

# ACRYLAMIDE

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## FOOD OCCURRENCE

Although human exposure to acrylamide is primarily occupational, the general public may be exposed through consumption of certain foods in their diet (Tareke et al. 2002). Acrylamide is formed during heating of starch-rich foods to high temperatures. Studies with laboratory-heated foods revealed a temperature dependence of acrylamide formation.

Moderate levels of acrylamide (5–50 mg/kg) were measured in heated protein-rich foods and higher contents (150–4000 mg/kg) in carbohydrate-rich foods, such as potato, beetroot, and also certain heated commercial potato products and crispbread. Acrylamide could not be detected in unheated control or boiled foods (< 5 mg/kg). Consumption habits indicate that the acrylamide levels in the studied heated foods could lead to a daily intake of a few tens of micrograms (Tareke et al. 2002).

## LEGISLATION

[http://ec.europa.eu/food/food/chemicalsafety/contaminants/study\\_area1.pdf](http://ec.europa.eu/food/food/chemicalsafety/contaminants/study_area1.pdf)

### Methods of sampling and analysis

EPA Method 8015 can be used to determine the concentrations of various non-halogenated volatile organic compounds, including acrylamide, in water, soil or sediment by gas chromatography with flame ionization detection. Aqueous process waste samples can be analysed by direct injection or the purge-and-trap method (EPA Method 5030); ground water and slightly contaminated soil and sediment samples must be analysed by the purge-and-trap method (US Environmental Protection Agency, 1986).

Biological monitoring of exposure to acrylamide involves determination of adducts of acrylamide with haemoglobin by gas chromatography-mass spectrometry, as tested experimentally (Farmer et al., 1986; Bailey et al., 1987) and in humans (Bergmark et al., 1993).

Methods have been reported for the determination of acrylamide in water, wipe samples and polyacrylamide (Going & Thomas, 1979; Skelly & Husser, 1978). Water samples were reduced in volume by evaporation and analysed by gas chromatography with a nitrogen-selective thermionic detector. The detection limit was approximately 1 mg/L. Polyacrylamide samples were extracted with 80% methanol and 20% water (pH 3.75) for 3 h, and the extracts were analysed by high-performance liquid chromatography with an ultraviolet detector at 200 nm. The limit of detection of the monomer was approximately 0.5 mg/g. An analytical method for acrylamide in air and surface wipe samples, adapted from Skelly and Husser (1978), was described by Cummins et al. (1992). Air samples collected on a glass-fibre filter and XAD-7 solid sorbent tubes were desorbed with 5% methanol in water and analysed by high-performance liquid chromatography with ultraviolet detection. Wipe samples obtained on moistened glass-fibre filters were extracted with water prior to analysis.

## CARCINOGENICITY (RoC)

### Properties

Acrylamide occurs in crystalline form and in aqueous solution. The solid monomer is a colorless to white, free-flowing crystal that is soluble in water, methanol, ethanol, dimethyl ether, and acetone, and is insoluble in benzene and heptane. It melts at 84 to 85°C and boils at 125°C. The crystalline acrylamide monomer is available as pellets of 98% and 95% purity. The 50% aqueous form is the preferred form for applications in which water can be tolerated. The monomer readily polymerizes at the melting point or under ultraviolet light. Solid acrylamide is stable at room temperature, but it may polymerize violently when melted or in contact with oxidizing agents. When heated to decomposition, acrylamide emits acrid fumes and nitrogen oxides. Commercial acrylamide monomer contains residual levels of acrylonitrile (1 to 100 mg/kg) (IARC 1986). Residual acrylamide monomer is present in the polymer at approximately 0.01% (Fujiki et al. 1985, IARC 1986).

