

Substance name: Hydrogen Sulfide

DRAFT as of 3/6/2018

CAS: 7783-06-4

MW: 34.076

Synonyms:

Hydrosulfuric acid

Molecular formula: H₂S



1 ppm to 1.4 mg/m³ conversion factors at 25 °C and 760 mm/Hg:

GHS Classification

Signal: Danger

GHS Hazard Statements

H220: Extremely flammable gas [Danger Flammable gases - Category 1]

H280: Contains gas under pressure; may explode if heated [Warning Gases under pressure - Compressed gas, Liquefied gas, Dissolved gas]

H319: Causes serious eye irritation [Warning Serious eye damage/eye irritation - Category 2A]

H330: Fatal if inhaled [Danger Acute toxicity, inhalation - Category 1, 2]

H370: Causes damage to organs [Danger Specific target organ toxicity, single exposure - Category 1]

H400: Very toxic to aquatic life [Warning Hazardous to the aquatic environment, acute hazard - Category 1]

H410: Very toxic to aquatic life with long lasting effects [Warning Hazardous to the aquatic environment, long-term hazard - Category 1]

Physical characteristics at room temp: Colorless gas with a strong odor of rotten eggs.

Special physical characteristics if any: Heavier than air.

Flammability and other hazards: Extremely flammable. Corrosive. Reacts with strong oxidants.

Upper Explosive Limit 44%

Lower Explosive Limit 4.0%

Major commercial form(s): Gas

Uses/applications: Main use is as precursor of elemental sulfur. Also as precursor of other chemicals used in paper manufacture, and in analytical chemistry

Occupations with Potential Exposure to Hydrogen Sulfide

Occupational exposures to hydrogen sulfide occur in such industries as animal husbandry and animal product production; sugar production; sewage, pipeline and other excavation trades; fermentation process industries; gas and petroleum production and pipeline maintenance; geothermal energy production; chemical production and processing; paper manufacture; synthetic fiber manufacture and metallurgy.

Occupational Exposure Limit recommendations

Title 8 PEL (1992): 10 ppm Ceiling 50 ppm STEL 15 ppm

OSHA PEL (1971) Ceiling 20 ppm, one-time 10 minute peak 50 ppm

ACGIH TLV (2010): 1 ppm STEL 5 ppm

NIOSH REL: 10 ppm 10 minute Ceiling(1977) 100 ppm IDLH(1994)

Other OELs (WEEL, MAK, etc.):

MAK (2006): 5 ppm, 7.1 mg/m³

WEEL (2013): Hydrogen Sulfide ERPG1: 0.1 ppm ERPG-2 30 ppm ERPG-3:100 ppm

Other recommendations:

Source and date	Findings/Recommendations	Basis/source/ref(s)	Discussion and Assessment
OEHHA REL	Acute: 42 µg/m ³ (30 ppb) Chronic: 10 µg/m ³	A: human volunteers exposed to increasing H ₂ S until odor detected. C: 90-day inhalation study in mice, CIIT 1983c	A critical effect: Headache, nausea, physiological responses to odor C critical effect: Nasal lesions of the mouse olfactory mucosa
HESIS PEL 2017	Recommended PEL-TWA 0.27 mg/m ³ (194 ppb)	Nasal lesions of the olfactory mucosa (Brenneman et al., 2000).	Male rats exposed to hydrogen sulfide by inhalation for 10 weeks were examined for nasal lesions of olfactory mucosa as the critical effect to identify a NOAEL which is used to derive PEL-TWA following application of a total UF of 10 to account for subchronic (√10) and interspecies (√10) extrapolation.
Prop 65	Not listed		
NTP	Not studied.		
EPA	IRIS RfC: 2.0 µg/m ³	Nasal lesions of the olfactory mucosa	Relevancy to humans of the olfactory lesions seen in rodents is suggested by reports of decreased persistent olfactory function in workers exposed chronically to hydrogen sulfide
IARC	Not classified		
EU	5 ppm TWA 10 ppm STEL	SCOEL/SUM/124 June 2007	An uncertainty factor of 2 used to account for differences in exposure pattern (sub-chronic vs. chronic) and limited dataset

Peer-reviewed journal articles used for proposed PEL

Respiratory

Bhambhani 1991; Bhambhani 1994; Bhambhani 1996; Bhambhani 1997

This series of studies on the physiological effects in controlled human exposure found metabolic effects from short-term exposure starting at 0.5 ppm H₂S that, while causing no clinical effect in the subjects, did result in altered enzymatic levels consistent with the accepted mode of action of H₂S toxicity. This toxic mode of action is considered to be the impairment of mitochondrial respiration by inhibition of cytochrome oxidase.

Study type: human volunteer

Method: Healthy male and female volunteers were exposed to 0.5 - 10 ppm H₂S for 30 minutes while operating a cycle ergometer at different energy intensities over the course of several studies. During these studies, metabolic and cardiovascular measurements were monitored at submaximal and maximal reference points so that H₂S-induced effects could be associated with moderate exercise and associated cardiac changes. Real-time physiological and perceptual responses were monitored and blood samples and muscle tissue biopsies obtained.

