeared saturated with moisture. In addition, several propane fork-lift trucks were exhausting their gases to the atmosphere. Also during these visits DMAS was being used in the re-lime pits. By the third visit, the outside weather was warmer and the tannery was being better ventilated. During this visit there were no strong odors in the air and the tannery had discontinued using DMAS. However, the propane driven fork-lift trucks were still operating within the hide receiving and wet process area.

Using the plant dimensions supplied by the plant personnel, the calculated air volume within the plant is about 1 x $10^5 m^3$. In order to produce the airborne concentration of NDMA observed during the first two visits there would have to be about 2 grams of NDMA in the air at any given time. If one assumes an air change each 30 min, then on a daily basis there is about 100 grams of NDMA in the air. The waste water content of 20 grams/day brings the total amount of NDMA needed to explain our findings to 120 g/day. The NDMA impurity found in the DMAS would amount to only 60 mg/day which is insufficient to account for the observed NDMA. We have failed to find a source for the NDMA in this plant except for the possibility for airborne or surface formation from the dimethylamine moiety of the DMAS and airborne NO_x from exhaust of the propane driven fork-lift trucks. We did not measure the dimethylamine or nitrogen oxide levels in the air during this survey. A crude measurement of the nitrosation capacity of the air in the tannery was made at a later date by drawing air through cartridges containing magnesium silicate coated with morpholine (10). We did find that N-nitrosomorpholine was indeed formed on these cartridges, thus indicating an airborne nitrosating agent was present in the tannery. The greatest amount of this airborne nitrosating agent was found in the wet process area where the previous high levels of NDMA were found. It should be noted that this is the same area where the propane driven fork-lift truck operated and where DMAS is used. As previously mentioned, the formation of NDMA in the gas phase and on surfaces from dimethylamine and nitrogen oxides has been demonstrated.

Tannery B. This tannery, also located in New England, employs 80 workers who process about 700 hides per day producing fully tanned and colored leather which are shipped to a separate facility, Tannery E, for surface and mechanical finishes. During the site visit on October 12, 1978, 19 air samples and 4 bulk samples were collected. The air samples were collected at all stages of the tanning operation. The bulk samples consisted of two waste water specimens, one steam system condensate and one floor scraping from the dye room.

Results. NDMA was found in the atmosphere of this plant at all stages of production except the new beam house. The highest level of 8 $\mu g/m^3$ was found in an unused loft above the unhairing process. In the production area, 3 $\mu g/m^3$ was found in the dye storage room with the remaining samples ranging from 1.2 $\mu g/m^3$ near the the unhairing process to 0.03 $\mu g/m^3$ in the hide drying area. The sample locations and NDMA concentrations are shown in Figure 4. The farther away from the unhairing process that the air samples were taken the lower the levels of NDMA. The finding of nearly 3 $\mu g/m^3$ of NDMA in the small dye room near the re-tanning area with levels of 0.1 - 0.2 $\mu g/m^3$ just outside (a 15 to 30-fold difference) suggests that there may be a source (contamination) for the NDMA within the dye room. The highest level of 8 $\mu g/m^3$ in the loft above the unhairing process is hard to explain unless the levels of NDMA in the plant were higher in the past. None of the bulk samples examined contained any N-nitroso compounds.

This plant does not presently use dimethylamine sulfate, but it has used this compound in the recent past. Another possible source for the dimethylamine precursors may be the hides or it may be formed during the unhairing step. The only potential nitrosating agent identified in any of the processes (except dyeing) was the antifungal agent Paranitro-phenol. Some of the dyes used by this plant contained C-nitro groups which could transnitrosate dimethylamine to form NDMA. However, an air sample taken inside one of the coloring drums was no higher in NDMA levels than the air outside of it. We did observe propane operated fork-lift trucks being used within the tannery and these will contribute nitrogen oxides to the plant atmosphere.

Tannery C. This tannery, located in the Midwestern United States, employs 135 workers who process about 3000 hides per day into chrome tanned hides. These "blue hides" are then shipped to Tannery D for re-tanning, coloring and final finishing. This tannery has used dimethylamine on an experimental basis but was not using it during this survey. During the site visit to this facility on January 16, 1979, 10 area air samples and 5 process air samples were collected along with 8 bulk samples. The bulk samples consisted of 6 process water specimens, one plant wastewater specimen and one steam system condensate. The process air samples were collected inside the hide processing drum. These hide processing drums resembled large cement mixers and were ven-