### Use

Acrylamide is a chemical intermediate used in the production and synthesis of polyacrylamides (IARC 1986, 1994). These highmolecular weight polymers can be modified to develop nonionic, anionic, or cationic properties for specific uses. The principle end use of acrylamide is in water-soluble polymers used as additives for water treatment, enhanced oil recovery, flocculants, papermaking aids, thickeners, soil conditioning agents, sewage and waste treatment, ore processing, and permanent-press fabrics (Kirk-Othmer 1978, Sax and Lewis 1987). Acrylamide is also used in the synthesis of dyes, in copolymers for contact lenses, and the construction of dam foundations, tunnels, and sewers (Kirk-Othmer 1979). The largest use for polyacrylamide is in treating municipal drinking water and waste water (IARC 1986). The polymer is also used to remove suspended solids from industrial waste water before discharge, reuse, or disposal. Polyacrylamide used for potable water should not contain more than 0.05% residual monomer (Kirk-Othmer 1978). The polymers bind with particles and form heavy aggregates that rapidly settle out of solution and leave a clear supernatant (IARC 1986). Ten to thirty percent of the annual production volume is used in oil-recovery processes in which the polyacrylamides increase water viscosity. Acrylamides also find use in oil-drilling processes to control fluid losses. In the pulp and paper industry, polyacrylamides are used as binders and retention aids for fibers and to retain pigments on paper fibers. The paper industry uses approximately 20% of the annual U.S. production volume.

Polyacrylamides are used to clarify waste water, recover tailings, and flocculate ores in mineral processing. They are incorporated in cement to slow the dehydration process to improve structural strength. Methylated polyacrylamide with subsequent radiation curing is used to produce waterproof concrete. Acrylamide is a soil stabilizer and also finds use in foundry operations to facilitate free sand flow into molds. Polyacrylamides are incorporated in coatings as dispersants and binders and in water-based paints for pigment suspension and flow. Home appliances, building materials, and automotive parts are coated with acrylamide

resins and thermosetting acrylics. Acrylamides are formulated in cosmetics and soap preparations as thickeners and in dental fixtures, hair grooming preparations, and preshave lotions. In the textile industry, polyacrylamides are used to size and shrink-proof material and as water repellents. Minor uses of acrylamide are as latex thickeners, emulsion stabilizers for printing inks, gelling agents for explosives, binders in adhesives and adhesive tape; in the production of diazo compounds; and for gel chromatography and electrophoresis (Sittig 1985, IARC 1986).

When added to herbicidal gels, polyacrylamides restrict herbicidal treatment to the bottom of lakes or reservoirs by allowing the herbicides to sink before they disperse. The FDA has regulated the use of acrylamide and polyacrylamide in foods. Up to 10 mg polyacrylamide/L water can be used to wash or peel fruits and vegetables; acrylamide monomer should not exceed 0.2%. Acrylamide resins may be added to water for steam that will contact food; the monomer should not exceed 0.05% by weight. Polyacrylamide may be used in gelatin capsules if no more than 0.2% of the monomer is present. Acrylamide polymers may be used in food packaging adhesives, and acrylamide resins, containing <0.2% monomer, may be used in food packaging paper and paperboard if the resin is  $\leq 2\%$  of the weight of the paper.

## **Production**

Currently, 33 U.S. suppliers of acrylamide are listed by Chem Sources (2001). The 1998 Chemical Buyers Directory named nine such companies (Tilton 1997). The 1997 Directory of Chemical Producers listed four producers of the compound, with a total output of 217 million lb (SRI 1997). Two U.S. manufacturers of acrylamide monomer were identified for 1994, but no production values were provided (USITC 1995). In 1992, three manufacturers were reported to produce 113.5 million lb of the chemical (USITC 1994). Two producers for acrylamide monomer were listed by USITC (1991, 1993) for 1990 and 1991, and three producers for 1988 (USITC 1989), without any production figures. Four U.S. producers reportedly manufactured 47.1 million lb in 1986 (USITC 1987), and an estimated 70 million lb was produced in 1974 (Sittig 1985).

For 1992, U.S. imports totaled 15 million lb and exports were estimated to be less than 2 million lb (EPA 1994). Twenty years earlier, the volumes were considered negligible (HSDB 2000).

## **Exposure**

Acrylamide can be absorbed through unbroken skin, mucous membranes and lungs, and the gastrointestinal tract (Klaassen et al. 1986, Merck 1989). NIOSH estimates that approximately 20,000 workers were potentially exposed to acrylamide in 1976 (IARC 1986). Human exposure to acrylamide is primarily occupational from dermal contact with the solid monomer and inhalation of dust and vapor (Kirk-Othmer 1978, Howard 1989). Occupational exposure to the aqueous form is primarily confined to maintenance and repair operations and connection and disconnection for transport. Routine exposure is minimal for captive cause peripheral neuropathy (Klaassen et al. 1986). Residual monomer in the polymers is a concern (Howard 1989). Improvements in the polymerization process have reduced the monomer content of the nonpotable water-grade polymers from 5% to 0.3% (Brown et al. 1982).