Results:

Bhambhani 1991

30-minutes exposures at 0, 0.5, 2.0 and 5.0 ppm H₂S. 16 males, age: 25.2 ± 5.5. Physiological measurements at submaximal and maximal exercise were obtained. There was a tendency for oxygen uptake to rise with increasing H₂S concentrations at all three exercise durations. Heart rate and expired ventilation were unaffected by H₂S concentration. Only at the maximum exercise level at 5.0 ppm was a significant difference in oxygen uptake observed between controls and H₂S exposed subjects. Blood lactate concentrations increased in each exposure group at each exercise intensity but only lactate increases in the 5.0 ppm exposed group were significantly different from controls. Maximal power output of this exposed group was not significantly different from controls.

Bhambhani 1994

30-minutes exposures at 50% aerobic power to 0 and 5.0 ppm H₂S. 13 males, age: 24.7 ± 4.6; 12 females age: 22.0 ± 2.1. There were no significant differences between the two exposures for metabolic, cardiovascular, arterial blood and perceptual measures in either sex. Blood lactate concentrations in exposed men and women were not significantly different from controls, although 70% of men and 83% of women had elevated lactate compared to controls.

Bhambhani 1996

30-minutes exposures at 50% aerobic power to 0 and 5.0 ppm H₂S. 13 males, age: 24.7 ± 4.6; 12 females age: 22.0 ± 2.1. Immediately following exercise, muscle biopsies were obtained and analyzed for markers of aerobic and anaerobic metabolism. Multiple measures of markers of energy metabolism determined by enzymatic activity of the muscle tissues obtained during exposure/exercise were mostly not significantly different from controls. Specifically, cytochrome oxidase activity, the putative enzyme associated with H₂S toxicity, was not significantly different between exposed men and women and controls. Citrate synthase decreased significantly (p=0.006) in exposed men and there was a tendency for cytochrome oxidase to decrease in exposed men but not significantly. In this study negative correlations were observed between aerobic

capacity and muscle lactate concentrations, leading the authors to suggest that the healthy capacity of the subjects was a factor in attenuating the effects of 5 ppm H₂S.

Bhambhani 1997

30-minute exposures at 50% aerobic power to 0 and 10.0 ppm H₂S. 15 males, age: 24.7 ± 4.6; 13 females age: 22.0 ± 2.1. Cardiorespiratory measurements were monitored as well as the other endpoints. A significant decrease in oxygen uptake and a significant increase in blood lactate was observed in exposed men and women. No significant differences were observed in arterial blood parameters and cardiovascular responses. The biochemical markers of energy production in muscle biopsies were not significantly different between controls and exposed subjects however there was a tendency for muscle lactate to increase and citrate synthase activity to decrease in both genders when exposed to 10.0 ppm H₂S.

Khan, 1998

Study Type: subchronic inhalation, rat

Methods: Fischer 344 rats were exposed to atmospheres containing 0, 1, 10, and 100 ppm (0, 1.4, 14, and 140 mg/m³) H₂S for 8 h/day, 5 days/ wk for 5 weeks. The biochemical activity of cytochrome oxidase was analyzed in lung, brain, and liver mitochondria.

Results: Exposure at the lowest concentration (1 ppm) did not cause any significant changes in activity of cytochrome oxidase; however, rats exposed to 10 and 100 ppm showed significantly lower activity ($p < 0.05$) of cytochrome oxidase in lung mitochondria than the control rats. The cytochrome oxidase activity in brain mitochondria also appeared to be lower in rats exposed to 10 ppm and 100 ppm H₂S than in the control rats, but the differences were not statistically significant. Cytochrome oxidase activity in the liver did not appear to be affected by H₂S treatments.

P Jappinen, 1990

Study type: cross-sectional

Methods: 26 male pulp mill workers (mean age 40.3) with a daily exposure to H₂S in the workplace (mean 4.5, range 1-11 ppm), and 10 volunteers, who had asthma (mean age 42.4) exposed to 2 ppm H₂S in a laboratory setting. The respiratory function of the pulp mill workers was monitored by measuring forced vital capacity (FVC), forced expiratory volume in one second (FEV₁) at least one day off work and at the end of a workday. Bronchial responsiveness was determined by administering histamine diphosphate aerosol at increasing concentrations until a fall of 15% in FEV₁ was achieved or the maximum histamine diphosphate concentration of 3.2% was reached. Likewise, bronchial responsiveness was determined after at least one day off work and at the end of a workday. The 10 asthmatic subjects were exposed to 2 ppm of H₂S for 30 minutes in an exposure chamber. Airway resistance (Raw) and specific airway conductance (SGaw) were assessed by a body plethysmograph, and the ventilatory capacities were measured with a flow volume spirometer. Values derived from a Finnish general population were used as predicted normal values for FEV₁, FVC, Raw, and SGaw.

Results: No significant changes in respiratory function or bronchial responsiveness related to exposure to hydrogen sulfide in the pulp mill workers were found. Similarly, no significant changes were observed in subsets of workers (workers exposed to at least 1 ppm, workers who smoked, exposed workers who had previous allergies or bronchial asthma, and five atopic subjects with a positive reaction in the skin prick test). There were no significant changes in the mean FVC, FEV₁, and forced expiratory flow values after exposure to H₂S in subjects with asthma. In two asthmatics, changes in Raw and SGaw were over 30% in indicating clinical bronchial obstruction.