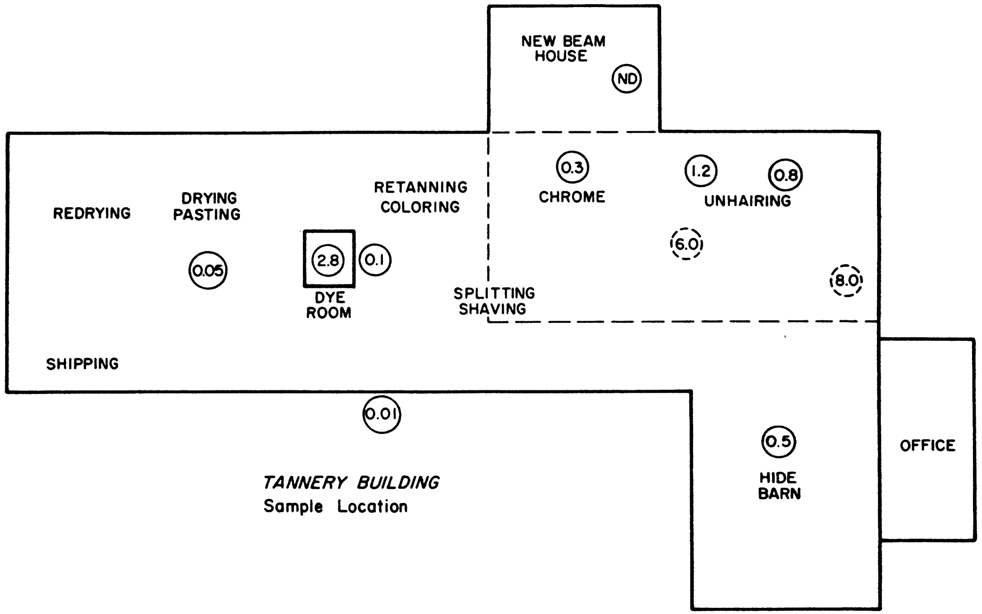


Figure 4. Air sample locations within Plant B. The circled numbers refer to $\mu g/m^3$ of N-*nitrosodimethylamine (NDI-1A).*

tilated to the outside air. All of the operations of this tannery, except the chemical mixing, were performed in a large 40,000 sq. ft unpartitioned building.

Results. Again NDMA was found in all of the air samples taken in this tannery with levels ranging from 0.2 $\mu g/m^3$ in the chemical processing room (sulfide stripping) to over 3 $\mu g/m^3$ in the center of the plant on a deck above the water treatment area. All other NDMA levels ranged from 1 to 2 $\mu g/m^3$ with a mean of 1.5 $\mu g/m^3$. These results indicate a fairly uniform distribution of the NDMA in the plant atmosphere. Air samples collected within the hide process drums had NDMA levels that were at or below the mean level within the plant. None of the bulk samples contained NDMA at a detection limit of 0.05 $\mu g/ml$.

A source for the NDMA was not found in this tannery. It was reported that they did use dimethylamine sulfate on an experimental basis and nitrosation of three of the bulk process water samples did result in the formation of 0.0015 to 0.0025 $\mu g/ml$ of NDMA. We also collected three air samples using acid pH traps and after nitrosating the content, found twice the level of NDMA, thus indicating the presence of the NDMA precursor amine in the air. In a further experiment we sampled air over magnesium silicate coated with morpholine and found that from 3-20% of the 30 μg of morpholine had been converted to N-nitroso morpholine thus indicating an airborne nitrosating agent.

This plant also uses propane driven fork-lift trucks and at the time of the survey direct gas fired heaters were being used to warm the air in the plants. Both of these combustion sources would contribute nitrogen oxides to the air.

Tannery D. This facility, located in New England, consists of a two-story building with 150,000 sq. ft of floor space employing 560 workers who process about 8-10,000 hides per day. This facility is a re-tanning and finishing operation that receives chrome tanned hides from other plants which it re-tans, re-colors and surface finishes. This facility was visited on February 5, 1979 when 21 air samples were collected at all stages of the operation. There was no reported use of dimethylamine sulfate or any other amines in this facility.

Results. Two air samples were found to contain N-nitrosomorpholine (NMOR) at levels of 0.1 and 0.25 $\mu g/m^3$ and in addition 0.05 $\mu g/m^3$ NDMA was found in the sample containing 0.1 $\mu g/m^3$ of NMOR. These levels of N-nitroso compounds are considerably lower than what has been found in other tanning operations.

Tannery E. This tannery, located in New England on the third floor of a three-story brick building, occupies 40,000 sq. ft and employs 60 workers who apply surface finishes to leather that has been fully tanned and colored at Tannery B. On the day this plant was visited (October 13, 1978) 17 air samples were taken at all stages of production. While there were many chemicals and dyes being used at this plant there were no known sources for amines or nitrosating agents.

Results. No N-nitroso compounds were found in any of the air samples collected at the facility.

Conclusion

The tannery industry was selected to be surveyed for N-nitroso compounds in their environment because of its reported use of dimethylamine sulfate in the hide unhairing process. Upon examination of a tannery using this compound we did find two N-nitroso compounds in its air, N-nitrosodimethylamine (NDMA) and N-nitrosomorpholine (NMOR). Other tanning operations which either did not use DMAS or had ceased its use had greatly reduced levels of these compounds in their environment. We were unable to identify any specific tanning process within the industry which was responsible for the observed NDMA. However, the data strongly suggests that it is being formed in the air or on surfaces. If this hypothesis is proven to be correct then any environment where nitrosatable amines and nitrogen oxides are found in a confined atmosphere (not just tanneries) are likely to be contaminated with N-nitroso compounds.

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