Workers in the paper and pulp, construction, foundry, oil drilling, textiles, cosmetics, food processing, plastics, mining, and agricultural industries are potentially exposed to acrylamide. Although exposure levels have not been reported for grouters, the potential exposure for these personnel may be greater than for other workers because of the uncontrolled nature of the exposure (WHO 1985). The National Occupational Health Survey (1972-1974) estimated that 10,368 workers were exposed to acrylamide (Howard 1989). The National Occupational Exposure Survey (1981-1983) estimated that 9,776 workers potentially were exposed (NIOSH 1984). This estimate was based on observations of actual use of the chemical (43%) and as an ingredient of trade name products (57%). Primary exposure occurs during the handling of the monomer. Two acrylamide manufacturing plants showed breathing zone concentrations of 0.1 to 3.6 mg/m<sup>3</sup> (IARC 1986). During normal operations, workers at another plant were exposed to not more than 0.3 mg/m<sup>3</sup>.

Although human exposure to acrylamide is primarily occupational, the general public may be exposed through consumption of certain foods in their diet (Tareke et al. 2002). Acrylamide is formed during heating of starch-rich foods to high temperatures. Studies with laboratory-heated foods revealed a temperature dependence of acrylamide formation. Moderate levels of acrylamide (5–50 mg/kg) were measured in heated protein-rich foods and higher contents (150–4000 mg/kg) in carbohydrate-rich foods, such as potato, beetroot, and also certain heated commercial potato products and crispbread. Acrylamide could not be detected in unheated control or boiled foods (< 5 mg/kg). Consumption habits indicate that the acrylamide levels in the studied heated foods could lead to a daily intake of a few tens of micrograms (Tareke et al. 2002).

Another source of exposure of the general public to acrylamide could be through contaminated drinking water from polyacrylamide flocculants used in water treatment (Brown et al. 1980a, Howard 1989). Residual acrylamide concentrations in 32 polyacrylamide flocculants approved for water treatment plants ranged from 0.5 to 600 ppm (Howard 1989).

Acrylamide may not be removed in many water treatment processes (Croll et al. 1974). Acrylamide remains in water after flocculation with polyacrylamides because it is very water soluble and is not readily adsorbed by sediment (Brown et al. 1980b). Acrylamide and polyacrylamides are used in the manufacture of a number of consumer products, including textiles, contact lenses, appliances, building materials, cosmetic and soap preparations, food, and gelatin capsules (Kirk-Othmer 1979).

Acrylamide may be released into the environment from waste during acrylamide production and the manufacture of polyacrylamides and other polymers (Howard 1989). Release to water also occurs from acrylamide-based sewer grouting and wastepaper recycling (Brown et al. 1980b, 1982, Howard 1989). The most important environmental contamination results from the use of acrylamide in soil grouting (WHO 1985). Acrylamide biodegrades in water in approximately 8 to 12 days (Howard 1989). Acrylamide may not be completely degraded in sewage works and water treatment facilities if residence times are relatively short (Brown et al. 1982, Howard 1989). Acrylamide degradation in a secondary sewage plant would be complete in approximately 10 days (Kirk-Othmer 1978). It has been detected in effluent from a sewage treatment plant. Adsorption to sediment and volatilization is not appreciable. Certain debris organisms that exist in anaerobic, light aerobic, or dark aerobic conditions in natural and polluted environments are able to degrade acrylamide (Brown et al. 1980b). Bacteriologic degradation will likely depend on temperature fluctuations in temperate

climates. Although acrylamide is highly mobile in aqueous environments, readily leaches into soil, and is carried great distances in ground water of deep rock aquifers where biodegradability is reportedly absent (WHO 1985), bioconcentration of acrylamide is unlikely because it degrades easily in surface waters and is highly water soluble (Kirk-Othmer 1978). In an EPA study of five industrial sites (beyond plant site perimeters) of acrylamide and polyacrylamide producers and one polyacrylamide user, acrylamide (1.5 ppm) was found in only one sample downstream from a polyacrylamide producer; no acrylamide was detected in soil or air samples (WHO 1985, Howard 1989). An average acrylamide concentration in air was  $<0.2 \mu\text{g}/\text{m}^3$  near six acrylamide or polyacrylamide plants. The vapour pressure of acrylamide is low, and the monomer is not expected to be distributed in the atmosphere (WHO 1985).