Brenneman et al. (2000)

Study type: sub-chronic inhalation in rats

Method: 10-week-old male CD rats (12/ group) were exposed to 0, 10, 30, or 80 ppm (0, 13.9, 42, or 111 mg/m³) H₂S for 6 hr/day, 7 days/week, for 10 weeks. Due to the complexity of the rat nasal cavity, animal noses were dissected and examined for lesions and neuronal effects at 6 levels.

Results: an array of effects at different concentrations were observed at the different levels of the olfactory region. No effects were observed in the control or 10 ppm exposure animals that were considered treatment-related. Nasal lesions of the olfactory mucosa were observed in the 30 and 80 ppm exposure animals mostly in a dose dependent manner. Basal cell hyperplasia was observed in both exposure groups at one level of the nasal cavity but was more pronounced in the 30 ppm exposure group. Olfactory neuronal loss and basal hyperplasia occurred at 2 of the 6 nasal levels from exposure to 30 ppm H₂S.

Ocular/ Irritation

Vanhoorne, 1991; 1995

Study type: Cross sectional; rayon “spinners” concurrently exposed in H₂S and CS₂ compared to non-exposed workers.

Method: 123 male viscose rayon workers in 17 different job categories exposed to H₂S and/or carbon disulfide (CS₂) and 67 referents not exposed to either of these chemicals answered questions on eye irritation complaints in a self-administered questionnaire.

Results: Personal exposure varied from 1.3 to 36 ppm for CS₂ and from 0.15 to 6.36 ppm. for H₂S. A combined exposure measure was calculated using principal component analysis. When categorized into exposure groups (H₂S: 0, 0-3.6, >3.6 ppm; CS₂: 0, 1-10, 11-29, >29 ppm), eye symptoms in exposed workers were significantly different from controls only in the highest exposure categories (H₂S > >3.6 ppm ; CS₂ >29 ppm). Eye irritation was not reported in workers exposed to H₂S < 3.6 ppm and CS₂ > 29 ppm or H₂S < 3.6 ppm and CS₂ < 29 ppm. It was not possible to discern what chemical caused the eye effects observed in this study however a NOAEL for the combined gas exposure was >3.6/>29 ppm H₂S/CS₂.

Fiedler, 2008.

Study Type: human volunteers exposed in test chamber.

Methods: 74 healthy subjects [35 females, 39 males; mean age (\pm SD) = 24.7 \pm 4.2) were exposed to 0.05, 0.5, and 5 ppm H₂S. During each 3-hour exposure session, subjects completed ratings and tests before H₂S exposure (baseline, first hour) and during the final hour of the 2-hr exposure period. Subjects completed analog scales to rate pleasantness, intensity, and irritation of the H₂S odor, and to evaluate environmental qualities. Behavioral (odor ratings, symptoms and sensory function) and cognitive measures (visual acuity and visual contrast sensitivity, simple reaction time, finger tapping and symbol-digit substitution) were evaluated.

Results: Dose–response relationships between a reduction in air quality and increases in ratings of odor intensity, irritation, and unpleasantness were observed. After controlling for baseline, a significant exposure \times time interaction for odor ratings, irritation, intensity and unpleasantness was observed at the start of exposure. After 2 hours, only the 5 ppm scores were significantly different from the other 2. Total symptom severity was not significantly elevated across any exposure condition, but anxiety symptoms were significantly greater in the 5-ppm than in the 0.05-ppm condition. No dose–response effect was observed for behavioral or cognitive measures. Verbal learning was compromised during each exposure condition.

Reproductive/Developmental

Dorman 2000

Study type: sub-chronic rat study, pre-mating, gestational and postnatal exposure

Method: SD male and female rats exposed for 4 weeks prior to mating for 6h/day, 7/day week to 0, 10, 30 and 80 mg H₂S mg/m³. Exposure continued to GD 19 and until PND 18. Offspring were evaluated using motor activity, passive avoidance, functional observation battery, startle response and neuropathology (PND 22 and 60).

Results: There were no effects on reproductive performance based on mating success and several litter characteristics. There was a nonsignificant higher incidence of testicular tubular degeneration at the highest dose.

Skrajny 1992

Study type: sub-chronic rat study, gestational and postnatal exposure

Method: exposed groups of 20 pregnant Sprague-Dawley rats to 0, 28, or 105 mg/m³ (0, 20, or 75 ppm) H₂S 7 hours/day from day GD 5 through PND 21.

Results: Increased ($p < .05$) serotonin levels were observed in the frontal cortex on day 21 postpartum of pups exposed to 20 ppm hydrogen sulfide, whereas increased ($p < .01$) serotonin levels were observed in both the cerebellum and frontal cortex on postpartum days 14 and 21 in pups exposed to 75 ppm hydrogen sulfide. Norepinephrine levels were increased ($p < .05$) at 75 ppm in the cerebellum at postpartum days 7, 14, and 21, whereas norepinephrine levels were significantly increased in the frontal cortex only at day 21 postpartum. At 20 ppm, frontal cortex norepinephrine levels were decreased compared to controls on days 14 and 21.

Hayden 1990

Study Type: sub-chronic rat study, gestational and postnatal exposure

Method: pregnant SD rats exposed to 28, 70 or 110 mg/m³ for 7 hr/day on GD 6 until PPD 21.

Results: Dose – dependent increase in mean parturition time and difficult delivery of 10, 20 and 42% over matched controls. No statistical analysis presented but parturition time in controls (82.5 - 124 min) was considered too variable for statistical comparison with treated groups (105-148). No difference in maternal body weight gain between two groups. Maternal liver cholesterol content was elevated significantly on day 21 postpartum following exposure to 75 PPM H₂S each day for 6 weeks.

Neurological

Roth 1995

Study Type: sub-chronic rat study, gestational and postnatal exposure

Method: SD rat dams exposed to 28 -70 mg 7 hr/day from GD5. Pups born to treated dams were exposed perinatally up to PND 21. Morphological analysis of one cerebellar Purkinje cell per pup was performed. A quantitative analysis of dendritic growth was conducted to distinguish random versus nonrandom growth.

Results: Cells from H₂S-exposed rats underwent a significant amount of nonsymmetrical or nonrandom growth, suggesting that H₂S affected the branching pattern. The resulting alterations in dendritic arborization appeared to be in response to H₂S exposure at the 20 and 50 ppm (28 or 70 mg/m³) levels such that the 20 ppm (28 mg/m³) level may be considered a low-effect rather than a no-effect level.

Hannah 1989

Study Type: sub-chronic rat study, gestational and postnatal exposure

Methods: Rats exposed from GD5 to PND 21 to 75 ppm H₂S for 7 hours/ day.

Results: Brain levels of aspartate, γ -aminobutyric acid (GABA), glutamate, and taurine were significantly depressed, but no follow-up studies were conducted to determine if these changes affected behavioral or structural development

Population Studies

Ecological investigations – community-based studies of low level H₂S exposure (ppb) - are difficult to evaluate for relevance to occupational exposure analysis. Many factors – continuous exposure to very low concentrations, confounders, lack of exposure measurements – limit the applicability of some studies to interpreting occupational exposures. There are unique studies of H₂S exposure from geothermal sources that do show little or no effect of H₂S exposure in the ppb range.

Bates 1998

Study Type: case-control

Methods: Cancer registry and hospital morbidity data were obtained from 1981 – 1990 for community adjacent to a geothermal H₂S and compared with non-exposed communities. Standardized incidence ratios (SIR) were calculated comparing the two groups. Diagnostic categories were based on known targets of H₂S toxicity – the respiratory, neurological and ocular systems.

Results: The exposed population had an elevated nasal cancer rate but cases were limited (4). For a subset of women, the SIR cancers of the trachea, bronchus and lung was 1.48 (1.03 – 2.06). For morbidity, diseases of the nervous system and the eye showed elevated SIR.

Bates 2015

Study Type: Ecological, cross-sectional

Methods: 1637 adults living 3 years or longer (median = 18 years) with low-level H₂S exposure from geothermal sources were randomly selected from high medium and low H₂S exposure areas. The median residential H₂S concentration was 20.3 ppb and the median workplace concentration 26.4 ppb. Spirometry testing was obtained of the participants and compared with predicted population values. Departures from the predicted value were outcomes for linear regression models using quartiles of the H₂S exposures. Separate models examined participants with and without asthma or COPD and never- and ever-smokers.

Results: None of the exposures were associated with lung function decrement. No evidence that long-term H₂S is associated with increased asthma or COPD risk.

Discussion: For all participants and sub-groups there was no evidence of an adverse association between ambient H₂S and any spirometric measures. More significantly, there was no evidence of an association between H₂S and COPD which might be expected from long-term exposure to a reactive, irritant gas. Potential exposure misclassification may have attenuated any actual exposure- response relationships but no effect was seen across 4 subgroups.

Bates 2017

Study Type: Ecological

Methods: 1637 adults living 3 years or longer (median = 18 years) with low-level H₂S exposure from geothermal sources were randomly selected from high medium and low H₂S exposure areas. The median residential H₂S concentration was 20.3 ppb and the median workplace concentration 26.4 ppb. Participants underwent comprehensive ophthalmic examination including pupil dilation and lens photography to capture evidence of any ocular opacities. Data analysis examined associations between the degree of opacification/nuclear color/cataract in relation to H₂S exposure.

Results: No associations were found between estimated H₂S exposures and any of the 4 ophthalmic outcome measures.

Reed 2014.

Study Type: ecological

Methods: 1637 adults living 3 years or longer (ages 18-65, median residence time = 18 years) with low-level H₂S exposure from geothermal sources were randomly selected from high medium and low H₂S exposure areas. H₂S exposure at the time of participation and past exposure were calculated from data obtained from H₂S monitoring stations and exposure metrics were created for contemporary and the prior 30 years. Neuropsychological tests of visual and verbal memory, attention, fine motor skills, psychomotor speed and mood administered to participants were reported as being affected by H₂S or relevant to neurotoxic assessment. Association between cognition and measures of H₂S exposure were investigated with multiple regression while covarying demographics and factors known to be associated with cognitive performance.

Results: No association was found between H₂S exposure and neuropsychological and psychomotor assessments.