Environmental contamination may result from disposal on land or from leaching of the residual monomer from polyacrylamides. The Toxic Chemical Release Inventory (TRI) estimated that 5,912,663 lb of acrylamide were released to the environment from 43 facilities that produced, processed, or used the chemical in the United States in 1996 (TRI96 1998). That number increased to 7,542,385 lb from 90 facilities in 1999. Of that total, 99.6% was released to underground injection. Forty-four facilities were responsible for the 24,874 lb of acrylamide emitted to air. Twenty-one facilities, each releasing  $>100$  lb to air, represented 98.7% of the total emission; one facility located in Greensboro, North Carolina, reporting under industrial classifications for chemical preparations, NEC (SIC Code 2899), and releasing  $>9,000$  lb of acrylamide, accounted for 39.8% of total air releases. Other 1999 total releases were 370 lb to water and 6,289 lb to land (TRI99 2001).

## CHEMICAL AND PHYSICAL DATA

### Nomenclature

Chem. Abstr. Serv. Reg. No.: 79-06-1

Chem. Abstr. Name: 2-Propenamamide

IUPAC Systematic Name: Acrylamide

Synonyms: Acrylic acid amide; acrylic amide; ethylenecarboxamide; propenamamide; propenoic acid amide; vinyl amide

### Structural and molecular formulae and relative molecular mass



$\text{C}_3\text{H}_5\text{NO}$

Relative molecular mass: 71.08

### Chemical and physical properties of the pure substance

- (a) Description: White crystalline solid (monoclinic or triclinic crystal structure) (Habermann, 1991)
- (b) Boiling-point:  $136^\circ\text{C}$  at 3.3 kPa (Habermann, 1991)

- (c) Melting-point: 84-85 °C (Lide, 1991)
- (d) Density: 1.122 g/mL at 30 °C (Habermann, 1991)
- (e) Spectroscopy data: Infrared [prism, 2998; grating, 8284], nuclear magnetic resonance, ultraviolet [3515] and mass spectral data have been reported (Weast & Astle, 1985; Sadtler Research Laboratories, 1991).
- (f) Solubility: Soluble in water (215.5 g/100 mL at 30 °C), acetone (63.1 g/100 mL at 30 °C), chloroform (2.7 g/100 mL at 30 °C), diethyl ether, ethanol (86.2 g/100 mL at 30 °C), ethyl acetate (12.6 g/100 mL at 30 °C) and methanol (155 g/100 mL at 30 °C); very slightly soluble in heptane (6.8 mg/100 mL at 30 °C) (Budavari, 1989; Lide, 1991)
- (g) Volatility: Vapour pressure, 0.9 Pa at 25 °C (Habermann, 1991)
- (h) Stability: The solid is stable at room temperature but polymerizes on melting or exposure to ultraviolet light (Budavari, 1989)
- (i) Octanol-water partition coefficient (P): log P, -0.78 (Sangster, 1989)
  - <sup>(i)</sup> Conversion factor:  $\text{mg/m}^3 = 2.91 \cdot \text{ppm}^a$

<sup>a</sup> Calculated from:  $\text{m/m}^3 = (\text{relative molecular mass}/24.45) \cdot \text{ppm}$ , assuming normal temperature (25 °C) and pressure (101.3 kPa)

## **OTHER RELEVANT INFORMATIONS**

[http://pdfserve.informaworld.com/83397\\_751315006\\_714030170.pdf](http://pdfserve.informaworld.com/83397_751315006_714030170.pdf)

[http://www.sciencedirect.com/science?\\_ob=MImg&\\_imagekey=B6T6P-4MSXT97-3-](http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6T6P-4MSXT97-3-)

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<http://www.springerlink.com/content/d48056242k2362p4/>

<http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0396.2005.00550.x/pdf>

<http://www.li.se/dokument/news/nyheter/Acrylamid%20Expertrapport%20Final.pdf>