Finnbjornsdottir 2016

Study type: Ecological, urban population exposed to H₂S from geothermal energy plant.

Methods: Hospital data from patient- and population-registers on heart disease, respiratory disease and stroke from an acute care institution in the study area were obtained from 1 January, 2007 and 30 June, 2014. The population was geocoded into 5 areas within the H₂S plume and the total number of individuals in each area calculated within age groups (18-59, 60-72, 73-80, and 81 and older) and gender. A national registry was used to count the total number of people at risk in the area according to the gender and age groups. Exposure estimates were modeled and exposure calculated by different percentiles 50% (2.46 µg/m³), 60% (3.16 µg/m³), 70% (4.14 µg/m³), 80% (5.74 µg/m³), 85% (7.00 µg/m³), 90% (8.80 µg/m³) and 95% (11.68 µg/m³). A generalized linear model assuming Poisson distribution was used to investigate the association between emergency hospital visits for each disease endpoint and H₂S exposure.

Results: The total number of emergency hospital visits was 32961 with a mean age of 70 years. In fully adjusted un-stratified models, H₂S concentrations exceeding 7.00µg/m³ were associated with increases in emergency hospital visits with heart disease as primary diagnosis (RR): 1.067; 95% confidence interval (CI): 1.024–1.111). Among males an association was found between H₂S concentrations exceeding 7.00µg/m³, and heart disease (RR: 1.087; 95% CI: 1.032–1.146) and among those 73 years and older (RR: 1.075; 95%CI: 1.014–1.140).

Campagna, 2004.

Study type: Ecological, urban population exposed to H₂S from local industrial and sources.

Method: The associations between ambient total reduced sulfur (TRS) and hydrogen sulfide (H₂S) levels, and hospital visits for respiratory disease among residents of two Nebraska cities from January 1998 to May 2000 was examined. The population was restricted to persons who sought emergency or nonscheduled outpatient care from January 1998 to May 2000 at the two local hospitals. Ambient H₂S levels were measured every 5min between February 5, 1999 and May 31, 2000. 30-min rolling averages were computed for each TRS and H₂S monitoring station. Levels were characterized as high if at least one of the daily rolling averages was >30 ppb, and low if all rolling averages were <30 ppb. The measure of association used was the mean percent change in the average number of hospital visits recorded following a day with a high exposure versus a day with a low exposure.

Results: For children less than 18 years of age, a positive association was found between asthma hospital visits and 1-day lagged TRS levels. For adults, a positive association was found between asthma hospital visits and

H2S levels on the previous day. A positive association also was found between hospital visits for all respiratory diseases, and H2S and TRS level so n the previous day for children but not for adults.

Industrial Hygiene Surveys

Astrakianakis, 1998

Study Type: Industrial hygiene survey of wood pulp mill

Methods: 1678 personal measurements were collected for 46 job titles during 73 day-shifts at a bleached-kraft pulp mill. Measurements included shift-long average and short-term exposures to carbon monoxide, chlorine dioxide (ClO₂), and H₂S; and shift-long average exposures to calcium oxide and wood dust (WD). The hygienists distributed 20–34 instruments each day, including 4 Electro-chemical sensors (ECS, Biosystems Toxilog, Middletown, Conn.) and an average of 16 Passive diffusion cards (PDC, Envirometrics ACT Monitoring Card System, Acculabs, Morrisville, N.C.). PDCs were selected to measure the shift-long time-weighted average (TWA) exposure to the three gases and had a detection limit for H₂S of < 0.13 ppm. ECS were selected to quantify short-term exposures to the three gases and had a detection limit for H₂S of 2 ppm.

Results: In total, 1678 personal exposure measurements were collected for 46 job titles involving 5 chemicals during 73 day-shifts from May to August 1994. Shift-long sampling for H₂S was suspended mid-study because none of the 307 PDC samples were above the detection limit (0.13 ppm). Forty-eight of 49 data-logging shift-long ECS read-outs for H₂S were unspoiled. None ECS samplers measured peaks that were greater than the STEL (48 samples) and the maximum measured peak exposure was 8.4 ppm.

Gikunju 2016

Study type: ambient air quality monitoring of H₂S at two geothermal plants.

Methods: Measurements of ambient H₂S were obtained in March and April 2012, at two geothermal energy plants using a gas monitor, QRAEII 4 gas monitor type. This gas monitor simultaneously displays the levels of H₂S Carbon Monoxide and Oxygen level. The readings were taken at a height of 1.5 m and the one-minute maximum concentrations at predetermined locations recorded. Historical data for the plants from 1997 to 2011 were gathered and reviewed to analyze the trends of H₂S over the period.

Results: The results of 2012 hourly readings of ambient H₂S during the study showed varying results with a maximum recorded at 3.2 ppm and a mean of 0.10 ppm. The historical analysis of H₂S at the older plant from 1997 to 2011 shows H₂S was detected in 20% of the total readings taken. In 3% of the total readings, the ambient H₂S was above 1.00. H₂S readings at the newer plant between 2003-2011 shows that 85% of the total readings taken did not detect H₂S. Less than 2% of the samples detected H₂S between 1 and 3 ppm. Reports of irritating smells by plant workers were associated with H₂S measurements between 2 – 3 ppm.

HEAC Health-based assessment and recommendation

Few occupational studies are available to assess the respiratory effects of H₂S. Many studies are of workers exposed to multiple irritant chemicals and the exposure are not well-characterized. Most H₂S measurements in Jappinen were between 2 and 7 ppm and in Vanhoorne H₂S concentrations ranged from 0.2 and 15 ppm so are comparable to those in the volunteer studies. No respiratory effects were observed and irritation only observed at > 5.0 ppm. Jappinen raises the concern of a healthy worker effect in that study however the lack of any differences in the 4 subgroups undergoing histamine challenge suggests that H₂S did not have respiratory impacts at 5.0 ppm.

The volunteer studies by Bhambhani demonstrate that effects of exposure to H₂S can be detected in humans at 5 ppm. The potential for H₂S to inhibit mitochondrial respiration is a function of several factors of exposure and physiology. When H₂S is inhaled, it is absorbed into the bloodstream, where it is detoxified primarily by oxygen bound to hemoglobin and in the process is oxidized into a sulfate or a thiosulfate that is excreted by the kidneys. The anionic moiety of H₂S (HS⁻) is known to form a complex with the ferric heme group of methemoglobin in a 1:1 stoichiometric ratio. A minor portion of the inhaled H₂S can enter the musculature, where it undergoes a similar fate because of the presence of oxygen in the form of oxymyoglobin. Trace amounts of the gas that are unoxidized are eliminated by the lungs as dissolved H₂S. This detoxification process takes place very rapidly and therefore H₂S does not act as a cumulative toxin. However, if the dose of H₂S exceeds the detoxification capacity, it can then impair mitochondrial respiration by inhibiting the activity of the enzyme cytochrome oxidase (c and aa3) in the various tissues, thereby reducing overall energy production. Because of the rapid speed of these reactions, the extent of cytochrome oxidase inhibition is greatest under constant and sustained concentrations of H₂S. Interindividual variability in blood oxygen levels is also a factor in H₂S detoxification.

The difficulty of utilizing the Bhambhani studies for estimating potential human effects is how to interpret the sub-clinical and short-term effects identified in the studies. H₂S produces a transient inhibition of cytochrome oxidase so sustained exposure at low-levels would be required for the cytochrome oxidase inhibition to accumulate and effect changes to respiration. Currently, little experimental information exists concerning the effects of repeated exposure of animals to low concentrations of H₂S. Khan (1998) found significantly reduced lung cytochrome oxidase activity in rats exposed to 10 ppm H₂S for 5 days/week 8 hrs/day for 5 weeks however no respiratory or pulmonary effects were measured. Pulmonary effects were assessed in rats after similar repeated exposure to low and moderate concentrations of H₂S (1, 10, 100 ppm); however, no significant changes were observed in either respiratory-tract physiological indices (airway resistance, dynamic compliance, tidal volume) or lung and tracheal histology other than cellular proliferation at the high (100 ppm H₂S) level (Hulbert 1989). This study also reported increased bronchial responsiveness (hypersensitivity) to methacholine challenge in rats from all H₂S treatment groups. Significant increases in blood lactate were observed at 5 and 10 ppm H₂S in the Bhambhani studies but the effect varied with concentration, level of exertion and physical condition of the subjects. Current methods to extrapolate this short-term effect to chronic workplace exertion are not available at this time.

Eye irritation is a common effect associated with H₂S however good exposure data for this effect are lacking. Many reports are from small volunteer studies, anecdotal observations from older studies or from workplace exposures to multiple eye irritants. In the workplace, H₂S is frequently a byproduct gas and can be highly variable in occurrence. One process where H₂S has been routinely detected is in the manufacture of viscose rayon. This process consists of two steps: isolation and processing cellulose fiber into a fluid (viscose) which is then spun into rayon fibers (spinning, <http://mytextilenotes.blogspot.com/2009/05/manufacturing-process-of-viscose-rayon.html>). CS₂ is used in the preparation of viscose and is removed during spinning, a process that runs the fiber through a H₂SO₄ solution. This acid treatment results in the formation of H₂S.

A description of the process and symptoms from Savic (1967) succinctly describes the process and associated air concentrations of CS₂ and H₂S.

“In a “cell fiber” operation the concentration of carbon disulfide in the working atmosphere was about 300 mg/cu m and sometimes but very rarely reached 1,000 mg/cu m. In a “production of viscose rayon” operation the maximal concentration was 176 mg/cu m with the average values always over 62 mg/cu m. Of 185 workers examined, 115 were from the cell fiber operation, and 70 from the spinning viscose rayon operation. The majority of the workers were 25 to 35 years old and had worked five to six years in the same place. Many of the workers (43.5% in the cell fiber operation and 95.7% in the production of viscose rayon operation) mentioned a sensation of “eye burning.” Some complained of photophobia, seeing of colors, dim vision, and weak night vision. These symptoms were thought to be caused principally by local irritation of the eyes by carbon disulfide, H₂S, H₂SO₄, and other irritant vapors and gases.”

Note that while much higher carbon disulfide exposure occurs during the cell fiber process, 5-fold lower concentrations during spinning results in a doubling of reported eye irritation. Other occupational reports have also observed a greater occurrence of eye irritation during the spinning process compared to the fiber process (Barthelemy, 1939); and with the fluctuation of H₂S concentrations during the spinning process (Masure, 1950, in Lambert, 2006). The conclusion of these and other studies is that there is little or no H₂S generated in the cell fiber process and the main cause of irritation during spinning is contributed by H₂S.

The studies by Vanhoorne provide a well-characterized workplace exposure study to evaluate the contribution of H₂S and CS₂ to eye irritation under co-exposure. The study was reported in two publications, one of the sampling and analytical results obtained from personal sampling at the rayon plant (Vanhoorne, 1991) and the other of the eye effects of the workers (Vanhoorne, 1995). Personal sampling of 123 workers was conducted over 5 years in 17 job categories, 13 of which consisted of co-exposure to H₂S and CS₂. Detailed assessments of multiple eye impairments were obtained. Sampling results for the seven categories with the highest co-exposures are presented in Table 1. The job categories spinners and first spinners had the highest H₂S exposure and the second and third highest CS₂ exposure. For the analysis of eye effects, co-exposures were grouped into 3 categories with the high exposure group defined as all workers exposed to CS₂ concentrations above 29 ppm and H₂S concentrations above 3.6 ppm. Workers in the high exposure category (spinners/first spinners only) had significantly higher complaints of pain, burning and irritation of the eyes than controls (Table 2). The spinning cake regulator group had the highest measured CS₂ exposure of any category but did not exceed an H₂S exposure of 2 ppm and therefore did not experience significant eye effects. This suggests that the significant eye effects from co-exposure were due to H₂S. The geometric mean H₂S concentration of the high exposure group was 8.9 mg/m³ whereas the geometric mean H₂S concentration of the moderate exposure group was 2.43 ppm. A NOAEL for eye irritation by H₂S can be estimated to occur between 2.43 and 6.36 ppm H₂S from this study.

Table 1: H2S and CS2 concentrations (ppm) from Vanhoorne, 1991 sampling study

H2S						
All operations	N	n	GM (ppm)	GSD	UCL	LCL
Spinner	49	13	6.36	1.81	11.27	3.63
First spinner	4	8	2.43	1.39	4.25	1.39
Spinning cake regulator	4	6	1.34	0.76	2.55	0.70
Shift technician	4	7	0.44	2.97	1.62	0.11
Bathman	6	9	1.42	1.57	2.57	0.79
Supervisor	7	4	3.52	2.09	19.35	0.64
Third man preparation	4	10	0.73	2.10	1.58	0.34
CS2						
Viscose Preparation	N	n	GM (ppm)	GSD	UCL	LCL
Third man preparation	4	9	17.84	0.57	27.77	11.47
preparation operative	7	9	28.81	0.51	44.57	20.06
Rayon Spinning	N	n	GM	GSD	UCL	LCL
Spinner	49	14	35.62	0.44	42.35	29.96
First spinner	4	10	32.24	0.48	59.20	24.07
Spinning cake regulator	4	10	47.04	0.46	60.83	37.38
Shift technician	4	7	16.96	0.40	20.82	14.01
Bathman	6	8	21.60	0.43	28.81	16.20
Supervisor	7	7	9.99	0.55	16.44	6.07

N = number of workers; n = sample size

Table 2: H2S and CS2 concentrations (ppm) from Vanhoorne, 1995 epidemiologic study

H2S	N	Pain	Burning	Irritation at Work
Unexposed	107	21.5	14.0	33.6
< 3.6 ppm	49	34.7	32.7	44.9
> 3.6 ppm	34	52.9**	47.1**	73.5**
All exposed	83	42.2**	38.6**	56.6**
CS2				
Unexposed	67	20.9	14.9	35.8
1-9.6 ppm	47	19.2	12.8	27.7
10-29 ppm	38	36.8	31.6	47.7
> 29 ppm	38	55.3**	50**	73.7**
All exposed	123	35.8*	30.1*	48.0
Combined exposure				
Unexposed	67	20.9	14.9	35.8
Moderate (all others)	89	29.2	23.6	38.2
High (> 3.6 ppm H2S; > 29 ppm CS2)	34	52.9*	47.1*	73.5**
All exposed	123	35.8*	30.1*	48.0

The developmental/neurological differences observed in rats at 20 ppm H₂S and above in Skrajny, Roth and Hannah are difficult to apply to the assessment of H₂S for a number of reasons. The toxicological significance of the neurochemical levels (Skrajny and Hannah) and morphological differences (Roth) have not been determined nor have they been repeated in additional studies. A mechanism of action of H₂S for these effects has not been identified. The biochemical and physiological role of H₂S is currently the subject of great interest as it was recently identified as a messenger molecule for a wide variety of cellular processes so new information about its neurological role will assist interpretation of these results at a later date.

The risk-based RfC for H₂S (EPA) can be adjusted to an occupational human equivalent concentration. The conditions for that estimate (Brenneman, 2000; 10 weeks, 6 hours/day, 7 days/week) can be adjusted to an occupational exposure rather than a continuous exposure. Converting the NOAEL (13.9 mg/m³) to the human equivalent 40 hour occupational exposure and applying an RGDR of 0.184 results in a human equivalent dose of 2.68 mg/m³ or 1.92 ppm (13.9 x 6/8 x 7/5 x 0.184). Dividing by a total uncertainty factor of 10 (3 for sub-chronic study and 3 for intraspecies uncertainty) gives a PEL of 0.27 mg/m³. An alternate approach to determining the RfC for the olfactory lesions observed in Brenneman utilized a fluid dynamic model (CFD) of the rat and human nose and a PBPK rat model to determine deposition and kinetics of H₂S in the rodent olfactory region (Schroeter, 2006). PBPK parameters from this study were scaled to human correlates based on an allometric scaling that was adjusted to account for the relative differences in nasal surface area between species. Using the 99th percentile olfactory flux values predicted by the human nasal CFD model, the study found that an H₂S exposure concentration of ~21 ppm will result in olfactory flux (and toxicity) equivalent to the rat exposed to 30 ppm. A NOAEL [HEC] for occupational exposure of 22.5 ppm can be calculated by adjusting to 8 hours (6/8) and 5 day (7/5) exposure conditions. Dividing by an uncertainty factors of 10 (3 for sub-chronic study and 3 for intraspecies uncertainty) gives a PEL of 2.25 ppm. As the CFD model used the 99th percentile for H₂S flux into human olfactory tissue, an intraspecies uncertainty factor may be unnecessary. Eliminating this uncertainty factor results in a PEL of 7.5 ppm for olfactory lesions.

Recommendation: A PEL of 5 ppm is recommended based on the studies of Vanhoorne (1991, 1995) and the range of risk-based estimates based on the Brenneman 2000 study. The weight of evidence in the Vanhoorne study indicates that H₂S is the cause of the eye effects observed in that study. That study reports that eye irritation was observed in workers exposed to a mean H₂S concentration of 6.4 ppm but not to a concentration of 3.4 ppm.

Lowering the 15-min STEL to 10 ppm is proposed. H₂S does not accumulate in the body and is rapidly cleared from blood and tissues so a sustained inhibition of respiration would not be expected from a short-term exposure to 10 ppm. The basis for the STEL is eye irritation between 10 – 20 ppm reported in multiple workplace investigations. These observations were obtained over longer exposure intervals (hours) however there is evidence that the threshold for H₂S eye irritation is lowered with co-exposure to other irritants so setting the STEL at 10 ppm will provide a margin of safety for this effect. No change to the 50 ppm Ceiling is proposed.

Usage information: EPA TSCA Chemical Data Reporting (CDR), EPA Toxics Release Inventories (TRI), other sources:

In 2015, there were 27 TSCA CDR records for hydrogen sulfide (usage in excess of 25,000 lbs) in U.S. Of these, 2 were in California. In 2016 there were 519 TRI records for hydrogen sulfide of which 20 were in California.

Measurement/Implementation Feasibility

	OSHA Method ID 141 (validated)	NIOSH Method 6013
Estimated LOD/LOQ	0.4/0.9 ppm (2 liters)	11 µg/ 17 µg
Measurement issues	silver nitrate impregnated filter	activated charcoal tube -some lots high S- filter

Both NIOSH and OSHA methods are adequate to detect at the respective Ceiling Limits. The OSHA method is adequate to detect the TLV of 1 ppm. An issue with the OSHA method is that cassettes would have to be changed each hour at the minimum flow rate of 0.1 L/min if concentrations were near the OSHA Ceiling Level. Another issue is handling of the impregnated filter with forceps is necessary, and the impregnated filters are light sensitive so the cassettes must be shielded with aluminum foil or black tape during storage and transport. Store in a dark environment.

Industrial hygiene surveys (Astrakianakis, 1998; Gikunju 2016) indicate that very few H2S samples exceeded 2 ppm over periods of continuous sampling so the recommended 8-hr TWA of 5 ppm seems to be achievable with little or no additional controls.

Economic Impact Analysis/Assessment

The Division has made a determination that this proposal is not anticipated to result in a significant, statewide adverse economic impact directly affecting businesses, including the ability of California businesses to compete with businesses in other states. This proposal will not have any effect on the creation or elimination of California jobs nor result in the creation or elimination of existing businesses or affect the expansion of existing California businesses. The Division anticipates that any potential costs will be balanced by avoiding or minimizing the costs inherent in workers' compensation claims, lost work time, and productivity losses that would have been caused by exposure related illness of employees.

The PEL proposed is consistent with recent scientific findings, of which professional health and safety staff and consultants of these employers and others with significantly exposed employees should be aware. Many of these entities already seek to control employee exposures to substances to levels below existing PELs in the interest of business continuity and minimization of tort and workers compensation liability.

Setting a Permissible Exposure Limit for hydrogen sulfide that is up-to-date and consistent with current scientific information and state policies on risk assessment will send appropriate market signals to employers with respect to the costs of illness and injury, which chemicals can impose on workers and their families, the government, and society at large. With appropriate market signals, employers may be better able to protect employees from hydrogen sulfide exposures in the workplace and also impose less of a burden on workers and society. There are no anticipated benefits to the state's environment.

The economic benefits from the proposed PEL will result primarily from reduced health risk among exposed workers.

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